BURLEIGH DODDS SERIES IN AGRICULTURAL SCIENCE

Achieving sustainable cultivation of tree nuts

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Introduction

Tree nuts such as almonds, walnuts and pistachio have long been grown for fresh consumption and as a food ingredient. It is estimated that 4 million metric tons of tree nuts are produced each year in over 40 countries. Demand is rising, in part because of research on the nutraceutical benefits of tree nuts. At the same time, these crops face particular challenges such as safety in the face of allergens and mycotoxin contamination. There is a need to increase production but in a more sustainable way in the face of climate change. This volume reviews the wealth of research addressing these challenges. The volume reviews current research on nutraceutical properties, as well as allergen and other safety issues relating to tree nuts. It also assesses advances in integrated disease and pest management to improve yields and sustainability. Finally, the volume summarises key advances in breeding and cultivation of the main tree nuts, from walnuts and almonds to chestnuts, pistachios and hazelnuts.

Part 1 Improving health, safety and sustainability

The first part of the volume discusses the growing number of studies on the health benefits of tree nuts. The subject of Chapter 1 is advances in understanding the health benefits of walnuts. Walnut fruit is rich in vitamins, carbohydrates, minerals, protein and unsaturated fats with Omega 3, for example, linked to improving brain and nerve cell function. The fruit is also a rich source of phytochemicals, including antioxidant compounds such as melatonin, ellagic acid, vitamin E, carotenoids, polyphenols, walnut oligopeptides (WOPs) and phytosterols. These compounds have been shown to have protective health effects against heart disease, some types of cancer, type 2 diabetes as well as some neurological illnesses. Walnut kernels also contain a very high amount of serotonin, a neurotransmitter involved in regulating both mood and blood pressure. The chapter also explores the antimicrobial and antioxidant properties of walnut green husk (WGH).

Moving from walnuts to almonds, Chapter 2 focusses on advances in understanding the health benefits of almonds. Almond (*Prunus dulcis*) is widely grown in countries with a Mediterranean climate and is considered a healthy source of many nutrients. The chapter discusses the nutritional composition of almonds and, in particular, those nutrients with nutraceutical properties, from phenolics and fatty acids to phytosterols. The chapter discusses how this unique nutritional profile translates into health benefits related to almond consumption. The chapter reviews the range of phenolic compounds found in almonds, as well as lipid and fatty acid content in different cultivars.

Chapter 3 examines advances in understanding the health benefits of hazelnuts. Hazelnuts (*Corylus avellana* L.) are rich in fats, protein, phytonutrients and antioxidants such as Vitamin E. The health benefits of hazelnut consumption arise from the synergic action of unsaturated fat or bioactive compounds including plant sterols and dietary fiber. After introducing the key nutritional features of hazelnuts, the chapter describes advances in metabolomics and outlines the results of epidemiological and clinical studies on the health benefits of hazelnuts.

As Chapter 4 sows, the production and consumption of chestnuts has shown a steady increase in recent years, driven by both increased consumer awareness about food composition and the health benefits of a nut-rich diet. The chapter provides an overview of the uses and health benefits of chestnuts (*Castanea* spp.). These nuts are rich in carbohydrates, minerals, vitamins, protein and fibre, and low in fat content, as well as being important sources of phenolics and flavonoids. The chapter also explores the effects of factors such as cultivar, post-harvest handling and storage as well as cooking on nutritional and nutraceutical properties. It discusses the potential value and uses co-products (bur, shell, leaves, curing wastewater, etc.) left behind by processing.

Chapter 5 looks at advances in understanding the health benefits of pistachio nuts. Pistachio is particularly rich in vegetable protein, fiber and bioactive compounds such as lutein-zeaxanthin and beta-carotene, all of which have been linked to potential benefits to health. The chapter summarises what we know about the nutritional composition of pistachio nuts and reviews the range of human, animal and *in vitro* research exploring the health benefits of pistachio nut consumption.

Moving on from health benefits to consider the challenge caused by allergies, Chapter 6 explains advances in detecting and identifying nut allergens. Together with peanut, tree nuts belong to a small group of allergens responsible for the great majority of food allergies. The chapter begins by providing an overview of tree nut allergies and their prevalence. It then discusses allergenic proteins and thresholds, as well as the required sensitivity of detection methods. Finally, the chapter reviews both general issues in developing effective detection methods as well the range of techniques available for particular tree nuts.

