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CHARACTERISTICS OF PLUMS AS A RAW MATERIAL WITH VALUABLE NUTRITIVE AND DIETARY PROPERTIES – A REVIEW

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In Poland plums are an important raw material used for desserts and processing. A traditional Polish plum preserve, called "powidła" being a kind of plum jam, exhibits high nutritive value, due to a considerable degree of raw material concentration, being a rich source of pectins, carotenoids, phenolic compounds and organic acids. Prunes are also products with an advantageous nutritive and dietary value, whose popularity as a wholesome snack has increased considerably in recent years.

Plums are a raw material rich in biologically-active substances with antioxidant properties, which is correlated with high contents of phenolic compounds, with the predominance of derivatives of caffeic acid, mainly neochlorogenic and chlorogenic acids, together with smaller amounts of anthocyanins, flavanols and flavonols. Numerous nutritional studies confirm the health-promoting action of plums, *e.g.* by improving the blood lipid profile, reducing bile acid levels, improving glucose and lipid metabolism or inhibiting osteoporosis.

INTRODUCTION

Garden plum (*Prunus domestica*) has been grown in Poland starting from the 12th century. It is a species highly varied in terms of the shape, colour, size and fruit ripening date. The species originates from the Caucasus, it appeared in Europe *ca.* 2,000 years ago [Łucka, 1994].

In the world fruit production plums rank eight (approx. 8 million tons). As much as 70% of the production is constituted by varieties of Japanese plum, while *Prunus dom*estica, the so-called European plum, accounts for approx. 20% [Grzyb, 2003]. In the structure of fruit trees growing in Poland plum trees rank third (6.7%), after apple trees (71.4%) and cherry trees (13.5%) [GUS, 2004]. Plum production in Poland is around 100 thousand tons annually [GUS, 2006]. These fruits are commonly grown in commercial orchards, as well as allotments and garden plots. They are eaten fresh or processed, frozen and dried. Annual plum consumption in Poland is 3 kg per capita (6% consumed fruit), while in Germany it is 7 kg, and in the Balkans it is over 20 kg [Hołubowicz, 1999; Grzyb & Rozpara, 2000]. The most popular plum preserve in Poland is a special plum jam "powidła", with a high nutritive value, being a source of dietary fiber, especially pectins, and polyphenols. In turn, recently introduced plum nectars and juices are considerably poorer in those compounds, as most of them are left in the pressed residues.

Due to their advantageous nutritive value and relatively high contents of biologically-active compounds, these fruits should be a permanent element of our diet, not only eaten fresh or in the traditional plum jam, but also as prunes. A popular drink in the United States is a nectar made from prunes, containing approx. 20% paste of these dried fruits.

CHEMICAL COMPOSITION OF PLUMS

Varietal variation within the plum species results in differences in their chemical composition. These fruits contain relatively large amounts of carbohydrates (up to 15 g/100 g fresh weight), constituting a source of readily available energy (30-60 kcal/100 g) (Table 1). In spite of a considerable content of monosaccharides, the consumption of plums does not result in a fast increase of blood glucose level, which is probably connected with high contents of dietary fiber, fructose and sorbitol [Stecewicz-Sapuntzakis *et al.*, 2001]. High dietary value of plums results from the considerable pectin contents, approx. 1% fresh weight, *i.e.* comparable with gooseberry, apricot, and slightly less than that of black currant. In the case of minerals potassium predominates (approx. 200 mg/100 g), while among vitamins it is β-carotene (up to 780 μg/100 g). These fruits, especially eaten as prunes, are an important source of boron, which – among other things – affects calcium availability and prevents osteoporosis. The amount of 100 g of prunes covers the daily requirement (2-3 mg) for this element [Stacewicz-Sapuntzakis *et al.*, 2001]. In contrast, plums are poor in vitamin C [Kazimierczak *et al.*, 2006; Kunachowicz *et al.*, 1998; Bhutani & Joshi, 1995; Piekarska & Łoś-Kuczera, 1983]. These fruits constitute a rich source of antioxidant compounds, such as phenolic acids, anthocyanins and other flavonoids [Nakatani *et al.*, 2000; Auger *et al.*, 2004].

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TABLE 1. Composition of plum fruit [Kunachowicz *et al*., 1998; Bhutani & Joshi, 1995; Piekarska & Łoś-Kuczera, 1983].

