Cladodes: a Source of Dietary Fiber

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INTRODUCTION

In the last decade, the developed countries have significantly changed their ways of life, and in particular their eating habits. Consumers prefer ready-to-eat foods and a diet that is low in calories, low in cholesterol, low in fat or in other words "healthy foods". In accordance with this trend, consumers also want to eat foods with a greater fiber content. Consumers know the relationships between fiber consumption and control of cholesterol, and prevention of illnesses such as diabetes and obesity(Hollingsworth, 1996; Grijspaardt-Vink, 1996; Sloan, 1994). Dietary fiber can also contribute to the prevention, or treatment of illnesses like gastrointestinal disorders, that are associated with a lack of dietary fiber intake. Thus the trend is to search for new natural foods of which fiber is a very appreciated component. This paper will illustrate that cactus cladodes have excellent potential as a new source of fiber in human nutrition.

DIETARY FIBER

Dietary fiber generally refers to parts of fruits, vegetables, grains, nuts and legumes that can not be digested by humans i.e. that are resistant to digestive enzymes.

Dietary fiber is composed of several chemical components that are resistant to digestive enzymes such as cellulose, hemicellulose, pectin, lignin, gums, etc. (Spiller, 1992; Periago et al, 1993). The fiber content of a food varies according to the species of the plant and stage of maturity, but seeds, berries, fruit skins and the bran layers of cereal grains generally contain large amounts of plant fiber.

According to its water solubility, dietary fiber is classified as being soluble or insoluble. Soluble fiber is composed of mucilage, gums, pectin and hemicellulose. In contrast, the insoluble fiber is composed of cellulose, lignin and the larger fraction of hemicellulose (Atalah and Pak, 1997).

Increased dietary fiber in the diet is associated with physiological effects such as decreased blood cholesterol. There is widespread belief that the effect of dietary fiber on plasma cholesterol concentrations may be largely mediated by enhanced fecal excretion of bile acids. Many types of dietary fiber that have been shown to be hypocholesterolemic in man do increase fecal bile acid output. However, increased fecal bile acid output due to fiber is not always accompanied by a reduction in plasma cholesterol. Hence, the mechanism by which fiber exerts its hypocholesterolemic effect remains an intriguing question (McPherson, 1992). Dietary fiber is also associated with blood glucose concentrations and thus with diabetes (Periago et al, 1993; McPherson, 1992). Dietary fiber may also play a role in reducing the risk of colon cancer and in reducing symptoms of chronic constipation, diverticular disease and hemorrhoids (Atalah and Pak, 1997; McPherson, 1992).

Properties of Dietary Fiber

Dietary fiber has several interesting physical properties that are probably related to its physiological effects. For example, dietary fiber increases the capacity of water holding and increases ion binding in the human digestive system. The insoluble lignins and polysaccharides are mainly responsible for the water holding properties while the ion binding properties of fiber are attributable to the uronic acid content of the fiber. These uronic acids link ions like calcium, magnesium, zinc and iron. Dietary fibers also form gels due mainly to the soluble fiber components such as pectin, gums and mucilage. Antioxidant properties of dietary fiber are due to the presence of lignins which inhibits free radical formation. The soluble portion of dietary fiber is 100% fermented and thus has a rapid transit time in the intestine. Bile acid binding properties of the soluble fiber, and lignin components of dietary fiber, increase the excretion of sterols and other toxic compounds (Pak, 1996).

Plants such as cereals, legumes, vegetables (e.g., onion, garlic, artichokes) and fruits (e.g. orange peels) are an excellent source of dietary fiber and there are many ways to obtain purified fiber fractions from these plant sources.

Soluble fiber can be used to control the rheological properties of foods. Soluble fiber can also be used as a gelling agent, emulsifier and for other effects. The amount of fiber added to the foods is commonly less than 10%, because above these levels, it decreases the sensory quality characteristics in much greater proportions than the amount added.

While the Americans currently consume an average of 11-15 g of dietary fiber daily, the National Cancer Institute advises an increase to 20 to 30 g per day.

An excellent but relatively unknown potential source of dietary fiber are cladodes from various *Opuntia* species that are commonly known as nopal in Mexico. Pimienta (1990) reported that the age of cladodes influence their chemical composition and that the crude fiber (only a portion of the dietary fiber) increased with the age of the cladodes (Table 1).

Table 1. Chemical Composition of Cladodes
(% dry matter basis)

Age (years)	Protein (%)	Fat (%)	Ash (%)	Crude Fiber (%)	Nitrogen-Free Extract (NFE) (%)
1	5.4	1.29	18.2	12.0	63.1
2	4.2	1.40	13.2	14.5	66.7
3	3.7	1.33	14.2	17.0	63.7

Source: Lopez et al. (1977) cited by Pimienta (1990)

Nopal (*Opuntia* spp) Flour

Sepulveda et al., (1995) obtained a natural high fiber concentrate from *Opuntia ficus-indica* which they called "nopal flour". This nopal flour was prepared as is shown in the flow diagram (Figure 1) from 2 to 3 year old cladodes. The cladodes were a very inexpensive raw material as they resulted from pruning operations of commercial fruit orchards.