The penultimate chapter in Part 1, Chapter 7, addresses the subject of integrated disease management in tree nut cultivation. Integrated disease management techniques to minimize environmental impact is key to the sustainable cultivation of tree nuts. The chapter explores the principles and practice of integrated disease management, taking as an example one of the most threatening diseases affecting chestnuts worldwide: ink disease caused by *Phytophthora* spp. The chapter introduces the concept of area-wide integrated ink disease management, including the use of techniques such as monitoring and GIS mapping of the disease. *Phytophthora* is easily dispersed via water and infected soil. The chapter therefore covers tree and soil treatments used to prevent as well as treat the disease, and reviews advances in breeding varieties resistant to the disease (breeding of interspecific hybrids has led to resistant rootstocks). The chapter concludes with a discussion on the importance of quality and certification of material for propagation.

The final chapter of the first part of the volume, Chapter 8, draws connections between tree nut cultivation, biodiversity and conservation. There is growing concern about the impact of agriculture on the environment as well as the consequences of this damage for sustainable production in the face of increased abiotic and biotic threats. It is now well accepted that a holistic approach is needed to ensure management techniques that ensure both conservation of the natural world and stable production levels. In nut crop production the complex interconnections among physical and biological structures, agricultural practices, functions and services strongly influence, and may be influenced by, factors such as orchard design, ground cover management, and pest management. By analysing the ecosystem services and dis-services that may affect, and can in turn be affected by, agricultural practices, the chapter shows how to develop more sustainable cultivation methods.

Part 2 Improving individual types of tree nuts

The second part of the volume addresses advances in breeding ad cultivation of particular nuts. Chapter 9 looks at breeding of walnut. Walnut breeding programs are facing the challenge of increasing production to meet growing demand but in a more sustainable way which adapts to but does not exacerbate climate change. The chapter reviews the development of new cultivars with genetic resistance to biotic and abiotic stresses, as well as the exploration and conservation of genetic diversity in walnut. Chapter 9 is complemented by Chapter 10 which reviews advances in the cultivation of walnuts. The chapter reviews the expansion of walnut production, examining key challenges such as the control of blight (*Xanthomonas arboricola pv. Juglandis*). The chapter reviews optimal methods for propagation, managing water, nutrients and planting density as well as recent advances in molecular genetics, including marker assisted selection.

Chapter 11 shifts the focus on to almond. The chapter offers an overview of the most recent advances in almond scion and rootstock genotypes as well as developments in orchard management, including irrigation and fertilization techniques. The focus is on understanding almond tree eco-physiology and yield potential which provides the foundation for more sustainable cultivation methods less reliant on environmentally-damaging agrochemical inputs.

Chapter 12 moves on to consider advances in the breeding of chestnuts. Over the two last centuries, diseases and pests have been introduced from Asia to chestnut plantations in both northern America and southern Europe, jeopardizing indigenous populations and some local chestnut varieties. Recent developments in tree genome mapping and sequencing have opened up new opportunities for breeders. The chapter describes developments in breeding varieties with resistance to diseases threatening chestnut orchards and includes the example of a French program for breeding ink-resistant rootstocks. The chapter then examines breeding for resistance to gall wasps, breeding for fruit quality, and breeding improved 'peel-ability' of chestnuts. Complementing Chapter 12, Chapter 13 looks at advances in the cultivation of chestnuts. The chapter includes sections on ecological conditions affecting the growth of chestnuts, chestnut management as coppice forest or orchards, propagation methods (including grafting, layering, cutting and micropropagation), and orchard establishment and management (including training, pruning, fertilization and irrigation). The chapter also discusses the harvesting and storage of chestnuts, as well as pest management in chestnut orchards.

Chapter 14 looks at advances in the breeding of pistachio. *Pistacia vera* L. (pistachio) has the only commercially important edible nuts in the genus, with wild species used for rootstock. Breeding in pistachio is complicated by a long juvenile period and the plant's dioecious character. The chapter describes the genetic resources available for pistachio breeding, and the importance of cytogenetics to this field. The chapter then examines the use of molecular markers, genome and transcriptome sequencing, the role of micropropagation and gives examples of new cultivars with improved properties. Building on this, Chapter 15 addresses advances in the cultivation of pistachio. The chapter includes a section on pistachio genetics and climatic requirements, which requires a period of chilling as well as a hot, dry climate for fruiting. The chapter discusses flower and fruit characteristics of pistachio and what this means for orchard design. The chapter also looks at propagation techniques (both by seed and budding), followed by a review of key research on establishing, planting and managing orchards. The chapter concludes with sections on managing pests and diseases and how to improve crop yield.

