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# Effects of drying methods on the functional properties of flaxseed gum powders

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ABSTRACT

The effects of different drying methods (spray drying, freeze drying, vacuum drying, oven drying at 80 and 105 °C, and ethanol precipitation) on the color and functional properties such as zeta potential, foaming, gelling, and emulsion properties of flaxseed gum were studied. Spray dried powders had the lightest color among all the powders. The powder obtained from ethanol precipitation had the lowest zeta potential and the resultant emulsion was in the most stable state. The ethanol precipitated powders had the best emulsion capacity and stability, better than even the untreated samples. The oven dried (105 °C) powders had the best foaming capacity and the foam stability, while the 80 °C oven dried powder had highest gel strength among all the dried samples. These results will be helpful in selecting suitable drying method depending on the functional properties of the flaxseed gum powders.



## 1. Introduction

Hydrocolloid gums are widely used in food industry as emulsifiers, stabilizers and thickeners (BeMiller, 1993; Huang, Kakuda, & Cui, 2001). The utilization of these gums depends on their unique functional properties such as viscosity, emulsion, gelling and foaming properties (Makri & Doxastakis, 2006). The functional properties of the hydrocolloid gums are sensitive to the preparation methods and could be altered by the drying processes to great extent (Jaya & Durance, 2009). For example, the encapsulating property of the gums in microencapsulation process would be different depending on whether they are obtained through spray drying or freeze drying (Shahidi & Han, 1993).

Flaxseed gum is a polysaccharide deprived from flaxseed (*Linum usitatissimum*) which makes up about 8% weight of this gum (Mazza & Biliaderis, 1989). This gum has attracted attention because of its beneficial effects in diabetes, heart disease and colorectal cancer (Cunnane et al., 1993; Tarpila, Wennberg, & Tarpila, 2005). It is reported to be a good gum whose functional properties are close to that of gum arabic (Mazza & Biliaderis, 1989; Wang et al., 2008). Flaxseed gum has been used in the emulsion preparation in order to enhance the emulsion stability. It stabilizes the emulsions by increasing the viscosity and decreasing the interfacial tension (Khalloufi, Alexander, Douglas Goff, & Corredig, 2008; Khalloufi, Corredig, Goff, & Alexander, 2009). Flaxseed gum has been found to stabilize the cloudy carrot juice owing to its macromolecular steric repulsion, further it was also found to reduce the creaming of cloudy carrot juice owing to its emulsion ability (Qin, Xu, & Zhang, 2005). It is reported that the flaxseed gum solutions are able to form thermo-reversible gel (Chen, Xu, & Wang, 2006). Thus, this gum is also used as stabilizer in salad dressing and meat based food (Chen, Xu, & Wang, 2007; Stewart & Mazza, 2000).

Flaxseed gum can be easily extracted from flaxseed using water as solvent (Cui, Mazza, & Biliaderis, 1994). However, the dehydration process after extraction could significantly affect the rheological as well as other functional properties of this gum (Wang, Wang, Li, Xue, & Mao, 2009). Drying methods such as ethanol precipitation, freeze drying and spray drying are commonly used in the dehydration of flaxseed gum (Fedeniuk & Biliaderis, 1994; Oomah & Mazza, 2001).

The functional properties of food hydrocolloids significantly influence the scope of their application and commercial value and are significantly affected by the drying processes (Carvajal-Millan et al., 2007; Islam, Phillips, Sljivo, Snowden, & Williams, 1997; Sundaram & Durance, 2008). The emulsion and foaming properties of flaxseed gum have been found to be affected by the extraction and drying processes (Fedeniuk & Biliaderis, 1994). However, the effects of drying process on the functional properties (zeta potential, foaming, gelling, and emulsion properties) of flaxseed gum have not yet been systematically studied. Hence, this study aimed at studying the effects of different drying methods

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(spray drying, freeze drying, vacuum drying, oven drying at two temperatures 80 and 105 °C, and ethanol precipitation) on color, zeta potential, foaming, gelling, and emulsion properties of the flaxseed gum. This study will help understanding the relationship between drying processes and functional properties of flaxseed gum and also provide useful information regarding their application in food industry.

## 2. Materials and methods

### 2.1. Materials

Flaxseed with 6.5% w/w moisture content was purchased from Hebei province of China. Commercial soybean oil was used to prepare emulsions and was purchased from local market (Fulinmen, Tianjin, China).

