Advance Journal of Food Science and Technology 3(2): 102-110, 2011
ISSN: 2042-4876

Received: December 27, 2010 Accepted: January 27, 2011 Published: April 10, 2011

Extrusion Processing of Cactus Pear

Preetam Sarkar, Nikhil Setia and Gour S. Choudhury
Center for Food Science and Nutrition Research, California State University, Fresno,
5300 N. Campus Drive M/S FF 17, Fresno, California-93740-8019, USA

Abstract: Whole fruit utilization using extrusion technology has received limited attention in the food processing industry. The objective of this study was to investigate the utilization of prickly pear fruit solids in extruded food products. Peeled prickly pear fruits were ground to form a paste. This paste was strained to remove the seeds and then mixed with rice flour in three different solid ratios. The three blends were dried to a moisture level of 13% (w/w basis) and ground to form fine flour. These feed mixes were extruded in a twin screw extruder (Clextral EV-25) at a feed rate of 15 kg/h, feed moisture content of 13% (w/w), screw speed of 400 rpm and L/D ratio of 40:1. The temperature profile from feed to die end was maintained as: 25, 30, 40, 50, 60, 70, 80, 100, 120, 140ºC. The extruded products were analyzed for physical and textural properties. Apparent density and breaking strength of the cactus pear extrudates increased from 116.07 to 229.66 kg/m^3 and 58.5 to 178.63 kPa, respectively with increase in fruit solid level. However, true density, porosity and radial expansion ratio decreased from 837.89 to 775.84 kg/m^3, 86.12 to 70.34% and 12.37 to 6.6, respectively with increase in fruit solid level. This study demonstrated the potential of extrusion processing to utilize peeled cactus pear fruits for production of expanded food products.

Key words: Cactus pear, rice flour, twin screw extrusion

INTRODUCTION

The cactus pear fruit derived from *Cactaceae* is one of the most morphologically distinct and impressive plant families. This fruit is abundantly found in Mexico and the United States (Piga, 2004), but is also grown in Africa, Madagascar, Australia, Sri Lanka and India (Piga, 2004). The pulp of this oval shaped fruit exhibits wide color variation; it can be greenish white, yellow red, cherry red or purple (Stintzing *et al*., 2001). The seeds and peels are important sources of hydrocolloids, lipids, sterols, fat soluble vitamins and proteins (Habibi *et al*., 2005a, b; Ramadan and Morsel, 2003a, b, c; Sawaya and Khan, 1982; Sepúlveda and Sáenz, 1988; Coskuner and Tekin, 2003; Majdoub *et al*., 2001; Hassanien and Morsel, 2003). The fruit pulp is rich in vitamin-C, minerals (calcium and magnesium), free amino acids (proline, taurine, glutamine, serine), polysaccharides, polyphenolic compounds (quercetin, kaempferol, isorhamnetin and their derivatives), pigments (betaxanthins and betacyanins responsible for yellow and red color, respectively) and flavor compounds (Flath and Takahashi, 1978; Stintzing *et al*., 1999; Stintzing *et al*., 2001; Castellar *et al*., 2003; Kuti, 2004; Piga, 2004; Matsuhiro *et al*., 2006; Stintzing and Carle, 2005).

The pulp, seed and peel of the fruits are sources of important nutrients that can be formulated into a number of commercial food products (Mobhammer *et al*., 2006). *Opuntia* pulp has been utilized in processing indigenous products such as *Queso de tuna* and *Melcocha* (Sáenz-Hernandez, 1995; Ortiz-Laurel and Mendez-Gallegos, 2000); fruit sheets (Sepúlveda *et al*., 2000); alcoholic beverage such as *Colonche* (Sáenz, 2000); minimum processed products (Piga *et al*., 2000, 2003; Corbo *et al*., 2004); canned and frozen products (Cerezal and Duarte, 2005; Sáenz-Hernandez, 1995; Sáenz and Sepúlveda, 2001); jams (Sawaya *et al*., 1983); syrups (Joubert, 1993); juice products (Sáenz and Sepúlveda, 2001); dehydrated products (Lahsasni *et al*., 2004; Rodríguez-Hernández *et al*., 2005) and alcoholic beverages (Lee *et al*., 2000).

