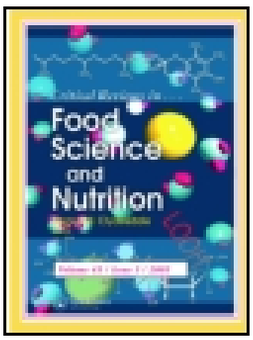

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Chemical Composition and Potential Health Effects of Prunes: A Functional Food?*

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KEY WORDS: phytochemicals, phenolic acids, neochlorogenic acid, sorbitol, laxative, boron, β-carotene.

ABSTRACT: Prunes are dried plums, fruits of *Prunus domestica* L., cultivated and propagated since ancient times. Most dried prunes are produced from cultivar d'Agen, especially in California and France, where the cultivar originated. After harvest, prune-making plums are dehydrated in hot air at 85 to 90°C for 18 h, then further processed into prune juice, puree, or other prune products. This extensive literature review summarizes the current knowledge of chemical composition of prunes and their biological effects on human health. Because of their sweet flavor and well-known mild laxative effect, prunes are considered to be an epitome of functional foods, but the understanding of their mode of action is still unclear. Dried prunes contain ~ 6.1 g of dietary fiber per 100 g, while prune juice is devoid of fiber due to filtration before bottling. The laxative action of both prune and prune juice could be explained by their high sorbitol content (14.7 and 6.1 g/100 g, respectively). Prunes are good source of energy in the form of simple sugars, but do not mediate a rapid rise in blood sugar concentration, possibly because of high fiber, fructose, and sorbitol content. Prunes contain large amounts of phenolic compounds (184 mg/100 g), mainly as neochlorogenic and chlorogenic acids, which may aid in the laxative action and delay glucose absorption. Phenolic compounds in prunes had been found to inhibit human LDL oxidation *in vitro*, and thus might serve as preventive agents against chronic diseases, such as heart disease and cancer. Additionally, high potassium content of prunes (745 mg/100 g) might be beneficial for cardiovascular health. Dried prunes are an important source of boron, which is postulated to play a role in prevention of osteoporosis. A serving of prunes (100 g) fulfills the daily requirement for boron (2 to 3 mg). More research is needed to assess the levels of carotenoids and other phytochemicals present in prunes to ensure correct labeling and accuracy of food composition tables in order to support dietary recommendations or health claims.

I. INTRODUCTION

There is a growing recognition that various food products may help to maintain optimal health and prevent chronic diseases. Such foods are often classified as functional foods or nutraceuticals. Prunes are among the most widely recognized foods with well-known physiological function, yet there is no systematic review of knowledge about their composition or health effects. This review summarizes the available literature about prunes in order to scrutinize their putative health claims.

Prunes are dried plums, fruits of *Prunus domestica* L., which originated in antiquity near the Caucasus Mountains, in the region bordering the Caspian Sea. The polyploid species emerged from two more ancient wild plums, the diploid cherry plum *Prunus cerasifera* Ehrh. (n = 8), and the tetraploid blackthorn *Prunus spinosa* L. (n = 16), followed by chromosome doubling.[52] The fortuitous product of this cross-breeding must have been noticed by humans, who cultivated and propagated it ever since, carrying it westward to Europe and later to other continents. This not very homogenous species is comprised of many cultivars. Some varieties of plum are not susceptible to fermentation when dried with the pits and were preserved by desiccation in the sun or in a warm

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oven for continuous consumption after the harvest season. The virtues of prunes were extolled by the ancient and medieval writers, who credited them with aiding digestion and curing mouth ulcers.[27]

Today most dried prunes are produced from *Prunus domestica* cv. d'Agen, a native of southwest France, which was introduced to California in 1856 by Louis Pellier.[19] There is confusion in the English language literature about plums and prunes, because authors do not adhere to the rule that the prune is a dried plum and tend to refer to all plums suitable for drying (with common names such as French, Italian, Sugar, or Imperial) as prunes. Sometimes it is difficult to determine if the authors have in mind fresh prune plums or dried prunes. The problem does not seem to arise in the French language, where there are two different names for fresh and dried plums of the same variety (*Prunus domestica*, cv. d'Agen). Although both are derived from Latin *Prunus*, the fresh fruit is called "prune d'Ente" and dried "pruneau d'Agen".[95,98,115] Therefore, we prefer to use descriptive phrases "prune plums" and "dried prunes" in our review. The term "prunes" will be used only for dried prunes and their products. Because of the paucity of information about dried prunes and their precursor, prune plums, we refer sometimes to other plum varieties that are not commonly used for drying as " fresh plums".

At present, California produces about 67% of the world's dried prune supply, 178 million kg of prunes per year.[20] After harvest, the prune-making plums are dehydrated to reduce their moisture content and are then further processed into prune juice, prune puree, prune paste, and prune powder. While an average consumer is familiar with packaged dried prunes, prune juice, and possibly prune puree, there is a plethora of commercial products developed by the food industry that can be used in baking, mixed with cereals, or even with ground meat.[21] Prune puree can replace fat in baking products, adding desirable moisture, sweetness, and dark color.[18]

Common experience indicates that prune purée and juice are consumed by infants, being available in convenient baby food packaging. Mothers are advised by pediatricians and infant care books to use prune puree and prune juice to alleviate constipation in their infants. Prune juice is also popular with the older generation for the same reason. Unfortunately, teenagers, young, and middle-aged adults tend to consume very little of prune products because of its association with a laxative effect. However, the same young adult population often purchase explicitly laxative products, pharmaceuticals that are effective but may be harmful with constant use. Moderate prune consumption does not produce excessive laxative effects. A standard serving of 5 prunes (40 g) or 8 oz of prune juice[42] can be a healthy ingredient of the daily diet, which should include 5 to 9 servings of fruits and vegetables.[147] Some sources list a much larger serving of 10 prunes (84 g),[11] which seems reasonable for a larger person, or for people who really like prunes and are accustomed to their frequent consumption. However, in order to make any health claims and recommendations for consumption levels, the product must be thoroughly investigated. This review attempts to bring together the existing and often conflicting information about the chemical composition of prunes and their effects on human health.

II. PROCESSING OF FRESH CALIFORNIA PRUNE-MAKING PLUMS

The fresh fruits are washed and then dehydrated from 75% moisture to 21% in hot air tunnel dehydrators for 18 h. The air temperature (85°C to 90°C) is designed to prevent excessive browning and burnt flavor. The product can be stored at ambient temperature for at least 1 year, but the prunes are too hard for direct consumption and must be rehydrated to 32% moisture, then packaged with sorbic acid to ensure microbial stability. The rehydrating takes place in a 77°C water bath, followed by steam treatment. Some dried prunes are mechanically pitted before packaging.[19]

Prune juice is produced by boiling dried prunes in water until the soluble solid content is 18.5%. The pits and solids are removed with a cloth filter. The juice may be standardized by blending with other batches to achieve a uniform product. While prune juice does not contain sorbic acid, it may have other additives, such as ascorbic acid or citric acid.

The characterization of the processes involved in production of dried prunes and prune juice is of the utmost importance. It explains the unique and specific composition of these products, as natural ingredients of fresh plums are concentrated, altered, or destroyed during processing. Fresh prune plums contain the enzymes invertase, peroxidase, and polyphenol oxidase (PPO), which play a very important role during prune processing. Purified PPO from the prune plum cv. d'Agen has a maximum activity at pH 4.25 and a special affinity for chlorogenic acid as a substrate.[98,116] Although quite resistant to elevated temperature of 54°C, it is quickly deactivated at 90°C. Polyphenol oxidases from other plum varieties were also investigated[52,125] and found to have similar properties. Following disruption of cell structures in hot air, PPO oxidizes phenolic compounds present in plums (enzymatic browning), which leads to the almost complete loss of some compounds and considerable degradation of others. Coupled oxidations degrade many susceptible vitamins and carotenoids. Thermal degradation of sugars and amino acids leads to the nonenzymatic formation of browning compounds (Maillard reaction), hydroxymethylfurfural and other artifacts absent in fresh fruits. Detailed discussions of qualitative and quantitative changes during processing are included in the following descriptions of prune constituents.

III. CHEMICAL COMPOSITION OF PRUNES

Table 1 lists components that have been quantified in fresh plums, dried prunes, and prune juice per 100 g of their ready-to-eat weight. Every attempt was made to find data for prune-making plum cultivars, but some values refer to fresh plums in general. The origin of values included in Table 1 and the common ranges are discussed below. The text also describes other substances in plums found in very small amounts or that have not yet been quantified, but may be of interest and importance for the reader. Table 2 compares the amounts of nutrients found in large servings of dried prunes and prune juice with existing dietary recommendations[41] to illustrate a contribution that can be achieved by consumption of these products.*

A. Sugars

Food composition tables for fruits usually list total carbohydrates without separating individual sugars. Table 3 is a compilation of published results of the individual sugar content in fresh prune-making plums, dried prunes, and prune juices.

1. Fresh Plums

The main sugars found in fresh plums are glucose, fructose, sucrose, and sorbitol.[157] High amounts of sorbitol are specific for the genus *Prunus*, and especially *Prunus domestica* fruits. However, some earlier reports did not measure sorbitol[90] or reported it together with glucose,[63] because their method, high-pressure liquid chromatography (HPLC), did not separate the two compounds. Alternatively, fructose may be poorly separated from sorbitol in the gas liquid chromatography (GLC) analysis of trimethylsilyl sugar derivatives.[81] Therefore, only reports with satisfactory separation of sorbitol are listed in Table 3. Although we limited the data to prune-making plums, there is still considerable variability between the reported studies, even of the same cv. d'Agen, which could be due to growing conditions and the degree of ripeness. Fresh prune plum juice data[148] were averaged with results for the fresh prune plums. Total sugar content in fresh fruit varied from 12.8 g to 29 g, with an average of 19.4 g/100 g. Individual sugar variability per 100 g was as follows: glucose content varied from 3.1 to 10.2 g (average 6.1 g); fructose from 2.5 to 5.1 (average 3.4 g); and sucrose from 2.9 to 6.2 g (average 4.5 g). Thus, on average, glucose constituted 31%, fructose 18%, sucrose 23%, and sorbitol 28% of total sugars. These averages are reported in Table 1 for the sugar composition of prune-making plums.

It could be argued that plums for prune making are harvested at a very ripe stage, and therefore the higher range of concentrations would be

* Dietary Reference Intakes are currently reevaluated for different life stages and gender groups, along with conversion factors for vitamins A and E. This new information appeared too late to be included in the present review (*Dietary Reference Intakes*. Food and Nutrition Board of the Institute of Medicine, National Academy Press, Washington, DC, 2001.)

TABLE 1
Chemical Composition of Fresh Prune-Making Plums, Dried Prunes, and Prune Juice (per 100 g)[a]

Component	Fresh Plums	Dried Prunes	Prune Juice
Water	78.0 g[b]	32.4 g	81.2 g
Carbohydrates	21.0 g	62.7 g	17.5 g
Protein	0.8 g	2.6 g	0.6 g
Fat	0.2 g	0.5 g	0.03 g
Sugars[c]			
Glucose	6.1 g	23.1 g	9.6 g
Fructose	3.4 g	13.1 g	6.2 g
Sucrose	4.5 g	0.6 g	—
Sorbitol	5.4 g	14.7 g	6.1 g
Total dietary fiber	1.5 g[d]	6.1 g[e]	0.01g
Pectin	0.76 g	2.1 g	—
Cellulose	0.23 g	0.9 g	—
Hemicellulose	—	3.0 g	—
Lignin	0.30 g	0.2 g	—
Amino acids			
Total	0.18 g[f]	0.53 g[f]	0.14 g[g]
Aspartic acid	0.13 g	0.30 g	0.06 g
Minerals			
Calcium	14 mg[d]	51 mg	12 mg
Iron	0.4 mg	2.5 mg	1.2 mg
Magnesium	10 mg	45 mg	14 mg
Phosphorus	18 mg	79 mg	25 mg
Potassium	221 mg	745 mg	276 mg
Sodium	1.7 mg	4 mg	4 mg
Zinc	0.1 mg	0.5 mg	0.2 mg
Copper	0.09 mg	0.4 mg	0.07 mg
Manganese	0.08 mg	0.2 mg	0.15 mg
Boron[h]	0.45 mg	2.2 mg	0.6 mg
Vitamins			
Ascorbic acid (C)	9.5 mg	3.3 mg	4.1 mg
Thiamin (B1)	0.04 mg	0.08 mg	0.02 mg
Riboflavin (B2)	0.10 mg	0.16 mg	0.07 mg
Niacin (B3)	0.5 mg	2.0 mg	0.8 mg
Pantothenic acid	0.18 mg	0.46 mg	—
Pyridoxine (B6)	0.08 mg	0.28 mg	—
Folate	2.2 µg	3.7 µg	0.4 µg
Vitamin A[i]	72 RE 717 IU	26 RE 259 IU	8 RE 80 IU
α-Tocopherol (E)[j]	0.85 mg 1.3 IU	1.76 mg 2.6 IU	—

TABLE 1 (continued)