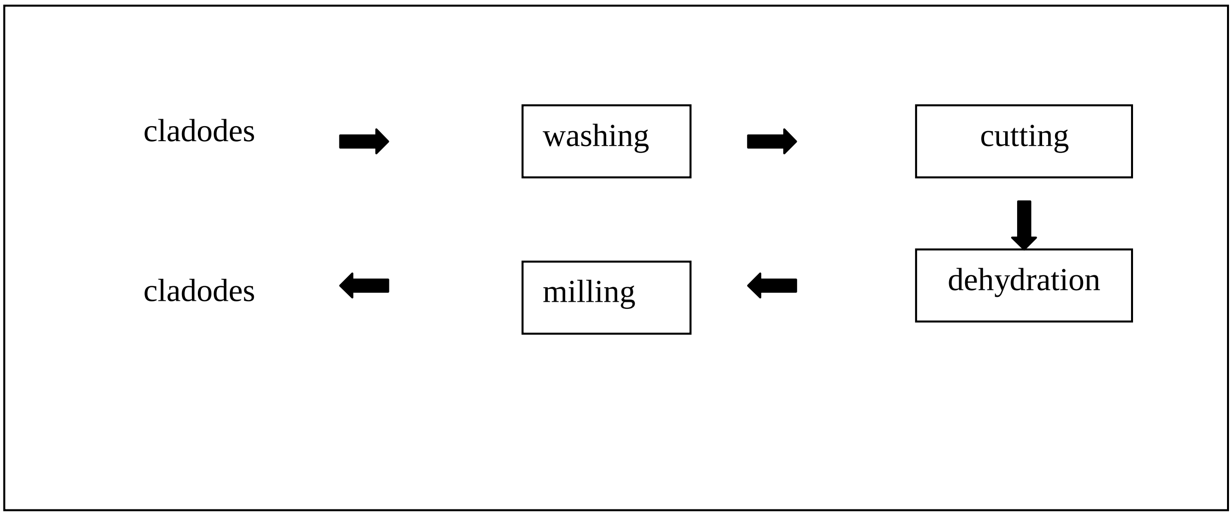

Figure 1. Flow Sheet for Production of Nopal Flour

Saenz et al., (1997) recently reported the effect of concentration (2.5, 5.0, and 7.0%), temperature and pH on the viscosity of the nopal flour suspensions. These characteristics are very important to know because other ingredients may change the pH which could greatly influence the food quality as it is consumed. Similarly, different preparation conditions and processing temperatures required for other co-products could also profoundly affect the condition of nopal based products when they are consumed.

The dietary fiber content of the nopal flour is shown in Table 2.

Table 2. Dietary Fiber Content of Nopal Flour

Type of Fiber	Value	cv (%)
Insoluble fiber	28.45	5.79
Soluble	14.54	13.08
Total dietary fiber	42.99	6.21

Source: Saenz et al. (1997)

This nopal flour had 42.99% total dietary fiber with 28.45% being insoluble fiber and 14.54% being soluble fiber. This high level of fiber is most promising as a source of dietary fiber. Rosado and D¡az (1995) reported a slightly greater dietary fiber content of 50.4% in dehydrated nopal flour. These differences could easily be attributable to the type of Opuntia, the climatic conditions where the plants grow or factors such as rain or irrigation.

The ratio of insoluble to soluble fiber in our study was 2:1. This proportion is a little lower than that reported by Pilch (1987) cited by Pak (1996) of 3:1. The crude fiber (6.8%) of this nopal flour (Pak, 1996) was much less than the total dietary fiber since the crude fiber is only a small portion of the dietary fiber.

Some chemical and physical characteristics of the nopal flour are presented in Table 3.

Table 3. Physical Parameters of Nopal Flour

Parameter		Value	cv (%)
aW		0.53	0.3
Color	L*	73.37	0.13
	a*	-5.20	0.9
	b*	26.1	0.02
I.A.A. (ml/g)		5.6	3.46

Source: Saenz et al. (1997)

The water activity (aw) of 0.53, was very low compared with the aw of marmalades (0.86) but it is still sufficient to preserve marmalades (Fellows, 1994). Low water activity is necessary for product stability during storage, as it limits the amount of free water to be used by microorganisms and chemical reactions.

The color of the flour, as defined by the L*, a* y b* parameters, indicates that the nopal flour is pale green with high lightness. This color is similar to that observed by Sepulveda et al. (1995) in earlier work. The color is not very intense and therefore is easy to change with the addition of natural colors contained in chocolate or caramel (Saenz et al., unpublished) when it is added to other products such as desserts and biscuits.