Component	Range
Water (%)	86-88
Protein (%)	0.4–0.9
Fat (%)	0.1–0.3
Total sugar (%)	6.7–15
Dietary fibers (%)	1.3–2.4
Pectin (%)	0.8–1.0
Ash (%)	0.3–0.4
Minerals (mg/100 g) - K - Ca - Mg	 120–208 6.0–45.0 4.0–8.0
Energy (kcal/100 g)	30–66
Vitamins - Vit.C (mg/100 g) - Vit.A (carotene) (μg/100 g) - Thiamin (μg/100 g) - Niacin (μg/100 g) - Riboflavin (μg/100 g)	 4–11 94–780 20–56 200–900 38-50

The predominant phenolic compounds in plums are derivatives of caffeic acid: 3-O-caffeicquinic (neochlorogenic acid), 5-O-caffeicquinic (chlorogenic acid) and 4-O-caffeicquinic (cryptochlorogenic acid) as well as caffeic acid, together with smaller amounts of anthocyanins, flavanols and flavonols [Nakatani *et al*., 2000]. Numerous literature data confirm high antioxidant activity of chlorogenic acid, which is manifested in its advantageous effect on human health, as it *e.g.* lowers blood LDL and glucose levels, inactivates reactive oxygen and nitrogen species, exhibits antimutagenic and anticarcenogenic action and inhibits the formation of conjugated dienes of linolic acid [Morishita & Kido, 1995; Kono *et al*., 1997; Chun & Kim, 2004]. Studies also confirm the antioxidant capacity of isomers of chlorogenic acid (3- and 4-O-caffeicquinic acids) [Nakatani *et al*., 2000]. When determining the superoxide radical anion ($O_2^{\bullet -}$) scavenging capacity by ESR (Electron Spin Resonance) it was found that all derivatives of chlorogenic acid exhibited similar rates of radical scavenging, which for chlorogenic acid was 30.1%, for neochlorogenic acid 31.3%, while for cryptochlorogenic acid it was 37% (40 s, 20°C). For comparison, the authors simultaneously determined radical scavenging capacity for ascorbic acid, which amounted to 47.3%. All measurements were taken for solutions of 50 μmol/L. According to literature data, depending on the variety, environmental conditions and applied analytical methods, contents of phenolic acids in plums fall within a wide range of values, *i.e.* neochlorogenic acid at 85-1300 mg/kg, chlorogenic acid at 13-430 mg/kg, and cryptochlorogenic acid at 9-56 mg/kg dry weight [Donovan *et al*., 1998; Łoś *et al*., 2000; Nakatani *et al*., 2000; Tomas-Barberan *et al*., 2001; Kayano *et al*., 2002]. Among flavonols quercetin 3-glucoside and -3-rutinoside predominate [Tomas-Barberan *et al*., 2001]. Flavanol compounds are represented mainly by catechin and epicatechin, as well as proanthocyanins (di- and trimers) [Łoś *et al*., 2000; Tomas-Barberan *et al*., 2001]. When assessing catechin concentrations in a group of 27 different fruit species its highest level was recorded in plums (49 mg/100 g f.w.), followed by apples (10-43 mg/100 g), whereas in berries it was 5-20 mg/100 g [Auger *et al*., 2004]. The main anthocyanin form in plums is cyanidine-3-glucoside, cyanidine-3-rutinoside and peonidine-3-rutinoside. Total anthocyanin content ranges from 18 to 125 mg/100 g fresh weight (Table 2) [Donovan *et al*., 1998; Łoś *et al*., 2000; Kim *et al*., 2003; Cevallos-Casals *et al*., 2006]. The concentration of the above mentioned compounds is higher in the epidermis than in the flesh (Table 3); however, in most studies either their contents were assayed in the whole fruit or the adopted sample preparation method was not specified.

