



## PHYSICOCHEMICAL PROPERTIES OF DIETARY FIBER GELS PRODUCED FROM SOME CEREAL WASTES

[15]

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### ABSTRACT

Dietary fiber gels for calorie reduced foods were prepared from some cereal wastes and their physicochemical properties were investigated. A 51.43, 50.56, 36.64 and 23.08 g of dietary fiber gel was produced from 100 g of rice straw, corn cobs, barely hulls and corn bran, respectively. Corn cobs and rice straw contained high levels of crude fiber (39.64 and 37.58 %, respectively) and low level of fat (0.94 and 0.42%, respectively). Some increase in total dietary fiber, insoluble dietary fiber, cellulose and hemicellulose and on the opposite side decrease in soluble dietary fiber and lignin were observed as a result of preparing fiber gels from different tested cereal wastes. Insoluble dietary fiber of gels obtained from corn bran, rice straw, corn cobs and barely hulls were 81.23, 78.84, 86.33 and 73.24%, respectively. Different fiber gels had higher water holding and oil absorption capacity values than the corresponding cereal wastes. Scanning electron microscope was also used to examine the morphological alteration of different cereal wastes and their fiber gels.

### INTRODUCTION

Air pollution is produced by the ash, fumes, and toxic organic gases produced by the incinera-

tion of rice husks. In Japan, such incineration is now prohibited in rice fields. A certain amount of rice husk waste in Japan is recycled in agricultural and livestock farms, but most is treated as agricultural waste, (Kumagai *et al* 2007).

Residues from agriculture and agroindustries are the nonproduct outputs from the growing and processing of raw agricultural products such as rice, corn, bean, and peanut. While such residues may contain valuable materials, their current economic values are less than the apparent cost of collection, transportation and processing for beneficial use. Therefore, they are often discharged as wastes, (Bagby and Widstrom, 1987).

Dietary fiber gels are prepared by chemical and physical treatment of dietary fiber substrates until the cellular structures are almost completely disintegrated. The gels are characterized by high viscosities and high hydration capacities and can easily be dried and reconstituted. The gels can be used in a range of foods and non-food compositions and are particularly useful as reduced calorie fat (Inglett, 1997).

A hydrocolloidal fiber composite made from rice bran and barley flour called Ricetrim (used as a fat substitute in Thai foods) was found to have similar rheological properties to coconut cream (Inglett *et al* 2004). Fiber gel was also prepared from hulls of corn or oats as reported by Carriere and Inglett, (2003).

Dietary fiber (DF) includes cellulose, lignin, hemicellulose, pectins, gums and other polysaccharides and oligosaccharides associated to plant.

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It is actually defined as "edible parts of plants or analogous carbohydrates that are resistant to digestion and absorption in the human small intestine with complete or partial fermentation in the large intestine". It is conventionally classified into two categories according to their water solubility: IDF, insoluble dietary fiber (cellulose, part of hemicellulose and lignin) and SDF, soluble dietary fiber (pentosans, pectins, gums mucilage) (Mongeau, 2003).

The hemicelluloses unites a big group of high molecular polysaccharides, are insoluble in water but soluble in alkaline solutions. These polysaccharides are associated with cellulose and lignin and play an important structurally supportive role in building up of plant cell walls (Bidlack *et al* 1992 and Nakamura, 2003).

For several years, fat substitutes have been used to partially or fully replace fat. There are three main groups of fat replacers including carbohydrate-based fat substitutes; protein-based fat substitutes and lipid-based fat substitutes (Akoh, 1998). The carbohydrate-based fat substitutes are derived from cereals, grains, and plants that include digestible and nondigestible carbohydrates (starch derivatives and gums). They provide some of the functions of fat by binding water, and providing texture, mouth coating, and opacity (Giese, 1996).