The subject of Chapter 16 is the development of hazelnuts as a crop. European hazelnut (*Corylus avellana*) is a major species of interest for food use and one of the few economically valuable commercial tree nut crops within the Betulaceae family. The chapter reviews the development of European hazelnut as industrial nut crop, highlighting its environmental requirement for good yields. The chapter discusses propagation and orchard management techniques, focusing on recent innovations in research including the exploitation of hazelnut biomass, and the application of precision farming strategies in newer large-scale hazelnut orchards. The chapter also reviews integrated pest management techniques for hazelnuts.

Complementing the previous chapter on hazelnut production, the volume's final chapter (Chapter 17) addresses advances in the breeding of hazelnuts. Cultivated hazelnut varieties differ from each other in such characteristics as nut size, shape, kernel ratio, shell thickness, etc. Key target characteristics for breeding not only include high yield but also good morphological and vegetative traits as well as resistance to pests and diseases. The chapter discusses advances in the breeding of hazelnuts. The chapter reviews floral biology, pollination and compatibility in hazelnut. The chapter examines the development of hazelnut varieties, focusing on key hazelnut breeding programmes in Turkey, Europe and the US (where the focus has been for breeding for resistance to Easter filbert blight).

Chapter 1

The nutritional and nutraceutical value of walnut

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1 Introduction

Walnut is one of the most popular and widely consumed tree nuts. It can be consumed in both raw, roasted or salted forms. Walnut is also widely used, in both shredded and oil form, as a flavour enhancer in biscuits, cakes and desserts as well as yoghurt, pizza and ice cream. As an example, in Middle Eastern Muslim countries, walnut is added to almond, date and grape to prepare a cake known as maamoul for Ramadan (Şen, 2011).

Walnut is rich in monounsaturated fatty acids. Walnut is a good source of Omega 3 (an essential fatty acid) and a source of arachidonic acid. Walnut is the source of many phytochemicals (Şen, 2013). These antioxidant compounds include melatonin, ellagic acid, vitamin E, carotenoids and polyphenols. These compounds have potential protective health effects against ageing, cancers, inflammations and neurological illnesses (Şen, 2013) (Table 1). Since the morphological structure of walnut resembles the human brain, it has traditionally been regarded as improving brain function and mood (Fig. 1). This chapter reviews the nutritional composition of walnuts and the evidence for their health benefits.

2 Walnut as a source of vitamins, protein, fat and carbohydrate

In terms of nutritional value, walnut is superior to pistachio, almond, hazelnut, pine nut and peanut, containing twice the level of antioxidants and vitamins

http://dx.doi.org/10.19103/AS.2018.0042.01

Figure 1 Anatolian walnut (*Juglans regia*).

(Vinson and Cai, 2012). Walnut consumption is therefore seen as an important component in healthy nutrition (Preedy et al., 2011). Walnut is a particularly good source of vitamin E. Vitamin E in walnut fat has two forms: alpha-tocopherol and gamma-tocopherol. A 100 g of walnut has 21 mg gamma-tocopherol (vitamin E), providing 140% of the daily requirement. Vitamin E is a strong fat-soluble antioxidant and is needed to protect the mucus and skin cell membranes against the harmful effects of free radicals (Martin and Preedy, 2015; Şen, 2013). Walnut also contains important vitamins such as riboflavin, niacin, thiamine, pantothenic acid, vitamin B6 and folate/B9 (Şen, 2013). As walnut has a preventive effect on inflammation, it decreases the risk of high blood pressure; it also helps to prevent arterial illnesses such as heart disease and stroke as well as chest diseases, colon and prostate cancers (Marangoni et al., 2007; Amaral et al., 2003).

Walnut contains significant amounts of single and multi-unsaturated fats. Whilst proteins and carbohydrates provide 4 calories/g, fats provide 9 calories/g. In consuming hard shell fruits, consumers therefore need to be careful about exceeding their recommended calorie intake (Tapsell et al., 2009; Şen, 2013; Crews et al., 2005; Martin and Preedy, 2015). Generally, there are 50 g (47.14) of multi-unsaturated fatty acids in 100 g of walnut. 40 g (38.09 g) of this acid content is Omega 6 (linoleic acid) whilst 10 g (9.08 g) is Omega 3 (linolenic acid) (Şen, 2013; Ma et al., 2010). Although calorie content is high, this is counterbalanced by the presence of healthier unsaturated which can help in weight control (Vinson and Cai, 2012; Şen, 2013). Research has shown that the Omega 3 content in walnuts can offset the harmful effects of high saturated fat diets (Roman et al., 2011; Martin and Preedy, 2015).