Plums are a raw material rich in phenolic compounds, which is correlated with its antioxidant capacity. In this respect it is superior to such fruits as grapes, kiwi, apples, pears, melons, bananas, while in the dried form it exhibits antioxidant capacity higher than that of black currants, blueberries, strawberries, *etc.* [Wang *et al*., 1996; Kayano *et al*., 2002]. The high antioxidant capacity of prunes, despite a considerable reduction of polyphenol concentrations during the drying process, results among other things from the formation of Maillard's reaction products. When investigating the effect of drying on changes in contents of phenolic compounds and antioxidant capacity of plums, Piga *et al*. [2003] found a decrease of the total polyphenol content by 40-46% at a drying temperature of 60°C and by 31-38% at 85°C, depending on the variety. In spite of a reduced polyphenol content in those samples antioxidant activity increased by 0-30% at a temperature of 60°C and by 90-250% at a temperature of 85°C,

TABLE 2. Content of anthocyanins in plum fruit.

Component	Range (mg/100 g f.w.)	Author
Cyanidin-3-glucoside	1.9–13.5 1.4–14.4	Kim *et al*. [2003] Chun *et al*. [2003]
Cyanidin-3-rutinoside	14.1–33.0 8.9–60.5	Kim *et al*. [2003] Chun *et al*. [2003]
Peonidin-3-glucoside	1.1–1.2 0.3–2.3	Kim *et al*. [2003] Chun *et al*. [2003]
Total anthocyanins	926 125 76 18-29	Bhutani & Joshi [1995] Cevallos-Casals *et al*. [2006] Donovan *et al*. [1998] Łoś *et al*. [2000]

TABLE 3. Type and concentration of phenolic compounds in plum fruits section.

Phenolic compound	Flesh	Peel	Author
Neochlorogenic acid (mg/100 g d.w.)	260	625	Raynal & Moutounet [1989]
Chlorogenic acid (mg/100 g d.w.)	11	137	Raynal & Moutounet [1989]
Catechin (mg/100 g d.w.)	10	74	Raynal & Moutounet [1989]
Anthocyanins total (mg/100 g d.w.) (mg/100 g f.w.)	 - 85-87	 630 344-872	 Raynal & Moutounet [1989] Cevallos-Casals *et al*. [2006]
Total phenolics (mg/100 g f.w.)	430-562 220-769	2385-2394 1630-3323	Cevallos-Casals *et al*. [2006] Gil *et al*. [2002]

depending on the variety. In prunes, especially after drying at 85°C, an increase was recorded in the content of hydroxymethylfural (HMF), one of Maillard's reaction products. The HMF concentration and the level of antioxidant activity were significantly correlated ($p=0.01$). Vinson *et al*. [2005] assessed polyphenol contents and antioxidant capacity in several species of dried fruits. The highest polyphenol content was recorded in dates (1959 mg/100 g f.w.), followed by cranberries (870 mg/100 g f.w.), plums (788 mg/100 g f.w.), grapes (551 g/100 g f.w.), apricots (402 mg/100 g f.w.) and figs (320 mg/100 g f.w.). Antioxidant capacity was expressed as a phenol concentration (μmol/L) in the fruit extract inhibiting oxidation of LDL and VLDL lipoproteins by 50% (IC_{50} – concentration to inhibit the oxidation by 50%). The highest antioxidant capacity was found for extracts from prunes (4.38 μmol/L) and figs (4.41 μmol/L), while lower levels of this capacity were recorded for raisins, *i.e.* dried grapes (3.45 μmol/L), cranberries (2.38 μmol/L), dates (2.17 μmol/L) and apricots (1.93 μmol/L). Since polyphenols are secondary plant metabolites protecting against adverse environmental factors such as UV radiation or microbial contamination, thus their highest concentration is found in external plant tissues, especially those exposed to solar radiation. For this reason, the quantitative distribution of polyphenols in fruits is far from uniform and it is found mostly in the epidermis, unfortunately removed in the course of many technological processes. When studying plums of European varieties a high correlation was found between total antioxidant capacity and total polyphenol content ($R^2=0.96$) and between the values of colour parameter L (lightness) and the total polyphenol content ($R^2=0.80$) [Rupasinghe *et al*., 2006]. It was found that with a decrease in the value of parameter L, which corresponds to a darker colour, the total antioxidant capacity and the total polyphenol content increase. For example, for var. V95141 with a light colour the L value was 49.8, polyphenol content was 100 mg/100 g f.w. and antioxidant capacity in terms of ascorbic acid equivalents was 115 mg /100 g f.w., while for var. V72511 with a dark skin these values were 23.0, 369 and 346, respectively. In the case of plums the concentration of polyphenols in the epidermis is 3-4 times higher than in the fruit flesh, while the concentration of anthocyanins falls within a wide range of values, depending on the variety being 3-10 times higher in the skin than in the flesh. However, taking into consideration the fact that the epidermis constitutes only 8% fruit weight, the fruit flesh contains approx. 70% total polyphenol content in fruits [Cevallos-Casals *et al*., 2006].