### 2.2. Flaxseed gum extraction

Flaxseed (100 g) was washed in water for 1 min to remove the surface dust. The properly washed flaxseeds were mixed with 900 mL deionised water and maintained at 60 °C using a water bath with constant stirring (300 rpm) as suggested by Cui (2001). The extracted flaxseed gum solution was filtered through 40-mesh screen. The resultant gum solution was diluted with deionised water to maintain the gum concentration to 1% w/w.

The protein content of extracted gum solids was 14.4 ± 0.2% as determined by Kjeldahl method (FOSS Kjeltec 2300, FOSS Co., Höganäs, Sweden). A conversion factor of 6.25 was used to determine the protein content. All the analyses were performed in triplicate.

### 2.3. Drying methods

The drying methods reported previously by Wang et al. (2009) were used in this study.

The diluted gum solution (1%) was spray dried using a benchtop spray drier (GPW120-II, Shandong Tianli Drying Equipment Inc., China). The inlet and outlet temperatures were set at 200 and 105 °C, respectively. The feed rate was 4 mL/min throughout the experiments. The dried gum was collected at the bottom of the cyclone.

Extracted flaxseed gum solution (1%) was freeze dried in a LGJ-18S freeze dryer (Beijing Songyuan Huaxing Technology Develop Co., Beijing, China) for 24 h. The freeze dryer was equipped with a temperature controller, which controlled the temperature to increase steadily.

The diluted gum solution (1%) was vacuum dried in a vacuum drier (DZ-3, Tianjin Taisite Instrument Co., China) for 24 h. The vacuum and temperature were maintained at 60 Pa and 60 °C, respectively.

The diluted gum solution (1%) was dried in a hot air oven (101-3, Luda Experimental Instrument Co., Shanghai, China) at two drying conditions, 105 °C for 8 h, and 80 °C for 24 h.

The diluted gum extract (1%) was precipitated with two volumes of 95% ethanol, according to the method of Cui et al. (1994) with some modification. The precipitated solid was subsequently dried in a hot air oven at 80 °C for 8 h.

### 2.4. Solution preparation

The gum solids dried using various methods described in Section 2.3 were redissolved in deionised water in order to carry-out the color, foaming, gelling, and emulsion tests. Solutions (1% w/w) were prepared for these tests by stirring the solids at 25 °C for 30 min. For zeta potential and conductivity tests, 0.09% w/w solutions were prepared in similar way.

### 2.5. Color measurements

The color of both the powder and the solution was evaluated using a WSC-S colorimeter (Shanghai Precision Scientific Instrument Co., Ltd., Shanghai, China). The color was expressed in terms of lightness ($L$), redness ($a$), yellowness ($b$) and total color difference ($E$).

### 2.6. Zeta potential

The zeta potential of 0.09% solutions was measured using Malvern Zetasizer Nano-ZS (ZEN3600, Malvern Instrument Ltd., Worcestershire, UK) across the capillary tube at 25 °C. The conductivity of samples was also measured at the same time.

### 2.7. Foaming properties

Foaming capacity and foam stability were determined using the methods proposed by of Shahidi, Han, and Symwiecki (1995) and Li, Jia, and Yao (2009) with some modifications. Solution of 60 mL was whipped at 15,000 rpm for 2 min with a high-speed homogenizer (T25, IKA Laboratory Technology, Staufen, Germany). The total volume was measured every minute after whipping until the foam volume decreased to half of its original (expanded) value. Foaming capacity was expressed as foam expansion immediately after whipping, while foam stability was expressed as the time required for the foam volume to decrease to its half. Foaming capacity was calculated using the following equation:

$$\text{Foaming capacity } (\%) = [(V - V_0)/V_0] \times 100\% \quad (1)$$

where $V$ and $V_0$ are the volumes immediately after whipping and before whipping, respectively.

### 2.8. Gel strength

Gel strength of the solutions was measured using AR2000ex rheometer (TA Instruments Ltd., Crawley, UK). An aluminum parallel plate geometry (40 mm diameter, 1 mm gap) was chosen for the gel strength measurements. A thin layer of low viscosity silicone oil was applied on the surface of the samples in order to prevent evaporation. The linear viscoelastic region was determined for each sample through strain sweeps at 1 Hz (data not shown). Viscoelastic properties (storage modulus, $G'$, and loss modulus, $G''$) of the solutions were determined within the linear viscoelastic region.