Table 1 The chemical structure of walnut

Energy/constituents	Nutritional value/100 g
Energy	2738 kJ (654 kcal)
Carbohydrates	13.71
Starch	0.06
Sugars	2.61
Lactose	0
Dietary fibre	6.7
Total fat	65.21
Saturated fat	6.126
Monounsaturated fat	8.933
Polyunsaturated fat	47.174
Protein	15.23
Vitamins	Amount (%)
Vitamin A equiv.	1 μg (0)
Beta-carotene	12 μg (0)
Lutein zeaxanthin	9 μg (0)
Vitamin A	20 IU
Thiamine (B1)	0.341 mg (30)
Riboflavin (B2)	0.15 mg (13)
Niacin (B3)	1.125 mg (8)
Pantothenic acid (B5)	0.570 mg (11)
Vitamin B6	0.537 mg (41)
Folate (B9)	98 μg (25)
Vitamin B12	0 μg (0)
Vitamin C	1.3 mg (2)
Vitamin D	0 μg (0)
Vitamin E	0.7 mg (5)
Vitamin K	2.7 μg (3)
Trace metals	Amount (%)
Calcium	98 mg (10)
Iron	2.91 mg (22)
Magnesium	158 mg (45)
Manganese	3.414 mg (163)
Phosphorus	346 mg (49)
Potassium	441 mg (9)
Sodium	2 mg (0)
Zinc	3.09 mg (33)
Other constituents	Amount (%)
Water	4.07
Alcohol (ethanol)	0
Caffeine	0

Percentages are roughly approximated using US recommendations for adults.
Source: USDA Nutrient Database.

3 Health-promoting properties of walnuts

As has been noted, walnuts are rich in antioxidants (Reiter et al., 2005; Canales et al., 2007; Fukuda et al., 2003; Negi et al., 2011). As a result, they have been shown to have positive effects on health (Tapsell et al., 2009; Ueshima et al., 2007; Ros et al., 2004). Research suggests that consuming walnut daily protects the body against heart disease, some types of cancer, type 2 diabetes and other health problems. Research has shown that walnut reduces the risk of heart attack since it improves blood flow (Şen, 2013; Fukuda et al., 2004; Gillen et al.,2005; Ma et al., 2010; Anderson et al., 2001). Walnut reduces cholesterol and the oxidative stresses caused by free radicals (Anderson et al., 2001; Morgan et al., 2002). Use of walnut oil has also been associated with improved skin health (Şen, 2013). Walnut oil alleviates skin conditions such as sunburn, skin ulcers and blisters (Anon., 2018b).

Research has established a link between Omega 3, brain and nerve cell function (Martin and Preedy, 2015). Adequate amounts of Omega 3 have been shown to assist in the transmission of electrical signals in the nervous system (Preedy et al., 2011). Studies have shown a correlation between an increase in depression rates and a decrease in Omega 3 fat intake (Mercola, 2004; Şen, 2013; Şen and Karadeniz, 2015). Other studies have linked hyperactivity, learning difficulties and behavioural problems in children with a low intake of Omega-3 in their diet (Richardson and Puri, 2002; Bélanger et al., 2009; Kirby and Derbyshire, 2018).

In a 2004 study, it was found that walnut extract was capable of inhibiting the fibrous structure of the amyloid beta protein, which is the origin of the amyloid plaques in the brains of Alzheimer's patients (Anon., 2018a). Another study has suggested that walnut may reduce or delay the risk of Alzheimer's disease by retaining amyloid-β protein in solution and preventing the deterioration of acetylcholine (Anon., 2018b). Walnut has also been linked to the prevention of some nervous disorders such as Parkinson's disease (Anon., 2018c).

The biological activity of aqueous extracts from walnut green husk (WGH) was evaluated which exhibited both antimicrobial and antioxidant properties. Therefore, walnut husk can be used as an alternative, cheap source of antioxidant and antimicrobial agents (Fernández-Agulló et al., 2013).

Walnut has also exclusive medicinal and biological properties. Recent studies show that walnut has small molecule peptides which are known as walnut oligopeptides (WOPs). The WOPs exhibit anti-fatigue properties which were examined in mice. The mice were orally administered with different doses of WOPs. After a month of treatment, the anti-fatigue activity was monitored by employing weight-loaded swimming test and determining particular biochemicals such as energy metabolism enzymes and glycogen storage, mitochondrial function and antioxidative capacity. It was noticed that the mice treated with WOPs exhibited long/extended swimming time, showed enhanced glycogen storage in liver and gastrocnemius muscle and diminished level of lactate dehydrogenase (LDH), blood lactic acid (BLA), creatine kinase (CK) and blood urea nitrogen (BUN). Furthermore, WOPs markedly repressed fatigue-induced oxidative stress by rising the activity of glutathione peroxidase (GPX), superoxide dismutase (SOD) and depressing the content of cell membrane injury marker malondialdehyde (MDA). Strikingly, WOPs augmented the action of Na^+-K^+-ATPase, pyruvate kinase (PK) and succinate dehydrogenase (SDH), and boosted the mRNA level of mitochondrial biogenesis factors and mitochondrial DNA content in skeletal muscles of mice. Thus these findings clearly indicate that WOPs have positive anti-fatigue effects, which may be associated with their specific impacts on enhancing glycogen storage, suppressing oxidative stress, fixing energy metabolism and boosting mitochondrial function in skeletal muscles and alleviating cell and muscular injury (Liu et al., 2018).