The Water Index Absorption (mL/g) of 5.6 is lower than that observed by Rosado and Diaz (1995), of 11.1 ml/g in dehydrated nopal and 7.1 ml/g in an extract of nopal fiber. These differences can probably be attributed to differences in the raw material used or slight differences in the analytical techniques used to determine the fiber. This index is a very important parameter from the viewpoint of the physiological effects of the fiber, because the water absorption increases the bolus and produces a satisfying effect. The absorption ability depends mainly of the particle size which can be modified in milling process. Generally, the smaller particle size, the greater is the water retention. However, if the particle size is too small an opposite effect can result due to the loss of the interstitial spaces. This behavior was observed in wheat bran flour.

The particle size of the flour is quite uniform with 77.5% of particles being between 150 and 190 μm. The remaining particles were smaller than 190μm (but greater mesh number). These results are consistent with Larrauri (1994), who stated that in general the products with high content of dietary fiber have a particle size between 150 and 430Fm. The size of the particles can be modified in the milling operation (S enz et al., 1997).

The low water content of nopal flour (7.15%) facilitates the mixing of this concentrate with other flours like wheat flour. However, the amount of water in the flour could be modified in the drying process (Lecaros, 1997).

The ash content was 15.9% with calcium having the highest concentration (3.4 g/100g) (Lecaros, 1997). The daily Ca intake recommended by the National Research Council (1989) is 800 mg for an adult person. It is important to study the biological value of this mineral because it occurs as calcium oxalate, which is not completely usable by the body (Pak cited by Lecaros, 1997).

Potassium, a mineral that aids in fluid balance and nerve transmission in the body, was also present in a considerable amount (2.1 g/100g). Because high levels of K do not occur in many foods, nopal flour could be a good natural source for this mineral. The low sodium content of the nopal flour (0.02 g/100g) is especially important for those on a low salt diet (Saenz et al., 1997).

The rheological behavior of this concentrate is especially important if it is added to liquid foods as it is affected by the concentration of the flour in the suspension. As in other dispersions or gum solutions (Saenz et al., unpublished), the viscosity of the nopal flour increases with concentration and decreases with higher temperatures.

PERSPECTIVES FOR USE OF THE NOPAL FLOUR

This flour is now being tested in foods such as vegetable soups and gelled desserts. The percentage of addition of the flour is limited by the effect in the sensory characteristics. Addition of greater than 20% nopal flour affected the texture of the product to such an extent that the sensory panel rejected the samples. In the vegetable soup the ingredients are similar to those of the commercial formulations (wheat flour, dehydrated spinach, onion, low fat milk, sugar, sodium chloride, flavor, etc.). Senz et al., (unpublished) tested 15, 20 and 25% replacement of wheat flour by nopal flour. The soup with the greatest acceptance had 15% replacement and had a mean sensory evaluation of 7 on a 1-9 scale. For the soup, the sensory parameters of appearance, color and aroma were good, but it was the high viscosity that most positively influenced the positive acceptability of the product.

The rheological properties of nopal flour must be studied in greater detail. Apparently, the dehydration temperature used in making the flour, affects the mucilage content, which in turn affects the viscosity of the suspensions. Preliminary tests show that dehydration temperatures above 75-80§C cause the viscosity of the nopal suspensions to decrease. However, this might not be entirely negative as then it would be possible to increase the proportion of the flour added to the foods (Lecaros, 1997).

The rheology of the flour may also be influenced by the management of the crop since Nobel (1992) stated that temperature can influence the mucilage content. It is possible that irrigation management practices and the rain distribution patterns could influence the mucilage contents.

In summary, the high content of dietary fiber of this flour makes the nopal an interesting source of this important component of the diet. It is also possible to use this nopal flour as an alternative to substitute for other plant fiber sources.

OTHER PRODUCTS FROM NOPAL

There are some others products that could provide fiber from nopal, but none of these potential products are currently used as diet foods. Crystallized cladodes and marmalades from the cladodes marmalade are examples of the kind of diet food that could be prepared (S enz et al., 1996).

Nopalitos (tender young stems) have considerable potential as a vegetable with a good fiber content. However, the demand for nopalitos is limited to Mexico and other countries with populations of Mexican origin (Flores-Valdez, 1992) where consumers have the habit to eat them as fresh or cooked vegetable. There is, however, an increasing demand in the United States and some European and Asian countries, where nopalitos are consumed sporadically in small volumes as an exotic food (Flores-Valdez, 1992; Cantwell, 1992). In the last 5 years small commercial plantations began in the south of the United States, where the stems are processed in different and attractive products. It would be most useful to introduce the products described here, and the new products produced commercially in the United States, to many other countries to stimulate the consumption of this vegetable which is an excellent natural source of dietary fiber and minerals.

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