The solutions were heated to 90 °C and held at this temperature for 2 min. The solutions were subsequently cooled to 10 °C at a cooling rate of 5 °C/min. The $G'$ and $G''$ values were determined during cooling using an angular frequency of 6.283 rad/s. The $G'$ and $G''$ values at 10 °C were taken as the measure of the gel strength.

### 2.9. Emulsion properties

The emulsions were prepared with an oil volume fraction $\phi$ = 0.098 using 50 mL emulsifier solution and 5 g soybean oil (density of soybean oil = 0.92 g/cm$^3$). A high-speed emulsifier (Ultra-Turrax T 25; IKA, Staufen, Germany) was used at 15,000 rpm for 3 min. All these tests were carried out in triplicates.

The emulsion activity was determined as turbidity $T$ (given by Eq. (2) below) immediately after the emulsions were prepared as suggested by Pearce and Kinsella (1978). The emulsions were serially diluted to 961 dilution (31 dilution carried out twice serially) with 0.1% w/v sodium dodecyl sulphate (SDS). The absorbance was

measured at 500 nm immediately after emulsification and 1 h later using an ultraviolet spectrophotometer (TU-1810, Beijing Purkinje General Instrument Co., Ltd., Beijing, China). The SDS solution was used as blank. The zeta potentials and conductivities of the diluted emulsions were measured using the method described in Section 2.6. The turbidity '*T* value' was calculated using Eq. (2) (Einhorn-Stoll, Weiss, & Kunzek, 2002).

$$T = \frac{2.303 \cdot A \cdot V}{I} \quad (2)$$

where, $T$ = turbidity in 1/m, $V$ = dilution factor, $A$ = absorbance at 500 nm, and $I$ = path length = 0.01 m.

The emulsion activity index (EAI) was calculated using Eq. (3) below.

$$\mathrm{EAI} = \frac{2T}{\phi \cdot c} \quad (3)$$

where, $\phi$ is the oil volume fraction of the dispersed phase, and $c$ is the concentration of flaxseed gum in emulsion.

The emulsion stability was expressed as the ratio of turbidity measured at an hour time to the one measured immediately after the emulsions were made, following Chen and Xu"s method as given by Eq. (4) (Chen & Xu, 2006).

$$\text{Emulsion stability } (\%) = T_1/T_0 \quad (4)$$

where, $T_0$ = turbidity immediately after emulsification, $T_1$ = turbidity after 1 h.

### 2.10. Statistical analysis

Duncan's multiple comparison tests were carried out to determine the effect of the above mentioned drying processes on the functional properties of dried flaxseed gum samples at $p < 0.05$ using the SPSS 13.0 (SPSS Inc., Chicago, USA).

## 3. Results and discussion

### 3.1. Color of flaxseed gum powders and their solutions

The color differences in flaxseed gum powders and solutions prepared by different drying methods are provided in Table 1. Ideally the flaxseed gum should be colorless in order to avoid any color changes in food products upon its addition. The spray dried powder has significantly high lightness ($L = 6.00$) and low redness ($a = 0.92$), indicating that this powder has a good quality in terms of color and potentially good applicability ($p < 0.05$). This is because the spray drying has very short residence time and the powder particles are subjected to drying condition for a very short time compared to other drying methods. The 105 °C oven dried powder has the lowest lightness ($L = 3.55$) and high redness ($a = 1.50$) which can be attributed to the thermal degradation caused by considerably long drying time at high temperature. As a result the oven dried (105 °C) powder appeared dark and red compared to other samples. Consequently its usage would be narrowed to limited products such as sausages.

In the case of the gum solutions, most samples show no significant difference except for the 105 °C oven dried sample as indicated by Duncan test (shown in Table 1). The solution prepared by 105 °C oven dried powder has similar color to the powder itself as indicated by low lightness ($L = 4.20$), high redness ($a = 1.17$), and low yellowness ($b = 2.83$). The similarity and high color quality in the other samples indicates that these powders can have similar and wider application when used as solutions.