Research on whole fruit utilization using extrusion technology has been limited. A few studies have focused on extrusion of dried fruits (figs, cranberries, prunes, raisins), fruit juice concentrates (orange, pineapple, grape, cranberry), and spray dried fruit powders (blueberry, cranberry, concord grape, raspberry) blended with cereal flours (Maga and Kim, 1989; Camire *et al*., 2007). McHugh and Huxsoll (1999) examined the effects of feed moisture level, temperature and sugar concentration on the physical and textural properties of drum dried peach

Corresponding Author: Preetam Sarkar, Department of Food Science, Purdue University, 745 Agriculture Mall Drive, West Lafayette, Indiana 47907, USA

Table 1: Total solids and sugar content in the three cactus pear fruit and rice flour blends

Rice flour: skinned prickly pear solids			Solids added	Dried mix (kg)	Sugar composition		
Fresh ratio	Solids ratio	Rice flour	Pulp		Total sugar (kg)	Sugar(kg)	Sugar [a](% TS)
1.5:1	10:1	31.6	3.2	40	34.8	2.1	6.0
1.25:1	8:1	30.9	3.9	40	34.8	2.5	7.2
1:1	6:1	29.8	5.0	40	34.8	3.2	9.2

[a]: % Sugar content was estimated from the data of El Kossori *et al*. (1998)

Table 2: Screw configuration used for extrusion of prickly pear fruit solids and rice flour blends

	Pitch		Length		
Element type	(mm)	(× D)	(mm)	(× D)	No of elements
Trapezoidal double flights (T2F)[A]	31.25	1.25D	31.25	1.25D	3
Conjugated double flights (C2F)	31.25	1.25D	31.25	1.25D	9
Conjugated double flights (C2F)	25	1.00D	25	1.00D	6
Conjugated double flights (C2F)	18.75	0.75D	18.75	0.75D	14
Conjugated double flights (C2F)	12.50	0.50D	12.50	0.50D	1
Transition Element (TE)	–	–	6.25	0.25D	1
Conjugated single flights (C1F)	18.75	0.75D	18.75	0.75D	3
Conjugated single flights (C1F)	12.50	0.50D	12.50	0.50D	3
Reverse Screw Element	12.5	0.50D	12.5	0.50D	2
Conjugated single flights (C1F)[B]	12.50	0.50D	12.50	0.50D	6

[A]: Feed end; [B]: Die end

puree processed in a twin screw extruder. According to El-Samahy *et al.* (2007) acceptable quality of extrudates can be produced by single screw extrusion processing of cactus pear pulp and rice flour blend. The literature search did not reveal any study on utilizing cactus pear fruit by twin screw extrusion. Our study was an attempt to develop an expanded extruded food product from cactus pear fruit solids. The objective was to evaluate the effect of three levels of cactus pear fruit solids on the physical and textural properties of the rice flour based extrudates.

MATERIALS AND METHODS

Materials: This study was carried out at the Center for Food Science and Nutrition Research at California State University, Fresno. Coarse white rice flour was obtained from Pacific Grain Products, Inc. (Woodland, CA, USA.). Fresh *Opuntia* fruits (yellow variety) were supplied by United States Department of Agriculture (USDA, Parlier, CA, USA).

Blend preparation: The fresh cactus pear fruits were hand peeled with a potato peeler and then blended to form puree using a Hobart Cutter Mixer (Model HCM450, Hobart Corp, OH, USA). The puree was strained using a conical, stainless steel sieve to separate the seeds from the pulp. The fruit solids were mixed with rice flour in three different solid ratios (rice flour solids: puree solids were 6:1, 8:1 and 10:1) using the Hobart Cutter Mixer. The blends were dried in a tray drier (Commercial Dehydrator Systems, Eugene, OR, USA) at a temperature of 165ºF. The drying process was terminated when the blends reached a moisture content of 13% on a total weight basis. The dried mixes were then converted to fine powder by grinding in a Hobart cutter mixer and commercial blender (Waring Inc., Torrington, CT, USA). Prior to extrusion processing, the moisture content of the blends were evaluated in a CSC Digital Moisture Balance (CSC Scientific Company Inc., Fairfax, VA, USA). If required, calculated amount of water was added to adjust the moisture level of the blends. They were mixed in a Varimixer at a minimum speed of 50 rpm (Welbilt, Shreveport, La., USA) to distribute the moisture equally within the fine powder. The sugar content in each of the three blends is shown in Table 1.