Dietary fibers had reported to produce numerous benefits to health, such as decreasing cardiovascular and gastrointestinal disease, decreasing blood cholesterol, and also preventing colon cancer, (Burton, 2000)

Properties of the gel from wheat fiber are listed to be colorless, odorless, good mouth feel, low calorie content, high roughage content, thixotropic and pseudo plastic tendency, heat and pH stable, high water binding and retaining capacity, inert and stable and insensitive to electrolytes, (Bollinger, 1995)

The objective of this study was to prepare dietary fiber gels from some cereal wastes (corn bran, rice straw, corn cobs and barely hulls) as a fat replacer for low calorie foods and evaluate their physicochemical characteristics.

## MATERIALS AND METHODS

### 1. Materials

Corn bran was obtained from Egyptian Company of Starch and Glucose, Mustorod, Cairo, Egypt. Barley hulls were obtained after milling

the barley seeds using a universal type laboratory rice mill, from Food Technology Research Institute, Agriculture Research Center, Giza, Egypt. Rice straw was mainly obtained from a farm in Agriculture Research Center, Giza, Egypt. Corn cobs were collected from a farm in Monofia, Egypt. Heat stable amylase.-A-0164, protease.-Fiberzym Kit 7367503, and amyloglucosidase. Fiberzym Kit 7367503, were obtained from Sigma Chemical Co.

## 2. Methods

### 2.1. Preparation of dietary fiber gels

Dietary fiber gel of rice straw, corn bran, corn cobs and barley hulls, were prepared according to the method described by Carriere and Inglett, (2003). In a 20 L plastic tank, one kg of fine ground fiber source was mixed with 11 L of water for the first stage of treatment. Approximately 10 gm of a 50% sodium hydroxide solution (sp.gr. 1.52 13.3% alkali concentration) was added to adjust the pH to 6.8. After heating the slurry to 90-94°C, 2.4 ml of  $\alpha$ -amylase (55.2 U/mg) was added to the mixture. The mixture was sheared in autoclave (Vision KMC 1221 made in Korea) at 90-98°C. After 15 min, 175 ml of a 50% sodium hydroxide solution was added to adjust the pH>12 and the shearing was continued for 45 min. The solids were washed two times with 200 L of

### 2.2. Chemical composition

Proximate analysis of cereal wastes and their fiber gels for moisture, protein, fat, ash and Crude fiber contents were determined according to A.O.A.C (2000) and for total dietary fiber (TDF), Soluble dietary fiber (SDF) and insoluble dietary fiber (InSDF) were determined according to the method described by A.A.C.C (1990). Cellulose matter and hemicellulose determined according to Myhre and Smith, (1960). Lignin determined according to Martion, (1964).

### 2.3. Water holding and oil absorption capacity

Water holding and oil absorption capacities were determined according to Knuckles and Kohler, (1982). Water holding capacity is expressed as weight of water boned per g dry sample. Oil absorption capacity is expressed as g oil boned per g dry sample.

#### 2.4. Scanning electron microscopy (SEM)

Scanning electron microscopy (SEM) was used to examine the morphological alteration of different cereal wastes and their fiber gel.

Different samples were taken and immediately fixed in glutaraldehyde (2.5%) for 24 h at 4 C°, then post fixed in osmium tetroxide (1% OsO<sub>4</sub>) for one hour at room temperature (Harley and Ferguson, 1990). The samples were dehydrated with passing through ascending concentrations of acetone, then dried till the critical point and, finally, the sample were sputter coated with gold. The examination and photographing were done through a jeol Scanning Electron Microscope (T.330 A) in the Central Laboratory of the Faculty of Agriculture, Ain Shams University.

#### 2.5. Statistical analysis

The excremental data were analyzed using analysis of variance (ANOVA) followed by Duncan's multiple range test ( $P \leq 0.05$ ) to determine a significant difference among samples. The data were analyzed according to User's Guide of Statis-

tical Analysis System (SAS, 1996) at the Computer Center of Faculty of Agriculture, Ain Shams University.

