

Energy and Nutritional Properties of the White Mulberry (*Morus alba* L.)

Małgorzata Łochyńska

Silkworms Breeding and Mulberry Cultivation Laboratory, Institute of Natural Fibres and Medicinal Plants, Wojska Polskiego 71B, Poznań, Poland

Abstract: The white mulberry (*Morus alba* L.) had been forgotten in Europe or known only as a plant associated with breeding of mulberry silkworms (*Bombyx mori* L.). The initial studies have shown great potential of this plant in energy, food and pharmaceutical industries. The leaves and fruits contain very valuable bioactive substances, which may be used in health care. Antioxidants of plant origin include flavonoids and vitamin C (ascorbic acid), and these substances are present in high amounts in anatomical parts of white mulberry. It has also been reported on the medicinal properties of this plant and its use in preventing diseases, such as atherosclerosis, diabetes, obesity and cancer. The food industry increasingly uses the white mulberry in food to provide human organism with precious bioactive substances. Functional food, due to the presence in its composition of valuable components, is beneficial to human health. What is more, very fast growth of mulberry causes that biomass of the plant may be used as biofuel or energy plant. The aim of this paper is to present the possibility of using the white mulberry as a raw material for functional foods and as an energy plant.

Key words: Energy plant, antioxidants, functional food, diseases of civilization.

1. Introduction

Morus alba Linnaeus, 1753 is one of numerous species in the Moraceae link family. Most of the mulberries are native to Asian regions with warm climate. These plants are characterized with milky sap in shoots. They are both monoecious and dioecious, their flowers are inconspicuous and odorless, and the small, multiple sweet fruits occur in the form of drupelets or nuts. The leaves are alternately arranged, simple, often lobed and serrated on the margin.

Nowadays, the white mulberry is almost forgotten in Europe or known only as a food plant of mulberry silkworm (*Bombyx mori* L.). Nevertheless, potential of this plant is really huge. Very fast growth of mulberry causes that the plant biomass may be used as biofuel. In India, all annual shoots, available after silkworm breeding season, are cut, dried and used as the main renewable source of fuel [1]. What is more, white

mulberry is also used as a natural dyeing plant [2], in the sport equipment industry and furniture industry [3], and the branches are used as a substrate for oyster mushrooms (*Pleurotus* sp.) [4]. But, the most important feature of the white mulberry is its high value in terms of healthfulness. Almost all parts of the mulberry are used in the food industry. Fruits are eaten directly and processed into wines, jams, juices; they are also added to cakes. Leaves are used as teas, infusions and as a salad ingredient. Moreover, roots are boiled and added to soups and casseroles. The literature also reports that the seeds were used in oil production [5].

Free radicals, formed during metabolic processes, are responsible for occurrence of numerous diseases. For neutralizing free radicals, and what follows, for preventing the diseases of lifestyle, natural antioxidants play an important role. Cardiovascular and respiratory system diseases, atherosclerosis, anemia, obesity, diabetes and cancer, the so called diseases of civilization, have become commonplace in

Corresponding author: Małgorzata Łochyńska, Ph.D., research fields: botany and sericulture.

the modern society. The causes of these diseases can be linked with rapid civilization progress, which brings about heavy pollution of natural environment, noise, stress and unhealthful dietary habits. Another, equally important factor is the commonplace occurrence of free radicals, which are present in industrial processes, atmospheric phenomena and in basic physiological processes.

Well balanced and proper diet allows human organism for good functioning, and good selection of the dietary components can also prevent the onset of diseases and alleviate their symptoms, which properties are characteristic for functional food. White mulberry, due to its healthy properties, should be used for functional food to a much greater extent than it is done nowadays. This could improve the quality of life of numerous groups of people.

The aim of this paper is to present the white mulberry properties, which are important for agriculture and human health, and discuss its utilisation in energy industry, functional food, food industry and civilization diseases prevention.

2. Energy Biomass

The mulberry shows great potential in fuel and energy production. In India, all annual shoots, available after silkworm breeding season, are cut, dried and used as the main renewable source of fuel [1]. There is no doubt that fast-growing mulberry, rich in cellulose (57.4%), hemicellulose (16.3%) and lignin (24.6%) possess huge energy value 14-17.9 MJ/kg [2, 6]. In addition, the mulberry shows a resistance to disease and pests, and has relatively low soil requirements. Mulberry plantations provide a low utilization of productive or degraded agricultural land. Therefore, it may be used to produce heat, electricity and liquid and gas fuel production (bulk, pellets, briquettes, slurry in anaerobic digesters). All these properties of the white mulberry show that it may be much better than energy willow *Salix viminalis*, rape straw, mallow *Sida hermaphrodita* and kenaf *Hibiscus*

cannabinus [7-10].