### 3.2. Zeta potential and conductivity of the gum solutions

The zeta potential and conductivity of 0.09% (w/w) gum solutions are presented in Table 2. The zeta potential is a reflection of stability of the solutions. High absolute values of zeta potential mean better stability because of the mutual repulsion between the electrical double layers of macromolecules (Acedo-Carrillo et al., 2006). On the other hand when the solutions have low absolute zeta potential value then there is no force to prevent the molecules coming together. The dividing line between stable and unstable dispersions is generally taken at either +30 or −30 mV. Solutions with zeta potentials higher than +30 mV or lower than −30 mV are normally considered stable (Sherman, 1970). The ethanol precipitation process decreased the zeta potential from −31.8 mV (untreated sample) to −39.1 mV, and the conductivity from 0.165 mS/cm (untreated sample) to 0.097 mS/cm, which means that the stability of the flaxseed gum solution was enhanced by the process. The 105 °C oven dried sample also lowered the zeta potential, albeit in a small amount. The remaining drying methods reduced the stability of the solution by increasing the zeta potential, however, there is no significant difference in zeta potential values among each other ($p < 0.05$). The spray and the vacuum dried samples have zeta potential higher than −30 mV (−27.7 and −29.5 mV, respectively), which means that their solutions will have slightly higher instability compared to the untreated sample. These results are in agreement with Chen et al.'s (2006) data, in which the zeta potential value of 0.08% (w/w) flaxseed gum solution was found to be −32 to −33 mV.

### 3.3. Foaming capacity and stability of flaxseed gum solutions

The effects of drying methods on the foaming capacity of flaxseed gum are shown in Fig. 1. The Duncan test showed that the drying methods had significant effect on the foaming capacity ($p < 0.05$). As shown in this figure, the untreated sample and 105 °C oven dried sample have the highest foaming capacity (above 40%). The spray dried and freeze dried samples have the lowest foaming capacity (about 10%), while the remaining three

**Table 1**
Color differences in flaxseed gum powders and solutions prepared by different drying methods.[a,b]

| | Powder | | | | Solution | | | |
|---|---|---|---|---|---|---|---|---|
| | *L* | *a* | *b* | *E* | *L* | *a* | *b* | *E* |
| Untreated sample | – | – | – | – | $4.86 \pm 0.11^{A}$ | $0.41 \pm 0.04^{B}$ | $3.17 \pm 0.07^{A}$ | $1.47 \pm 0.07^{A}$ |
| Spray drying | $6.00 \pm 0.03^{A}$ | $0.92 \pm 0.03^{C}$ | $3.91 \pm 0.02^{A}$ | $2.42 \pm 0.03^{A}$ | $4.77 \pm 0.14^{A}$ | $0.50 \pm 0.13^{B}$ | $3.12 \pm 0.08^{A,B}$ | $1.33 \pm 0.13^{A,B}$ |
| Freeze drying | $5.66 \pm 0.01^{B}$ | $1.13 \pm 0.02^{B}$ | $3.71 \pm 0.01^{B}$ | $1.99 \pm 0.01^{B}$ | $4.74 \pm 0.07^{A}$ | $0.48 \pm 0.16^{B}$ | $3.11 \pm 0.04^{A,B}$ | $1.33 \pm 0.12^{A,B}$ |
| Vacuum drying | $4.66 \pm 0.24^{C}$ | $1.31 \pm 0.10^{D}$ | $3.10 \pm 0.15^{C}$ | $0.81 \pm 0.30^{C,D}$ | $4.64 \pm 0.06^{A}$ | $0.59 \pm 0.21^{B}$ | $3.05 \pm 0.05^{A,B}$ | $1.17 \pm 0.20^{A,B}$ |
| 105 °C oven drying | $3.55 \pm 0.09^{E}$ | $1.50 \pm 0.07^{A}$ | $2.38 \pm 0.06^{E}$ | $0.54 \pm 0.11^{D}$ | $4.20 \pm 0.15^{B}$ | $1.17 \pm 0.16^{A}$ | $2.83 \pm 0.08^{C}$ | $0.44 \pm 0.10^{C}$ |
| 80 °C oven drying | $4.03 \pm 0.08^{D}$ | $1.53 \pm 0.16^{A}$ | $2.70 \pm 0.04^{D}$ | $0.14 \pm 0.02^{E}$ | $4.69 \pm 0.17^{A}$ | $0.63 \pm 0.14^{B}$ | $3.09 \pm 0.10^{A,B}$ | $1.18 \pm 0.17^{B}$ |
| Ethanol precipitation | $4.79 \pm 0.24^{C}$ | $0.97 \pm 0.02^{C}$ | $3.12 \pm 0.14^{C}$ | $1.05 \pm 0.25^{C}$ | $4.64 \pm 0.07^{A}$ | $0.43 \pm 0.09^{B}$ | $3.01 \pm 0.04^{B}$ | $1.28 \pm 0.05^{A,B}$ |

[a] Values represent the mean ± standard deviation of triplicate tests.
[b] Values in a column with different superscripts were significantly different ($p < 0.05$).