### RESULTS AND DISCUSSION

#### 1. Chemical composition of some cereal wastes

Table (1) presents the chemical composition of some cereal wastes used to prepare fiber gel. It can be observed that different tested cereal wastes were differed significantly ( $P \leq 0.05$ ) in their chemical composition. Corn bran contained low crude fiber and ash (16.38% and 2.42%, respectively) high fat and carbohydrates contents (2.74 and 70.22%, respectively) compared to the other cereal wastes. Corn cobs and rice straw had a high crude fiber (39.64% and 37.58%, respectively) and less fat than the other tested samples. Barely hulls and corn bran significantly contained more protein than other cereal wastes. Rice straw had a higher content of ash (16.42%) followed by barely hulls. Similar results were obtained by El-Amry, (2006) and Sosulski and Wu, (1988) that they have been worked.

Table 1. Chemical composition of some cereal wastes (on dry weight basis)

Cereal wastes	Moisture (%)	Protein (%)	Fat (%)	Ash (%)	Crude fiber (%)	Carbohydrates* (%)
Rice straw	6.41 <sup>c</sup>	4.22 <sup>b</sup>	0.42 <sup>d</sup>	16.42 <sup>a</sup>	37.58 <sup>b</sup>	41.36 <sup>d</sup>
Corn bran	4.22 <sup>d</sup>	8.24 <sup>a</sup>	2.74 <sup>a</sup>	2.42 <sup>d</sup>	16.38 <sup>d</sup>	70.22 <sup>a</sup>
Corn cobs	7.42 <sup>b</sup>	1.84 <sup>c</sup>	0.94 <sup>c</sup>	3.45 <sup>c</sup>	39.64 <sup>a</sup>	54.13 <sup>c</sup>
Barely hulls	7.83 <sup>a</sup>	8.53 <sup>a</sup>	1.67 <sup>b</sup>	9.23 <sup>b</sup>	21.64 <sup>c</sup>	58.93 <sup>b</sup>

Means in a columns showing the same letter are not significantly different ( $p > 0.05$ ).

\*calculated by difference.

#### 2. Yields of dietary fiber gel produced from some cereal wastes

Yield of dietary fiber gel produced from corn bran, rice straw, corn cobs and barely hulls, was given in Table (2). Rice straw and corn cobs recorded the highest yield (51.43% and 50.56% respectively) of fiber gel, reflecting the predominance of insoluble dietary fiber (cellulose and lignin) in these fiber sources. The results showed also that corn bran had the least yield of fiber gel (23.08%) compared to the other tested samples. Also, barely hulls yield moderate fiber gel

(36.64%). Carriere and Inglett, (2003) found that the yield of corn fiber gel was 41%.

Table 2. Yields of dietary fiber gel produced from some cereal wastes

Cereal wastes	Yield (%)
Rice straw	51.43
Corn bran	23.08
Corn cobs	50.56
Barely hulls	36.64

### 3. Chemical composition of different dietary fiber gels

Table (3) showed the chemical composition of dietary fiber gel prepared from different cereal wastes. Rice straw gel contained higher crude fiber (50.33%) but lower moisture and fat contents compared with the other fiber gel. Oppositely, corn bran gel contained the highest content of carbohydrates, fat and protein. Corn cobs gel presented a moisture content (6.44%) higher than different samples. The higher ash content was recorded for barely hulls gel (8.46%).

The major modification in cereal wastes composition after pretreatment with alkaline hydrogen peroxide to produce dietary gel was a decrease in ash, due to removal of high amount of silica reaction with sodium hydroxide in the pretreatment resulted in soluble silicates, that were eliminated during the washing procedure (Houston, 1972).

A reduction in protein and fat content was also occurred. Soluble proteins and saponified fatty acids (due to the alkaline pH) were probably lost during washing (Chen and Houston, 1970 and Nawar, 1985). Minor causes, like fatty acid oxidation by oxidryl and superoxide radicals formed during decomposition of hydrogen peroxide should be also considered (Jacks and Hensarling, 1989). Total fiber should relative increase that could be attributed to be the decrease of other components. In this respect Inglett and Carriere, (2001) found similar decrease in fat, protein, and minerals in corn bran gel as a result of such treatment.