Carotenoids [i]			
Lutein	240 g	120 g	37 μg
α-Carotene	—	31 g	10 μg
β-Carotene	430 μg	140 g	43 μg
Organic acids			
Total	0.5 g [k]	1.5 g [k]	0.8 g [g]
Malic acid	0.3 g	1.1 g	0.1 g
Quinic acid	0.2 g	0.4 g	0.7 g
Phenolic compounds [l]			
Total	111 mg	184 mg	44 mg
Neochlorogenic acid	81 mg	131 mg	22.5 mg
Chlorogenic acid	14.4 mg	44 mg	19.3 mg
Caffeic acid	—	0.9 mg	0.3 mg
Coumaric acid	—	1.0 mg	0.4 mg
Anthocyanins	7.6 mg	—	—
Catechins	5.4 mg	—	—
Rutin	2.5 mg	3.3 mg	0.4 mg
Sorbic acid (preservative) [l]	—	82 mg	—
Hydroxymethylfurfural [l] (artifact from heating sugars)	—	22 mg	53 mg

[a] Edible parts, no pits. Values are from USDA [145] unless otherwise stated.
[b] Wehmeyer and Nortje.[153]
[c] See averages of best studies in Table 3.
[d] Souci et al.[130]
[e] Labavitch et al.[79]
[f] Fernandez-Flores et al.[39]
[g] van Gorsel et al.[148]
[h] Anderson et al.[4]
[i] Reed-Mangels et al.[119]
[j] Piironen et al.[112]
[k] Puech and Jouret.[115]
[l] Donovan et al.[31]

TABLE 2
Percentage of Reference Daily Intake in a Large Serving of Dried Prunes (100 g) or Prune Juice (250 mL)

Nutrient	RDI [a]	%RDI in Prunes	%RDI in Prune Juice
Vitamin A	5000 IU	5	4
Vitamin E	30 IU	9	—
Vitamin C	60 mg	6	18
Folate	0.4 mg	1	—
Thiamin	1.5 mg	5	3
Riboflavin	1.7 mg	10	11
Niacin	20 mg	10	11
Pantothenic Acid	10 mg	5	—
Pyridoxine (B_6)	2 mg	14	—
Calcium	1000 mg	5	3
Phosphorus	1000 mg	8	7
Iron	18 mg	14	18
Magnesium	400 mg	11	9
Copper	2 mg	20	9
Zinc	15 mg	10	4
Manganese	2 - 5 mg [b]	10	20
Potassium	3500 mg [c]	21	21
Boron	2 - 3 mg [d]	100	80
Dietary fiber	25 g [c]	24	—

[a] Reference Daily Intake (RDI) for adults and children 4 or more years of age.[41]
[b] estimated safe and adequate daily dietary intake.[104]
[c] Daily Reference Value (DRV) based on 2000 kcals diet.[41]
[d] mean daily intake of boron; minimum requirement established at 1 mg/ day.[107]

TABLE 3
Sugar Composition of Prune Plums, Prunes, and Prune Juice (g/100 g)

Sample	Glucose	Fructose	Sucrose	Sorbitol	Total
Prune Plum (South Africa)[55]	10.2	4.1	6.2	8.5	29.0
Prune Plum (US)[120]	3.1	3.3	4.4	2.7	13.5
Prune Plum (Australia)[156]	4.1	2.5	2.9	4.0	13.5
Prune Plum (Italy)[43]	4.5	2.7	3.0	2.6	12.8
Prune Plum juice (US)[148]	10.1	5.1	4.4	6.4	26.0
Prune Plum juice (US)[148]	4.4	2.9	6.1	8.0	21.4
Average for prune plums	**6.1**	**3.4**	**4.5**	**5.4**	**19.4**
	31.4%	**17.5%**	**23.2%**	**27.8%**	
Dried Prunes, California (US)[71]	23.4	16.0	ND [a]	15.0	54.4
Dried Prunes, French (US)[71]	19.6	13.0	0.8	10.0	43.4
Dried Prunes, Imperial (US)[71]	22.8	12.2	2.4	9.4	46.8
Dried Prunes, Robe de Sergent (US)[71]	26.6	15.0	ND	16.2	57.8
Dried Prunes d'Agen (South Africa) [55]	26.0	13.7	0.4	19.3	59.4
Dried Prunes (Japan)[66]	20.0	8.6	ND	18.0	46.6
Average for prunes	**23.1**	**13.1**	**0.6**	**14.7**	**51.5**
	44.9%	**25.4%**	**—**	**28.5%**	
Packaged Prunes (Australia) [156]	12.3	8.1	ND	6.2	26.8
Prune Juice, with pulp (US) [148]	7.0	4.6	0.1	4.4	16.1
Prune Juice, no pulp (US) [148]	11.6	7.4	ND	7.4	26.4
Prune Juice, reconstituted (US) [148]	10.2	6.6	ND	6.5	23.3
Average for prune juice	**9.6**	**6.2**	**—**	**6.1**	**21.9**
	43.8%	**28.3%**		**27.9%**	

[a] ND = not detected

more appropriate. In general, prune-making plums contain twice as much total sugar at harvest than other varieties of plums.[55] When plums d'Ente were periodically harvested during the last month of ripening,[68] their sucrose content increased from a low of 2.1 g/100 mL to a high of 14.0 g/100 mL fresh plum juice. The last value was obtained from the naturally abscised plums, picked from the ground under the trees. The authors did not measure sorbitol, but reported that the content of reducing sugars (glucose and fructose) remained nearly stable at 6 to 10 g/100 mL of fresh plum juice. There was another interesting study of sugar dynamics in fruit and leaves of plum d'Agen during the ripening season, where sugar content was followed during 3 months of summer.[47] The results were expressed in mg/g of dry weight for purpose of comparison and could not be included in our compilation. However, it was found that the leaves contained mostly sorbitol, which decreased toward the end of fruit maturation, while in the fruits sucrose steadily increased, becoming the main sugar at the end of summer (54% of total sugar). Fructose then constituted only 9.4% of total sugars, glucose 21.9 %, and sorbitol 11.3%. This study also found small amounts of galactose (3.4% of total sugars) and traces of inositol. While these results are quite different from those reported in Table 3, they indicate that the degree of ripeness can have a major effect on the sugar composition of harvested fruit.

2. Dried Prunes

When compared with fresh prune plums, the concentration of sugar increases in dried prunes, because of the dehydration, but there are also qualitative changes in the proportion of individual sugars. The most striking change is the nearly total disappearance of sucrose, which is hydrolyzed to glucose and fructose during processing. The high temperature of drying disrupts cell structure, releasing fruit acids and invertase, which catalyze the conversion during the first few hours of drying.[156] The same study indicated that prolonged drying can cause some loss of glucose and fructose due to the formation of browning compounds with amino acids (Maillard reaction), and finally loss of all three sugars (glucose, fructose, and sorbitol) in thermal degradation (caramelization). It is interesting to find that packaged prunes (Fancy d'Agen Australian Dessert Prunes) described in this study seem to be much less dehydrated and consequently contain less sugar per 100 g than those reported in other studies with dried prunes (Table 3). Thus, we did not include this product in our calculation of the average sugar content of dried prunes. The total sugar content of dried prunes varied from a low of 26.8 g/100 g for the partially dehydrated Australian prunes to a high of 51.4 g/100 g for South African dried prunes of the same d'Agen variety. The differences are probably due to degree of dehydration, which is not always reported. Dried prunes contain from 19.6 to 26.6 g/100 g glucose (average 23.1 g), 12.2 to 16 g of fructose (average 13.1 g), 9.4 to 18 g (average 14.7 g) of sorbitol, which amounts to 45%, 25.5%, and 28.5% of total sugars, respectively. One study[66] reported the presence of sorbose (1.8 g/100 g) in dried prunes. Sorbitol is relatively well preserved during processing, as it does not enter into Maillard reactions with nitrogen containing compounds due to its lack of a carbonyl group. It may even protect prunes from browning during processing, as it is slow to caramelize at high temperatures. The presence of sorbitol adds a very desirable quality of retaining water (humectant), improving the texture of baking products or ground meat, to which prune puree is incorporated.[21,123,126]

3. Prune Juice

Prune juice has a similar sugar profile as dried prunes, because it is made from dried prunes by hot water extraction. There is no sucrose, and the proportions of glucose, fructose, and sorbitol (44%, 28%, and 28%, respectively) reflect those in dried prunes. Prune juice without pulp had the highest total and individual sugar content, while prune juice with pulp had the lowest values.[148] It probably indicates that the extracted pulp has a low sugar content due to excellent sugar solubility in hot water. The reconstituted juice had intermediate values for sugar content. On the average, prune juice contains 9.6 g of glucose, 6.2 g of fructose

and 6.1 g of sorbitol, which represents a total of 21.9 g of sugars per 100 mL.

Both dried prunes and prune juice contain hydroxymethylfurfural (HMF), which is an artifact produced from fructose during prolonged heating. Prune juice was reported to contain 90.4 ± 10.1 mg/100 mL in one study,[148] and 52.8 ± 9.1 mg/100 mL in a more recent report.[31] The difference may reflect improvements in the production of the prune juice in California, which was the site of both studies. Dried prunes contain less HMF than juice, 22.0 ± 18.9 mg/100 g for pitted prunes and 29.1 ± 20.5 mg/100 g for extra large prunes with pits. Toxicological studies of HMF did not show any adverse effects when rats were fed diets containing 450 mg/kg.[80]

Other dried fruits also contain comparable amounts of total sugars, but the individual sugar content is different and characteristic for each species (Table 4). Apricots (*Prunus armeniaca* L.) belong to the same genus, yet their main sugar is sucrose (74% of total sugars), with glucose, fructose, and sorbitol constituting only 12.0, 3.5, and 4.0% of total sugars, respectively.[55] Another study[66] found much less sucrose in apricots (37% of total sugars, with 31% glucose, 24% fructose, and 8% sorbitol). The same report found that raisins (*Vitis vinifera* L.) do not contain sorbitol or sucrose, but large amounts of glucose and fructose in approximately equal proportion.[63,66] Grapes are not sorbitol-containing fruits, but the sucrose undergoes conversion to fructose and glucose during processing in raisins in a manner analogous to prunes, while apricots retain most of their sucrose content during drying.[66] Physiological differences between fruits, as well as differences in processing technology, influence the final pattern of sugar distribution in dried fruits.

B. Dietary Fiber

Due to differences in methods of analysis, the estimates of fiber in dried prunes range from 6 to 16 g/100 g. However, these data are very sketchy and difficult to reconcile. According to USDA Food Composition Tables,[145] fresh plums contain 0.6 g, dried prunes 2.0 g, and prune juice only 0.01 g of fiber per 100 g. European Food Composition Tables[130] list 0.6 g of crude fiber for fresh plums, and 1.5 g of total dietary fiber per 100 g. It seems that the USDA tables are limited to crude fiber and do not report total dietary fiber. European tables also estimate that fresh plums contain 0.8 g pectin, 0.3 g lignin, and 0.2 g cellulose per 100 g. French plums d'Ente were found to contain about 1 g of total pectin/100 g of fresh pulp, but the soluble pectin increased during ripening from 0.1 to 0.5 g/100 g.[68] Japanese plums contain less than 0.5 g pectin per 100 g.[70]

The provisional USDA table of fiber content[146] estimates that dried prunes contain 6 to 7 g of total dietary fiber per 100 g, and similar values are used for the labeling of dried prunes (6.0 g/100 g) in the U.S. Tinker et al.[138] measured the total dietary fiber content of prunes and also found 6.0 g fiber per 100 g prunes. In another study,[79] California dried prunes were analyzed and the total dietary fiber content was given as 6.2 g/100 g, including 2.1 g pectin, 3.0 g hemicellulose, 0.9 g cellulose, and 0.2 g lignin. Ethanol-extracted prune fiber was found to contain 49% of soluble and 51% of insoluble dietary fiber.[139] Prosky,[114] who used methanol extraction, reported 42% of insoluble and 58% of soluble dietary fiber in a similar product made of milled dried prunes. The same proportion of soluble to insoluble fiber is listed in his recent publication,[33] with fresh plums

TABLE 4
Sugar Composition of Dried Fruits (g/100 g)

Sample	Glucose	Fructose	Sucrose	Sorbitol	Total
Apricots (South Africa)[55]	6.0	1.8	37.1	5.2	50.6
Apricots (Japan)[66]	14.6	11.2	17.4	3.6	46.8
Prunes (average from Table 3)	23.1	13.1	0.6	14.7	51.5
Raisins (Japan)[66]	34.4	32.7	ND [a]	ND [a]	67.1

[a] ND = not detected.

containing 1.6 g, dried prunes 7.3 g, and prune juice 1.0 g of dietary fiber per 100 g.

