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Exotic fruits as therapeutic complements for diabetes, obesity and metabolic syndrome

Samir Devalaraja, Shalini Jain, Hariom Yadav *

National Institute of Diabetes and Digestive and Kidney Diseases, National Institutes of Health, Bethesda, MD, USA

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A B S T R A C T

The prevalence and severity of obesity, type 2-diabetes, and the resultant metabolic syndrome are rapidly increasing. As successful preventive and therapeutic strategies for these life-threatening health ailments often come with adverse side effects, nutritional elements are widely used in many countries as preventive therapies to prevent or manage metabolic syndrome. Fruits are important dietary components, and contain various bioactive constituents. Many of these constituents have been proven to be useful to manage and treat various chronic diseases such as diabetes, obesity, cancer and cardiovascular diseases. Although exotic fruits are understudied throughout the world due to their limited regional presence, many studies reveal their potent ability to ameliorate metabolic derangements and the resultant conditions i.e. diabetes and obesity. The aim of this article is to review the role of exotic fruits and their constituents in the regulation of metabolic functions, which can beneficially alter diabetes and obesity pathophysiology.

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1. Introduction

The prevalence of obesity and type 2 diabetes is rapidly increasing around the world, and its growth has become a major challenge for health care professionals to combat (Hossain, Kawar, & Nahas, 2007; Young, 2010). Obesity is characterized by the accumulation of excess fat in adipose tissues, and results in various life threatening complications such as cardiovascular diseases, type 2 diabetes, and cancer (Lois & Kumar, 2009). At heart, the obesity epidemic arises from the sedentary modern lifestyle, in which unhealthy dietary practices place a heavy strain on the delicate balance between energy intake and energy expenditure (Lois & Kumar, 2009). It is well established that a correction of lifestyle, such as the intake of a healthy and low energy diet along with increased physical activity is the most effective preventive therapy to ameliorate the prevalence of obesity and diabetes in society. Therefore, research exploring nutritional composition is robustly expanding in the field of obesity and diabetes (Foltran et al., 2010). Recently, the bioactive components in foods and functional foods have become popular and have been considered as complementary or alternative therapeutic agents to manage and/or treat chronic diseases. Moreover, it is illustrated that in addition to standard prescribed therapies, a host of complementary and alternative herbs and dietary supplements are widely used to manage obesity and diabetes (Connell, 2001). Currently, approximately one-third of patients with diabetes mellitus employ some form of complementary and alternative medicine (Metcalfe, Williams, McChesney, Patten, & Jetté, 2010).

Fruits are important components of our daily diet that contain various bioactive nutraceuticals, which enhance our body's strength to fight various illnesses. Various ethnically and geographically specific fruits are used in traditional therapies for treatment of various health problems including diabetes and obesity (Babio, Bulló, & Salas-Salvadó, 2009). Ancient Chinese medicine heavily incorporates local fruits to treat diabetic patients (Ceylan-Isik, Fliethman, Wold, & Ren, 2008). Some of these ancient Chinese natural therapeutics have been shown to have a high content of antioxidants, which is well known to directly improve metabolic syndrome (Liu, Qiu, Ding, & Yao, 2008). In India and Bangladesh, Ayurvedic medicines employ a wide range of locally harvested fruits (Krishnaveni & Mirunalini, 2010). Recent research has also indicated that fruits local to India, such as *Garcina indica*, possess potent medicinal uses (Baliga, Pai, Bhat, Palatty, Boloor, in press). However, many of these fruits are "exotic" to the rest of the world, thus the global community at large does not benefit from their potentially bio-defensive effects. The vast majority of basic research is conducted in countries in which these

Abbreviations: BMI, Body Mass Index; FFA, Free Fatty Acid; TNF-α, Tumor Necrosis Factor-α; PGE2, Prostaglandin E2; ROS, Reactive Oxygen Species; SOD, Super Oxide Dismutase; DPPH, 2-2 Diphenyl-1-Picrylhydrazyl; NO, Nitric Oxide; iNOS, Inducible Nitric Oxide Synthase; COX2, Cyclooxygenase 2; WAT, White Adipose Tissue; CRP, C-Reactive Protein; IFN-γ, Interferon-gamma; PEPCK, Phospho-Enol-Carboxy Kinase; HDL, High Density Lipoprotein; LDL, Low Density Lipoprotein; MDA, Malondialdehyde; GSH, Glutathione; GSH-Px, Glutathione-Peroxidase; PPAR-γ, Peroxisome Proliferator-Activated Receptor-gamma; MUFA, Mono-Unsaturated Fatty Acid; TGF-β, Transforming Growth Factor-beta; ACE, Angiotensin-Converting Enzyme; STZ, Streptozotocin; HbA1c, Glycosylated Hemoglobin.

* Corresponding author at: Diabetes, Endocrinology and Obesity Branch, Clinical Research Center, Building 10, NIDDK, National Institutes of Health, Bethesda, MD 20892, USA.

E-mail address: yadavh@mail.nih.gov (H. Yadav).

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fruits are grown—mainly in developing countries. Due to various resource limitations, the anti-diabetic and anti-obese potential of exotic fruits is under-studied. Hence, we believe it is immensely important that the global scientific community should further evaluate the potential of these exotic fruits and their constituents to prevent the pathogenesis of diabetes, obesity and metabolic syndrome.

2. Pathophysiology of diabetes and obesity

Before discussing the anti-diabetic or anti-obese effects of exotic fruits and their bioactive nutraceuticals, it is important to discuss the pathophysiological mechanism of diabetes and obesity. Obesity itself is defined by the World Health Organization (WHO) as a body mass index (BMI) of 30 kg/m^2 or higher, and is significantly associated with increased predisposition to all-cause and cause-specific morbidity and mortality (Prospective Studies Collaboration, 2009). Overweight and obesity are conditions well established to increase the likelihood of hyperlipidemia, hyperglycemia, insulin resistance (type 2-diabetes) and cardiovascular diseases (Lois & Kumar, 2009). Among others, obesity and diabetes lead to the pathogenesis of metabolic syndrome, characterized by a state of chronic low grade inflammation, oxidative stress, hyperlipidemia and insulin resistance (Martínez, 2006; Neligan, 2010). Obesity, diabetes and the resultant metabolic syndrome thus serve as a trigger for a host of multi-organ complications, from cardiovascular disease to cancer. Curtailing hyperglycemia, hyperlipidemia, insulin resistance, inflammation and oxidative stress are critical factors that could be used for therapeutic/preventive targets to combat the pathogenesis of metabolic syndrome (Fig. 1).

In *in-vitro* systems, animal models, and clinical trials, various exotic fruits have been demonstrated to decrease the abovementioned parameters (Table 1). The current article explores the immense potential of exotic fruits to ameliorate the pathogenesis of metabolic syndrome by acting on various targets.

3. Exotic fruits and their biodefensive potential in metabolic syndrome

3.1. Litchi

The botanical name of Litchi is *Litchi chinensis.* Litchi is originally from Southeast Asia, and is a tropical/ subtropical crop that has experienced a gradual increase in production in both the Southern and Northern hemispheres (Huan & Xu, 1983). The fruit's stunning red skin and savory taste has resulted in increased exports to other parts of the world, including Europe and North America (Huan & Xu, 1983). A 100 g edible portion of litchi contains water (81.76 g), protein (0.83 g), lipids (0.44 g), ash (0.44 g), carbohydrates (16.53 g), fiber (1.3 g) and sugars (15.23 g) (Table 1). Both *in-vitro* and *in-vivo* studies have been conducted exploring the beneficial effects of Litchi, most of which suggest a solid potential for the use of Litchi extract as a supplemental therapeutic to ameliorate diabetes, obesity and its complications (Huang & Wu, 2002; Guo et al., 2004; Obrosova, Chung, & Kador, 2010).

It has been found that feeding of Litchi water extract improved the metabolic profile of rats, characterized by decreased body weight, fasting blood glucose, total cholesterol, triglycerides, free fatty acid (FFA), leptin, and fasting insulin levels (Guo et al., 2004). Furthermore, Guo et al. (2004) also found that the water extract of Litchi diminished insulin resistance in these rats. Later on, it has been found that the anti-diabetic potential of the water extract of Litchi was through the anti-inflammatory effects in these rat models (Guo et al., 2004). Guo and colleagues illustrated that tumor necrosis factor (TNF-α), a cytokine involved in system inflammation, was significantly decreased after feeding litchi water extract in type 2 diabetic rats. These findings suggest that the Litchi fruit possesses bioactive components that enhance the body's immune system, which can protect from diabetes or obesity induced chronic inflammation. It was further explored that Litchi extract enhances basal prostaglandin E2 (PGE2) production in a macrophage cell line (RAW264.7), which is considered a key inhibitor of the inflammatory immune response (Huang & Wu, 2002).

Glucose induced cataract (blindness/ retinopathy) is a major complication that arises from the long term existence of uncontrolled diabetes (Cheung, Mitchell, & Wong, 2010). Aldose reductase is the critical initiator of cataractogenesis (Obrosova et al., 2010). This enzyme exists around the cornea, and catalyzes the first reaction of a polyol pathway and induces sorbitol formation. In diabetic or hyperglycemic conditions, the enhanced activity of aldose reductase renders excess formation of sorbitol. Higher sorbitol formation leads to accumulation around the cornea, and the subsequent development of cataract. Methanol and ethylacetate extracts of Litchi fruit preicarp (LFP) were found to be potent inhibitors of rat lens aldose reductase *in-vitro*. Interestingly, Delphinidin 3-O-β galactopyranoside-3′-O-β-glucopyranoside was isolated from the ethylacetate extract of LFP and demonstrated potent inhibitory activity for rat lens aldose reductase. This suggests that LFP and its constituents contain potent inhibitors of

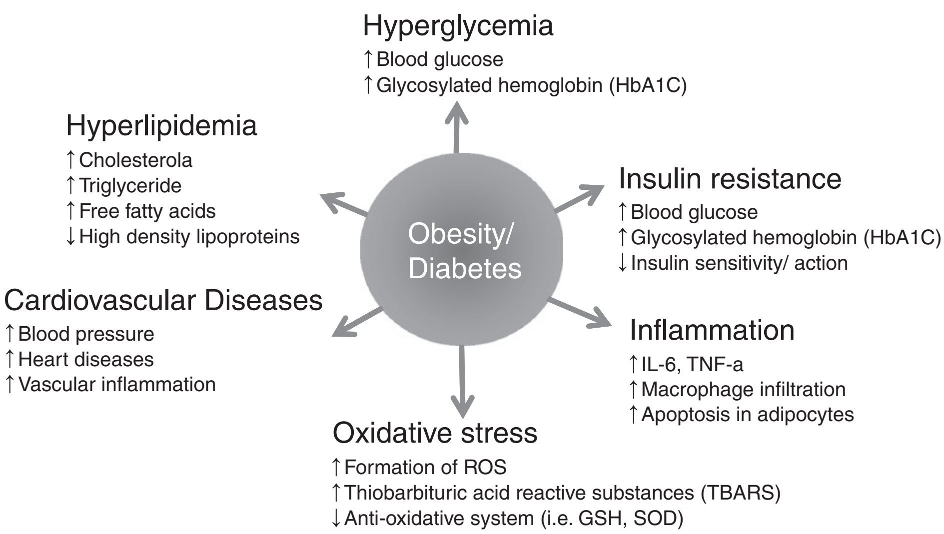

Fig. 1. Pathophysiology of obesity and diabetes, and their associated factors.