### 4. Dietary fiber fractions

The polysaccharides were divided into three fractions depending on their solubility in water and alkali. These fractions were pectin substances, (soluble in water), hemicellulose (insoluble in water but soluble in dilute alkali) and cellulose (insoluble in a strong alkali). The major polysaccharide was cellulose which is a linear beta-linked glucan of high molecular weight, ranging between 500,000 and 1 million Dalton (Candido and Campos, 1996).

Total dietary fiber (TDF) of some cereal wastes and their fiber gel, soluble dietary fiber (SDF) and insoluble dietary fiber (InSDF). The latter including cellulose, hemicellulose and lignin are given in Table (4).

Results indicated that the values of TDF, SDF, InSDF, cellulose, hemi cellulose and lignin were

changed after treatment of cereal wastes to prepare a fiber gel. These changes were recorded an increase in TDF, InSDF, cellulose, and hemi cellulose and a decrease in SDF and lignin. These means that preparation process of fiber gel from fiber samples led to an increase in the insoluble dietary fiber and a decrease in SDF. For example, InSDF values of rice straw, corn bran, corn cobs and barely hulls were 72.23%, 60.68%, 78.47% and 45.72% respectively and they increased to 78.84%, 81.23%, 86.33% and 73.24% for the corresponding gels. On the other hand SDF reduced from 12.87%, 5.61%, 8.73% and 18.04% for corn bran, rice straw, corn cobs and barely hulls to 7.84%, 6.75%, 5.45% and 9.43% for their gels respectively. In conclusion corn cobs gel characterized by the highest contents of TDF, InSDF and cellulose and the lowest value of SDF.

Similar result was obtained by Inglett and Carriere, (2001) who found that corn bran gel contains 86.21% TDF. Sandak, (2004) found the same increasing in TDF, InSDF, and cellulose when prepared fiber gel from soy bean hull and broad bean hull.

### 5. Water holding capacity

Water holding capacity (WHC) is the ratio of moisture retained in sample to the initial moisture content, so higher percentage indicates release of less moisture (Pietrasik and Duda, 2000).

Water holding capacity of some cereal wastes and their fiber gel was given in Fig. (1) The water holding capacity increased from 4.42, 3.75, 4.18 and 2.43 g water /g fiber for rice straw, corn bran, corn cobs and barely hulls to 7.67, 6.34, 8.24, 6.34 for the corresponding gels, respectively. These increased value may be due to the result of removal of ash, (silica) and lignin solubilization (Tables 3 and 4). Houston, (1972) described rice hulls as containing a resistant structure formed by lignin and silica. The destruction of this rigid structure could increase the size of interstitial spaces within the cell wall material and facilitate the hydration of cell wall components. According to various authors (Gould 1984; Gould *et al* 1989a and Jasberg *et al* 1989), alkaline hydrogen peroxide removed lignin by solubilization, while at the same time modifying cellulose crystallinity and increasing water absorption. Ning *et al* (1991) stated that the modification of water absorption capacity may be partially due to the swelling of the physical structure of the fiber by alkaline.

Table 3. Chemical composition of fiber gel produced from some cereal wastes (on dry weight basis)

Samples	Moisture (%)	Protein (%)	Fat (%)	Ash (%)	Crude fiber (%)	Carbohydrates*
Rice straw gel	2.74 <sup>d</sup>	0.94 <sup>b</sup>	0.45 <sup>b</sup>	6.45 <sup>b</sup>	50.33 <sup>a</sup>	41.83 <sup>d</sup>
Corn bran gel	5.72 <sup>b</sup>	2.54 <sup>a</sup>	1.72 <sup>a</sup>	0.43 <sup>d</sup>	23.64 <sup>d</sup>	71.67 <sup>a</sup>
Corn cobs gel	6.44 <sup>a</sup>	0.64 <sup>c</sup>	0.68 <sup>b</sup>	2.74 <sup>c</sup>	42.17 <sup>b</sup>	53.77 <sup>b</sup>
Barely hulls el	4.73 <sup>c</sup>	0.82 <sup>bc</sup>	0.53 <sup>b</sup>	8.46 <sup>a</sup>	39.93 <sup>c</sup>	50.26 <sup>c</sup>

Means in a columns showing the same letter are not significantly different ( $p>0.05$ ).