European Food Composition Tables[130] give a much higher value of 16.1 g/100 g for total dietary fiber of dried prunes. This value is quoted in a published review [128] as derived from the work of Paul and Southgate,[110] who estimated that 80% of dietary fiber in prunes comes from pectin, with the rest supplied by hemicellulose and cellulose. The French Prune Association[15] quotes 13 to 16 g of dietary fiber/100 g for dried prunes d'Agen with 40% pectin and 60% insoluble fiber (cellulose and hemicellulose). They also compared prunes to dried apricots (13.7 g/100 g), figs (11.0 g/100 g), and dates (5.1 g/100 g). Among dried fruits, prunes and apricots are probably the highest in dietary fiber.

Prune juice is very low in fiber, with values listed from 0.01 to 1.0 g of dietary fiber/100 mL.[19,33] Most of the fruit skin and pulp are removed by filtration in the process of making prune juice from dried prunes, followed by depectinization to prevent gelling of the juice.[24]

C. Minerals

The mineral content of fruits depends to a certain degree on the soil of the growing region. However, the methodology of mineral assessment has been perfected for a long time in the form of atomic absorption spectroscopy. There should be no losses of minerals during the dehydration process and the amount in dried prunes should reflect, in concentrated form, the proportions present in prune-making plums. The mineral content of fresh plums (unspecified Japanese and hybrid varieties) reported in the USDA Food Composition Tables[145] was far too low to be consistent with values for dried prunes taken from the same publication. Therefore, we used the European Food Composition Tables[130] as the source for our Table 1 for fresh plums, as probably closer to the prune-making variety used in the U.S. French plums d'Ente[68] were found to contain 160 to 220 mg K, 0.5 to 1.0 mg Na, 8 to 12 mg Ca, and 12 to 17 mg Mg/100 ml fresh juice depending on their maturity, with higher values reflecting very ripe fruits. Eleven varieties of fresh plums grown in the Aegean region of Turkey[105] had a high sodium content of 16.2 mg per 100 g fruit (vs. 1.7 mg/100 g in European Tables[130]), but an average amount of potassium and iron (223 mg and 0.5 mg/100 g, respectively) and a low calcium content (2.5 mg/100 g). In a South African study[153] of prune-making plums, d'Agen and van der Merwe varieties, the following averages were obtained from four lots of fruits: Ca 39 mg; Mg 43 mg; P 70 mg; Fe 1.3 mg; Na 2.2 mg; K 1005 mg; Cu 0.2 mg; Zn 0.6 mg per 100 g of dry weight. Inasmuch as the authors reported water content of fresh plums (79.5% for d'Agen and 77.8% for van der Merwe variety), the above values can be converted to find the average mineral content for fresh prune-making plums in this study: Ca 8.3 mg; Mg 9.1 mg; P 15 mg; Fe 0.3 mg; Na 0.5 mg; K 214 mg; Cu 0.04 mg; Zn 0.13 mg per100 g of fresh fruit, which is close to those values reported in Table 1.

Dehydrated California prunes (19% moisture) were found to contain 3.2 mg Fe, 990 mg K, and 78 mg Ca per 100 g dry weight.[9] Rehydration did not cause significant losses of minerals, with resulting concentrations of 1.6 to 2.2 mg Fe, 605 to 708 mg K, and 51 to 57 mg Ca/100 g of rehydrated prunes. A study of four sun-dried prune varieties from Uzbekistan[77] reported similar to U.S. values for copper, calcium, and magnesium, but an extremely high content of iron and manganese (11 mg and 1.54 mg/100 g of fruit, respectively, adjusted for moisture content). Among the minerals with known recommendations, iron, magnesium, copper, zinc, manganese, and potassium are present in physiologically significant amounts in dried prunes (Table 2). A 100-g serving of dried prunes will deliver 20% of the daily reference value (DRV) of potassium, 20% of the reference daily intake (RDI) for copper, 14% of the RDI for iron, about 10% of the RDI for magnesium and zinc, and 10% of safe and adequate intake for manganese. A cup of prune juice will meet 20% of the DRV for potassium, 20% of the RDI for iron and 20% of safe and adequate intake for manganese. Copper and magnesium levels in one cup of prune juice are close to 10% of the RDI for these minerals.

A recent study from Australia[102] found that plums contain significant amounts of boron (0.45 mg/100 g fruit), while dried prunes have 1.88 mg/

100 g and prune juice 0.60 mg/100 mL. American sources[4] report similar values of 0.42 mg/100 g in plums and 2.15 mg/100 g for dried prunes. The amount of boron in a 100-g serving of dried prunes is equal to an average daily intake for adult males, 2.23 ± 1.3 mg boron per day.[102] Humans probably have a dietary boron requirement of 1 mg/day.[107] The high boron content of dried prunes is associated with their high sorbitol content, because the transport of boron to plums in the phloem of the *Prunus domestica* tree is dependent on a boron-sorbitol complex and proceeds concurrently.[14] The boron-sorbitol complex is formed in the leaves, where sorbitol is the major product of photosynthesis, while boron is absorbed from soil by the roots and translocated to the leaves through the xylem.

D. Vitamins

Table 1 lists the quantities of vitamins in fresh plums (not prune-making variety), dried prunes, and prune juice according to the USDA Food Composition Tables.[145] European Composition Tables[130] provide similar values for some vitamins, while the others are quite different. Thiamin (B_1) is twice as high in both fresh plums and dried prunes, while pyridoxine (B_6) is twice as low in plums and prunes in European tables compared with the USDA tables. We could not find good comparative studies of the vitamin content in fresh prune-making plums and dried prunes, but it is reasonable to assume that some vitamins, especially ascorbic acid (vitamin C), are degraded during the dehydration processing at high temperatures. Others may be concentrated by dehydration, making dried prunes more nutrient dense than plums and other fresh fruits.

Some estimates of vitamin C in fresh plums of prune-making varieties were made by Wehmeyer and Nortje[153] in South Africa. They found that fresh prune plums d'Agen contained 5.1 mg ascorbate/ 100 g fruit, while cv. van der Merwe had 5.7 mg /100 g. Although these values for vitamin C are lower than those of average plums in the USDA Food Composition Tables, they agree with the European Food Composition Tables (5.4 mg/100 g fruit). Tomasevic and Naumovic[141] found an average of 8.8 mg vitamin C per 100 g of plums in Yugoslavia. Two prune-making fresh plum varieties from Turkey[105] had vitamin C levels of 5.8 mg/100 g for Imperial Epineuse, and 16.5 mg/100 g for the Krikon Damson cultivar.

The vitamin C content of dried prunes is reported as 3.3 mg/100 g of fruit in the U.S.,[145] and 4.0 mg/100 g in Europe.[130] However, in a study of four varieties of sun-dried prunes from Uzbekistan, Korobkina[77] reported an average of 8.7 mg of vitamin C/100 g dry weight, which is equal to 7.2 mg/100 g of ready-to-eat prunes, correcting for their moisture content (17%). Therefore, a large serving of dried prunes could provide 6 to 10% of the RDI of vitamin C. Prune juice contains more vitamin C, because some may be added in processing, and a cup of prune juice may contain nearly 20% of the RDI.

According to one study in Finland,[112] a pooled sample of unspecified fresh plums contained 0.85 mg α-tocopherol/100 g, while dried prunes had 1.76 mg α-tocopherol/100 g. Considering that the plums and prunes in this study had 86.2 and 35.7% moisture, respectively, the prunes retained only 44% of their vitamin E content after the dehydration processing. Despite this loss, a 100-g serving of dried prunes could provide 9% of the RDI for vitamin E (Table 2). Other tocopherols were present only in trace amounts: 0.04 mg of β-tocopherol and 0.13 mg of γ-tocopherol/100 g of dried prunes. No data are available on vitamin E content of prune juice. Fresh plums were reported to contain moderate amounts of phylloquinone (vitamin K_1 – 8 μg/ 100 g),[73] but we are not aware of any studies of the vitamin K content of dried prunes or prune juice. The South African study[153] compared the content of some vitamins in freeze-dried plums and sun-dried prunes of the same varieties. On a dry weight basis, sun-dried prunes had 34% less thiamin and 20% less niacin, but riboflavin was 42% higher than in freeze-dried prunes. The average vitamin content for two varieties of sun-dried prunes was 0.12 mg thiamin, 0.17 mg riboflavin, and 2.2 mg niacin /100 g dry weight (no data on moisture content of dried prunes reported).

Table 2 compares the RDI for vitamins[41] with amounts contained in a large serving of dried

prunes (100 g ≈ 12 prunes) or prune juice (250 mL ≈ 1 cup). The following vitamins could provide a significant contribution to the daily requirements: vitamin C (as discussed above), riboflavin, niacin, and pyridoxine, which are present in dried prunes at levels of 10% of the RDI per serving. According to the European Food Composition Tables,[130] there is twice the thiamin in dried prunes reported in U.S. tables, which would put its level also at 10% of the RDI. A careful reevaluation of vitamin content in dried prunes is necessary in order to gain the information that can be passed to consumers by correct labeling on packages. At present only vitamin A is listed on the label and that claim could be overstated (*vide infra*).

E. Vitamin A and Carotenoids

Carotenoids are bright-colored (yellow to red) fat-soluble pigments, a few of which can be converted to vitamin A in the body, if they possess an intact β-ionone ring. Fresh prune plums contain a provitamin A carotenoid (β-carotene) and oxycarotenoids (xanthophylls) without vitamin A activity. Of the xanthophylls, lutein is most important, because it is well absorbed by humans and present in the macula of the eye, possibly protecting it from light damage and macular degeneration.

There are very few studies of carotenoids in dried prunes or prune juice. Even the estimate of the provitamin A value on current packaging is questionable. The older studies, which extracted β-carotene and measured absorbance at 450 nm, often overestimated it by poor separation from other carotenoids. Modern analytical techniques require thorough extraction with organic solvents, saponification to release the carotenoid from its plant matrix and to hydrolyze carotenoid esters, and then careful separation of individual carotenoids, preferably by HPLC. A South African study[153] found 0.22 mg of β-carotene/100 g (370 IU) for fresh prune plums d'Ente and 0.34 mg of β-carotene/100 g (570 IU) for fresh prune plums van der Merwe. Aczel[1] reported that 38% of carotenoids in Hungarian plums was β-carotene, amounting to 0.57 mg/100 g of fruit (950 IU). None of these studies used modern HPLC techniques, and therefore they must be regarded with caution.

Carotenoids of Italian prune plums from Iowa were analyzed in great detail using countercurrent distribution and column chromatography,[26] while a combination of column and subsequent thin layer chromatography (TLC) was used for the investigation of French plums cv. Saghiv from Israel.[53] Both studies employed saponification of extracted carotenoids and achieved separation and identification (sometimes tentative) of 15 to 30 carotenoids present in fresh prune plums. Table 5 shows a similar pattern of carotenoid distribution in both varieties of plums, with violaxanthin (zeaxanthin diepoxide) constituting 32 to 35%, β-carotene 19 to 25%, and lutein 10 to 15% of total carotenoids. The vitamin A activity was mainly due to their β-carotene content, but other carotenoids (α-carotene, cryptoxanthin, cryptoflavin, and mutatochrome) also contributed to a total of 340 IU/100 g of French plums cv. Saghiv, and 870 IU/100 g of Italian prune plums. Both studies found a significant amount of C_{25} apocarotenol, persicaxanthin (60 μg/ 100 g), usually present in peaches. Italian prune plums contained 2.1 mg and French plums cv. Saghiv only 0.75 mg total carotenoids per 100 g fresh fruit. In both studies the pits were removed, but the French plums were also peeled, because the investigator declared the absence of carotenoids in their bluish-black skin.[53] However, other species of plums, golden yellow fruits of *Prunus salicina* and *Prunus institia*, are known to have a high concentration of carotenoids in the skin.

The USDA Carotenoid Database,[119] which currently is used in most epidemiological studies, accepted only one study for their estimate of carotenoids in fresh plums and dried prunes.[56] This Finnish study found 240 μg of lutein and 430 μg of β-carotene/100 g of fresh plums (unknown variety), but only 120 μg lutein, 140 μg β-carotene, and 31 μg α-carotene in dried prunes. It seems that considerable degradation of carotenoids occurs during processing of prune plums to dried prunes. Assuming 30% moisture in dried prunes and 80% moisture in fresh plums, the level of β-carotene decreases to less than 10% of its original content during processing and/or storage. Using

Table 5
Carotenoids in Prune Plums (μg/100g fruit)

Compound	Italian Prune Plums[a]	French Plums cv Saghiv[b]
Phytoene	27	—
Phytofluene	23	58
α-Carotene	11	11
β-Carotene	393	180
Mutatochrome	8	—
Cryptoxanthin	153	20
Cryptoxanthin 5, 6-epoxide	74	7
Cryptoxanthin 5', 6'-epoxide	—	5
Cryptoflavin	13	—
Violaxanthal	—	11
Lutein	326	77
Zeaxanthin	8	5
Mutatoxanthin	4	4
Antheraxanthin	44	23
Luteoxanthin	91	—
Violaxanthin	735	240
Persicachrome	2	6
Persicaxanthin	61	60
Neoxanthin	29	38
Total carotenoids	2100	750

[a]Adapted from Curl.[26]
[b]Adapted from Gross.[53]

the conversion factor of 1 IU = 0.6 μg β-carotene or 1.2 μg α-carotene, dried prunes contain only 259 IU of provitamin A activity per 100 g. It constitutes only 5% of the RDI for vitamin A (5000 IU/day) and makes prunes a quite insignificant source of vitamin A, contrary to the present claim. A package of prunes in the U.S. is supplied with information that a 40-g serving provides 10% of the daily value of vitamin A (25% of the RDI for 100g serving). European Food Composition Tables[130] list 210 μg of β-carotene/100 g of plums and 610 μg of β-carotene/100 g of dried prunes, which can be converted to 350 IU and 1020 IU/100 g, respectively. This value of provitamin A for dried prunes is similar to the U.S. package claim (22% of the RDI). However, the USDA Food Composition Tables[145] report that dried prunes contain 2000 IU of vitamin A per 100 g (40% of the RDI), while plums contain only 320 IU/100 g. Considering the difference in moisture content, it would mean that dried prunes are produced from a variety exceptionally rich in β-carotene and that β-carotene does not degrade during the dehydration process.