**Table 2**
Zeta potential and conductivity of 0.09% (w/w) flaxseed gum solutions prepared by different drying methods[a,b].

| | Zeta potential (mV) | Conductivity (mS/cm) |
|---|---|---|
| Untreated sample | −31.8 ± 1.6$^{B,C}$ | 0.165 ± 0.008$^{A}$ |
| Spray drying | −27.7 ± 1.9$^{C}$ | 0.15 ± 0.026$^{A}$ |
| Freeze drying | −31.5 ± 3.2$^{B,C}$ | 0.161 ± 0.011$^{A}$ |
| Vacuum drying | −29.5 ± 2.8$^{B,C}$ | 0.161 ± 0.008$^{A}$ |
| 105 °C oven drying | −32.7 ± 1.1$^{B}$ | 0.158 ± 0.006$^{A}$ |
| 80 °C oven drying | −31.4 ± 0.9$^{B,C}$ | 0.154 ± 0.003$^{A}$ |
| Ethanol precipitation | −39.1 ± 4.2$^{A}$ | 0.097 ± 0.004$^{B}$ |

[a] Values represent the mean ± standard deviation of triplicate tests.
[b] Values in a column with different superscripts were significantly different ($p < 0.05$).

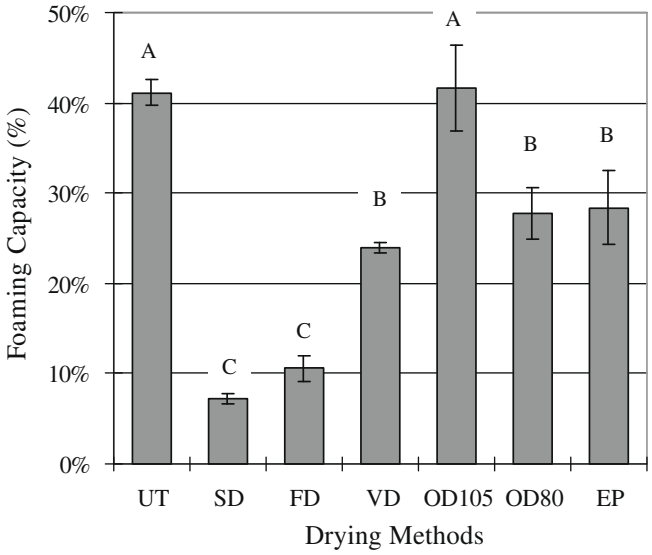


**Fig. 1.** Effects of drying methods on foaming capacity of flaxseed gum (UT, untreated sample; SD, spray drying; FD, freeze drying; VD, vacuum drying; OD105, 105 °C oven drying; OD80, 80 °C oven drying; EP, ethanol precipitation). Values of each bar with different labels were significantly different ($p < 0.05$).

drying methods have medium foaming capacity (between 20% and 30%). Except 105 °C oven dried sample, all the other drying processes reduced the foaming capacity of flaxseed gum solutions.

The foaming capacity of 0.5% xanthan and guar gum solutions was reported to be 15% and 27% when tested using similar method (Sciarini, Maldonado, Ribotta, Pérez, & León, 2009). When the difference in the concentration is considered, it appears that the foaming capacity of flaxseed gum resembles that of xanthan gum and guar gum. It was previously reported that the foaming capacity of flaxseed gum solution (1%, w/v) to be 75% that of ovalbumin (Mazza & Biliaderis, 1989). Polysaccharide gums impart positive effects in foaming properties in food system because of their high viscosity (Mott, Hettiarachchy, & Qi, 1999; Xie & Hettiarachchy, 1998). Hence flaxseed gum has potential to be used in food systems to improve foaming properties because of its moderate foaming capacity and relatively high viscosity (Wang et al., 2009).