\*calculated by difference

Table 4. Dietary fiber fractions of some cereal wastes and their dietary fiber gel. (on dry weight basis)

Components (%)	Cereal wastes			
	Rice straw	Corn bran	Corn cobs	Barely hulls
Total dietary fiber (IDF)	77.82 <sup>b</sup>	73.53 <sup>c</sup>	87.19 <sup>a</sup>	63.75 <sup>d</sup>
Soluble dietary fiber (SDF)	5.61 <sup>d</sup>	12.87 <sup>b</sup>	8.73 <sup>c</sup>	18.04 <sup>a</sup>
In Soluble dietary fiber (In SDF)	72.23 <sup>b</sup>	60.68 <sup>c</sup>	78.47 <sup>a</sup>	45.72 <sup>d</sup>
Cellulose	39.81 <sup>b</sup>	29.24 <sup>c</sup>	49.14 <sup>a</sup>	26.12 <sup>d</sup>
Hemicellulose	19.41 <sup>c</sup>	21.93 <sup>a</sup>	21.25 <sup>b</sup>	16.82 <sup>d</sup>
Lignin	17.34 <sup>a</sup>	3.63 <sup>d</sup>	9.33 <sup>b</sup>	7.34 <sup>c</sup>
Components (%)	Dietary fiber gel			
	Rice straw	Corn bran	Corn cobs	Barely hulls
Total dietary fiber (IDF)	85.53 <sup>c</sup>	89.03 <sup>b</sup>	91.72 <sup>a</sup>	83.20 <sup>d</sup>
Soluble dietary fiber (SDF)	6.75 <sup>c</sup>	7.84 <sup>b</sup>	5.45 <sup>d</sup>	9.43 <sup>a</sup>
In Soluble dietary fiber (In SDF)	78.84 <sup>c</sup>	81.23 <sup>b</sup>	86.33 <sup>a</sup>	73.24 <sup>d</sup>
Cellulose	48.05 <sup>c</sup>	45.13 <sup>d</sup>	57.95 <sup>a</sup>	51.58 <sup>b</sup>
Hemicellulose	32.05 <sup>a</sup>	29.63 <sup>b</sup>	24.13 <sup>c</sup>	17.14 <sup>d</sup>
Lignin	4.65 <sup>ab</sup>	0.94 <sup>c</sup>	5.03 <sup>a</sup>	4.13 <sup>b</sup>

Means in a rows showing the same letter are not significantly different ( $p>0.05$ ).

The water holding capacity in high dietary fiber sources depend on their chemical and physical structure Mongeau and Brassard (1982) and Gould *et al* (1989b) indicated that this increase may be attributed to the increases in the amount of interstitial space within the particles, that will be seen in the scanning electron micrographs. These results are in agreement with that published by Sosulski and Gadden (1982) who found that the WHC was increase by increasing the contents of cellulose. Also, cellulose has the ability to stabi-

lize large quantities of water by the formation of gel with lubricant and flow properties similar to in at happened by the lipids and cellulose gel which was used as a fat replacer (Candido and Campos 1996).