However, a study of California dried prunes[9] found a much lower content of β-carotene (0.95 mg/100 g dry weight), with further degradation during rehydration procedures (Table 6). When dried prunes (18 to 20% moisture) were rehydrated at various temperatures to 30% moisture with hot water or steam, provitamin A value decreased significantly, except during very rapid rehydration at 120°C. Commercial processing involves 77°C water bath followed by steam treatment, which resulted in this study in 18% loss of β-carotene. The steam-rehydrated prunes contained 0.56 mg β-carotene/100 g (930 IU) of wet weight, which is less than half of provitamin A activity reported by the USDA Food Composition Tables.[145] Korobkina[77] reported an average 1.0 mg β-carotene/100 g dry weight in four varieties of Uzbek prunes, which were sun dried to 17% moisture (0.83 g β-carotene/100 g of fruit or 1380 IU). This is similar to 0.95 mg β-carotene/100 g dry weight reported for California prunes.[9]

The most detailed study of carotenoid changes in prune production was described by Moutounet.[97] Fresh prune plums d'Agen from two different

TABLE 6
Effect of Rehydration on Provitamin A Value of California Prunes [a] (100g)

Procedure	Time (min)	Dry weight (IU)	Dry weight (mg β-carotene)	Wet weight (IU)	Wet weight (mg β–carotene)
No rehydration	—	1590	0.94	1290	0.77
Water, 120°C	4	1540	0.92	1050	0.63
Water, 90°C	20	1480	0.89	960	0.58
Water, 70°C	30	1420	0.85	970	0.58
Steam	40	1290	0.77	930	0.56

[a] Adapted from Bolin.[9] The calculations were based on reported moisture content (19% for dehydrated prunes, 28 to 35% for rehydrated prunes) and conversion factor: 1 IU = 0.6 μg β-carotene.

harvests (1972 and 1974) were analyzed for their carotenoid content by extraction, solvent partition, saponification, column chromatography, and thin layer chromatography. The only provitamin A carotenoid identified was β-carotene, which represented 25% of all carotenoids. The remaining 75% were oxycarotenoids (xanthophylls), including lutein, violaxanthin, and neoxanthin. The amounts of individual oxycarotenoids were not reported. The plums were processed to dried prunes and the carotenoid content analyzed again. The amounts of β-carotene and xanthophylls were expressed in mg/kg of dry weight to observe changes due to processing. It appears that prune plums from 1972 lost 75% of their total carotenoids during dehydration, while those from 1974 lost only 45%. β-Carotene is less susceptible to degradation than xanthophylls. It was reduced by 65% in 1972 and by 40% in 1974. Inasmuch as the prune plums from 1974 contained nearly twice the carotenoids of those from 1972, the difference in carotenoid content of dried prunes was magnified. Apparently, the dehydration process causes a rather definite loss of carotenoids (50 to 64 mg/kg dry weight), independent of the total amount of carotenoids available. Therefore, the resulting carotenoid content of dried prunes depends on conditions of a particular growing season and location.

Table 7 describes the carotenoid content in prunes from the Moutounet[97] study after converting the values from mg/kg dry weight to mg/100 g wet weight. It would be more accurate if the original moisture content was available, but the authors reported drying the prunes to 30% moisture, and fresh prune plums d'Ente contain about 80% water.[43,153] There are large differences in provitamin A activity and carotenoid content of the same variety of prune plums processed in an identical way into dried plums, depending on the growing season. This may explain the discrepancies found in data from different sources.

According to the USDA Food Composition Tables[145] prune juice contains only traces of vitamin A activity, which could be explained by the fact that it is produced by hot water extraction of dried prunes with subsequent filtration. Prune juice with pulp may contain more carotenoids, but studies to determine this are lacking. Further research on carotenoids in fresh plums, dried prunes, and prune juice is necessary to establish their provitamin A activity and carotenoid profile.

F. Organic Acids

Not much data are available on the organic acid content of dried prunes, except an estimate of 2 g/100 g from the European Food Composition Tables,[130] calculated as citric acid. Industry sources[17,123] quote the same value, stressing that it is mainly malic acid. French Prune Association[15] lists 1.6 g of organic acids per 100 g of dried prunes d'Agen, predominately malic acid at 1.5 g/100 g.

However, these values for dried prunes do not seem to reflect the true composition of organic acids. The fresh prune-making plums contain mainly two organic acids, malic and quinic. Various sources report diverse concentrations of those acids in fresh prune plums. The older studies, which used fractionation and paper chroma-

TABLE 7
Seasonal Changes in Carotenoid Content during Processing of Plums d'Agen (mg /100 g Fruit)

Sample	β-Carotene		Xanthophylls	Total carotenoids
Fresh plums, 1972	0.34	(570 IU) [a]	1.01	1.35
Dried prunes,1972	0.53	(880 IU)	0.69	1.22
Fresh plums, 1974	0.56	(930 IU)	1.77	2.33
Dried prunes, 1974	1.21	(2020 IU)	2.49	3.70

[a] β-carotene provitamin A value in International Units (1 IU = 0.6 μg β-carotene).
Adapted from Moutounet.[97]

tography,[28] express their acid content in milliequivalents and cannot be easily converted to g/100 g. They noticed the presence of quinic acid,[28,90] but mentioned its low recovery by existing analytical techniques. Both quinic and malic acids were found in Victoria plums.[30] The more accurate study of Fernandez-Flores et al.[38] used GLC with trimethylsilyl derivatization and found 0.22 g of quinic acid in fresh Italian prune plums along with 1.95 g malic acid/100 g, a rather high value, which could be due to relative immaturity of plums. A study of prune plums d'Ente[68] found that malic acid content of their juice decreased tenfold during the last month before the ripe fruits naturally abscised from the tree. The accompanying pH measurement changed from 3.3 to 3.8.

Better data exist on the organic acid profile in prune juice. An older careful study[37] lists 0.32 g of malic acid per 100 g of prune juice. A recent investigation of various fruit juices by HPLC[148] reported larger amounts of quinic acid (0.67 g/100 g) in purchased prune juice with pulp, and only 0.10 g of malic acid. The high concentration of quinic acid seems to be characteristic of prune juice, as well as rather low amounts of malic acid. Roysum fresh plum juice, made of another variety of plums, which is not used for prune production, contained 0.21 g of quinic acid and 0.29 g of malic acid per 100 mL of juice.

There is an excellent older study of organic acids in French plums d'Ente[115] and dried prunes obtained from the same lot. The fruits were lyophilized, extracted, and analyzed by paper chromatography, column fractionation, and GLC. Malic acid content remained nearly constant after dehydration of plums to prunes (15.5 mg vs. 15.0 mg/dry weight), while quinic acid decreased by 34% (from 9.1 to 6.0 mg/g dry weight). Converting these results to wet weight (80% water for prune plums,[43] 30% water for prunes) we arrived at the values used in Table 1 for organic acids content: 0.18 g quinic acid and 0.31 g malic acid/100 g fresh plums d'Ente, 0.42 g quinic acid and 1.05 g malic acid/100 g dried prunes. It is interesting to note that the dehydration does not alter the acidity of prunes, because their pH remains stable at 3.6.[157]

A minor constituent of potential importance is salicylic acid, which can be found in fresh plums at 0.1 to 0.2 mg /100 g concentrations, but canned plums contain 1.2 mg/100 g.[137] Canned Letona prunes contained as much as 6.9 mg/100 g, which most likely indicates that those prunes first were dehydrated and then canned (Australian product). This naturally occurring salicylic acid may protect dried prunes from spoiling. However, an earlier study[121] found much lower concentrations of salicylic acid in plums (0.003 mg/100 g) and prunes (0.034 mg/100 g).

G. Free Amino Acids

Fresh prune plums, dried prunes, and prune juice contain very small amounts of free amino acids (0.18 g, 0.53 g, and 0.14 g/100 g, respectively), which nevertheless are important in browning reactions during dehydration, because they enter into the Maillard reaction with glucose and fructose. There were some detailed studies of amino acid composition in dried prunes[39] and prune juice[148] for the purpose of characterizing those products and protecting prune juice from adulteration. Moutounet and Jouret[95] compared the amino acids in fresh prune plums d'Ente and dried prunes d'Agen (same variety). However, they expressed their results per kg of lyophilized pulp, which makes the data difficult to compare with other studies and with USDA Composition

Tables.[145] The results of the above-mentioned studies are not easy to reconcile. Moutounet and Jouret[95] reported that asparagine represents 80% of the total amino acid content in both fresh and dried prunes, and the remainder is composed of aspartic acid (7%), alanine (7%), valine (1.5%), and γ-aminobutyric acid (2.5%). Drying and sterilization did not alter the profile of amino acids, although it decreased the total amount of amino acids by about 20%. However, storing sterilized dried prunes at ambient temperature caused a large decrease in amino acid content down to 30% of the initial value after 10 months of storage. The greatest change was noticed in the asparagine content, which decreased by 90%, while the amount of aspartic acid doubled during the same period. It seems that asparagine may be hydrolyzed to aspartic acid even during storage by nonenzymatic reactions. All other studies of fresh plums, dried prunes, and prune juice do not quantify asparagine, although it is mentioned by van Gorsel[148] as the major free amino acid in all fruit juices, together with glutamic acid. Both, however, are "not separable" by methods used in the van Gorsel[148] study. Instead, aspartic acid seems to be the main amino acid in dried prunes,[39] plums,[145] and prune juice,[148] accounting for about 50% of all amino acids. Possibly asparagine is hydrolyzed during analysis and included together with aspartic acid, but the issue is not obvious. The remaining amino acids were most thoroughly investigated in prune juice by van Gorsel et al.[148] and include proline (9% of total amino acids), γ-aminobutyric acid (6%), taurine (9%), and *o*-phosphoethanolamine (8%) among the most abundant and characteristic for this juice (Table 8). The same study analyzed juice made of fresh prune plums from two different sources in California. Its composition should be similar to fresh plums, but also reflect the proportions of amino acids in dried prunes. Instead, one sample did not seem to have any aspartic acid, but 37% of proline and 21% of γ-aminobutyric acid. In the other sample γ-amino-butyric acid was predominant (31% of all amino acids) with 18% of aspartic acid and 13% of proline. Another variety of fresh plum, Roysum, yielded juice with proline as the most abundant amino acid (30%) and aspartic acid at 22% of total amino acids. This very confusing picture of the free amino acid content in prunes requires further careful studies with special attention to standardization of analytical methods and complete recovery of all major amino acids. For nutrition information, an estimate of the total amino acid profile, both free and bound in proteins, would be more useful, although the quantities contained in prunes are trivial compared with human requirements.

TABLE 8
Free Amino Acids in Prune Juice

Compound	Amount (mg/dL)	Compound	Amount (mg/dL)
α-amino-adipic acid	0.4	Isoleucine	1.5
α-amino-butyric acid	4.0	Lysine	0.2
γ-amino-butyric acid	8.5	Methionine	0.04
Alanine	5.0	Ornithine	2.5
β-alanine	0.3	Proline	13.0
Phenylalanine	2.6	Hydroxy-proline[a]	0.2
Arginine	0.2	Serine	3.5
Citrulline	4.0	*o*-phospho-L-serine	2.4
Cysteine	0.4	Threonine	3.4
Glutamine	0.3	Tryptophan	0.7
Glycine	0.5	Tyrosine	2.0
Histidine	1.4	Valine	2.0
1-Methyl-L-histidine	2.5	*o*-Phospho-ethanolamine	9.0
Leucine	1.8	Taurine	12.8

[a] Found only in fresh plum juice.
Adapted from van Gorsel et al.[148]

H. Phenolic Compounds

Fresh prune-making plums are a rich source of phenolic compounds, many of them concentrated in the skin of the fruit, exocarp,[116,117] which contains about five times more phenolics per unit of weight than the pulp. The skin contains mainly anthocyanins (6.3 mg/g dry weight): cyanidin 3-rutinoside and peonidin 3-rutinoside, 44 and 42%, respectively. Anthocyanins in the skin give the fresh prune plums their purple color at pH 3.6, which is typical for plums. Equal to anthocyanins is the content of neochlorogenic acid (3'-caffeoylquinic acid) at 6.25 mg/g dry weight of plum skin. Exocarp contains significant quantities of rutin (2.2 mg/g dry weight) and catechins (0.74 mg/g dry weight). Chlorogenic acid (5'-caffeoylquinic acid) is also prominent (1.37 mg/g dry weight), but there are only traces of free caffeic acid. The pulp does not contain anthocyanins or rutin, and very little catechins. During the dehydration of prune plums, the rate of degradation in the exocarp is much more rapid than in the pulp, so anthocyanins and catechins are absent in dried prunes.[31] Other phenolic compounds are also degraded by activation of peroxidase and polyphenol oxidase, resulting from cell disruption in the processing of prune plums. From calculations based on the dry weight of fresh prune-making plums and dried prunes, it appears that half of the total phenolic compounds are lost during processing. Although very useful for understanding the physiology of the changes during processing, the study of Raynal et al.[116,117] is difficult to interpret in terms of phenolic content in whole fruits, fresh or dried. An earlier study from the same laboratory[115] found 40% degradation of phenolic acids in French prunes d'Agen when compared with prune-making plums from the same lot. Neochlorogenic acid decreased from 3.1 to 1.9 mg, chlorogenic acid from 0.5 to 0.3 mg, and cryptochlorogenic (4'-caffeoylquinic) acid from 0.4 to 0.25 mg/g dry weight of lyophilized samples.