HEALTH-PROMOTING PROPERTIES OF PLUMS

Due to the abundance of bioactive compounds such as phenolic acids, anthocyanins, carotenoids, minerals and pectins, plums constitute a valuable component of our diet, both in terms of their nutritive and dietary value. These fruits are becoming an increasing popular object of nutritional studies conducted on humans and animals, assessing the effect of plum consumption on the functioning of the organism.

For many decades plums have been used in Indian medicine as a component of natural drugs used in case of leucorrhea, irregular menstruation and miscarriage [Chopra *et al*., 1956]. Numerous studies confirmed the health-promoting action of plums as a dietary component. An improvement of the blood lipid profile and a reduction of osseous mass losses, with no adverse effects on the functioning of the alimentary tract, such as constipation or diarrhea, were observed when administering 100 g prunes (10–12 prunes) daily for three months to a group of post-menopausal women [Lucas *et al*., 2004]. Moreover, it was found that supplying larger amounts of energy – in comparison to the control by 1989 and 1673 Kcal, respectively, did not result in any significant differences in body weight or body mass index (BMI) of the analysed women. A similar diet was applied in the case of a group of men with a medium level hypercholesterolemia [Tinker *et al*., 1991]. Men were given 100 g of prunes, while the control group was provided with 360 mL of grape juice a day. Daily food rations had identical levels of energy, carbohydrates, proteins and fat, while differed in the amounts of cholesterol and dietary fiber. In the diet with an addition of plums cholesterol level reached 277 mg and that of fibre 24 g, while in the diet with an addition of juice the values were 255 mg and 18 g, respectively. After an 8-week experiment a significant reduction ($p=0.02$) of blood LDL level was observed (3.9 mmol/L *vs*. 4.1 mmol/L), along with a reduction of bile acid levels (0.95 mg/g d.w. stool *vs*. 1.20 mg/g d.w. stool) and an increase of faeces mass by 20% in comparison to the group consuming grape juice. Based on the statistical analysis it was found that an increase in the daily uptake of dietary fiber by 1.0 g resulted in a decrease of total cholesterol concentration by 0.016 mmol/L, while that of the LDL cholesterol fraction by 0.013 mmol/L. Plums as a source of dietary fiber, especially pectins, play a positive role in the regulation of defaecation and improve lipid and glucose metabolism [Tinker *et al*., 1994]. When investigating the effect of dietary fiber consumption on the blood lipid profile, Tinker *et al*. [1994] conducted experiments on rats, in which four types of dietary fiber-rich diets were applied (6% cellulose, 3% or 6% dietary fiber in the form of prune extract and 3% apple pectin) and at the same time a high-fat diet, inducing hyperlipidaemia in relation to the control diet, containing 6% cellulose with no addition of components inducing hyperlipidaemia. After 4-week experiments it was found that in all animals fed the prohyperlipidaemic diet the blood and liver cholesterol levels as well as those of the LDL fraction were higher than in the control. However, at the same time in the group consuming the diet with an addition of plum fiber or pectins the levels of these compounds were lower than in the control with induced hyperlipidaemia and an addition of pure cellulose. The total blood plasma cholesterol concentration in the control without hyperlipidaemia was 2.27 mmol/L, in the control with hyperlipidaemia – 4.02 mmol/L, in the group with a 3% plum fiber addition it was 3.19 mmol/L, in the group with a 6% plum fiber addition – 3.23 mmol/L, whereas in the group with an addition of pectins – 2.84 mmol/L. Hepatic cholesterol concentration was 0.09, 0.91, 0.68, 0.65 and 0.58 mmol/L, respectively. The authors did not observe a significant effect of the amount of dietary fiber from plums on the levels of the analysed parameters. A reduction of blood cholesterol level and hepatic lipid concentration as a result of plum consumption was also confirmed in nutritional studies conducted on female rats with induced menopause after ovariectomy [Lucas *et al*., 2000]. Rats were fed a diet with a low (5%) and high (25%) addition of powdered prunes. After 45 days, the total blood cholesterol level was 2.89 mmol/L in the group with a 5% plum addition, 2.51 mmol/L in the group with a 25% addition of plums in comparison to 3.04 mmol/L in the control, while hepatic cholesterol level was 2.84, 2.96 and 3.01 mmol/L, respectively. A study by Utsunomiya *et al*. [2002] demonstrated the advantageous action of plum juice concentrate ("Bainiku-ekisu") in coronary heart disease and hypertension. Antioxidant properties of plums as a source of polyphenolic compounds were confirmed in genetic studies on rats, on the basis of changes in the concentration of the oxidation marker (MDA – malondialdehyde) in the liver and blood serum [Mateos *et al*., 2005]. In the experiment the basal diet and a diet inducing hypercholesterolaemia (with an addition of 20 g cholesterol and 4 g cholic acid salts kg basal diet) were applied, while within these nutritional groups 4 diet variants were introduced: with a 12% addition of lyophilized strawberries, 12% of lyophilized plums, 16.5% coconut fiber and the control diet with a 5% addition of cellulose. After 8 weeks of feeding, the blood MDA concentration in rats without hypercholesterolaemia was 2.2 nmol/mL in the control, 1.8 nmol/mL in the group with an addition of strawberries and coconut and 1.7 nmol/mL in the group with an addition of plums. In turn, among rats fed a diet with an addition of cholesterol, these indices were 2.8, 2.3, 2.0 and 1.7 nmol/mL, respectively. A similar effect was recorded in terms of changes in MDA biomarker levels in the livers of the analysed rats.