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Table 1
Nutrient composition of exotic fruits.
This data was adopted from: USDA National Nutrient Database, 2010, 2011.

Nutrient (units)	Litchi	Durian	Jackfruit	Mangosteen	Acai	Pomegranate	Avocado	Persimmon	Guava	Blueberry
	Value per 100 g									
Proximates										
Water (g)	81.76	64.99	73.23	80.94	88.4	77.93	73.23	80.32	80.8	84.21
Energy (kcal or kJ)	66	147	94	73	45	83	160	70	68	57
Protein (g)	0.83	1.47	1.47	0.41	0	1.67	2	0.58	2.55	0.74
Total lipid (g)	0.44	5.33	0.3	0.58	0	1.17	14.66	0.19	0.95	0.33
Ash (g)	0.44	1.12	1	0.16	0.62	0.53	1.58	0.33	1.39	0.24
Carbohydrate (g)	16.53	27.09	24.01	17.91	10.98	18.7	8.53	18.59	14.32	14.49
Fiber, total dietary (g)	1.3	3.8	1.6	1.8	0	4	6.7	3.6	5.4	2.4
Sugars, total (g)	15.23	ND	ND	ND	10.57	13.67	0.66	12.53	8.92	9.96
Minerals										
Calcium, Ca (mg)	5	6	34	12	1	10	12	8	18	6
Iron, Fe (mg)	0.31	0.43	0.6	0.3	0.81	0.3	0.55	0.15	0.26	0.28
Magnesium, Mg (mg)	10	30	37	13	ND	12	29	9	22	6
Phosphorus, P (mg)	31	39	36	8	98	36	52	17	40	12
Potassium, K (mg)	171	436	303	48	ND	236	485	161	417	77
Sodium, Na (mg)	1	2	3	7	28	3	7	1	2	1
Zinc, Zn (mg)	0.07	0.28	0.42	0.21	ND	0.35	0.64	0.11	0.23	0.16
Copper, Cu (mg)	0.148	0.207	0.187	0.069	ND	0.158	0.19	0.113	0.23	0.057
Manganese, Mn (mg)	0.055	0.325	0.197	0.102	ND	0.119	0.142	0.355	0.15	0.336
Selenium, Se (μg)	0.6	???	0.6	ND	ND	0.5	0.4	0.6	0.6	0.1
Vitamins										
Vitamin C (mg)	71.5	19.7	6.7	2.9	40.7	10.2	10	7.5	228.3	ND
Thiamin (mg)	0.011	0.374	0.03	0.054	ND	0.067	0.067	0.03	0.067	ND
Riboflavin (mg)	0.065	0.2	0.11	0.054	ND	0.053	0.13	0.02	0.4	ND
Niacin (mg)	0.603	1.074	0.4	0.286	ND	0.293	1.738	0.1	1.084	ND
Pantothenic acid (mg)	???	0.23	ND	0.032	ND	0.377	1.389	???	0.451	ND
Vitamin B-6 (mg)	0.1	0.316	0.108	0.018	ND	0.075	0.257	0.1	0.11	ND
Folate, total (μg)	14	36	14	31	ND	38	81	8	49	ND
Folic acid (μg)	0	???	0	0	ND	0	0	0	0	ND
Folate, food (μg)	14	36	14	31	ND	38	81	8	49	ND
Folate, DFE (μg)	14	???	14	31	ND	38	81	8	49	ND
Choline, total (mg)	7.1	???	ND	ND	ND	7.6	14.2	7.6	7.6	ND
Vitamin B-12 (μg)	0	0	0	0	ND	0	0	0	0	ND
Vitamin A, RAE (μg_RAE)	0	2	15	2	ND	0	7	81	31	ND
Retinol (μg)	0	0	0	ND	ND	0	0	0	0	ND
Carotene, beta (μg)	0	23	ND	16	ND	0	62	253	374	ND
Carotene, alpha (μg)	0	6	ND	1	ND	0	24	0	0	ND
Cryptoxanthin, beta (μg)	0	0	ND	9	ND	0	28	1447	0	ND
Vitamin A, IU (IU)	0	44	297	35	6	0	146	1627	624	ND
Vitamin D (D2 + D3) (μg)	0	ND	ND	0	ND	0	0	0	0	ND
Vitamin D (IU)	0	ND	ND	0	ND	0	0	0	0	ND
Vitamin E (mg)	0.07	ND	ND	ND	1.83	0.6	2.07	0.73	0.73	ND
Vitamin K (μg)	0.4	ND	ND	ND	ND	16.4	21	2.6	2.6	ND

ND: not detected.

aldose reductase, and can be used to prevent diabetes-induced blindness and retinopathy (Lee, Park, Park, & Moon, 2009).

Oxidative stress is the hallmark of various chronic diseases (Spiteller, 1993). In diabetes and obesity (metabolic syndrome) the levels of oxidative stress i.e. production of reactive oxygen species (ROS) get significantly increased and led to damage in micro and macro-vascular tissues (Spiteller, 1993). Litchi polysaccharides from pulp tissue demonstrated potential antioxidant capacities (Kong et al., 2010). Four polysaccharide-enriched fractions extracted from pulp tissue of Litchi have been shown to exhibit a dose-dependent free radical scavenging activity (Kong et al., 2010). The LFP-III demonstrated the highest scavenging activity against the DPPH radical, superoxide, and hydroxyl radicals and chelating ability (Kong et al., 2010). A new litchi derived polyphenol mixture, coined Oligonol (Amino Up Chemical Co., Ltd., Sapporo, Japan), significantly decreased the levels of ROS and the gene expression level of superoxide dismutase (SOD) in white and brown mouse adipocytes. The Litchi polyphenol mixture also attenuated the gene expression of the adipokines TNF-α, MCP-1, PAI-1, adiponectin and leptin in white adipocytes, all of which strongly contribute to the pathogenesis of obesity-associated metabolic syndrome (Sakurai et al., 2008). Thus, the Litchi polyphenol mixture has marked promise in preventing and alleviating obesity-induced metabolic syndrome.

3.2. Durian

Durian is widely distributed in Southeast Asia and is considered as “the king of fruits.” Durian (*Durio zibethinus*) commonly grows up to 30 cm long and 15 cm in diameter. Hundred grams of the edible portion of durian contains water (64.99 g), protein (1.47 g), lipids (5.33 g), ash (1.12 g) and carbohydrate (27.09 g), fiber (3.08 g) (Table 1). Although only a small number of studies have been conducted to explore the anti-diabetic and anti-obesity potential of durian, these studies show that durian can be further explored to detail its anti-diabetic and anti-obese potential. Durian exhibits potential effects on metabolic parameters in human and animal models (Roongpisuthipong, Banphotkasem, Komindr, & Tanphaichitr, 1991; Leontowicz et al., 2007; Toledo et al., 2008). When rats were fed durian in addition to a cholesterol enriched diet (1% cholesterol), it positively influenced the plasma lipid profile, plasma glucose and antioxidant activity. These metabolically beneficial effects of durian might be due to the higher contents of bioactive compounds with various biological activities, such as metabolic enhancer and antioxidant. This suggests that durian consists of a few critical bioactive components that can be further evaluated for hypoglycemic and anti-hyperlipidemic effects (Leontowicz et al., 2007). Interestingly, in a small clinical trial, durian has been shown to improve glucose homeostasis by altering insulin secretion and its action (Roongpisuthipong et al., 1991). After ingestion of durian, the insulin response curve of 10 diabetic patients was significantly improved compared to the ingestion of other fruits (mango, pineapple, banana, rambutan) and control (no fruit) (Roongpisuthipong et al., 1991). Various durian cultivars have also been shown to possess anti-oxidant capacities due to the relatively high level of total polyphenols (Toledo et al., 2008). This anti-oxidant property of durian and its components can be useful for prevention of oxidative stress mediated induction of diabetic and obesity complications. Studies delineating the anti-inflammatory properties of durian are yet to be reported. Although preliminary research of the durian fruit demonstrate fairly promising anti-diabetic and anti-obesity effects, in-depth studies are essential to solidify durian and identify specific components that can be used as therapeutic complements to combat diabetes, obesity and their associated metabolic derangements (Table 2).