The effects of drying methods on foam stability of flaxseed gum solutions were tested and shown in Fig. 2. It appears that the flaxseed gum solutions have weak foam stability. Only the 105 °C oven dried sample has high foam stability (approximately 47 min, highest among all the samples). Because of its best foam stability and foaming capacity, the 105 °C oven dried sample can be considered having best foaming properties among all the samples. Ethanol precipitated and spray dried samples also have higher foam stability than untreated one ($p < 0.05$). The remaining samples (freeze

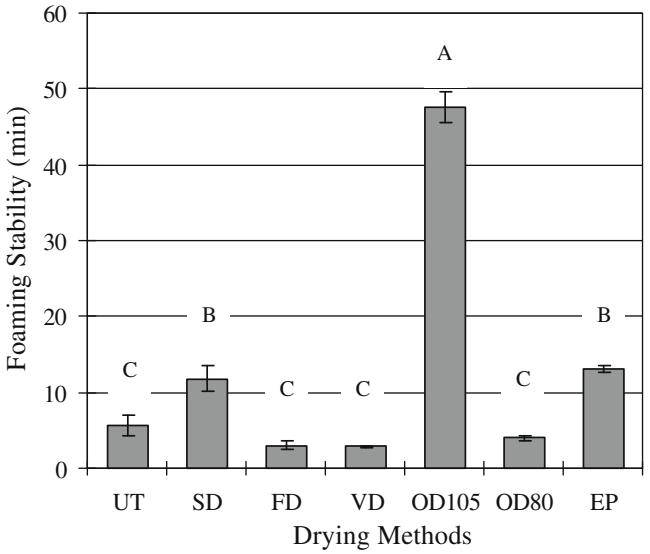


**Fig. 2.** Effects of different drying methods on foam stability of flaxseed gum (UT, untreated sample; SD, spray drying; FD, freeze drying; VD, vacuum drying; OD105, 105 °C oven drying; OD80, 80 °C oven drying; EP, ethanol precipitation). Values of each bar with different labels were significantly different ($p < 0.05$).

dried, oven dried at 80 °C and vacuum dried) show no significant difference in foam stability compared with the untreated sample ($p < 0.05$).

Gums (gum arabic, xanthan, locust bean, and β-glucan gums) were not only stabilize their own foams but also significantly contribute to the stability of protein systems (Burkus & Temelli, 2000; Makri & Doxastakis, 2006). This is because the gum molecules tend to move to the interface and reduce the interfacial tension, thereby contributing to the stability of the foams (Sciarini et al., 2009). Thus, the current research on foam stability of flaxseed gum would prove to be useful for its greater application in food systems.

### 3.4. The gel strength

The effects of drying methods on the gel strength of gum solution are shown in Fig. 3. The gel strength is expressed in terms of elastic modulus ($G'$) and loss modulus ($G''$) values following the heating and cooling process. As can be seen from this figure, all the drying methods decreased the gel strength of flaxseed gum (lower $G'$ and $G''$ values), compared to the untreated sample ($p < 0.05$). As shown in Fig. 3a, the ethanol precipitated samples have the lowest $G'$ value (2.0 Pa), while the untreated sample has the highest $G'$ (6.6 Pa). The remaining drying methods showed no significant difference among each other in Duncan test ($p < 0.05$). As shown in Fig. 3b, spray drying decreased the $G''$ value to the greatest extent (1.3 Pa), while the untreated sample has the highest loss modulus (2.3 Pa). The remaining five drying methods show no significant difference among each other ($p < 0.05$).

### 3.5. The emulsion properties

The different drying methods have significant effects on emulsion activity index (EAI) of flaxseed gum solution, as shown in Fig. 4. Three drying methods (vacuum drying, 105 °C oven drying and ethanol precipitation) significantly increased the EAI of the gum ($p < 0.05$). Freeze drying and 80 °C oven drying did not change the EAI significantly compared to the untreated sample while spray drying was the only drying method which reduced the EAI value. These results are similar with the EAI of 3% whey protein isolate (57.0 ± 1.0 $m^2/g$) and sodium caseinate (82.0 ± 11.2 $m^2/g$) solutions