3. Chemical Composition

Mulberry fruits, leaves and roots contain high amounts of bioactive substances, thus this plant has been traditionally used in medicine for ages [11]. Previous studies have shown that leaves and dark fruits are the richest in bioactive compounds [12-14]. It is reported that leaves contain on dry weight 15.31%-30.91% of high quality proteins, 2.09%-7.92% fat, 9.9%-13.85% crude fiber, 27.6%-43.6% neutral dietary fiber and 11.3%-17.24% ash contents [15]. Moreover, chemical investigation of leaves showed occurrence of ascorbic acid (100-200 mg/100 g), beta-carotene (8.44-13.13 mg/100 g), oxalates (183 mg/100 g), phytates (156 mg/100 g), tannic acid 0.13%-0.36% and minerals iron (19-50 mg/100 g), zinc (0.72-3.65 mg/100 g), calcium (786.66-2,726.66 mg/100 g), phosphorus (970 mg/100 g) and magnesium (720 mg/100 g) [15].

Mulberry leaves are a rich source of 14 polyphenolic substances. Leaf extracts contain considerable quantity of flavonoids, i.e., quercetin 3-(6-malonyl glucoside), rutin, kaempferol 3-(6-malonyl glucoside), astragaloside and phenol acids of chlorogenic and caffeic. In the total content of antioxidants, chlorogenic acid and quercetin constitute the major part [16]. The total content of phenols ranges from 12.81 mg gallic acid equivalents (GAE)/g dry weight (dw) to 15.50 mg GAE/g dw. The total content of four caffeoylquinic acids (CQAs) for *Morus alba* ranges from 6.78 mg/g dw to 8.48 mg/g dw and total 10 flavonols range from 3.66 mg/g dw to 9.75 mg/g dw [12]. Moreover, leaves contain 18 polyhydroxylated alkaloids, including the most popular 1-deoxynojirimycin (DNJ), which ranges from 0.28 mg/g to 3.88 mg/g [17, 18]. What is more, mulberry leaves possess very high antioxidant capacity. Two assays 2, 2'-azinobis (3-ethylbenzthiazoline-6-acid) (ABTS) and (2, 2-diphenyl-1-picrylhydrazyl) (DPPH) were used to evaluate antioxidant activity, and the means values from 10.6 Trolox/g dw to 13.15 mg

Trolox/g dw for ABTS and from 10.62 Trolox/g dw to 12.64 mg Trolox/g dw for DPPH were presented [12].

Phytochemical investigations have indicated also polysaccharides in the white mulberry leaves. The content of soluble carbohydrate was detected from 81.18% to 83.42% [15, 19, 20]. The detailed information about carbohydrate composition showed that total soluble carbohydrates was 3.1 g/100 g fresh weight (fw), reducing sugars of 1.5 g/100 g fw, monosaccharides fructose and glucose of 0.3 g/100 g fw and sucrose of 1.1 g/100 g fw [21]. Moreover, mulberry leaves extracts provide strong antibacterial potential due to the presence of albanol B, kuwanon C and G, halkomoracin, morusin, mulberofuran G, sangennon B and D [15, 22].

The mulberry fruits are also of significant importance in human nutrition. The content of fruits protein was 1.55 g/100 g dw, lipid content of 0.48 g/100 g dw, the crude fibre of 1.47 g/100 g dw, ash content of 0.57 g/100 mg dw, total carbohydrates content of 14.21 g/100 g dw and moisture of fresh weight was 81.72 g/100 g dw [23]. The sugars content (total 7.55 g/100 g fw), vitamin B₂ (riboflavin, 0.088 mg/100 g fw), niacin (3.10 mg/100 g fw), ascorbic acid (15.2 mg/100 g fw) were also detected [23]. The detailed information about carbohydrate composition in fruits showed that total soluble carbohydrates was 3.4 g/100 g fw, reducing sugars 1.7 g/100 g fw, monosaccharides fructose 3.0 g/100 g fw, glucose 3.1 g/100 g fw, fructooligosaccharides 1-ketose 0.1 g/100 g fw, nystose 0.01 g/100 g fw and inulin 0.04 g/100 g fw [21, 24]. What is more, mulberry fruits are rich in minerals. The content of macro-elements on dry weight basis is: N (1.62-2.13 g/100 g), P (0.24-0.31 g/100 g), K (1.62-2.13 g/100 g), Ca (0.19-0.37 g/100 g), Na (0.01 g/100 g), Mg (0.12-0.19 g/100 g), S (0.08-0.11 g/100 g); and micro-elements is: Fe (28.2-46.74 mg/kg), Cu (4.22-6.38 mg/kg), B (13.78-19.48 mg/100 g), Mn (12.33-19.38 mg/kg), Zn (14.89-19.58 mg/kg) and Ni (1.40-2.62 mg/kg) [13]. Moreover, mulberry fruits are rich in phenolic