3.3. Jackfruit

The jackfruit, (*Artocarpus heterophyllus*), is native to Western Ghats in India and is widely prevalent throughout the Southeast Asian region. It is rich in phenolic compounds such as flavonoids, stilbenoids and arylbenzofurons (Hakim et al., 2006). A 100 g edible portion of jackfruit contains water (73.23 g), protein (1.47 g), lipids (0.3 g), ash (1 g), carbohydrates (24.01 g), fiber (1.6 g) and Vitamin A (297 IU). A considerable number of studies have explored various health benefits of jackfruit, as reviewed elsewhere (Jagtap & Bapat, 2010). Although research exploring the detailed anti-obesity and anti-diabetic effects of jackfruit is fairly naïve, there are strong preliminary results that suggest the important effects of jackfruit and its components to ameliorate diabetes and obesity. In one study, the extracts of jackfruit (at an oral dosage of 20 g/kg of starting material) significantly improved glucose tolerance in both normal and diabetic patients (Fernando, Wickramasinghe, Thabrew, Ariyananda, & Karunanayake, 1991). Studies have also explored the anti-inflammatory role of jackfruit, which can be important for the prevention of the progression of obesity-associated low grade inflammation and its complications. Phytochemical investigations of ethyl acetate extracts of jackfruit led to the isolation of the phenolic compound artocarpesin [5,7,2′,4′-tetrahydroxy-6-(3-methylbut-3-enyl) flavone], which was further shown to possess potent anti-inflammatory effects in RAW264.7 murine macrophage cells by suppressing lipopolysaccharide (LPS) induced production of nitric oxide (NO) and prostaglandin E 2 (PGE2) (Vuolteenaho et al., 2009). NO and PGE2 are potential inflammatory molecules and play important roles in the pathogenesis of the low-grade state of inflammation associated with obesity and diabetic complications (Vuolteenaho et al., 2009). Further, artocarpesin significantly suppressed LPS-induced inflammation by reducing NO synthesizing enzyme [inducible nitric oxide synthase (iNOS)] and PGE2 producing enzyme [cyclooxygenase 2 (COX2)] protein expressions (Fang, Hsu, & Yen, 2008).

Moreover, the antioxidant capacity of jackfruit is fairly well established (Feng et al., 1998; Soong & Barlow, 2004; Jagtap & Bapat, 2010). The ethanolic extracts of jackfruit were shown to have DPPH scavenging activity (IC50 410 μg/ml). The antioxidant characteristics of prenylflavones from jackfruit inhibited ferric-induced lipid peroxidation in rat brain homogenate. Cycloheterophyllin scavenged 1,1-diphenyl-2-picrylhydrazyl (DPPH), and artonins A and B scavenged hydroxyl and peroxyl radicals that were generated by 2,2′-azobis (2-amidinopropane) dihydrochloride and the Fe^{3+}–ascorbate–EDTA–H_2O_2 system (Feng et al., 1998). Interestingly, the seeds of jackfruit demonstrate much higher antioxidant capacities than the edible portion (Soong & Barlow, 2004; Jagtap & Bapat, 2010).

3.4. Mangosteen

The mangosteen fruit, (*Garcina mangostana*), grows on tropical trees in India, Myanmar, Malaysia, Philippines, Sri Lanka, and Thailand. A 100 g edible portion of mangosteen contains water (80.94 g), protein (0.41 g), lipids (0.58 g), ash (0.16 g), carbohydrates (17.91 g) and fibers (1.8 g) (Table 1). Mangosteen fruit has long been used throughout Southeast Asia as a medical plant for a wide variety of treatments, including specific diabetic complications. Low grade inflammation in white adipose tissue (WAT) plays an important role in the pathophysiology of obesity and its associated complications. A vast number of studies have demonstrated the anti-inflammatory properties of mangosteen. In a clinical study, mangosteen juice exhibited potential anti-inflammatory potential. Udani, Singh, Barrett, and Singh (2009) conducted an 8 week randomized, double blind, placebo-controlled trial with 40 subjects and a proprietary mangosteen juice blend (XanGo Juice, 18 oz per day) was fed. Interestingly, they found that, XanGo juice significantly reduced c-reactive protein (CRP) levels in humans compared to those taking placebo (Udani et al., 2009). Also, a trend towards a decrease in BMI was noticed, which is the indicator of the anti-obese potential of mangosteen juice. Although mangosteen juice has shown preliminary anti-inflammatory and anti-obese (decreased BMI) potential, larger and more defined studies are required to establish mangosteen's benefits in prevention/treatment of obesity and diabetes, and their associated life threatening complications. Further research exploring the role of mangosteen *in-vitro* demonstrates that mangosteen inhibits key features that are critical for inflammatory cytokine production in WAT. Primary human adipocytes treated with xanthones, the major bioactive compounds found in mangosteen, demonstrated reduced LPS-induced expression of pro-inflammatory genes (i.e. TNF-α, IL-6, IFN-γ and IL-10) (Bumrungpert et al., 2009; Bumrungpert et al., 2010). In RAW264.7 macrophage cells, mangosteen extract, α-mangostin and γ-mangostin demonstrated a clear ability to inhibit NO and PGE2 release, along with the gene encoding iNOS and COX-2 (Tewtrakul, Wattanapiromsakul, & Mahabusarakam, 2009).

In addition, the antioxidant compounds of mangosteen are well documented in the literature. Various extracts from the fruit hull of mangosteen demonstrated antioxidative capacities that might be due to the presence of phenolic compounds (Ngawhirunpat et al., 2010). A host of xanthones isolated from mangosteen demonstrated antioxidant capacities (Jung, Su, Keller, Mehta, & Kinghorn, 2006). Mangostin (Fig. 2), one of the most potent xanthones isolated from mangosteen, exhibited a potential free radical scavenging property and protected oxidation of low density lipoprotein (Williams, Ongsakul, Proudfoot, Croft, & Beilin, 1995). α-Mangostin also demonstrated a protective effect by reducing oxidative stress in tissues during isoproterenol-induced myocardial infarction in rats (Devi Sampath & Vijayaraghavan, 2007). α-Mangostin, mangostanin, xanthones (1,2-dihydro-1,8,10-trihydroxy-2-(2-hydroxypropan-2-yl)-9-(3-methylbut-2-enyl)furo [3,2-a]xanthen-11-one and 6-deoxy-7-demethylmangostanin and 1,3,7-trihydroxy-2,8-di-(3-methylbut-2-enyl) xanthone) isolated from the fruit mangosteen all exhibited quinone reductase-inducing activity, and γ-mangostin exhibited hydroxyl radical-scavenging activity (Devi Sampath & Vijayaraghavan, 2007).

3.5. Açaí

The açaí fruit (*Euterpe oleracea*), grows on a large palm tree indigenous to South America, and serves as a major source of food to the native people of Brazil, Columbia and Suriname. It is a dark, purple, berry like fruit, and has been widely used as a medicinal agent by the indigenous people of various South American countries. A 100 g

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Table 2
Biological activities of exotic fruits and their bio-constituents.

	Anti-adipocity	Anti-hyperlipidemia/ dyslipidemia	Anti-hyperglycemia	Anti-inflammation	Anti-oxidant	Other(s)
Litchi	Decreased body weight gain, which correlates with adipocity (Guo et al., 2004).	Decreased total cholesterol, triaglycerol, free fatty acid, leptin in type II diabetic rats (Guo et al., 2004).	Decreased blood glucose in type II diabetic rats (Guo et al., 2004).	Decreased TNF-α, increased PGE2 production in type II diabetic rats (Huang & Wu, 2002; Guo et al., 2004).	Dose dependent free radical scavenging activity, decreased SOD and ROS levels in mouse adipocytes (Sakurai et al., 2008; Kong et al., 2010;	Reduced glucose induced cataract shown through aldose reductase *in-vitro* (Lee et al., 2009; Cheung et al., 2010; Obrosova et al., 2010)
Durian		Improved plasma lipid profile in rats fed cholesterol enriched diet	Decreased hyperglycemia and improved insulin response curve in NIDDM patients (Roongpisuthipong et al., 1991; Leontowicz et al., 2007)		High levels of total polyphenols results in antioxidant capacity (Toledo et al., 2008)	
Jackfruit			Improved glucose tolerance in normal and diabetic patients (Fernando et al., 1991;	Suppressed LPS induced production of nitric oxide and PGE2 in RAW264.7 murine macrophage cells (Fang et al., 2008; Vuolteenaho et al., 2009)	Ethanolic extracts possess DPPH scavenging activity, inhibited ferric induced lipid peroxidation in rat brain (Feng et al., 1998)	
Mangosteen	Significantly decreased BMI, which is an indirect measure of adipocity in human subjects (Udani et al., 2009;)	Reduced CRP levels in human subjects (Udani et al., 2009;)		Reduced LPS induced expression of proinflammatory genes (TNF-α, IL-6, etc.) in primary human adipocytes, inhibited nitric oxide and PGE2 release in RAW264.7 macrophage cells (Bumrungpert et al., 2009; Bumrungpert et al., 2010)	Xanthones such as mangostin demonstrated tremendous antioxidant capacities (Williams et al., 1995; Jung et al., 2006; Ngawhirunpat et al., 2010)	
	Adipocity	Hyperlipidemia	Hyperglycemia	Inflammation	Oxidative stress	Other
Acai	Reduced adipocity specific markers i.e. PEPCK (Sun et al., 2010)	Improved survival of Drosophila fed with a high-fat diet, improved food efficiency in female Fischer fed a hypercholesterolemic diet (Sun et al., 2010; deSouza et al., 2010)	Supresses gluconeogenic genes in high-fat diet Drosophila (Sun et al., 2010)		High contents of anthocyanins and polyphenols contribute to immense antioxidant capacity (Schauss, Wu, Prior, Ou, Huang et al., 2006; Schauss, Wu, Prior, Ou, Patel et al., 2006; Chin et al., 2008; Spada et al., 2009; deSouza et al., 2010)	
Goji	Decreased body weight in NIDDM rats (Luo et al., 2004; Zhao et al., 2005)	Improved plasma lipid profile in alloxan induced hyperlipidemic and NIDDM rats (Luo et al., 2004; Zhao et al., 2005;	Reduced blood glucose in alloxan induced diabetic rats (Luo et al., 2004)		Superoxide scavenging activity in rat liver, enhanced antioxidant markers such as SOD in healthy adults (Wu et al., 2004; Yu et al., 2006; Li, 2007; Li et al., 2007; Zhao et al., 2009)	
Pomegranate	Reduced weight gain in CD-1 male mice and ameliorate adipogenesis (McFarlin et al., 2009; Hontecillas et al., 2009)	Decreased hepatic triaglycerol and MUFA levels in OLETF rats, 4 week clinical trial improved lipid profile in hyperlipidemic subjects (Arao et al., 2004; Mirmiran et al., 2010)	Activates PPARg and PPARg downstream expression in 3T3-L1 pre-adipocytes (Hontecillas et al., 2009)	Markedly decreased expression of vascular inflammatory markers such as thrombospondin and TGF-β (de Nigris et al., 2007)	Rich in polyphenolic antioxidants, which repress oxidation-sensitive genes at the site of stress (Basu & Penugonda, 2009)	Prevented high blood pressure in Ang II diabetic rats (Mohan et al., 2010)
Avocado	Decreased body fat mass in energy restricted diet in humans (Pieterse et al., 2005)	Decreased serum total cholesterol levels in humans (Lerman-Garber et al., 1994; Pieterse et al., 2005)	Maintained glycemic control in NIDDM patients (Lerman-Garber et al., 1994)	Suppressed iNOS and COX-2 in mouse macrophage cell line (Kim, Murakami, Nakamura et al., 2000; Kim, Murakami, Takahashi et al., 2000)	Tremendous antioxidant capacity demonstrated in various models (Kim, Murakami, Nakamura et al., 2000; Kim, Murakami, Takahashi et al., 2000)	
Persimmon		Demonstrated hypolipidemic activity in STZ-induced diabetic rats (Lee, Cho et al., 2007; Lee et al., 2008)	Demonstrated hypoglyemic activity in STZ-induced diabetic rats (Matsumoto et al., 2006; Lee, Cho et al., 2007; Dewanjee, Maiti et al., 2009).	Overall protective effect against oxidative stress related inflammatory processes and diabetes (Lee, Cho et al., 2007; Lee et al., 2008)	Potent antioxidant effects in diabetic conditions (Lee, Cho et al., 2007; Lee et al., 2008; Dewanjee, Das et al., 2009; Dewanjee, Maiti et al., 2009)	