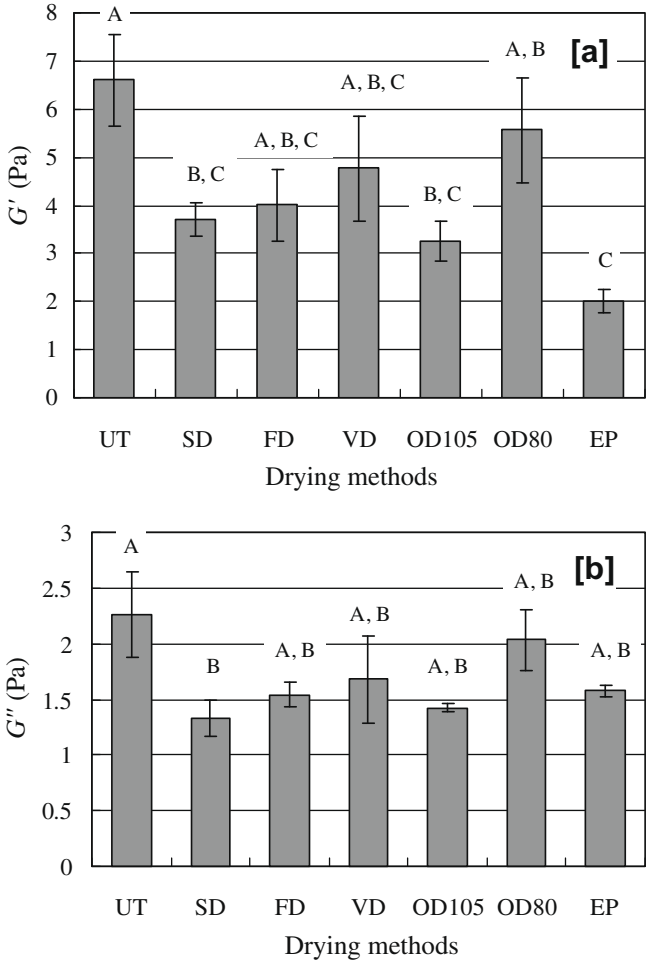


**Fig. 3.** Effects of different drying methods on gel strength of flaxseed gum (UT, untreated sample; SD, spray drying; FD, freeze drying; VD, vacuum drying; OD105, 105 °C oven drying; OD80, 80 °C oven drying; EP, ethanol precipitation). Values of each bar with different labels were significantly different ($p < 0.05$) (a is for storage modulus, b is for loss modulus).

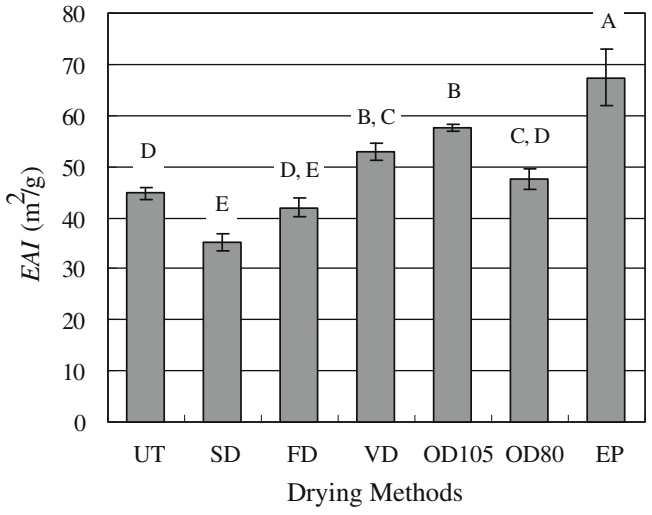


**Fig. 4.** Effects of different drying methods on emulsion ability of flaxseed gum (UT, untreated sample; SD, spray drying; FD, freeze drying; VD, vacuum drying; OD105, 105 °C oven drying; OD80, 80 °C oven drying; EP, ethanol precipitation). Values of each bar with different labels were significantly different ($p < 0.05$).

reported in previous study employing the same test method (Webb, Naeem, & Schmidt, 2002).

The emulsion stability of flaxseed gum solutions are shown in Fig. 5. All the drying methods enhanced the emulsion stability as shown by Duncan test ($p < 0.05$). Ethanol precipitated, 105 °C oven dried, and vacuum dried samples show high emulsion stability compared to the remaining samples. Considering that these three samples also possessed high emulsion ability (shown in Fig. 4), it can be concluded that these three drying methods will be preferred if powders with good emulsion properties are desired. The ethanol precipitation method appears to be the best one to produce powders with best emulsion properties.