Dietary fiber may reduce cholesterol concentration through different mechanisms, *e.g.* by enhancing the secretion of sterols and transformation of cholesterol to bile acids [Truswell, 1993]. Plums, both fresh and dried, exhibit a strong capacity to bind bile acids, preventing their reabsorption and stimulating the conversion of cholesterol to bile acids [Kahlon & Smith, 2007]. In this way they contribute to a reduction of cholesterol level and a reduced risk of cholesterol deposits in bile ducts and blood vessels. The binding of cholesterol and bile acids prevents their transformation into cancerogenic and mutagenic compounds [Costarelli *et al*., 2002]. Kahlon & Smith [2007] carried out an *in vitro* study to assess the capacity of different fruits to bind bile acids. Analyses were conducted on lyophilized blueberries, plums, prunes, strawberries, cherries, cranberries, apples and cholestyramine (anion resin) as the control. Among the tested fruits fresh plums and prunes ranked second and third, after blueberries, in terms of the effectiveness of bile acid binding. For blueberries this index was 0.73, for plums 0.6, for prunes 0.53, while for the control it was 10.29 μmol/100 mg d.w.

CONCLUSIONS

Due to the increasing interest in functional food, produced based on natural bioactive compounds, the need to investigate raw materials and a selection of appropriate cultivars with the possibly highest contents of such components become increasingly important. Such raw materials are fruits and vegetables, being sources of compounds exhibiting antioxidant activity and binding in the organism undesirable components of diet or products of metabolism, *e.g.* dietary fiber binding excess cholesterol and bile acids. Plum is a fruit with considerable contents of bioactive compounds, such as polyphenols, carotenoids and pectins. The supply of fresh plums on the market is limited to approx. two-three months. The plum preserve with the qualitative composition similar to that of the raw material is a traditional-style plum jam "powidła", although their consumption is relatively low. Thus dried fruit needs to be pointed out as a valuable processed plum product, preserving the abundance of bioactive components of the raw material. Traditional drying of plums in Poland is combined with the process of smoking in the smoke of fruit or deciduous trees, such as beech, oak or hornbeam, which provides a unique taste. It is also possible to dry plums using osmosis in a 60% sucrose solution and next to complete drying using the fan drying method [Szymczak & Płocharski, 1998]. Thanks to this, the product obtained from Polish plum varieties is characterised by a higher solids:acidity ratio. For a dozen or so years the production and consumption levels of prunes have been increasing, especially in the USA, Japan, Great Britain, Germany and the Scandinavia. The consumption of several prunes a day has an advantageous effect on human health, *e.g.* by lowering blood cholesterol, reducing osteoporosis or regulating digestion processes. Prunes are fruit snacks which could replace high-calorie chocolate bars, crisps or other products defined as "snack food".

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