An excellent comparative study of the phenolic composition of fresh prune-making plums, dried prunes, and prune juice was published recently.[31] The data from this study were used in preparing Table 1. The study confirms many findings of earlier researchers[129] and clarifies the concentrations and relative proportions of different phenolic compounds. Fresh prune-making plums contain 111 mg of total phenolic compounds per 100 g of fruit. Characteristically for plums,[86,93] predominant are neochlorogenic acid (73% of total phenolics) and chlorogenic acid (13%). Together, hydroxycinnamates (caffeoylquinic acids) constituted 86% of total phenolics. Minor phenolic compounds in fresh prune plums are anthocyanins (7%), flavan-3-ol catechin (5%), and flavonol rutin (2%). Other studies of different plum varieties found 2 to 5 mg flavonol glycosides per 100 g of fruit,[58] mainly 3-rutinoside of quercetin (rutin) and of kaempferol. Quercetin (rutin aglycon) amounted to 0.9 mg/100 g plums.[63] Some older studies[135] hydrolyzed hydroxycinnamates before employing thin layer chromatography and found 21 mg of caffeic acid/100 g of fresh ripe plums, along with 1.5 mg ferulic acid, 2 mg *p*-coumaric, 1 mg (+)-catechin, and 1 mg (-)-epicatechin. It is interesting that plums infected with fungus *Taphrina pruni* accumulate large quantities of chlorogenic acid as well as its isomers, neochloro-genic, and cryptochlorogenic acids, 15 times more than uninfected fruit, which may be a defensive response against fungal enzymes.[46] The phenolic compounds are metabolized by plum polyphenol oxidase to quinones, which are toxic to the invading pathogen. The fungus, in turn, excretes 4-pentadecylpyridine, which inhibits plum polyphenol oxidase activity, and was also found in the infected plums.[44,45]

Dried prunes contain higher amounts of phenolic compounds (184 mg/100 g of fruit) than prune-making plums,[31] because dehydration concentrates the constituents despite partial degradation. Neochlorogenic acid represents 71% of the total phenolics and chlorogenic acid 24%, raising the content of hydroxycinnamates to 95% of all phenolic compounds. Rutin is still present at 2% of all phenolics. Small amounts of caffeic and coumaric acids (1% of phenolics) appear in dried prunes, probably as a result of cinnamate hydrolysis during processing. Plum jams contain, on average, 14.3 mg caffeic acid per 100 g[140] because of the more extensive processing of fruit. 3'-Coumaroylquinic acid was tentatively identified

both in fresh prune-making plums and dried prunes at levels of 1.0 and 1.5 mg/100 g fruit, respectively.[31]

Prune juice should contain similar proportions of phenolic compounds as dried prunes, and apparently the total content of phenolics in relation to soluble solids does not change.[31] The dilution factor accounts for a total phenolic content of 44 mg/100 mL juice, and hydroxycinnamates constitute 95% of phenolic compounds. However, neochlorogenic acid represents 51% and chlorogenic acid 44% of phenolics in prune juice, an unexpected change compared with the proportions found in dried prunes.

There is another, less exhaustive study of phenolic compounds in prune juice[148] that did not measure neochlorogenic acid. Chlorogenic acid was reported as 34 mg/100 mL (vs. 19 mg/100 mL in Donovan et al.[31]). The catechin level at 16 mg/100 mL seems extremely high, because none was detected by Donovan et al.,[31] and it is highly susceptible to degradation. Similar amounts of caffeic acid (3 to 4 mg/ 100 mL) were found in both studies. Phenolic composition of prune juice varied greatly between two growing seasons, 1988 and 1989, with the latter containing 50% more (+)-catechin and 200% more chlorogenic acid as well as caffeic acid. The differences may be due to growing conditions, maturity at harvest, storage conditions, and processing procedures.

Dried prunes are quite high in phenolics, surpassed only by blueberries, which contain 450 mg per 100 g of fruit. Prune juice has a higher content of phenolic compounds than most fruit juices, except red grape juice and red wines.[31]

I. Lipids

There is very little fat in fresh plums and dried prunes, but the amounts published in the USDA Food Composition Tables[145] do not fit well together. The fat content of dried prunes and fresh plums is nearly identical, 0.5 and 0.6% of weight of fruits. Dehydrated prunes should have more fat than fresh plums. European Food Composition Tables[130] report 0.17% of fat in plums and 0.5% in dried prunes. Prune juice has only traces of fat, 0.03 g/100 mL. The prevailing fatty acids in prunes are the monounsaturated oleic acid (18:1) and polyunsaturated linoleic acid (18:2). Fresh plums contain about 7 mg phytosterols per 100 g of fruit in the form of β-sitosterol,[130] an amount too small to affect cholesterol absorption from the intestine.

A small fraction of plum lipids covers the whole fruit as epicuticular wax. There is only about 30 mg of this wax in 100 g of fresh plums,[67,69]consisting mainly of long chain secondary alcohols (nonacosan-10-ol, heptacosan-8-ol), primary alcohols (C_{24}, C_{26}, C_{28}) and their esters, as well as β-sitosterol in prune plums d' Ente[69] (Table 9). Golden Egg plums [67] were found to contain also ketones and aldehydes, proportionally more hydrocarbons (20%), and ursolic acid (1%). Both varieties of plums had a significant amount of oleanolic acid (5 to 6%) in their epicuticular wax. The waxy cuticle protects the fruit and contributes to its aroma by concentrating the volatiles from the exocarp and releasing them from the surface.

In contrast to fruit pulp, plum seeds contain a lot of fat (39.5% dry weight), which may be pressed out or extracted, and the resulting oil used for consumption or in various industries.[8] The Hungarian plum (prune-making variety) seed oil contains 73.4% oleic acid, 14.8% linoleic acid, 8.9% saturated fatty acids, 7.7% glycerol, and 0.7% nonsaponifiable substances. The nonsaponifiable substances of prune seed oil[136] were found to contain 37.5% sterols, mainly β-sitosterol (91.8% of sterols), δ-5-avenosterol (3.6%), stigmasterol (3.1%), and campesterol (1.4%).

J. Volatile Compounds

Fresh plums contain many volatile compounds contributing to their characteristic odor and flavor. They are found in minute amounts, and therefore are very difficult to measure quantitatively. The approximate amounts of various volatile compounds were determined in the fresh Japanese plum variety Blackamber[50] (*Prunus salicina* Lindl.), and were found to total 427 μg/kg of fruit (Table 10). Another Japanese plum variety, Friar, had only 123 μg of total volatiles per 1 kg of fruit. Some of the major volatile compounds from this

TABLE 9
Cuticular Wax Components in Prune Plums d' Ente and Golden Egg Plums

Compounds	Prune Plums d' Ente [a]		Golden Egg Plums [b]	
	mg/100 g	%	mg/100g	%
Hydrocarbons (C_{29})	2.6	9	5.6	20.1
Esters (of C_{16}, C_{18}, C_{24}, C_{28} acids and C_{24}, C_{26}, C_{28} alcohols)	5.4	19	2.3	8.2
Free Primary Alcohols (C_{24}, C_{26}, C_{28})	4.9	17	0.8	3.0
Free Secondary Alcohols (C_{29}-10-ol, C_{27}-8-ol)	6.0	21	13.5	48.3
Free Fatty Acids (C_{29}, C_{28})	0.9	3	0.1	0.5
Sterols (β-sitosterol)	4.4	15	—	
Ketones (C_{29}-10-one)	—		0.3	1.0
Aldehydes (nonanal)	—		0.3	1.1
Triterpenoic acids				
Oleanolic	1.7	6	1.5	5.4
Ursolic	—		0.3	1.0
Total cuticular wax	29		28	

Note: Major components of each fraction are listed in parentheses.
[a] Adapted from Jouret and Puech.[69]
[b] Adapted from Ismail.[67]

TABLE 10
Volatile Compounds in Blackamber Plums

Compound	Amount (µg/100 g)	Compound	Amount (µg/100 g)
3-hexanone	0.2	Acetophenone	0.2
2-hexanone	0.2	3-tetradecene	0.1
1-methylcyclopentanol	0.1	Linalool	1.8
Hexanal	1.9	Nonanal	5.1
Butyl acetate	0.1	Undecenal	0.5
2,3-dimethyl-2-pentene	1.0	(*Z*)-3-hexenyl butanoate	0.1
(*E*)-2-hexenal	1.2	Naphthalene	0.5
(*Z*)-3-hexen-1-ol	1.3	(*E*)-2-hexenyl butanoate	1.1
(*E*)-2-hexen-1-ol	0.5	Ethyl octanoate	0.5
Hexanol	3.3	α-terpineol	0.1
1,4-dimethylbenzene	0.2	Tetradecanal	0.2
Styrene	0.2	β-cyclocitral	0.1
2,4-dimethyl-2-decene	0.2	Isoborneol	0.4
9-methyl-5-undecene	0.1	Nerol	0.1
β-pinene	0.2	Bornyl acetate	0.6
1,2,3-trimethylbenzene	0.2	(*E,Z*)-2,4-decadienal	0.5
(*E,E*)-2,4-heptadienal	0.3	(*Z*)-3-hexenyl hexanoate	1.4
(*Z*)-3-hexenyl acetate	1.6	Geranyl acetone	0.5
Hexyl acetate	4.3	2,6-bis (1,1-dimethylethyl)-2,5-cyclohexadiene-1,4-dione	0.5
(*E*)-2-hexenyl acetate	0.6	γ-decalactone	0.3
2,2,8-trimethyldecane	0.2	β-ionone	0.8
2-ethylhexanol	0.4	BHT (butylated hydroxy-toluene)	4.0
Limonene	0.6	Diethyl phthalate	0.4
2,5-dimethyl-2-undecene	0.3	γ -dodecalactone	1.6
Phenylacetaldehyde	2.8	2,6-bis(1,1-dimethylethyl)-4-ethylphenol	0.2
Citral methyl acetal	0.3	6,10,14-trimethyl-2-pentadecanone	0.1
Isophorone	0.1	α-copaene	0.5
3,8-dimethylundecane	0.1		

Adapted from Gómez et al.[50]

study are listed in Table 11, together with an estimate of their importance to the typical aroma of plums. The most important ingredient seems to be β-ionone, a hydrocarbon ring compound arising from the degradation of β-carotene, with a floral, violet-like aroma. The concentration of β-ionone in plums is very low (8 μg/kg), but the odor threshold of this compound is minuscule (0.07 μg/L of water), which means that we can detect it with great sensitivity. Another significant contributor is nonanal (51 μg/kg), with a fragrant woody aroma, which is found in the aldehyde fraction of plum cuticular wax.[67] Hexyl acetate (43 μg/kg) is very important in Blackamber plums and hexanal (19 μg/kg) actually has a plum-like aroma. Phenylacetaldehyde and linalool were identified by Moutounet[99] as appearing in dried prunes during the dehydration procedure, and γ-dodecalactone was found both in fresh plums and dried prunes d'Agen.

Many volatile compounds are glycosidically bound in fresh plums[78] (Table 12) and may be released by enzymatic reactions when the fruit is crushed or heated during processing. Although there must be an inevitable loss of volatiles during drying of prune-making plums, novel volatile compounds are formed through the degradation of various constituents. Studies of the formation of volatile compounds during processing of fresh plums d'Agen variety into dried prunes were undertaken by French investigators.[96,99] Their GLC analysis revealed a considerable loss of typical plum volatiles during dehydration. The most volatile C_6 compounds (hexanal, hexanol, hexenal, hexenol) were evaporating during processing, and the concentrations of lactones ($C_6 - C_{18}$) with the most abundant γ-decalactone also decreased greatly. Degradation of carotenoids produced dihydroactinidiolide and γ-damascenone in dried prunes. Maillard reactions of amino acids (especially asparagine) and sugars formed furan derivatives (furfural, methyl-5-furan, acetyl furan, acetyl-2-pyrrole). Degrading phenolic compounds produce volatile phenols, like phenylacetaldehyde, phenylethanol, ethylcinnamate, and vinyl phenol. Unfortunately, this interesting study did not provide exact quantification of volatile compounds.