#### 6. Oil absorption capacity

Fig. (2) showed that the oil absorption capacity was increased from 4.17, 2.09, 2.83 and 3.01 g oil /g fiber for rice straw, corn bran, corn cobs and barely hulls to 5.96, 3.78, 5.42 and 5.63 g oil /g

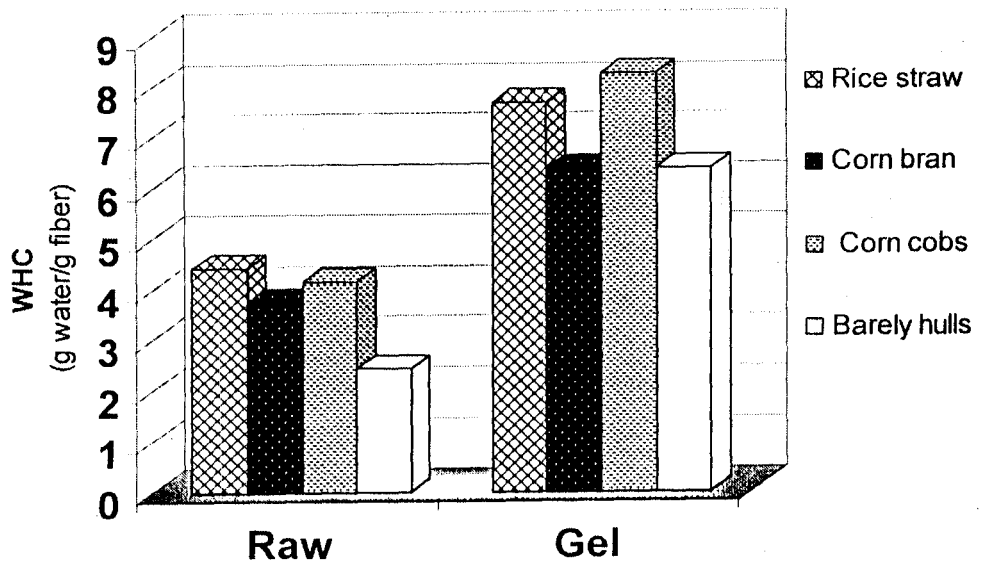


Fig. 1. Water holding capacity (WHC) of some cereal wastes and their fiber gel (g water/g fiber)

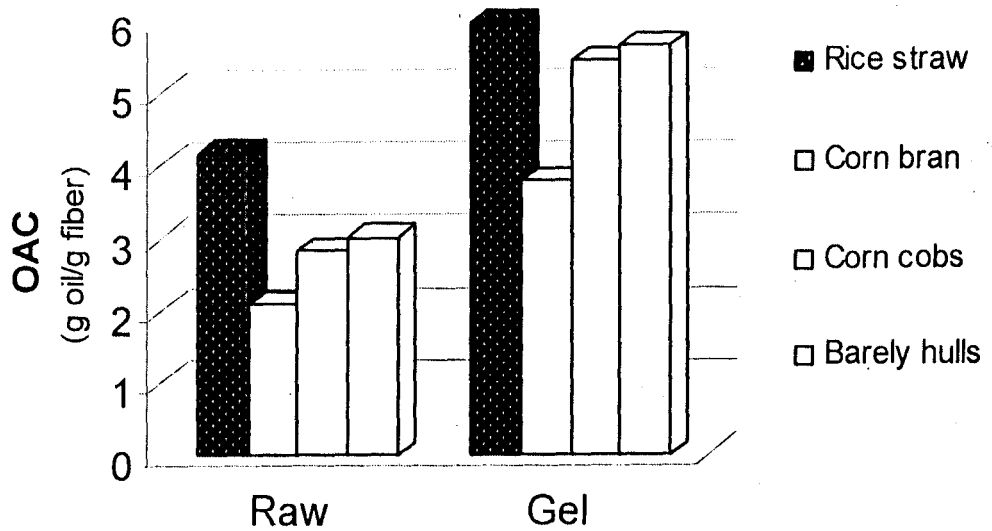


Fig. 2. Oil absorption capacity (OAC) of some cereal wastes and their fiber gel (g Oil /g fiber)