Serotonin is a famous neurotransmitter derived via the serotonin pathway from tryptophan (Guillén-Casla et al., 2012). This is found in the serotonergic neurons in the central nervous system and mainly produced in the enterochromaffin cells of the gastrointestinal tract (Watanabe et al., 2010). This neurotransmitter has a very important role in the regulation of moods, feelings of happiness, sleep, anxiety, appetite and blood pressure (Watts et al., 2012). Suppressed levels or diminishing of its synthesis can promote several diseases like obesity, depression and schizophrenia (Spadaro et al., 2015). Thanks to plants, serotonin is not only produced in humans but also in different tissues of plants such as leaves, flowers, fruits, seeds and roots (Kang and Back, 2006; Kang et al., 2007). Recently, serotonin content was determined in different nuts such as pine nut, walnut, macadamia nut and pecan. It was found that in walnut, serotonin content (155 ± 57 μg/g) was at the highest level among all other nuts (Yılmaz et al., 2019). Therefore, consumption of walnut on a daily basis can promote human well-being efficiently. Albeit, walnut has some allergenic protein, however, a few small molecules like gallic acid and/or ellagic acid have immunomodulatory functions. Recently, the compound effects on mice T cells (immune cells) have been tested for their growth and activation. It was found that the compounds effectively decreased the T-cell activation/growth and the secretion of interleukin-4, interleukin-10 and interferon-γ. These findings implied that walnuts also contained compounds that can alleviate allergens' effects. Fortification of hydrolysable tannins to walnut-containing foods might mitigate allergic reaction by walnut consumption (Hamada et al., 2019).

Phytosterols have health-promoting effects such as alleviating diabetes mellitus, obesity, hyperlipidaemia and hypertension (Marinangeli and Jones, 2010; Misawa et al., 2012; Mohamed, 2014). Luckily recent reports revealed that walnut kernel is rich in phytosterols. There exist three phytosterols, namely, $\Delta^{5,23}$-stigmastadienol, cycloeucalenol and 28-methylobtusifoliol, reported for the first time in black walnut. Further, these findings illustrated that walnut is rich in compounds which are also bioactivities (Vu et al., 2019).

WGH is a pericarp of walnut fruit which is also rich in polyphenols, naphthoquinones (Zhou et al., 2015a), diarylheptanoid and other active components (Huo et al., 2017) and flavones and terpenoids (Qiu et al., 2017). Further, WGH also has anti-inflammatory, anti-cancer (Zhou et al., 2015b), antitumor (Hu, 2016), antibacterial (Zhang et al., 2017) and anti-ageing effects (Lu et al., 2011). Obesity is recognized as a serious problem of modern lifestyle (Eid et al., 2017; Yanovski, 2018) due to the consumption of a high-fat diet (HFD). The high-fat diet can disturb the ratio of Bacteroidetes and Firmicutes, leading to the onset of obesity and other metabolic disorders (Choi et al., 2017). Recently, the WGH effect on the reduction of body weight and improvement of total cholesterol and total triglycerides has been reported. Further, fat accumulation, hepatic steatosis and adipose tissue hypertrophy of HFD were diminished by WGH. Thus the positive effect of WGH on the alleviation of fatness and fat disorders could be correlated with the modulation of the gut microbiota (Wang et al., 2019).

4 Conclusion

Walnut is a very healthy fruit for humans and contains nutrients like vitamins, minerals, proteins, unsaturated fats and phytosterols. It has been suggested that walnut should be consumed from childhood onwards to increase heart and brain health, with a suggested intake of 20–30 g/day. Further, WGH has alleviating effect on obesity and well-being. Health promoting contents can be improved in walnut by different breeding methods. Methods such as introduction, hybridization, selection and mutation breeding can enhance nutritional level as well as size and yield of the walnuts. In Turkey, the Horticulture Department, Agriculture Faculty of Sütçü Imam University, Kahramanmaraş, Turkey, and in the United States, the Walnut Breeding Program of The University of California-Davis is actively involved in breeding high quality walnut cultivars in order to improve human health.

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