K. Alkaloids

Prunes contain small amounts of β-carboline alkaloids,[142] formed by condensation of tryptamine with formaldehyde or acetaldehyde. A serving of 100 g of prunes may deliver 1 μg of tryptamine, 1 μg of tetrahydro-β-carboline (TBC), and 10 μg of methyl-tetrahydro-β-carboline (MTBC). The authors did not specify if they used fresh prune plums or dried prunes. Red and yellow plums contained 10 times less TBC, and from 1 to 9 μg MTBC/100 g of fruit. Tryptamine was much higher in plums, 23 μg/100 g in red variety and 200 μg/100 g in yellow plums. Other fruits, like tomato, banana, pineapple, and kiwi, also contain tetrahydro-β-carboline at similar levels, depending on the degree of ripeness, although their tryptamine levels may reach 0.5 to 1 mg/100 g.

Recently, plum jam was found to contain 18 μg of tetrahydro-β-carboline-3-carboxylic acid and 70 μg of methyl-tetrahydro-β-carboline-3-car-

TABLE 11
Contribution of Major Volatile Compounds to Blackamber Plum Odor

Compound	Content (μg/kg)	Odor units [a]	Odor threshold [b]
Hexanal	19	4	5
Hexyl acetate	43	22	2
Phenylacetaldehyde	28	7	4
Linalool	18	3	6
Nonanal	51	51	1
β-ionone	8	114	0.07
γ -dodecalactone	16	2	7

[a] Odor units: concentration of the compound divided by its odor threshold.
[b] Odor threshold: the lowest concentration (μg/L) of the compound in water detectable by human subjects

Adapted from Gómez et al.[50]

TABLE 12
Glycosidically Bound Volatiles in Yellow Plums

3-methyl-1-butanol	Octanoic acid
3-hydroxy-2-butanone	Eugenol
1-hexanol	4-vinylguaiacol
(*E*)-2-hexen-1-ol	(E)-2,6-dimethylocta-2,7-diene-1,6-diol
Acetic acid	4-vinylphenol
Benzaldehyde	Benzoic acid
Linalool	Dodecanoic acid
Butanoic acid	Vanillin
2- and 3-methylbutanoic acid	Tyrosol
α-terpineol	3-hydroxy-7,8-dihydro-β-ionol
Methyl salicylate	4-hydroxyacetophenone
Hexanoic acid	3-hydroxy-β-ionone
Geraniol	3-hydroxy-5,6-epoxy-β-ionone
Benzyl alcohol	Vomifoliol
2-phenylethanol	Dehydrovomifoliol
Phenol	

Adapted from Krammer et al.[78]

boxylic acid per 100 g of product.[59] These relatively high concentrations may be due to processing of plums and indicate that similar analysis should be performed on dried prunes. An older study of physiologically active amines in common fruits and vegetables[143] found tryptamine at levels 0.2 to 0.5 mg/100 g of red, purple, and blue plums as well as serotonin (5-hydroxytryptamine) at 0.8 to 1.0 mg/100 g in red and purple plums. Red plums also had tyramine at 0.6 mg/100 g and traces of norepinephrine. These amounts are too small to produce any physiological effects in humans.

L. Cyanogenic Glycosides

Stone fruits of Rosaceae family are known to contain cyanogenic glycoside amygdalin in their kernels (seeds) and its precursor prunasin, which can also be found in the pulp.[151] Amygdalin and prunasin release hydrogen cyanide (HCN) after tissue disruption, but in the intact seeds separate compartments of cyanogenic glycosides and specific β-glucosidases prevents a premature detonation of the *Prunus* "cyanide bomb".[113]

In a study of fresh and canned fruits (plums, apricots, peaches, and cherries), Voldrich and Kyzlink[151] discovered that the canning process may release HCN from seeds into pulp and syrup. They recommend high-temperature processing of fruits with pits in order to inactivate quickly the natural β-glucosidases contained in the seeds. Lower temperatures activate HCN release from amygdalin and prunasin by these enzymes. Even more advisable is choosing fruits with a low content of cyanogenic glycosides and removing the pits before processing. The authors[151] calculated that canned cherries could contain 3 to 4 mg HCN/kg, which would not be an excessive dose for a 70-kg adult, but a child weighing 15 kg should not consume more than 180 g of canned cherries. The same authors determined that fresh plum pulp has 9.8 mg of prunasin/kg (equivalent to 0.9 mg of HCN/kg of pulp) and plum seeds contain 0.26% amygdalin (equivalent to 150 mg HCN/kg of seeds). After canning, the pulp contained 0.5 mg HCN/kg, while the syrup contained 0.6 mg HCN/kg. When the plums were canned without pits, the content of HCN was only 0.02 mg/kg of pulp and 0.04 mg/kg of syrup.

Defatted Hungarian (prune) plum seeds were found to contain 2.5% amygdalin,[8] which is 10 times higher than reported above,[151] possibly due to removal of fat, water, and hard endocarp before the analysis. About 85% of amygdalin could be hydrolyzed by the enzymes present in plum seeds, after heating the powdered seeds in distilled water for 30 min, producing a corresponding amount of HCN (1.5 mg HCN/1 g defatted plum seeds). The high content of amygdalin in plum seeds is used to produce desirable organoleptic properties (bitter

almond odor and flavor) in plum spirits, by adding crushed pits to the fermenting plums.[106] Volatile HCN (boiling point 25.6°C) is then distilled together with ethyl alcohol, producing plum spirits, which may contain as much as 25.5 mg HCN/L. The addition of whole pits produced 10.5 mg HCN/L, while plums fermented without pits yielded only 0.7 mg HCN/L of spirits. Poland allows 3 mg HCN/L in spirits, while Switzerland and Czech Republic permit up to 40 mg HCN/L of spirits.

These findings raise the question whether dried prunes, which are processed with pits, may contain HCN or cyanogenic glycosides in their pulp. Further research is necessary to resolve this problem, because cyanogenic glycosides may be hydrolyzed in the intestinal tract by acid and enzymatic reactions.

M. Preservatives

Dried prunes are not susceptible to microbial spoilage if their water content is less than 25%, due to their low pH (3.5 to 4.0), high organic acid, and phenolic content. However, dried prunes are usually rehydrated to 30 to 35% moisture content, and addition of sorbic acid inhibits growth of molds and yeasts. Sorbic acid is a generally recognized as safe (GRAS) compound, and toxicological studies on cats and dogs showed no ill effects when it constituted up to 5% of their diet.[29] Analytical procedures for measuring the sorbic acid content in dried prunes have been published.[10,131,132] Recent analyses showed 82 mg of sorbic acid/100 g of dried pitted prunes, but only 42.5 mg/100 g of extra large prunes with pits.[31] A study of Moroccan prunes[34] found that 42 mg potassium sorbate/100 g combined with anaerobic packaging (40 to 80% CO_2 atmosphere) inhibited growth of yeasts and molds, extending the shelf-life at 30°C to at least 6 months. Sulfites are not used for preservation of dried prunes and prune products, which is important for people who may be allergic to sulfites.

IV. POTENTIAL HEALTH EFFECTS OF PRUNES

The following sections discuss various biological effects of prune consumption in humans and animals, as well as *in vitro* experiments with prune extracts and individual compounds, which were identified in prunes.

A. Laxative Effects

Dried prunes are well known in common experience to alleviate constipation, but physiological reasons of their effect on the bowel are not well understood. Some researchers ascribe it to the high fiber content of prunes, which would be reasonable if we accept the highest estimate of 16 g of total dietary fiber/100 g of dried prunes. It would represent 64% of the DRV for total dietary fiber, which is 25 g per day.[41] The lower estimate of 6 g of total dietary fiber/100 g fruit (24% of the DRV) would be less likely to promote a laxative action, although it would probably improve bowel function if dried prunes were part of the daily diet. Just such a study[138] was conducted with 41 adult men who consumed a supplement of 12 dried prunes (100 g) per day in addition to their usual diets for 4 weeks. Fecal wet and dry weights were about 20% higher after the prune supplementation period than after the control period. The difference was statistically significant, but this amount of prunes clearly did not cause diarrhea, because the water content of stools was the same for the prune and control period. It is interesting to note that prunes are traditionally used in north Italy as both a laxative and antidiarrheal remedy.[83] The combination of soluble and insoluble fiber in dried prunes probably acts in a gentle way in the lower intestine, softening the stool, increasing its bulk and promoting intestinal mobility.

However, long ago it was noticed that the laxative principle in dried prunes is water soluble and therefore present in prune juice, which is also very effective in promoting bowel function, although it contains very little dietary fiber. There are some constituents in dried prunes and prune juice that can help to explain this phenomenon. Both dried prunes and prune juice are very rich in sorbitol, a sugar alcohol characteristic of fruits of *Prunus* spp. Sorbitol was reported to cause a laxative action[35] in animals and humans when administered as a syrup (83% sorbitol). A dose of 16 to 25 g of sorbitol was effective in 12 individuals to

cause "very soft or watery stools". Twelve large dried prunes (~15 g sorbitol) or a cup of prune juice (24 g sorbitol) could reach this threshold of sorbitol content, especially in susceptible individuals. The dose would probably vary with age, health, and dietary history of the subject and may depend on the intestinal microflora. Koizumi et al.[74] found no observable laxative effects with doses of sorbitol in the range of 0.15 g/kg body weight for men and 0.30 g/kg body weight for women, but 50% of subjects experienced laxative effects when the dose was 0.4 g/kg body weight for men and 1.0 g/kg body weight for women. Although some studies[2] report rapid metabolism of labeled sorbitol by conversion to glucose and expired CO_2, with little excretion in the feces, the absorption of sorbitol is much slower than glucose[40] and a considerable amount could enter the bowel, where microbial fermentation may cause flatulence and loose stools.[89] On the other hand, undigested sorbitol can soften stools due to its ability to hold moisture, the so-called humectant quality, well known and utilized by the cosmetic and food industries.

Other prune constituents, phenolic compounds, can also contribute to the laxative effect. Phenolphthalein, a structurally similar compound not present in prunes, is known to have such an effect by altering the electrolyte balance in the intestinal tract.[64] Chlorogenic acid was found to favor the dissipation of the sodium electrochemical gradient, thus impairing the efficiency of active glucose absorption in rat intestinal brush border membrane vesicles.[154] *In vivo* it could cause more glucose to pass from the jejunum to the bowel, enhancing microbial fermentation. Early studies on the laxative action of prunes speculated that caffeic acid and chlorogenic acid were the active principles,[36,100] and it was noted that they resembled the physiologic and chemical properties of the laxative pharmaceutical "Isacen" (diacetyl dioxyphenyl isatin). In their experiments, prune extracts and their fractions induced contractions in the isolated intestinal sections from various laboratory animals. The existence of diphenyl isatin in prunes was reported by Baum et al.[7] on the basis of a colorimetric test of crude prune extract, but this substance was never isolated from any plant as a natural product.

The famous laxative effect of dried prunes can be ascribed to a combined action of their fiber content, presence of large amounts of sorbitol, and possibly phenolic compounds. The similar effect of prune juice is probably due to the soluble components sorbitol and phenolics. More research is necessary with numerous subjects, from different age groups, comparing the action of dried prunes, prune juice, prune fiber, sorbitol, chlorogenic and neochlorogenic acids to confirm this hypothesis.

B. Sugar Metabolism

Dried prunes provide a substantial amount of energy (239 kcal/100 g of prunes, 181 kcal/8 oz prune juice),[145] due to their high sugar content. However, they do not seem to elevate blood sugar levels very rapidly, and their total glycemic response or index (GI) is in the moderate range (prune GI = 54, vs. glucose GI = 100). The glycemic response of dried prunes was measured recently[65] in eight healthy young men, who consumed 50 g of carbohydrates in the form of dried prunes, or in 100 g of white bread (GI = 69) as a control, after fasting. The subjects were also found to have reduced concentrations of plasma insulin and C-peptide, a product of insulin breakdown, in response to prune ingestion. The same report[65] described a long-term feeding study with eight subjects consuming 250 g of dried prunes per day in divided portions. After 22 days on a prune-supplemented diet the subjects were found to have reduced levels of insulin secretion.