compounds, including flavonols and phenolic acids, as well as anthocyanins, particularly in the case of dark fruits [13]. The total phenolic contain in fruits ranged from 7.7 to 11.2 mg GAE/g dw, and flavonols from 0.07 to 0.51 mg/g dw [13]. Moreover, the high amount of alkaloids (660 mg/100 g) was found in fresh fruits [23]. The antioxidant capacity of dark fruits is significant, while mean values ranged from 3.84 mg Trolox/g dw to 20.73 mg Trolox/g dw for ABTS and from 3.62 mg Trolox/g dw to 12.91 mg Trolox/g dw for DPPH [13].

The mulberry seeds contain 25%-35% of yellow oil rich in precious fatty acids group omega-3 [3]. The fatty acids examination shows that within 13 recorded acids, seven are mono- and poly-unsaturated fatty acids (MUFAs and PUFAs), which belong to very precious fatty acids group omega-3. Linoleic acid (LA, C18:2n6c; 76.84%) and oleic acid (C18:1n9c; 7.09%) show the highest content. Trace amounts of other unsaturated fatty acids, such as linolenic, stearidonic, eicosadienoic, eicosanoic and erucic acid, were also recorded [3, 15].

Moreover, root bark of the white mulberry contains flavonoids, alkaloids and stilbenoids and leachianone G against herpes simplex type 1 virus (HSV-1) [15].

4. Health Care Properties

Human organism is equipped with a protective mechanism against free radicals, which system comprises endogenous antioxidants. However, exogenous antioxidants play an important role in reducing the oxidative damage. The white mulberry is very rich source of antioxidants, including ascorbic acid (vitamin C), anthocyanins and polyphenols. These active substances are crucial in protecting and preventing human organism against civilization diseases, such as atherosclerosis, diabetes, obesity and cancer [24].

Traditional Chinese medicine still uses leaves and fruits of mulberry in treating fever, eye diseases, for rinsing throat in inflammations of upper respiratory

system, as sudorific and anti-parasitic preparations, in strengthening of joints, and lowering high blood pressure and high cholesterol levels. Root extracts are used as anti-inflammatory medicines, painkillers and preparations for protecting liver and kidneys [25]. In addition, the mulberry seeds contain 25%-35% of a yellow oil, white mulberry may be used as an oil-bearing plant. Detected unsaturated fatty acids are essential unsaturated fatty acids (EUFA), so called vitamin F, which can not be produced in human organism and must be supplied with food. They prevent arteriosclerosis, thrombosis and embolism, so that they are used in prevention of heart disease [3].

However, the white mulberry is mainly known for its excellent antidiabetic action. The flavonoids contained in the leaves and bark of mulberry, especially quercetin and DNJ, significantly lower blood glucose levels by inhibiting enzyme activity, such as α -glucosidases, sucrase and maltase [26]. It was shown that ethanol extracts of mulberry leaves can prevent obesity [27]. What is more, the components of mulberry extracts also significantly inhibit the atherosclerotic by low-density lipoprotein (LDL) oxidation and increasing resistance to blood cholesterol deposits [15, 28, 29]. In addition, the extract from the mulberry bark achieves good results in relieving the state of atherosclerosis, oxidation, aggregation and retention of LDL [25]. The white mulberry contains also high amounts of β -carotene, curcumin, gingerol, galusan epigallocatechins and resveratrol, which are considered as components of antioxidants important in cancer prevention [15]. The mulberry flavonoids (rutin, isoquercitrin, astragal, quercetin) and anthocyanins—the most important antioxidants, show cytotoxic activity against liver cancer cells in rats, human leukemia and melanoma cells in mice [30-32]. The polysaccharides from the roots bark stimulate lymphocyte proliferation and reduce the production of antibodies, which plays a significant role in treatment against allergies and is used in allergic diseases [33]. Moreover, the cyanidin

from fruits protects human brain against endothelial dysfunction and reduces the likelihood of Alzheimer's disease [34]. The literature data also reported considerable capacity of mulberry for local whitening of skin (depigmentation). The extract of mulberry causes strong inhibition of dihydroxyphenylalanine (DOPA) oxidase and exhibits activity against tyrosinase, which inhibits the overproduction of melanin and causes its degradation in local hyperpigmentations, e.g., melanoma, ephelide, lentigo [35, 36]. Bioactive compounds extracted from mulberry exhibit also strong antiviral and antibacterial activity [37]. Leaves extracts provide antimicrobial potential against *Bacillus subtilis*, *Staphylococcus aureus*, *Escherichia coli*, *Streptococcus faecalis*, *Streptococcus mutans*, *Mycobacterium smegmatis*, and root bark with leachianone G against HSV-1 [15].