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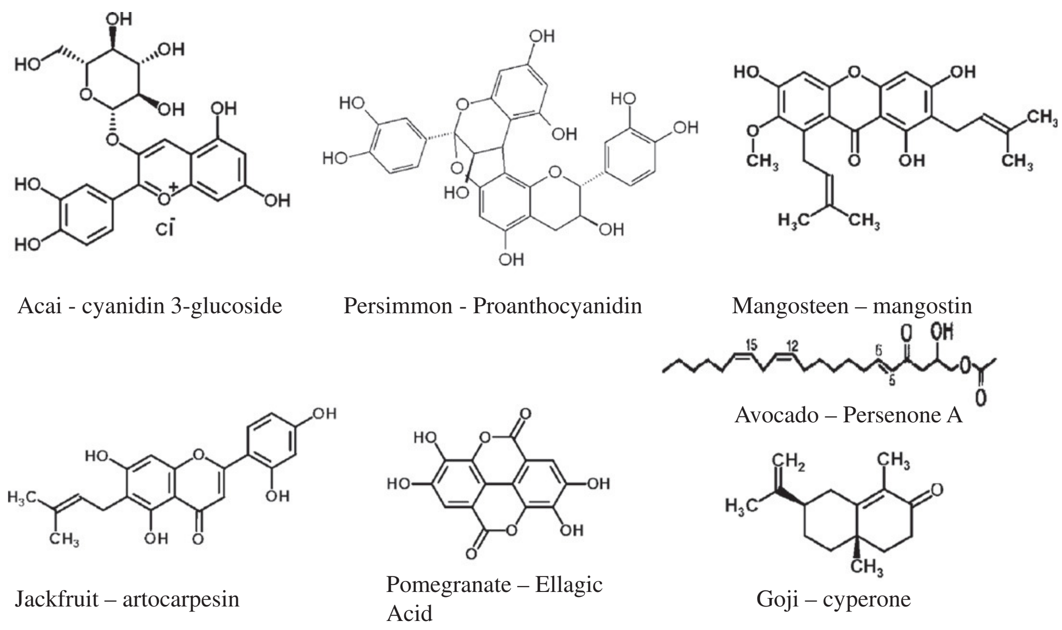

Fig. 2. Chemical structures of few bioactive components isolated from exotic fruits.

portion of açaí fruit contains water (3.4 g), protein (8.1 g), fat (32.5 g), ash (0.62 g), carbohydrates (10.98 g), and sugars (10.57 g) (Table 1). Açaí palm fruit pulp has been shown to improve the survival of *Drosophila melanogaster* fed with high-fat diet, possibly by activation of stress response pathways and suppression of the gene expression i.e. PEPCK, a key WAT marker and hepatic-gluconeogenic enzyme (Sun et al., 2010). Administration of açaí pulp in female Fischer rats fed a hypercholesterolemic diet, dramatically improved the food efficiency and reduced total and non-high-density lipoprotein cholesterol, suggesting a clear hypocholesterolemic effect (deSouza, Silva, Silva, Oliveira, & Pedrosa, 2010).

In addition, açaí possesses antioxidant and anti-inflammatory properties. Supplementation of açaí to a hypercholesterolemic diet also demonstrated decreased serum levels of end products of oxidative stress i.e. carbonyl proteins, protein sulfhydryl groups, PON-arylesterase and PON-paraoxonase activities, and increased SOD activity. These findings demonstrate that açaí pulp improves the biomarkers of physiological oxidative stress (deSouza et al., 2010). Current research strives to explore the general antioxidant capacity of specific compounds of the açaí fruit in *in-vitro*, animal, and human models. Açaí fruit possesses high contents of anthocyanins and polyphenols, both of which were shown to synergistically contribute to the majority of the fruit's antioxidant capacity in MCF-7 cells stressed with H_2O_2 (Chin, Chai, Keller, & Kinghorn, 2008). Pretreatment of frozen açaí fruit pulp on cerebral cortex, hippocampus, and cerebellum of rats treated with the oxidizing agent H_2O_2 significantly decreased H_2O_2 induced damage of both lipids and proteins in all tissues. In addition, açaí was able to reduce SOD and catalase (CAT) to basal levels. Overall, there was a negative correlation between total polyphenol content of açaí and levels of lipid and protein damage, clearly indicating the involvement of polyphenols in the demonstrated antioxidant activity (Spada et al., 2009). In an acute (24 h) human trial of 11 subjects, administration of açaí juice (7 mL/kg) significantly increased plasma antioxidant capacity, and suppressed generation of reactive oxygen species (Mertens-Talcott et al., 2008).

However, although several anthocyanins and various flavonoids have been reported and well studied in the açaí berry, the major phytoconstituents contributing to the antioxidant capacity are yet to be identified. Of the anthocyanin and polyphenolic compounds present in açaí, cyanidin 3-glucoside (1040 mg/L) was the predominant anthocyanin that contributed to the fruit's antioxidant capacity (Del-Pozo-Insfran, Brenes, & Talcott, 2004). However, a later published study found that cyanidin 3-glucoside contributed to less than 10% of the açaí's antioxidant activity, suggesting that unidentified compounds are responsible for the majority of its antioxidant capacity (Lichtenthäler et al., 2005; Schauss, Wu, Prior, Ou, Huang et al., 2006; Schauss, Wu, Prior, Ou, Patel et al., 2006). Açaí was also found to be a potential COX1 and COX2 inhibitor and exhibited potential inflammatory potential (Schauss, Wu, Prior, Ou, Huang et al., 2006; Schauss, Wu, Prior, Ou, Patel et al., 2006). A recent public analysis that examined consumer knowledge of the benefits of flavonoids calls for increased public awareness of their potent benefits (Lampila, Lieshout, Gremmen, & Lahteenmaki, 2009).

3.6. Goji

The goji fruit (*Lycium barbarum*) is a native to East Asia, and is heavily used in Traditional Chinese medicine to alleviate a spectrum of health ailments including diabetes and obesity. For the past 10 years, goji, or wolfberry, has become tremendously popular throughout the world due to its medicinal potential and as a result experienced a tremendous spike in its consumption (Potterat, 2010). There are in fact two closely related species of goji—*L. barbarum* and *Lycium chinense* (Potterat, 2010). Based on existing literature and purpose of this review, both species are considered as one goji fruit (Potterat, 2010). Goji fruit appears to have promising therapeutic applications for obesity, diabetes and the resultant complications. Goji fruit's water decoction, crude polysaccharide extracts, and purified polysaccharide fractions markedly reduced blood glucose levels, serum total cholesterol and triglyceride content and increased HDL levels in alloxan-induced diabetic or hyperlipidemic rabbits. These results clearly suggest a hypoglycemic and hypolipidemic effect of the goji fruit and its constituents (Luo, Cai, Yan, Sun, & Corke, 2004). In addition, it has been found that goji fruit administration decreased body weight, plasma insulin levels, and increased the insulin sensitive index in diabetic rats (Zhao, Li, & Xiao, 2005). Subsequent studies demonstrated that this effect is possibly mediated by increasing the cell-surface level of GLUT-4 and improving GLUT-4 trafficking and insulin signaling (Zhao et al., 2005).

Goji fruit also possesses potent antioxidant and cardio-protective effects. A plethora of literature is available documenting the antioxidant effects of goji in diverse models (Jia, Dong, Wu, Ma, & Shi, 1998; Huang, Lu, Shen, & Lu, 1999; Li, Yang, Ren, & Wang, 2002). In rat liver homogenate, goji fruit extract showed an inhibitory effect on iron-chloride induced lipid peroxidation and a superoxide scavenging activity (Wu, Ng, & Lin, 2004). Further, goji polysaccharide treatment (10 mg/kg) for 4 weeks resulted in decreased levels of blood glucose, malondialdehyde (MDA) and NO, while increased levels of SOD in the serum of fasting rats. The study thus suggests that goji is able to regulate glucose metabolism and homeostasis, and render significant protection from diabetes-induced oxidative stress-mediated complications (Wu, Guo, & Zhao, 2006). In healthy adults, goji may have antioxidative effects by enhancing endogenous antioxidant markers such as SOD, glutathione peroxidase (GSH-Px) and lipid peroxidation (Amagase, Sun, & Borek, 2009). Recent research establishes the antioxidant capacity of goji in multiple organs and stress models, and revolves around exploring the role that specific polysaccharides play in ameliorating obesity and diabetes induced oxidative stress (Yu, Ho, So, Yuen, & Chang, 2006; Li, 2007; Li, Ma, & Liu, 2007; Zhao, Li, Li, & Zhang, 2009).