In an evaluation of 11 medium to long-term intervention studies, based on lowering the GI of the total diet, Brand-Miller[13] found all but one study successful in lowering parameters of diabetic control. The successful studies were able to lower the GI of the total diet from about 66 to 54, and sometimes to 38. Because Iron et al.[65] found that the GI for prunes is 54, dried prunes and prune juice may be reasonable choices on a GI-lowering diet for patients with either NIDDM (noninsulin-dependent diabetes mellitus) or IDDM (insulin-dependent diabetes mellitus). For comparison, raisins (sultanas)[13] have a GI of 61, while dried apricots only 30. The differences are due to

variation in sugar profiles and fiber content of the fruits. Dried prunes contain, on the average, 23 g of glucose, 13 g of fructose, and 15 g of sorbitol, as well as at least 6 g of dietary fiber per 100 g serving (Table 1). Glucose has the highest glycemic response of 100, because it is assimilated very rapidly. Fructose has a glycemic response of only 20, because it is slowly and incompletely absorbed by the intestinal mucosa, having no active absorption mechanism.[144] The fasting plasma insulin concentration does not seem to change after ingestion of fructose, although later postprandial values may rise due to conversion of fructose to glucose in the liver. Sorbitol had only an 80% caloric utilization of glucose in rat studies,[40] and it is metabolized by humans in large part by gut bacteria.[89] It did not raise insulin demand when added to the diet of diabetic children.[133] The combination of glucose, fructose, and sorbitol in dried prunes with significant amounts of dietary fiber may have a beneficial influence on glucose metabolism and diabetes management, because most successful trials in the treatment of diabetes have included the consumption of high-fiber foods that impede carbohydrate absorption.[13]

Phenolic compounds present in dried prunes may also play an important role in glucose absorption and metabolism. Chlorogenic acid at 1 m*M* concentration was found to abolish 80% of glucose active transport capacity in brush border membrane vesicles isolated from the rat small intestine.[154] The action was independent of the chlorogenic acid oxidation state, because it occurred even when phenolics were added with polyphenoloxidase. A reduction of glucose uptake was accomplished through the dissipation of the Na^+ electrochemical gradient, which provides the driving force for active glucose accumulation. Phenolic compounds may also inhibit formation of endogenous glucose in the liver. Chlorogenic acid was identified as a specific inhibitor of glucose-6-phosphate translocase in the enzyme system in microsomes of rat liver.[57] Further experiments should be conducted with neochlorogenic acid and prune extracts to establish possible efficacy of their inhibition of glucose uptake in the intestine and homeostatic regulation of blood glucose.

Copper deficiency causes alterations in glucose metabolism[82] with symptoms including glucose intolerance, insulin resistance, and diabetes-like effects. It may be important that in addition to beneficial sugar profile, prunes contain 0.4 mg copper/100 g, providing at least 20% of safe and adequate intake for human adults, which is estimated to be from 1 to 3 mg/day.[127]

C. Bone Metabolism

Dried prunes contain about 50 mg of calcium, a similar amount of magnesium and 80 mg of phosphorus in 100 g of fruit. While the mineral content is not high, compared with the RDI for these nutrients (Table 2), the high organic acid content of prunes may improve the absorption of bone-building minerals, especially when prunes and other calcium-containing foods are consumed at the same time. Prunes are also rich in copper, which is essential for bone building processes, because copper containing lysyl oxidase promotes cross-linking of lysin residues in collagen and elastin.[82] Copper-deficient rats and chicks had abnormal bone development.[109,122]

Dried prunes have a high content of boron (2.2 mg/100g fruit),[4] while the daily boron requirement for humans is estimated to be about 1 mg/day.[107] Boron was found to increase plasma steroid hormone concentrations and reduce the urinary excretion of calcium both in humans and laboratory animals. In a study of the dietary effects of boron in rats,[23] bones accumulated boron and retained it for more than 8 months after 2 to 3 months of exposure. The vertebral resistance to compression was significantly increased in all treatment groups (200 to 9000 mg boron/kg of diet). In a controlled dietary study of 12 postmenopausal women,[108] the subjects were fed a diet low in boron (0.25 mg/day) for 4 months and then a diet supplemented with 3 mg of boron per day for 48 days. Boron supplementation doubled their serum testosterone and 13-β-estradiol levels, with differences being statistically significant ($p < 0.05$). The urinary excretion of calcium and magnesium decreased significantly, preventing the loss of those bone-building minerals. Changes both in hormonal levels and mineral output were not gradual, but occurred abruptly after 1 week on the boron-supplemented diet, and the levels re-

mained steady for the rest of the supplementation period. Boron may be an important nutritional factor in the prevention of the incidence of osteoporosis.

In a study of ovariectomized rats fed diets containing 5 to 25% dried prune powder (by weight) interesting changes in bone metabolism occurred.[5,6] Ovariectomized rats are a good model of postmenopausal osteoporosis because they experience bone loss due to hormonal deficiency, as do postmenopausal women. Prune diets prevented bone loss when started immediately after ovariectomy, and restored femur and lumbar vertebrae bone densities when applied 40 days after the operation. The authors tentatively ascribed the effect to the high levels of phenolic compounds in prunes, but it could have been a result of increased boron intake. Prunes were not reported to contain isoflavones, which apparently prevent bone loss related to ovarian hormone deficiency in postmenopausal women and ovariectomized rats. It would be instructive to continue similar research with laboratory animals and human subjects, measuring the boron content of prune-supplemented diets, boron excretion, and tissue (or plasma) concentrations, as well as any associated hormonal changes. Boron may have more ubiquitous regulatory functions, reminiscent of steroid hormone therapy.[107]

D. Cardiovascular Health

Certain constituents of dried prunes and prune juice may have a beneficial influence on cardiovascular health. There are three major risk factors involved in cardiovascular disease — hypertension, dyslipidemia (high LDL-cholesterol levels), and oxidative stress (which damages blood lipids and vascular epithelium).

1. Hypertension and Electrolyte Balance

A high concentration of potassium (745 mg/100 g of dried prunes, 706 mg/8 oz of prune juice) and a very low concentration of sodium may protect against hypertension. Inasmuch as the DRV for potassium is 3500 mg/day,[41] these products should make a valuable contribution to the diet. Potassium is a major factor in maintaining proper electrolyte balance, kidney function, and acts as a muscle relaxant, which contributes to its role in preventing hypertension. A high potassium intake may prevent the adverse effects of high sodium consumption.[85]

2. Dyslipidemia

Dried prunes contain significant quantities of soluble fiber in the form of pectin, at least 3 g of pectin per 100 g of fruit (Table 1). Pectin has been shown to decrease plasma concentrations of cholesterol, possibly through increased bile acid excretion in the feces.[48] In a study with 41 adult men, who ingested 100 g of dried prunes per day for 4 weeks,[138] plasma LDL-cholesterol decreased slightly but significantly, compared with 4 weeks of supplementary grape juice for the same subjects in a crossover design. There was no difference between the baseline (their usual diet before the study) and prune period levels of plasma LDL cholesterol, but drinking 360 mL (~ 1.5 cups) of grape juice each day raised plasma LDL cholesterol significantly. Possibly grape juice displaced some fruits and vegetables with high fiber content from the subjects' diets, which led to elevation of LDL cholesterol levels. Dietary fiber intake was estimated to be significantly lower than baseline during the grape juice period (18 g/day vs. 21 g/day), but higher during the prune period (24 g/day). These are the average dietary fiber intakes, but the variability among the free-living subjects was great (baseline range 8 to 54 g fiber per day). The results for individual subjects suggest that plasma cholesterol decreased because the prune intervention was more effective in the subjects who were consuming a habitually low-fiber diet. Careful experiments with subjects starting on a controlled low-fiber diet, followed by a prune-supplemented diet, should be performed to establish if the reported cholesterol-lowering effect is real.

Similar controlled experiments were conducted in male rats with diet-induced hyperlipidemia[139] and feeding different forms of fiber: 6% cellulose, 3% prune fiber, 6% prune fiber, or 3%

pectin. Groups of rats consuming prune fiber had significantly lower cholesterol concentrations in plasma and liver than those on a control high lipid diet with 6% cellulose. There was no significant difference between the two levels of prune fiber, 3% and 6% of total diet, and both were nearly as effective as 3% of pectin. The fiber extracted from prunes contained 74% of total dietary fiber, half of it soluble and half insoluble.

Recently, a study was conducted on ovariectomized female rats ingesting a diet that included 5 or 25% of dried powdered prunes.[84] Ovariectomy significantly raised the levels of total cholesterol in rats, which is similar to the effects seen in menopausal women. This rise was completely suppressed by the 25% dried prune diet, which could be due to the increased soluble fiber content of the prune containing diet or some estrogen-like action of prunes. Extracts of plums have been reported to have estrogen-like activity in laboratory rodents.[12] Alternatively, phytosterols of prunes [130] (32 mg/100 g dried powdered prunes) could decrease reabsorption of biliary cholesterol in the rat intestine, especially on the 25% dried prune diet. Prune feeding normalized hepatic LDL receptor transcript levels and increased 7-α-hydroxylase activity,[25] the rate limiting enzyme in the bile acid synthesis. These data suggest that prunes may help to reduce postmenopausal hypercholesterolemia.

3. Oxidative Stress

Formation of atherosclerotic plaque may be due more to cholesterol or fatty acid oxidation than to the total amount of cholesterol or LDL cholesterol in plasma.[16] The dietary antioxidants which inhibit oxidation of lipids, especially in low-density lipoproteins, could be very important in the prevention of heart attacks and strokes. Dried prunes and prune juice contain significant levels of antioxidant phenolic compounds, which were found to inhibit the oxidation of human LDL *in vitro*. Both chlorogenic and neochlorogenic acids, which are the main phenolic components in prunes, inhibited 90% of copper-induced LDL oxidation at a 5 μ*M* concentration.[91] Even 0.3 μ*M* of chlorogenic acid produced 50% inhibition of LDL oxidation.[149,150] In a similar experiment, dried prune extracts and prune juice extracts were also effective inhibitors of human LDL oxidation.[31] There are no data on the absorption and metabolism of hydroxycinnamates in humans, which could help to estimate their possible efficacy in prevention of LDL oxidation *in vivo*.

Prunes contain small amounts of flavonoids, especially quercetin, which affect the function of the enzyme system involved in immune response and generation of inflammatory processes by decreasing synthesis of prostaglandins, inhibiting histamine release, and reducing cell aggregation or adhesion in various types of cells comprising immune system.[92] As the formation of atherosclerotic plaque involves an inflammatory response to oxidized LDL within arterial walls, with macrophages engulfing oxidized LDL and becoming foam cells, prevention of LDL oxidation may be very important in reducing the incidence of atherosclerosis. In addition, the antithrombotic effect of flavonoids may further help to decrease the incidence of heart attack and stroke by preventing clot formation and vascular occlusion. *In vitro*, flavonoids have been shown to disperse platelet thrombi adhering to rabbit aortic endothelium.[54]

The presence of copper in prunes (0.4 mg/100 g) may also be considered beneficial for cardiovascular health, because it is needed for the integrity of blood vessels and hemoglobin formation.[82] Copper deficiency results in a shortened life span of erythrocytes, microcytic anemia,[61] vascular lesions, and cardiac hypertrophy. In addition, copper deficiency alters lipid metabolism, resulting in elevated plasma cholesterol and triglycerides, as well as enhanced lipid oxidation in cell membranes. Many oxidative (cytochrome C oxidase, lysyl oxidase) and antioxidative (superoxide dismutase) enzymes are copper dependent, and adequate intake of copper (1 to 3 mg/day) may play an important role in maintaining oxidant/antioxidant balance.[82]

E. Potential Antitumor Effects

Cancer results from unrepaired mutations of DNA, which can be caused by oxidative damage

from free radicals. Therefore, antioxidants that neutralize free radicals may be crucial in the prevention of cancer.[3] The total antioxidant capacity of fruits has been measured by an oxygen radical absorbance capacity (ORAC) assay.[152] Fresh plums had a rather high ORAC value (9.5 μ*M* Trolox equivalents/g fruit), second only to strawberries. When expressed on a dry matter basis, the ORAC value was 79.1 units/g dry weight. Recently, dried prunes were found to have the highest ORAC value of all plant foods[88] (57.7 units/g), while raisins had 28.3, and blueberries 24. In another assay of antioxidant activity based on the inhibition of Cu^{++} catalyzed LDL oxidation *in vitro*,[31] dried prune extract produced a 98% inhibition at a concentration of 20 μ*M* of gallic acid equivalents, and prune juice extract at the same concentration was also very effective (97% inhibition). At lower concentrations prune juice extract was considerably less protective than dried prune extract. It would be instructive if the authors had reported inhibition of LDL oxidation on the basis of actual concentration of phenolic compounds in their prune extracts, because the amounts identified by HPLC did not agree with the gallic acid equivalents estimated by the Folin-Ciocalteu method.

Phenolic compounds have been studied for their inhibitory effect on the carcinogenic action of many chemical carcinogens. Caffeic and chlorogenic acids suppressed the mutagenic activity of *N*-methyl-*N*′-nitro-*N*-nitroso-guanidine (MNNG) in *Salmonella typhimurium* test,[22] when administered together with the carcinogen. Dietary chlorogenic acid inhibited formation of tumors in the bowel and liver of hamsters that were injected with methylazoxymethanol (MAM) before the treatment.[94] A diet containing 0.025% chlorogenic acid was fed for 24 weeks, and by itself did not have any adverse effects on control animals. Besides reducing the total number of tumors in MAM-injected hamsters, no adenocarcinomas, hemangiomas, or liver cell adenomas were found in the chlorogenic acid-treated group, only adenomas of the large intestine and bile duct were found at a reduced rate. Focal hyperplastic liver cell lesions were also significantly less frequent in hamsters consuming a chlorogenic acid diet after MAM injection. It would be useful to perform similar experiments with diets containing dried prune powder on various animal models of carcinogenesis.