5. The White Mulberry in Food Industry

The properties of leaves and fruits of the white mulberry are used more and more commonly for production of food of beneficial effect on human health. Moreover, nutritional effects of mulberry, improvement of health state and well-being and/or reduction of risk of disease are also used in functional foods production. Apart from that, there are more terms for dietary products containing extracts or dried mulberry.

These days, innovative health care food with mulberry extract is prepared for improving human immunity and health [13, 15, 38]. Chocolate represents functional properties due to its high level of flavonoid content. Polyphenol-rich chocolate, probiotic and prebiotic chocolate or chocolate with mulberry extract or anthocyanins were studied and produced [39].

These days, dried and powdered mulberry leaves or its extracts are used in many ways. Tea infusion does not contain caffeine and is characterized with mild and pleasant flavour. Infusion of leaves shows very good properties when used during flu, cold and throat

inflammations. Dried material is also used in Indian cooking for baking bread from wheat flour called “paratha” and in Thailand for rice snacks with added powdered leaves of white mulberry. In addition, the white mulberry fruits are added to muesli and it is able not only to increase the antioxidant capacity of product, but also to reduce the advanced oxidative changes of the product [40]. New functional yogurts using jam and leaves of mulberry were also analyzed [41]. What is obvious, the mulberry fruits usage is also for preparing jams, ice-creams, vinegars, juices, wine and cosmetic products [42]. In comparison with grape wine, mulberry wine has higher antioxidant potential and better phenolic profile [43].

The white mulberry fruits contain 20% sugars, mainly glucose, maltose, sucrose and fructose [44]. They also contain organic acids: citric and cider acids and volatile oils. Due to such high content of easily digestible sugars, populations of high mountain regions dry mulberry fruits then were grinded to flour and added to various dishes.

The dietary fiber refers to different carbohydrates and lignin that resist hydrolysis by human digestive enzymes, but can be fermented by colonic microflora. This definition includes polysaccharides (cellulose, hemicellulose, pectins, gums, betaglucans), inulin, fructooligosaccharides (FOS), galactooligosaccharides (GOS), resistant starch. Some of these fiber components satisfy strictly criteria to be considered as prebiotics (inulin, FOS, GOS, soy oligosaccharides) [45].

According to the inulin content, *Morus alba* has very beneficial activities for colonic microflora *Bifidobacterium* and *Lactobacillus* [46]. One of the ways of increasing the number of beneficial intestinal microorganisms is the use of prebiotic ingredients, and to be able to generate the bifidogenic effect is necessary for the counting of cultures prebiotics in the colon [47]. The oligosaccharides associated with intestinal bacteria guide the T lymphocytes maturation,

closely linked to the prevention of gastrointestinal diseases [24].

Moreover, dried mulberry fruits are used as a source of regenerative and strengthening food [48, 49]. The root bark of mulberry contains flavonoids, alkaloids and stilbenoids. It has antimicrobial, skin-whitening, cytotoxic, anti-inflammatory and anti-hyperlipidemic activity [50].

6. Conclusions

High energy value of mulberry shoots, their very fast growth and high content of cellulose, hemicellulose and lignins, a resistance to disease and pests and relatively low soil requirements cause that the white mulberry is really good new source of green energy. Leaves collected from mulberry plantations may be used in sericulture, pharmaceutical industry, in medicine and food industry, and shoots in energy industry as bulk, pellets, briquettes, slurry in anaerobic digesters. All these properties of white mulberry show that this plant may be used multi-directionally. That is why it is much better than energy willow *Salix viminalis* and other energy plants.

Numerous studies indicate significance of the antioxidative properties of the white mulberry in preventing and treating lifestyles diseases. Its beneficial effect is observed for extracts obtained from various parts of the plant. Thus, constant and systematic supplementation in antioxidants to balance their levels in the organism seems advisable. It is believed that functional food is the best way to introduce exogenic antioxidants to human organism. A functional food is a natural food, which components have been added or removed by technological or biotechnological means. Therefore, functional food is the safest for human health and does not interfere with other treatments.

Although the healthful properties of mulberry have been well documented, further research is needed on the characterization of bioactive components of

mulberry. Promoting diets rich in natural sources of antioxidants should be the main aim of health policy.

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