3.7. Pomegranate

The pomegranate (*Punica garanatum L.)* is an ancient fruit native to regions from the Himalayas in northern India to Iran. In recent years, however, cultivation of pomegranate has disseminated throughout many dry regions of the world, including parts of the United States. The fruit itself has a distinctive rich red, leathery skin and can grow up to 13 cm. Inside the fruit are many seeds covered by little amounts of red juice, each separated by a membranous white pericarp. A 100 g edible portion of pomegranate contains water (77.93 g), protein (1.67 g), lipids (1.17 g), ash (0.53 g), carbohydrates (18.7 g), fiber (4 g) and sugars (13.67 g). Pomegranate has been heavily used in various ancient medicines, such as Ayurveda, for treatment of diabetes. As a result of its rapidly increasing production and consumption throughout the world, a considerable amount of recent research has explored the potential of pomegranate to fight for obesity and diabetes. A study in CD-1 male mice showed that consumption of pomegranate seed oil reduced weight gain, improved key markers that lead to the development of type-2 diabetes, and improved insulin sensitivity—all suggesting a diminished development to type-2 diabetes (McFarlin, Strohacker, & Kueht, 2009). Experiments in 3T3-L1 pre-adipocytes demonstrated that punicic acid, a conjugated linolenic acid found in pomegranate, activates peroxisome proliferator-activated receptor-gamma (PPAR-γ), an important target of insulin action and energy metabolism. Pucinic acid also augmented PPAR-γ downstream gene expression, and demonstrates an impaired ability to alleviate the pathogenesis of diabetes in PPAR-γ knockdown immune cells (Hontecillas, O'Shea, Einerhand, Diguardo, & Bassaganya-Riera, 2009). This suggests that pomegranate may be a natural complement to the synthetic thiazolidinediones (anti-diabetic drugs and PPAR-γ agonists), and alleviate pathogenesis of obesity and diabetes through a PPAR-γ mediated mechanism. In the Otsuka Long–Evans Tokushima Fatty (OLETF) rat model, pomegranate seed oil rich in punicic acid significantly decreased hepatic triacylglycerol contents and levels of monounsaturated fatty acid (MUFA), which can be preventive for development of hepatic steatosis (Arao et al., 2004). In obese Zucker rats, a model of metabolic syndrome, supplementation with pomegranate fruit extract and juice markedly decreased expression of vascular inflammatory markers such as thrombospondin and TGF-β (de Nigris et al., 2007). Also, a 4 week clinical trial administering 400 mg of pomegranate seed oil twice a day in hyperlipidemic subjects significantly improved the lipid profile as shown by a decreased triglyceride: HDL cholesterol ratio (Mirmiran, Fazeli, Asghari, Shafiee, & Azizi, 2010). Furthermore, pomegranate has shown dramatic antioxidant potential. It has been shown that pomegranate fruit extract, which is rich in polyphenolic antioxidants, represses the expression of oxidation-sensitive genes at the site of stress. More recently, studies show that pomegranate juice extract may prevent high blood pressure induced by Angiotensin II in diabetic rats by ameliorating oxidative stress and inhibiting Angiotensin-converting enzyme (ACE) activity (Mohan, Waghulde, & Kasture, 2010). Research is also heading towards development of a synergistic combination of various extracts. Recently, Fenercioglu, Saler, Genc, Sabuncu, and Altuntas (2010) demonstrated antagonizing effects on oxidative stress and lipid peroxidation of a supplement containing pomegranate extract, green tea extract, and absorbic acid in type 2 diabetic patients. All the above mentioned results clearly suggest that pomegranate can play an important role in the prevention of diabetes, obesity and their associated complication. Basis on these findings it can be suggested that pomegranate can be considered as a rational complementary therapeutic agent to ameliorate obesity, diabetes and the resultant metabolic syndrome. A thorough review of biological properties of pomegranate has been recently published elsewhere (Basu & Penugonda, 2009).

3.8. Avocado

Avocado (*Persea americana*) is a fruit native to the Caribbean, Mexico, South America and Central America. A 100 g edible portion contains water (73.23 g), protein (2 g), lipids (14.66 g), ash (1.58 g), carbohydrates (8.53 g), fibers (6.7 g) and sugars (0.66 g) (Table 1). Although many claims have been made about the unhealthy effects of avocados, key research debunks the myth that avocados are fattening and must be avoided in any sort of energy-restricted diet. Surprising data from a clinical trial came out that, the feeding of 55 subjects with 200 g/day of avocado for 6 weeks with an energy restricted diet dramatically decreased demonstrated body weight, body mass index and percentage body fat, suggesting that consumption of avocado plays a role in regulating energy homeostasis and maintains body weight balance (Pieterse et al., 2005). Indeed, the MUFAs highly present in avocado might be responsible agents showing an improved lipid profile and adequately maintained glycemic control in patients with type 2 diabetes (Lerman-Garber, Ichazo-Cerro, Zamora-González, Cardoso-Saldaña, & Posadas-Romero, 1994). In another study, MUFAs decreased serum total cholesterol levels by 17%, LDL-cholesterol by 22%, triglycerides by 11%, and increased HDL-cholesterol by 11% in mild hypercholesterolemic patients (López Ledesma et al., 1996). Furthermore, the antioxidant and anti-inflammatory capacities of avocado are well established, suggesting that incorporation of avocado into the diet might ameliorate the pathogenesis of metabolic syndrome (Kim, Murakami, Nakamura et al., 2000). Persenone A, a compound isolated from the avocado fruit, nearly wholly suppressed protein expression of iNOS and COX-2 in RAW 264.6 mouse macrophage cells (Kim, Murakami, Takahashi et al., 2000). Overall, the results from studies exploring the role of avocado in various models can be well correlated with the preventive effects of avocado to obesity and diabetes. However, it is critical to note that an optimal quantity of avocado must be consumed for the observed anti-diabetic and anti-obese effects, which is true to any natural components or food function.

3.9. Persimmon

The persimmon fruit (*Diospyros digyna*), is native to Japan and China. The published literature demonstrates a potent anti-diabetic and anti-obesity capacity of the persimmon fruit (Lee, Cho, Tanaka, & Yokozawa, 2007; Dewanjee, Das, Sahu, & Gangopadhyay, 2009; Matsumoto, Watanabe, Ohya, & Yokoyama, 2006). Proanthocyanidin is the major component isolated from persimmon peel and has been demonstrated to play a role in obesity and diabetes. Administration of proanthocyanidin from the peel of persimmon in streptozotocin (STZ)-induced diabetic rats decreased the elevation of lipid peroxidation, suppressed generation of reactive oxygen species, decreased serum glucose, glycosylated hemoglobin (HbA1c), serum urea nitrogen, urinary protein, and renal advanced glycation endproducts under diabetic conditions. This clearly suggest an overall protective effect against oxidative stress-related inflammatory processes and diabetes

(Lee, Cho et al., 2007). In addition, administration of persimmon exhibited dose dependent hypoglycemic and hypolipidemic activity in STZ-induced diabetic rats. In addition, the activity of SOD, catalase, and glutathione content was increased in the liver and kidney, which is highly correlated with preventing oxidative stress mediated diabetic complications in this severe diabetic model (Dewanjee, Das et al., 2009). In the diet-induced obesity mouse model, feeding of persimmon significantly attenuated the elevation in plasma lipids (total cholesterol, triglyceride, LDL cholesterol) (Matsumoto et al., 2006). In male *db/db* mice (leptin receptor deficient mice), administration of proanthocyanidins reduced hyperglycemia through reduction of serum glucose and glycosylated protein levels, and hyperlipidemia (reduction of triglyceride, total cholesterol and non-esterified fatty acids) (Lee, Cho, & Yokozawa, 2008). Polymers from proanthocyanidins of persimmon exhibited a strong inhibitory effect on α-amylase, while oligomers exerted a stronger protective activity against α-glucosidase activity and AGE formation, suggesting that oligomers may have more potential as anti-diabetic agents (Lee, Kim, Cho, & Yokozawa, 2007). Proanthocyanidins from persimmon also attenuated the increased oxidative stress in *db/db* mice by suppressing lipid peroxidation, ROS, protein expression of iNOS and COX-2, and increasing the reduced glutathione/oxidized ratio (Lee et al., 2008). Another study in Wistar albino diabetic rats also suggests persimmon is rendered a hypoglycemic effect from its antioxidant defense mechanisms (Dewanjee, Maiti, Sahu, Dua, & Mandal, 2009). Tanin, also isolated from persimmon pulp, was demonstrated to have hydroxyl radical scavenging antioxidant capacities (Gu et al., 2008). Overall, the studies suggest that polymerization of proanthocyanidin has an important effect on its ability to combat the obese and diabetic phenotype, and that its oligomers are the more potent and promising compounds.

3.10. Guava

According to ancient Chinese Medicine, guava (*Psidium guajava*) is highly useful in the treatment of diabetes and other chronic diseases. However, the results regarding the anti-diabetic potential of guava fruit are ambiguous, clearly suggesting the need for further characterization for its hypoglycemic effects (Cheng & Yang, 1983; Roman-Ramos, Flores-Saenz, & Alarcon-Aguilar, 1995).

In alloxan-treated diabetic mice, intraperitoneal administration of 1 g/kg of guava juice dramatically reduced the blood glucose levels (Cheng & Yang, 1983). However, other studies have over counted with a non-significant effect of guava treatment on glucose homeostasis in rabbits (Roman-Ramos et al., 1995). But here this might be because of the difference in doses and duration of treatment. In STZ-induced diabetic rats, oral administration of guava fruit peel extract actually induced a hyperglycemic effect, suggesting that guava fruit peel should be peeled before eating in diabetic patients (Rai, Singh, Kesari, & Watal, 2007). In contrast, another study found that oral administration of guava fruit peel extract demonstrated significant hypoglycemic and hypolipidemic effects in the same model (Rai, Mehta, & Watal, 2010). Hence, it is highly evident that the literature is inconclusive regarding the hypoglycemic and hypolipidemic effects of guava; larger studies in diverse diabetic and obesity models are critical to solidly characterize the role of guava in glucose and energy homeostasis. Moreover chemical composition analysis of guava constituents will give further opportunity to develop a unique anti-diabetic and anti-obese component.