Table 3 shows the zeta potential and conductivity of flaxseed gum emulsions, diluted 961 times with 0.1% SDS before tests. The zeta potential ranges from −94.25 to −113.65 mV. The powders obtained from three drying methods (oven drying at 80 and 105 °C and ethanol precipitation) decreased the zeta potential of emulsion compared to the untreated sample. Since all the samples were negatively charged, the lower the zeta potential values, the higher the stability of the emulsion. The powders obtained from remaining three drying methods (freeze drying, spray drying and vacuum drying) have higher zeta potential values compared to the untreated one. No significant difference was found on conductivity of emulsions obtained from these drying methods ($p < 0.05$). Zeta potential values in this study were much higher than those reported by Khalloufi et al. (2008), in which zeta potentials were reported to range between −31.4 and −49.9 mV, depending on the flaxseed gum concentration (0.005–0.333%). It may be due to the

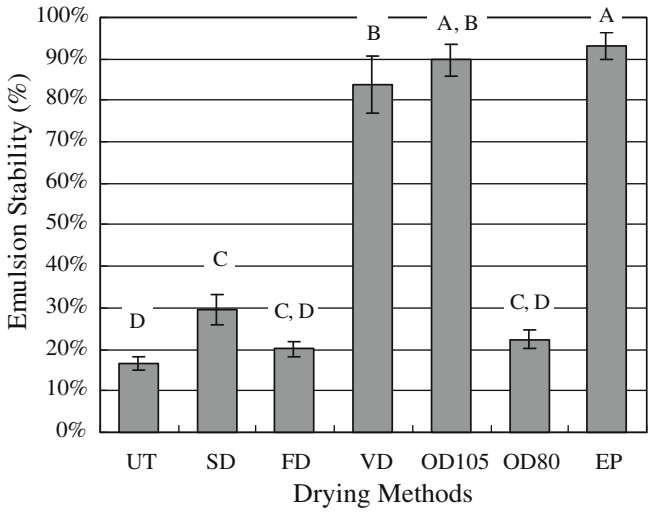


**Fig. 5.** Effects of different drying methods on emulsion stability of flaxseed gum (UT, untreated sample; SD, spray drying; FD, freeze drying; VD, vacuum drying; OD105, 105 °C oven drying; OD80, 80 °C oven drying; EP, ethanol precipitation). Values of each bar with different labels were significantly different ($p < 0.05$).

**Table 3**
Zeta potential and conductivity of flaxseed gum emulsions prepared by different drying methods[a,b].

| | Zeta potential (mV) | Conductivity (mS/cm) |
|---|---|---|
| Untreated sample | $-101.99 \pm 3.06^{B,C}$ | $0.265 \pm 0.001^{B}$ |
| Spray drying | $-98.42 \pm 1.35^{C}$ | $0.254 \pm 0.001^{A}$ |
| Freeze drying | $-100.72 \pm 2.91^{C}$ | $0.264 \pm 0.001^{B}$ |
| Vacuum drying | $-94.25 \pm 1.68^{C}$ | $0.269 \pm 0.002^{A,B}$ |
| 105 °C oven drying | $-112.67 \pm 0.67^{A}$ | $0.268 \pm 0.004^{A,B}$ |
| 80 °C oven drying | $-113.65 \pm 3.02^{A}$ | $0.264 \pm 0.002^{B}$ |
| Ethanol precipitation | $-109.58 \pm 1.08^{A,B}$ | $0.268 \pm 0.002^{A,B}$ |

[a] Values represent the mean ± standard deviation of triplicate tests.
[b] Values in a column with different superscripts were significantly different ($p < 0.05$).

fact that 0.6% (w/w) whey protein isolate was used in emulsion in that work.

## 4. Conclusion

The effects of different drying methods on the functional properties of flaxseed gum were investigated in this study. The spray dried and 105 °C oven dried samples had the lightest and the darkest appearances, respectively. The ethanol precipitated powder provided the lowest zeta potential value indicating the best emulsion stability, while spray dried one had the highest zeta potential indicating the poorest stability. Only the powder obtained from 105 °C oven drying increased the foaming capacity compared to the untreated sample. All the other powder samples decreased foaming capacity. Three drying methods namely 105 °C oven drying, ethanol precipitation, and spray drying increased the foam stability of flaxseed gum. All the drying methods reduced the gel strength of resultant gum compared with the untreated sample. Three drying methods (ethanol precipitation, 105 °C oven drying, and vacuum drying) significantly increased emulsion ability compared to the untreated sample. The flaxseed gum powders obtained from different drying methods appears to have significantly different functional properties which could lead to different application in food processing.

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