On the other hand, there was a study of clastogenic activity of dried fruits, measured by frequency of chromosome aberrations induced in Chinese hamster ovary cell cultures.[134] Extracts of dried fruits were added to cell cultures for 3 h, and 20 h later the cells were examined for chromosome breaks and exchanges. All dried fruit extracts, including prunes, raisins, dates, figs, bananas, and apricots, significantly increased the frequencies of metaphase plates with one chromosome break (37.4% for prunes vs. 0.7% for controls), and the average number of chromosome exchanges per metaphase plate (0.65 for prunes, none for controls). These values were obtained with 1:1 dilution of water extract of dried California prunes, which was prepared by homogenization of prunes with a double weight of distilled water. Clastogenic activity decreased with more diluted extracts in the culture medium. The authors ascribe the chromosome damage to possible formation of mutagens during processing. A comparable effect was obtained in the same study with pyrazine and caramel powder, both products of overheating amino acids and/or sugar-containing foods. Alternatively, cytotoxicity tests on *in vitro* cell cultures may indicate anticancer activity of plant extracts. Fresh plum extracts produced negative results in a human breast cancer cell line.[124] However, plum extracts were quite effective in the prophage induction test in the *Escherichia coli* system,[32] which indicates potential inhibition of DNA metabolism and a possible cancerostatic effect.

It is difficult to extrapolate the results of animal cell cultures to whole animal or human organisms. Dried fruits have never been noticed to produce any damage to the rapidly dividing gastrointestinal epithelium, and high doses of prune powder in the diet[5,6] were not observed to cause any harmful effects in rats.

It is well known that high dietary fiber is inversely related to the risk of colon and rectal cancer.[62,103] A combined analysis of data from 13 large case-control studies in different countries found that people with the highest intake (31 g/day) have about half the risk of those with the lowest (10 g/day) intake. Dietary fiber shortens the intestinal transit time when harmful mutagens

in undigested residue and feces remain in contact with epithelium of lower intestine. Among those substances, the concentration of secondary bile acids, which are formed in the bowel from primary bile acids by microbial action, has been associated with an increased risk of colon cancer.[118] In a study of 41 men ingesting 100 g of dried prunes for 4 weeks, the total amount of excreted bile acids did not change, but their concentration in the stool was lower, because the fecal weights increased significantly, both wet and dry.[138] Fecal concentration of secondary bile acids, especially lithocholic acid, was significantly lower (0.95 mg/g dry weight) during the prune diet when compared with baseline or control grape juice diet (1.20 mg/g dry stool weight). These results indicate that ingestion of dried prunes could have a protective effect against colon cancer.

Large epidemiological studies of a Finnish population (~10,000 people) found that flavonoid intake was inversely associated with the incidence of all cancers combined.[72] The effect was mainly attributed to lung cancer incidence, which presented a relative risk of 0.54 (95% confidence interval 0.34 to 0.87), between the highest and the lowest quartiles of flavonoid intake, adjusted for potentially confounding factors (smoking, other dietary antioxidants). In younger persons (under 50 years) and nonsmokers, the association was very strong, with RR of 0.33 (confidence interval 0.15 to 0.77), and 0.13 (confidence interval 0.03 to 0.58), respectively. The authors estimated that the daily intake of flavonoids in the highest, most protective quartile was more than 5 mg per day (measured as aglycons), and found that the consumption of apples contributed greatly to lower the risk of lung cancer. Dried prunes contain about 4.2 mg of flavonols per 100 g serving, mainly as rutin.[31] Rutin is quercetin-3-rutinoside, and converted to its aglycon, quercetin, would amount to 2.1 mg/100 g dried prunes. Dried prunes are probably only a minor source of flavonoids in the daily diet. Dietary flavonoid intake estimates vary from 23 to 1000 mg/day,[111] and the Finnish intake of flavonoids may be greatly underestimated.

F. Antimicrobial Effects

Prunes were used as a remedy against diarrhea, cough, and mouth ulcers in traditional folk medicine[83,155] and old medical texts.[27] All of those symptoms could be caused by infectious agents, bacteria, and viruses, especially in susceptible individuals with a weakened immune system. Various types of prune extracts have been evaluated *in vitro* for antiviral, antibacterial, and antifungal activity with mixed results. At best, the results are weak against most of the test organisms. Undoubtedly, the low level of activity can be attributed to the presence of the well-known weak antimicrobial activity of hydroxycinnamic acids, that is, chlorogenic, caffeic, ferulic acids, and their isomers and derivatives.

The antiviral activity of fresh prune plums was tested on polio virus, pretreated with fruit extract, and then inoculated on cell cultures.[75] The plum extract was prepared by homogenization with an equal weight of water and brought to pH 7. Less than 1% of the virus survived a 24-h incubation at 4°C in prune plum extract, and 2% survived when the extract was diluted in the proportion 1:10. The same authors used the above described test for a prune drink[76] and found that it was ineffective at its natural pH of 3.6, but at pH 7 the survival of polio virus in the prune drink was less than 1% after a 2-h incubation at ambient temperature. Diluted to 1:4 proportion, prune drink still caused a 50% reduction in polio virus survival. Grape juice, apple juice, tea, and cranberry drink were even more effective than the prune drink. The authors concluded that the antiviral activity could be due to polyphenolic compounds in fruits and tea. Chlorogenic acid was effective against polio virus at concentrations between 1 and 0.1 mg/mL.

The antimicrobial activity of many plant extracts, including fruits of *Prunus domestica*, were screened against 23 different bacteria, yeast, and fungi growing on agar plates.[32] Plums were mildly effective against *Staphylococcus aureus*, which causes boils and wound infections, and against the fungus *Scopulariopsis* spp. Questionable activity was found against bacilli (*B. globifer, B. mycoids, B. subtilis*), *Micrococcus luteus, Serratia marcescens*, *Proteus morganii*, and *Mycobacterium smegmatis*. Other bacteria (*Escherichia coli, Aeorobacter aerogenes, Pseudomonas pyocyaneu*s, *Mycobacterium phlei*), yeasts, and fungi (*Fusarium culmorum* and *F. solani, Penicillium notatum*) were not inhibited by plum ex-

tract. In a similar earlier experiment,[51] plum extracts were found active against *Escherichia coli* and *Staphylococcus aureus*, but inactive against *Mycobacterium tuberculosis*. Plum extract was also not effective against avian influenza virus replicating in a human breast cancer cell line.[124]

Prune juice concentrate was tested with other commonly used food flavoring substances for immunotoxicity in mice.[49] No effects were seen in a battery of tests after multiple dosing with 1.25 to 5 g/kg body weight/day. Prune polysaccharides were patented in Japan[101] as therapeutic immunochemical activators. The authors extracted 200 g of prunes (most likely dried prunes, but it is not specified) with water and then precipitated the filtered extract wtih ethanol to yield 6 g of polysaccharides. When a dose of 5 g/day of freeze-dried extract was administered to subjects for 20 days, their α-type interferon level doubled when compared with the baseline before treatment. These results indicate that prune consumption may protect against some infections, expecially within the alimentary tract.

SUMMARY

In the mind of the public, prunes have long been considered a functional food merely related to bowel function. Now there is justification for a web of physiologically important functions for the most crucial constituents in prunes (dietary fiber, sorbitol, potassium, copper, boron, and phenolic compounds), with each of them playing a role in many aspects of human health (Figure 1). High amounts of dietary fiber, sorbitol, and perhaps phenolics, help in the regulation of both digestion and sugar metabolism and may be involved in lowering plasma cholesterol concentration and risk of bowel cancer. Substantial but not excessive amounts of potassium are important for cardiovascular health, while high boron content may improve bone metabolism, especially in conditions of steroid hormone deficiency after menopause. Copper is involved in maintaining bone structure, integrity of arterial walls, hemoglobin synthesis, and functionality of oxidative and antioxidative enzymes. Phenolic compounds in prunes are the main contributors of their antioxidant properties, which may, on further investigation, play a role in cancer prevention, antibiotic action, and lowering the risk of heart disease. Interestingly, chlorogenic acid was found to be a potent inhibitor of monoamine oxidase (MAO) activity in cultured glial cells, which may provide protection against oxidative neurodegeneration implicated in Parkinson's disease.[87]

More research is needed in all these areas (Table 13), especially epidemiological surveys of prune consumption and health risks (such as cancer and cardiovascular disease), as well as human feeding trials with controlled intake of prunes and equivalent amounts of components suspected to play a possible role. It would be useful to conduct comparative experiments with prunes, prune juice, prune fiber (both soluble and insoluble), and sorbitol on a greater number of subjects from different age groups to establish the efficacy and dose levels of the laxative action. The assessment of oxidative stress and DNA damage in subjects on diets containing prunes would be of great importance. Chlorogenic acid, coumaric acid, rutin, and catechin have been studied extensively, primarily *in vitro*, for their antioxidant and other effects. However, the major phenolic compound in prunes, neochlorogenic acid, has been neglected, and more studies should be directed toward investigating the potential health effects of this compound. The levels of carotenoids, vitamin E, and other vitamins should be reassessed with the best analytical techniques to ensure correct labels on food packaging and accurate information in food composition tables. A well-organized research program could benefit the producers and the consumers of prunes, establishing their role as truly functional food.

TABLE 13
Future Research Recommendations

1. Survey of prune consumption
2. Association of prune consumption with health risks
3. Feeding trials to assess laxative action, oxidative stress, glycemic index, bone metabolism and other potential health effects
4. *In vitro* and *in vivo* studies of biological effects of neochlorogenic acid
5. Reassessment of carotenoids and vitamin content of prunes
6. Optimal methods for prune processing to preserve their nutrients and phytochemicals

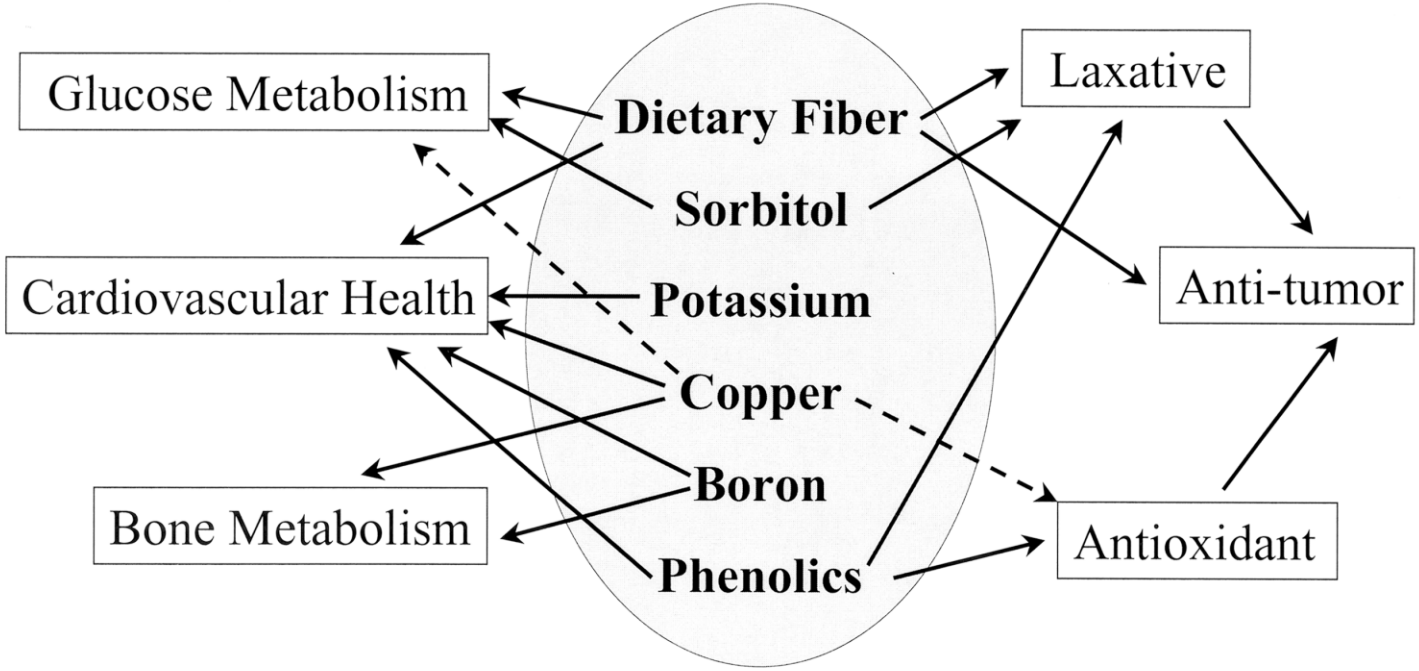

FIGURE 1. Potenial biological functions of prune constituents.

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