3.11. Other exotic fruits (recent findings)

In an effort to include the most up-to-date research on the role of exotic fruits in obesity and diabetes, a brief summary of ongoing research (articles in press) is presented. A recent study demonstrated a potential antioxidant capacity for raw *Spondias pinnata* K., an exotic fruit of India. The authors suggest *S. pinnata* K. may contain neutraceutical and therapeutic potential for chronic diseases like diabetes (Satpathy, Tyagi, Gupta, in press). Yang et al. review the potent therapeutic effects of the Longan fruit, emphasizing its potent antioxidant and anti-glycated activity, hinting a role in prevention of diabetic complications (Yang, Jiang, Shi, Chen, Ashraf, in press). A review of the Kokum fruit, which is widely used in many Ayurvedic therapies, displays its evident anti-diabetic and anti-obese effects (Baliga, Pai, et al., in press; Baliga, Bhat et al., in press). In addition to lowering circulating glucose levels in streptozotocin-induced type 2 diabetic rats, Kokum has been shown to possess free radical scavenging properties and anti lipid peroxidation (Baliga, Pai, et al., in press; Baliga, Bhat et al., in press). Furthermore, hydroxycitric acid and cyaniding 3-glucoside were isolated and found to have potent anti-obesity effects through mechanistic pathways described in the review (Baliga, Pai, et al., in press; Baliga, Bhat et al., in press). *Copaifera langsdorffii* Desf., the fruit of which is widely distributed in Brazil, demonstrate potential cholesterol and glucose-lowering effects (lower LDL, HDL, triglycerides, blood glucose, liver and fecal lipids) in male rats fed a 10% fruit supplemented diet (Esteves et al., in press). The Bakul fruit, native to India, has been shown to have many anti-diabetic effects; oral administration of the extract resulted in a significant decrease in blood glucose and glycosylated hemoglobin levels, and an increase in serum insulin levels, along with other positive effects (reviewed by Baliga et al.) (Baliga, Pai, et al., in press; Baliga, Bhat et al., in press). Recently Hervert-Hernández, García, Rosado, Goñi (in press) reported that less consumption of fruits and vegetables is strongly related to obesity in women in rural Mexico. They suggested that this might be because of an insufficient supply of dietary bioactive polyphenols and their anti-oxidant potential. Another study conducted by Arancibia-Avila et al. (in press) screened-out various bioactive compounds with anti-oxidant properties, which suggest that these compounds can be further studied for their role in obesity and diabetes pathophysiology. Ongoing research in the field is robust, and the potential of exotic fruits to aid as therapeutics for metabolic conditions is promising.

4. Effects of exotic fruit consumption in fatty liver disease

Fatty liver disease is characterized by extra accumulation of fat droplets in the liver, and this condition is independent of alcohol consumption and termed Non-Alcoholic Fatty Liver Disease (NAFLD) (Krawczyk, Bonfrate, & Portincasa, 2010). Fatty liver disease is common in obesity and type 2 diabetes and is considered a major cause of hepatic insulin resistance. Hepatic insulin resistance plays an important role to induce hyperglycemia in type 2 diabetic patients through increased hepatic endogenous glucose production (Lockman & Nyirenda, 2010). The major cause of fatty liver disease is consumption of high fat/calorie diet. Hence the low calorie and high fiber diet is highly recommended for healthy liver function (Yki-Järvinen, 2010). Exotic fruits contain higher amount of fibers and various other bio-constituents that can enhance liver function and protect this precious organ from obesity/diabetes induced metabolic derangements. For example, Oh et al. (2005) described the beneficial effects of *P. guajava* (guava) in the type 2 diabetic and fatty liver disease phenotype in $Lep^{db/db}$ mice. Interestingly, they found that extract of *P. guajava* (10 mg/ kg body weight) significantly decreased blood glucose levels and accumulation of fat droplets in liver tissues of $Lep^{db/db}$ mice. This effect was mediated through the inhibition of protein tyrosine phosphatase 1B (a negative regulator of insulin signaling). Recently, Abidov et al. (2010) found that the combination of pomegranate seed oil (PSO) and brown marine algae fucoxanthin (Xanthigen) significantly reduced occurrence of fatty liver disease in human subjects. The findings were characterized by significantly decreased body weight, waist circumference, hepatic fat content, triglyceride and improved liver function tests. The mechanism of Xanthigen for these beneficial effects were through increased whole body energy expenditure that was characterized by increased resting energy expenditure in Xanthigen fed subjects (Abidov, Ramazanov, Seifulla, & Grachev, 2010).

5. Conclusions

Exotic fruits have various bioactive components with potential health benefits, including anti-diabetic, anti-obese, anti-oxidant and anti-inflammatory. Alone or together, a combination of these health beneficial effects rendered by the reported exotic fruits is very important to prevent the development of complex pathophysiology of obesity and diabetes. The whole fruit(s) and their bio-constituents can act on various pathophysiological targets of obesity and diabetes. However, the anti-diabetic and anti-obese effects of the exotic fruits reviewed here and their bioactive constituents are clearly under-studied. Further large scale and defined basic and clinical studies are critical to determine optimal dietary regimens to achieve the desired beneficial health effects. In addition, components of exotic fruits are clearly attractive targets for the scientific community to develop novel anti-diabetic and anti-obese compounds for future treatment/prevention of these life-threatening diseases.

References

Abidov, M., Ramazanov, Z., Seifulla, R., & Grachev, S. (2010). The effects of Xanthigen in the weight management of obese premenopausal women with non-alcoholic fatty liver disease and normal liver fat. *Diabetes, Obesity & Metabolism*, *12*, 72–81.

Amagase, H., Sun, B., & Borek, C. (2009). *Lycium barbarum* (goji) juice improves in vivo antioxidant biomarkers in serum of healthy adults. *Nutrition Research*, *29*, 19–25.

Arancibia-Avila, P., Toledo, F., Leontowicz, H., Leontowicz, M., Suhaj, M., Pasko, P., Werner, E., Gorinstein, S. (in press). Partial Characterization of a new kind of Chilean Murtilla-like berries. Food Research International.

Arao, K., Wang, Y. M., Inoue, N., Hirata, J., Cha, J. Y., Nagao, K., et al. (2004). Dietary effect of pomegranate seed oil rich in 9cis, 11trans, 13cis conjugated linolenic acid on lipid metabolism in obese, hyperlipidemic OLETF rats. *Lipids in Health and Diseases*, *3*, 24.

Babio, N., Bulló, M., & Salas-Salvadó, J. (2009). Mediterranean diet and metabolic syndrome: The evidence. *Public Health Nutrition*, *12*, 1607–1617.

Baliga, M., Pai, R., Bhat, H., Palatty, P., Boloor, R. (in press) Chemistry and medicinal properties of the Bakul (*Mimusops elengi* Linn): A review. Food Research International.

Baliga, M., Bhat, H., Pai, R., Boloor, R., Palatty, P. (in press) The chemistry and medicinal uses of the underutilized Indian fruit tree *Garcinia indica* Choisy (kokum): A review. Food Research International.

Basu, A., & Penugonda, K. (2009). Pomegranate juice: A heart-healthy fruit juice. *Nutrition Review*, *67*, 49–56.

Bumrungpert, A., Kalpravidh, R. W., Chitchumroonchokchai, C., Chuang, C. C., West, T., Kennedy, A., et al. (2009). Xanthones from mangosteen prevent lipopolysaccharide-mediated inflammation and insulin resistance in primary cultures of human adipocytes. *The Journal of Nutrition*, *139*, 1185–1191.

Bumrungpert, A., Kalpravidh, R. W., Chuang, C. C., Overman, A., Martinez, K., Kennedy, A., et al. (2010). Xanthones from mangosteen inhibit inflammation in human macrophages and in human adipocytes exposed to macrophage-conditioned media. *The Journal of Nutrition*, *140*, 842–847.

Ceylan-Isik, A. F., Fliethman, R. M., Wold, L. E., & Ren, J. (2008). Herbal and traditional Chinese medicine for the treatment of cardiovascular complications in diabetes mellitus. *Current Diabetes Review*, *4*, 320–328.

Cheng, J. T., & Yang, R. S. (1983). Hypoglycemic effect of guava juice in mice and human subjects. *The American Journal of Chinese Medicine*, *11*, 74–76.

Cheung, N., Mitchell, P., & Wong, T. Y. (2010). Diabetic retinopathy. *Lancet*, *376*, 124–136.

Chin, Y. W., Chai, H. B., Keller, W. J., & Kinghorn, A. D. (2008). Lignans and other constituents of the fruits of *Euterpe oleracea* (Açaí) with antioxidant and cytoprotective activities. *Journal of Agricultural and Food Chemistry*, *56*, 7759–7764.

Connell, B. S. O. (2001). Complementary and integrative medicine: Emerging therapies for diabetes, Part 2: Preface. *Diabetes Spectrum*, *14*, 196–197.

de Nigris, F., Balestrieri, M. L., Williams-Ignarro, S., D'Armiento, F. P., Fiorito, C., Ignarro, L. J., et al. (2007). The influence of pomegranate fruit extract in comparison to regular pomegranate juice and seed oil on nitric oxide and arterial function in obese Zucker rats. *Nitric Oxide*, *17*, 50–54.

Del-Pozo-Insfran, D., Brenes, C. H., & Talcott, S. T. (2004). Phytochemical composition and pigment stability of Açai (*Euterpe oleracea* Mart.). *Journal of Agricultural and Food Chemistry*, *52*, 1539–1545.

deSouza, M. O., Silva, M., Silva, M. E., Oliveira, R. P., & Pedrosa, M. L. (2010). Diet supplementation with açaí (*Euterpe oleracea* Mart.) pulp improves biomarkers of oxidative stress and the serum lipid profile in rats. *Nutrition*, *26*, 804–810.

Devi Sampath, P., & Vijayaraghavan, K. (2007). Cardioprotective effect of alpha-mangostin, a xanthone derivative from mangosteen on tissue defense system against isoproterenol-induced myocardial infarction in rats. *Journal of Biochemical and Molecular Toxicology*, *21*, 336–339.

Dewanjee, S., Das, A. K., Sahu, R., & Gangopadhyay, M. (2009). Antidiabetic activity of *Diospyros peregrina* fruit: Effect on hyperglycemia, hyperlipidemia and augmented oxidative stress in experimental type 2 diabetes. *Food Chemistry and Toxicology*, *47*, 2679–2685.