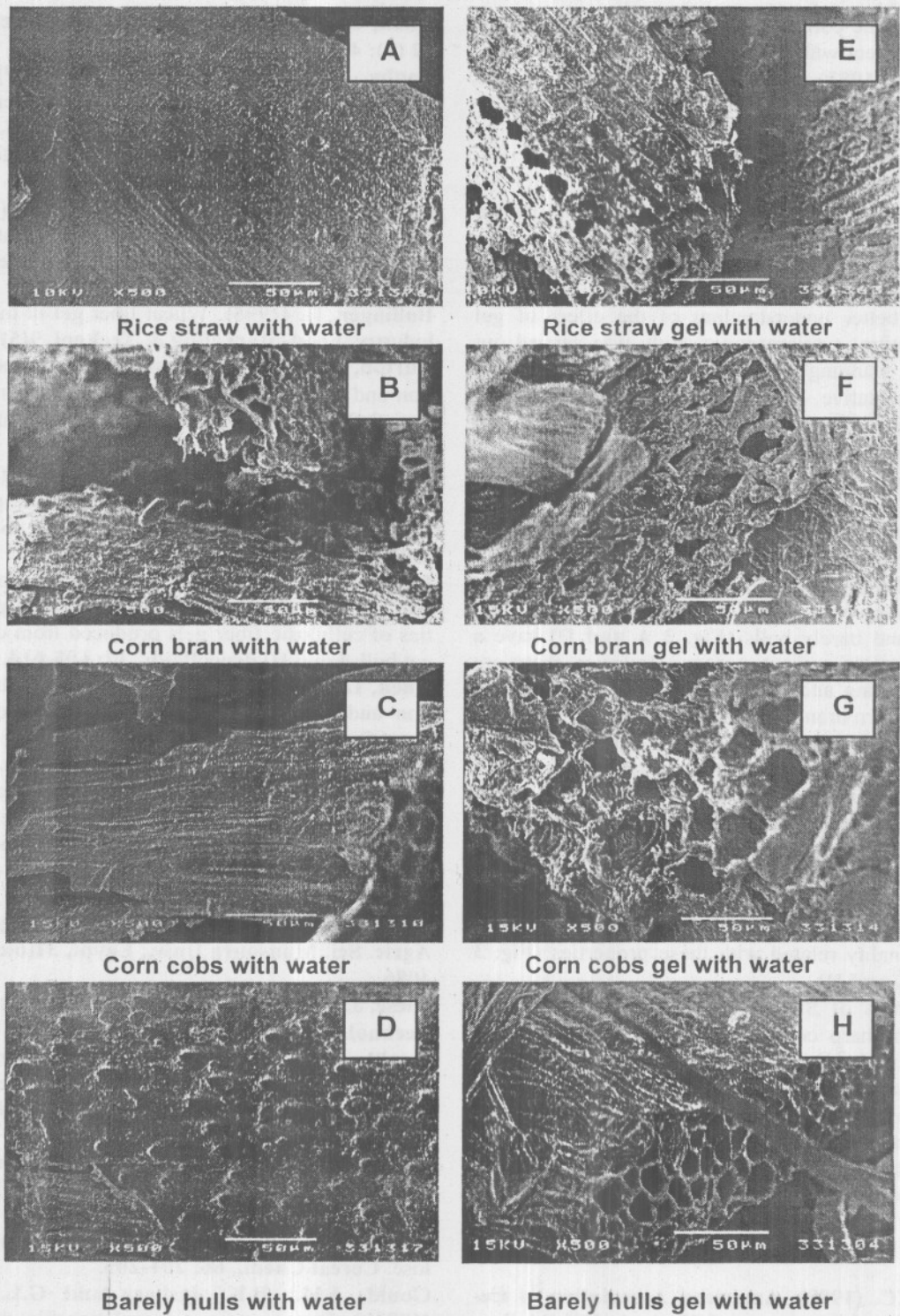


Fig. 3. SEM scanning electron micrographs (500x) of some cereal wastes samples (A-D) and their fiber gel (E-H), mixed with water and air dried on surface

fiber for the corresponding gels. These results are in agreement with that published by (Sosulski and Gadden, 1982) who found that the OAC was increase by increasing the contents of cellulose.