Dewanjee, S., Maiti, A., Sahu, R., Dua, T. K., & Mandal, V. (2009). Effective control of type 2 diabetes through antioxidant defense by edible fruits of *Diospyros peregrina*. *Evidence Based Complementary and Alternative Medicine Jul*, *7*, 1–6.

Esteves, E., Oliveira, L., Pires, S., Batista, A., Dessimoni-Pinto, N., Santana, R. (in press) Nutritional composition of *Copaifera langsdorffii* Desf. aril flour and its effect on serum lipids and glucose in rats. Food Research International.

Fang, S. C., Hsu, C. L., & Yen, G. C. (2008). Anti-inflammatory effects of phenolic compounds isolated from the fruits of *Artocarpus heterophyllus*. *Journal of Agricultural and Food Chemistry*, *56*, 4463–4468.

Fenercioglu, A. K., Saler, T., Genc, E., Sabuncu, H., & Altuntas, Y. (2010). The effects of polyphenol-containing antioxidants on oxidative stress and lipid peroxidation in Type 2 diabetes mellitus without complications. *Journal of Endocrinology Investigations*, *33*, 118–124.

Feng, N. K., Zhi, J., Cheng, A., Chun, N., Lin, B., & Chen, M. T. (1998). Scavenger and antioxidant properties of prenylflavones isolated from *Artocarpus heterophyllus*. *Free Radical Biology & Medicine*, *25*, 160–168.

Fernando, M. R., Wickramasinghe, N., Thabrew, M. I., Ariyananda, P. L., & Karunanayake, E. H. (1991). Effect of *Artocarpus heterophyllus* and *Asteracanthus longifolia* on glucose tolerance in normal human subjects and in maturity-onset diabetic patients. *Journal of Ethnopharmacology*, *31*, 277–278.

Foltran, F., Verduci, E., Ghidina, M., Campoy, C., Jany, K. D., Widhalm, K., et al. (2010). Nutritional profiles in a public health perspective: A critical review. *The Journal of International Medical Research*, *38*, 318–385.

Gu, H., Li, C., Xu, Y., Hu, W., Chen, M., & Wan, Q. (2008). Structural features and antioxidant activity of tannin from persimmon pulp. *Food Research International*, *41*, 208–217.

Guo, J., Li, L., Pan, J., Qiu, G., Li, A., Huang, G., et al. (2004). Pharmacological mechanism of Semen Litchi on antagonizing insulin resistance in rats with type 2 diabetes. *Zhong Yao Cai*, *27*, 435–438.

Hakim, E. H., Achmad, S. A., Juliawaty, L. D., Makmur, L., Syah, Y. M., Aimi, N., et al. (2006). Prenylated flavonoids and related compounds of the Indonesian Artocarpus (Moraceae). *Journal of Natural Medicine*, *60*, 161–184.

Hervert-Hernández, D., García, O.P., Rosado, J.L., Goñi, I. (in press). The contribution of fruits and vegetables to dietary intake of polyphenols and antioxidant capacity in a Mexican rural diet: Importance of fruit and vegetable variety. Food Research International.

Hontecillas, R., O'Shea, M., Einerhand, A., Diguardo, M., & Bassaganya-Riera, J. (2009). Activation of PPAR gamma and alpha by punicic acid ameliorates glucose tolerance and suppresses obesity-related inflammation. *Journal of the American College of Nutrition*, *28*, 184–195.

Hossain, P., Kawar, B., & Nahas, M. E. (2007). Obesity and diabetes in the developing world—A growing challenge. *The New England Journal of Medicine*, *356*, 213–215.

Huan, H. B., & Xu, J. K. (1983). The developmental pattern of fruit tissues and their correlative relationship in *Litchi chinensis* Sonn. *Scientia Horticultureae.*, *19*, 335–342.

Huang, Y., Lu, J., Shen, Y., & Lu, J. (1999). The protective effects of total flavonoids from *Lycium barbarum* L. on lipid peroxidation of liver mitochondria and red blood cell in rats. *Wei Sheng Yan Jiu*, *28*, 115–116.

Huang, C. J., & Wu, M. C. (2002). Differential effects of foods traditionally regarded as 'heating' and 'cooling' on prostaglandin E(2) production by a macrophage cell line. *Journal of Biomedical Science*, *9*, 596–606.

Jagtap, U. B., & Bapat, V. A. (2010). Artocarpus: A review of its traditional uses, phytochemistry and pharmacology. *Journal of Ethnopharmacology*, *129*, 142–166.

Jia, Y. X., Dong, J. W., Wu, X. X., Ma, T. M., & Shi, A. Y. (1998). The effect of *Lycium barbarum* polysaccharide on vascular tension in two-kidney, one clip model of hypertension. *Sheng Li Xue Bao*, *50*, 309–314.

Jung, H. A., Su, B. N., Keller, W. J., Mehta, R. G., & Kinghorn, A. D. (2006). Antioxidant xanthones from the pericarp of *Garcinia mangostana* (Mangosteen). *Journal of Agricultural and Food Chemistry*, *54*, 2077–2082.

Kim, O. K., Murakami, A., Nakamura, Y., Takeda, N., Yoshizumi, H., & Ohigashi, H. (2000). Novel nitric oxide and superoxide generation inhibitors, persenone A and B, from avocado fruit. *Journal of Agricultural and Food Chemistry*, *48*, 1557–1563.

Kim, O. K., Murakami, A., Takahashi, D., Nakamura, Y., Torikai, K., Kim, H. W., et al. (2000). An avocado constituent, persenone A, suppresses expression of inducible forms of nitric oxide synthase and cyclooxygenase in macrophages, and hydrogen peroxide generation in mouse skin. *Biosciences, Biotechnology and Biochemistry*, *64*, 2504–2507.

Kong, F., Zhang, M., Liao, S., Yu, S., Chi, J., & Wei, Z. (2010). Antioxidant activity of polysaccharide-enriched fractions extracted from pulp tissue of *Litchi chinensis* Sonn. *Molecules*, *15*, 2152–2165.

Krawczyk, M., Bonfrate, L., & Portincasa, P. (2010). Nonalcoholic fatty liver disease. *Best Practice & Research Clinical Gastroenterology*, *24*, 695–708.

Krishnaveni, M., & Mirunalini, S. (2010). Therapeutic potential of *Phyllanthus emblica* (amla): The Ayurvedic wonder. *Journal of Basic and Clinical Physiology and Pharmacology*, *21*, 93–105.

Lampila, P., Lieshout, M., Gremmen, B., & Lahteenmaki, L. (2009). Consumer attitudes towards enhanced flavonoid content in fruit. *Food Research International*, *42*, 122–129.

Lee, Y. A., Cho, E. J., Tanaka, T., & Yokozawa, T. (2007). Inhibitory activities of proanthocyanidins from persimmon against oxidative stress and digestive enzymes related to diabetes. *Journal of Nutritional Sciences and Vitaminology (Tokyo)*, *53*, 287–292.

Lee, Y. A., Cho, E. J., & Yokozawa, T. (2008). Effects of proanthocyanidin preparations on hyperlipidemia and other biomarkers in mouse model of type 2 diabetes. *Journal of Agricultural and Food Chemistry*, *56*, 7781–7789.

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Lee, Y. A., Kim, Y. J., Cho, E. J., & Yokozawa, T. (2007). Ameliorative effects of proanthocyanidin on oxidative stress and inflammation in streptozotocin-induced diabetic rats. *Journal of Agricutural and Food Chemistry*, *55*, 9395–9400.

Lee, S. J., Park, W. H., Park, S. D., & Moon, H. I. (2009). Aldose reductase inhibitors from *Litchi chinensis* Sonn. *Journal of Enzyme Inhibition and Medicinal Chemistry*, *24*, 957–959.

Leontowicz, M., Leontowicz, H., Jastrzebski, Z., Jesion, I., Haruenkit, R., Poovarodom, S., et al. (2007). The nutritional and metabolic indices in rats fed cholesterol-containing diets supplemented with durian at different stages of ripening. *Biofactors*, *29*, 123–136.

Lerman-Garber, I., Ichazo-Cerro, S., Zamora-González, J., Cardoso-Saldaña, G., & Posadas-Romero, C. (1994). Effect of a high-monounsaturated fat diet enriched with avocado in NIDDM patients. *Diabetes Care*, *17*, 311–315.

Li, X. M. (2007). Protective effect of *Lycium barbarum* polysaccharides on streptozotocin-induced oxidative stress in rats. *International Journal of Biological Macromolecules*, *40*, 461–465.

Li, X. M., Ma, Y. L., & Liu, X. J. (2007). Effect of the *Lycium barbarum* polysaccharides on age-related oxidative stress in aged mice. *Journal of Ethnopharmacology*, *111*, 504–511.

Li, G., Yang, J., Ren, B., & Wang, Z. (2002). Effect of *Lycium barbarum* L on defending free radicals of mice caused by hypoxia. *Wei Sheng Yan Jiu*, *31*, 30–31.

Lichtenthäler, R., Rodrigues, R. B., Maia, J. G., Papagiannopoulos, M., Fabricius, H., & Marx, F. (2005). Total oxidant scavenging capacities of *Euterpe oleracea* Mart. (Açaí) fruits. *International Journal of Food Science and Nutrition*, *56*, 53–64.

Liu, H., Qiu, N., Ding, H., & Yao, R. (2008). Polyphenols contents and antioxidant capacity of 68 Chinese herbals suitable for medical or food uses. *Food Research International*, *41*, 363–370.

Lockman, K. A., & Nyirenda, M. J. (2010). Interrelationships between hepatic fat and insulin resistance in non-alcoholic fatty liver disease. *Current Diabetes Review*, *6*, 341–347.

Lois, K., & Kumar, S. (2009). Obesity and diabetes. *Endocrinology and Nutrition*, *56*, S38–S42.

López Ledesma, R., Frati Munari, A. C., Hernández Domínguez, B. C., Cervantes Montalvo, S., Hernández Luna, M. H., Juárez, C., et al. (1996). Monounsaturated fatty acid (avocado) rich diet for mild hypercholesterolemia. *Archives of Medical Research*, *27*, 519–523.

Luo, Q., Cai, Y., Yan, J., Sun, M., & Corke, H. (2004). Hypoglycemic and hypolipidemic effects and antioxidant activity of fruit extracts from *Lycium barbarum*. *Life Sciences*, *76*, 137–149.

Martínez, J. A. (2006). Mitochondrial oxidative stress and inflammation: A slalom to obesity and insulin resistance. *Journal of Physiology and Biochemistry*, *62*, 303–306.

Matsumoto, K., Watanabe, Y., Ohya, M. A., & Yokoyama, S. (2006). Young persimmon fruits prevent the rise in plasma lipids in a diet-induced murine obesity model. *Biological & Pharmaceutical Bulletin*, *29*, 2532–2535.

McFarlin, B. K., Strohacker, K. A., & Kueht, M. L. (2009). Pomegranate seed oil consumption during a period of high-fat feeding reduces weight gain and reduces type 2 diabetes risk in CD-1 mice. *The British Journal of Nutrition*, *102*, 54–59.

Mertens-Talcott, S. U., Rios, J., Jilma-Stohlawetz, P., Pacheco-Palencia, L. A., Meibohm, B., Talcott, S. T., et al. (2008). Pharmacokinetics of anthocyanins and antioxidant effects after the consumption of anthocyanin-rich açaí juice and pulp (*Euterpe oleracea* Mart.) in human healthy volunteers. *Journal of Agricultural and Food Chemistry*, *56*, 7796–7802.

Metcalfe, A., Williams, J., McChesney, J., Patten, S. B., & Jetté, N. (2010 Oct 18). Use of complementary and alternative medicine by those with a chronic disease and the general population—Results of a national population based survey. *BMC Complementary and Alternative Medicine*, *10*, 58.

Mirmiran, P., Fazeli, M. R., Asghari, G., Shafiee, A., & Azizi, F. (2010). Effect of pomegranate seed oil on hyperlipidaemic subjects: A double-blind placebo-controlled clinical trial. *The British Journal of Nutrition*, *104*, 402–406.

Mohan, M., Waghulde, H., & Kasture, S. (2010). Effect of pomegranate juice on Angiotensin II-induced hypertension in diabetic Wistar rats. *Phytotherapy Research*, *2*, S196–S203.

Neligan, P. J. (2010). Metabolic syndrome: Anesthesia for morbid obesity. *Current Opinions in Anaesthesiology*, *23*, 375–383.

Ngawhirunpat, T., Opanasopi, P., Sukma, M., Sittisombut, C., Kat, A., & Adachi, I. (2010). Antioxidant, free radical-scavenging activity and cytotoxicity of different solvent extracts and their phenolic constituents from the fruit hull of mangosteen (*Garcinia mangostana*). *Pharmaceutical Biology*, *48*, 55–62.

Obrosova, I. G., Chung, S. S., & Kador, P. F. (2010). Diabetic cataracts: Mechanisms and management. *Diabetes/Metabolism Research and Reviews*, *26*, 172–180.

Oh, W. K., Lee, C. H., Lee, M. S., Bae, E. Y., Sohn, C. B., Oh, H., et al. (2005). Antidiabetic effects of extracts from *Psidium guajava*. *Journal of Ethnopharmacology*, *96*, 411–415.

Pieterse, Z., Jerling, J. C., Oosthuizen, W., Kruger, H. S., Hanekom, S. M., Smuts, C. M., et al. (2005). Substitution of high monounsaturated fatty acid avocado for mixed dietary fats during an energy-restricted diet: Effects on weight loss, serum lipids, fibrinogen, and vascular function. *Nutrition*, *21*, 67–75.

Potterat, O. (2010). Goji (*Lycium barbarum* and *L. chinense*): Phytochemistry, pharmacology and safety in the perspective of traditional uses and recent popularity. *Planta Medicine*, *76*, 7–19.

Prospective Studies Collaboration (2009). Body–mass index and cause-specific mortality in 900000 adults: Collaborative analyses of 57 prospective studies. *Lancet*, *373*, 1083–1096.

Rai, P. K., Mehta, S., & Watal, G. (2010). Hypolipidaemic & hepatoprotective effects of *Psidium guajava* raw fruit peel in experimental diabetes. *The Indian Journal of Medical Research*, *131*, 820–824.

Rai, P. K., Singh, S. K., Kesari, A. N., & Watal, G. (2007). Glycaemic evaluation of *Psidium guajava* in rats. *The Indian Journal of Medical Research*, *126*, 224–227.

Roman-Ramos, R., Flores-Saenz, J. L., & Alarcon-Aguilar, F. J. (1995). Anti-hyperglycemic effect of some edible plants. *Journal of Ethnopharmacology*, *48*, 25–32.

Roongpisuthipong, C., Banphotkasem, S., Komindr, S., & Tanphaichitr, V. (1991). Postprandial glucose and insulin responses to various tropical fruits of equivalent carbohydrate content in non-insulin-dependent diabetes mellitus. *Diabetes Research and Clinical Practices*, *14*, 123–131.

Sakurai, T., Nishioka, H., Fujii, H., Nakano, N., Kizaki, T., Radak, Z., et al. (2008). Antioxidative effects of a new lychee fruit-derived polyphenol mixture, oligonol, converted into a low-molecular form in adipocytes. *Biosciences, Biotechnology and Biochemistry*, *72*, 463–476.

Satpathy, G., Tyagi Y., Gupta, R. (in press) Preliminary evaluation of nutraceutical and therapeutic potential of raw *Spondias pinnata* K., an exotic fruit of India. Food Research International.

Schauss, A. G., Wu, X., Prior, R. L., Ou, B., Huang, D., Owens, J., et al. (2006). Antioxidant capacity and other bioactivities of the freeze-dried Amazonian palm berry, *Euterpe oleraceae* mart. (Açaí). *Journal of Agricultural and Food Chemistry*, *54*, 8604–8610.

Schauss, A. G., Wu, X., Prior, R. L., Ou, B., Patel, D., Huang, D., et al. (2006). Phytochemical and nutrient composition of the freeze-dried amazonian palm berry, *Euterpe oleraceae* mart. (Açaí). *Journal of Agricultural and Food Chemistry*, *54*, 8598–8603.

Soong, Y. Y., & Barlow, P. J. (2004). Antioxidant activity and phenolic content of selected fruit seeds. *Food Chemistry*, *88*, 411–417.

Spada, P. D., Dani, C., Bortolini, G. V., Funchal, C., Henriques, J. A., & Salvador, M. (2009). Frozen fruit pulp of *Euterpe oleraceae* Mart. Açaí prevents hydrogen peroxide-induced damage in the cerebral cortex, cerebellum, and hippocampus of rats. *Journal of Medicinal Food*, *12*, 1084–1088.

Spiteller, G. (1993). Review: On the chemistry of oxidative stress. *Journal of Lipid mediators*, *7*, 199–221.

Sun, X., Seeberger, J., Alberico, T., Wang, C., Wheeler, C. T., Schauss, A. G., et al. (2010). Açai palm fruit (*Euterpe oleracea* Mart.) pulp improves survival of flies on a high fat diet. *Experimental Gerontology*, *45*, 243–251.

Tewtrakul, S., Wattanapiromsakul, C., & Mahabusarakam, W. (2009). Effects of compounds from *Garcinia mangostana* on inflammatory mediators in RAW264.7 macrophage cells. *Journal of Ethnopharmacology*, *121*, 379–382.

Toledo, F., Arancibia-Avila, P., Park, Y. S., Jung, S. T., Kang, S. G., Heo, B. G., et al. (2008). Screening of the antioxidant and nutritional properties, phenolic contents and proteins of five durian cultivars. *International Journal of Food Science and Nutrition*, *59*, 415–427.

Udani, J. K., Singh, B. B., Barrett, M. L., & Singh, V. J. (2009). Evaluation of Mangosteen juice blend on biomarkers of inflammation in obese subjects: A pilot, dose finding study. *Nutrition Journal*, *8*, 48.

Vuolteenaho, K., Koskinen, A., Kukkonen, M., Nieminen, R., Päivärinta, U., Moilanen, T., et al. (2009). Leptin enhances synthesis of proinflammatory mediators in human osteoarthritic cartilage—Mediator role of NO in leptin-induced PGE2, IL-6, and IL-8 production. *Mediators of Inflammation*, 345838.

Williams, P., Ongsakul, M., Proudfoot, J., Croft, K., & Beilin, L. (1995). Mangostin inhibits the oxidative modification of human low density lipoprotein. *Free Radical Research*, *23*, 175–184.

Wu, H., Guo, H., & Zhao, R. (2006). Effect of *Lycium barbarum* polysaccharide on the improvement of antioxidant ability and DNA damage in NIDDM rats. *Yakugaku Zasshi*, *126*, 365–371.

Wu, S. J., Ng, L. T., & Lin, C. C. (2004). Antioxidant activities of some common ingredients of traditional chinese medicine, *Angelica sinensis*, *Lycium barbarum* and *Poria cocos*. *Phytotherapy Research*, *18*, 1008–1012.

Yang, B., Jiang, Y., Shi, J., Chen, F., Ashraf, M. (2011). Extraction and pharmacological properties of bioactive compounds from longan (*Dimocarpus longan* Lour.) fruit — A review. *Food Research International,* in press

Yki-Järvinen, H. (2010). Nutritional modulation of nonalcoholic fatty liver disease and insulin resistance: Human data. *Current Opinion in Clinical Nutrition and Metabolic Care*, *13*, 709–714.

Young, J. B. (2010). Diabetes, obesity, and heart failure: The new pandemic. *Methodist DeBakey Cardiovascular Journal*, *6*, 20–26.

Yu, M. S., Ho, Y. S., So, K. F., Yuen, W. H., & Chang, R. C. (2006). Cytoprotective effects of *Lycium barbarum* against reducing stress on endoplasmic reticulum. *International Journal of Molecular Medicine*, *17*, 1157–1161.

Zhao, R., Li, Q. W., Li, J., & Zhang, T. (2009). Protective effect of *Lycium barbarum* polysaccharide 4 on kidneys in streptozotocin-induced diabetic rats. *Canadian Journal of Physiology and Pharmacology*, *87*, 711–719.

Zhao, R., Li, Q., & Xiao, B. (2005). Effect of *Lycium barbarum* polysaccharide on the improvement of insulin resistance in NIDDM rats. *Yakugaku Zasshi*, *125*, 981–988.

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