### 7. Scanning electron microscopy (SEM)

The numerous applications of dietary fiber are based on their distant fiber morphology. Thus, there may be a relation between the surface feature and the properties of dietary fiber. In order to attain a better understanding of the effect of gel preparation, a microscopic study was carried out using scanning electron microscopy (SEM). Representative SEM micrograph, taken at the magnification of 500x of some cereal wastes and their gels with water was shown in Fig. (3).

SEM micrographs of different tested cereal wastes and their fiber gels with water clearly indicate that the differences in microstructure of various samples are significant as shown in Fig. (3). Also, different examined samples were characterized by several unique structural properties. Rice straw and barely hulls (Fig. 3 A and D) have a smooth and compact surface. However, there are slight pitting and cracking or crazing on the surface of corn bran and corn cobs (Fig. 3 B and C).

The micrographs of dietary fiber gels are in sharp contrast to the initial cereal wastes before processing into gels. Using magnification of 500x, there is visual evidence of rough morphological cell-wall material, along with some porosity and spherical structures of dietary fiber gels. This structure, more open than the cereal wastes could facilitate water penetration and absorption, improving functionality related with these properties (Fig. 3 E, F, G and H).

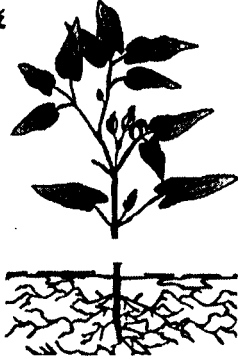
Results of SEM confirmed that dietary fiber gels, in sharp contrast to cereal wastes, had the ability to retain large amount of water in smooth deformable particles and porosity structure as can be seen in Fig. (1). These results are in accordance with Larrea *et al* (1997), Inglett and Carriere, (2001); Colom *et al* (2003); Xie *et al* (2007) and Yin *et al* (2007).

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## الخصائص الفيزيوكيماوية لجل الالياف الغذائية الناتج من بعض مخلفات الحبوب

[١٥]

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الالياف الغذائية الذائبة واللجنين نتيجة تحضير جل الالياف الغذائية من مخلفات الحبوب تحت الدراسة. وبلغت الالياف الغذائية غير الذائبة فى الجل المتحصل عليه من ردة الذرة ، قش الارز ، قوالح الذرة وقشرة الشعير ٣ ٨١،٢ ، ٤ ٧٨،٨ ، ٣٣ ٨٦،٣٣ و ٢٤،٧٣ ٪ على التوالي . وتميز جل الالياف الغذائية الناتج بارتفاع القدرة على الاحتفاظ بالماء وامتصاص الزيت عن مخلفات الحبوب تحت دراسته المحضر منها. كما تم استخدام الميكروسكوب الالكترونى الماسح لفحص التغيير (التعديل) المورفولوجي لمخلفات الحبوب المختلفة وجل الالياف المحضر منها.

تم تحضير جل الالياف الغذائية من بعض مخلفات الحبوب لانتاج اغذية منخفضة السعرات الحرارية وكذلك دراسة الخصائص الفيزيوكيماوية له. ووجد ان كمية جل الالياف الغذائية الناتجة من ١٠٠ جم قش الارز، قوالح الذرة ، قشرة الشعير وردة الذرة بلغت ٤٣،٥١ ، ٥٦،٥٠ ، ٦٤،٣٦ و ٨،٢٣ جم على التوالي. واظهرت النتائج ارتفاع محتوى قوالح الذرة وقش الأرز من الالياف الخام (٣٩،٦٤ و ٥٨،٣٧٪ على التوالي) وانخفاض محتواها من الدهن ( ٩٤،٠ و ٤٢،٠ ٪ على التوالي)، ولوحظ وجود زيادة فى كلا من الالياف الغذائية الكلية والالياف الغذائية غير ذائبة والسليولوز والهيميسليولوز، وانخفاض فى كلا من