Extrusion experiments: Clextral co-rotating intermeshing twin screw extruder (Model EV 25 A108, Clextral, Firminy Cedex, France) was used to extrude the cactus pear and rice flour blends. A volumetric feeder (K-Tron Corp., Pitman, NJ, USA) was used to feed the mixes into the extruder. The temperature profile of the extruder (ten barrel sections) from the feed to die end during experimentation was maintained as follows: 25, 30, 40, 50, 60, 70, 80, 100, 120, 140ºC. Monitoring of feed flow rate, screw speed, barrel temperatures, percent torque, die pressure and die temperature was performed using the Programmable Logic Control (PLC) FITSYS + version 2.01 software from a computer installed on the extruder. Screw speed, feed flow rate and feed moisture content during extrusion were maintained at 400 rpm, 15 kg/h, and 13% (total weight basis), respectively. Die diameter and extruder length/diameter ratio were 4.5 mm and 40:1, respectively. When the extruder reached steady state conditions indicated by constant percent torque, die pressure and die temperature, cylindrical shaped extrudates were collected. The samples were stored overnight under ambient conditions (25±1ºC) for analysis of physical and textural properties. All the data obtained are average numbers of three extrusion replications. The extruder screw configuration used during this study is shown in Table 2.

Statistical analysis: Three levels of the feed composition was the independent variable in this research. The specific tests used for analyzing the data included descriptive statistics, correlational analysis, analysis of variance (ANOVA) and comparison of means (Tukey's HSD multiple comparison test). These data analyses were performed using SPSS version 17.0 statistical software (SPSS, Chicago, IL, U.S.A.). The correlation and bar charts were plotted using the PSI-Plot software, version 9.01 (Poly Software International, 2009). Any significant difference revealed by ANOVA analysis was further analyzed by Tukey's HSD multiple comparison test with a significance level of 0.05.

Response variables:

Densities: Seven random samples were selected from each trial and their mass was recorded. A digital caliper (accuracy: ± 0.01 mm) was used to measure fifty diameters and ten lengths on each sample (General Tools, NY, USA). Average diameter and length values were calculated for each sample and these average numbers were used in all the calculations.

Apparent density: The apparent density was calculated using the following equation (Choudhury and Gautam, 2003):

Apparent density = Mass of samples (Kg)/Apparent volume of samples (m^3)

True density: The true density was obtained as the ratio of extrudate mass to the true volume. (Choudhury and Gautam, 2003). True volume was measured using a multipynometer (Quantachrome Instruments, Boynton Beach, Fla., U.S.A.) (Chang, 1988). Ultrapure helium gas is used to penetrate the smallest of the orifices in the extruded samples. True volume of the extruded samples was calculated from the reference cell pressure (P_1 = 17 psig approximately) and:

$$\text{True volume } (V_p) = V_C - V_R\,[P_1/P_2 - 1]$$

sample cell pressure (P_2) values. The equation for calculation of true density is shown below (Choudhury and Gautam, 2003), where, V_p= True Sample Volume, V_C = Cell Volume, V_r = Reference Cell Volume, P_1 = Reference Cell Pressure (Psig), P_2 = Sample Cell Pressure (Psig).

Porosity: Extrudate porosity was calculated using the following equation (Choudhury and Gautam, 2003):

Porosity = Apparent volume – True volume (m^3) / Apparent volume (m^3)

Expansion ratios:

Radial expansion ratio: Cross-sectional area of the extrudates divided by the cross-sectional area of the circular extruder die (die diameter: 4.5 mm) yielded radial expansion ratio (Bhattacharya and Choudhury, 1994; Choudhury and Gautam, 2003). The equation for this calculation is shown as follows (Choudhury and Gautam, 2003):

Radial expansion ratio = Cross-sectional area of extrudate / Cross-sectional area of die

Overall expansion ratio: The overall expansion ratio was calculated as the ratio of apparent specific volume to true specific volume of the extruded samples (Sokhey *et al*., 1996; Kollengode *et al*., 1996; Hanna *et al*., 1997; Choudhury and Gautam, 2003).

Overall expansion ratio = Apparent specific volume/ True specific volume

Axial expansion ratio: The axial expansion ratio was obtained as the ratio of overall expansion to the radial expansion (Sokhey *et al*., 1996; Kollengode *et al*., 1996; Hanna *et al*., 1997; Choudhury and Gautam, 2003).

Axial expansion ratio = Overall expansion ratio/ Radial expansion ratio

Texture: TA-XT Plus Texture Analyzer (Texture Technologies Corp., Scarsdale, NY., USA) was used to evaluate the breaking strength of the extruded samples. A Warner-Bratzler stainless steel shear probe (probe thickness: 1.00 mm, shear angle: 60º) was used for cutting the extrudates into two parts at a pre-test and test speed of 1.5 mm/sec and post-test speed of 10 mm/sec. The maximum force required for this action was recorded from the force-time plot generated on the computer. This peak force was divided by the cross-sectional area of the extrudates to obtain the breaking strength (Maurice and Stanley, 1978; Owusu-Ansah *et al*., 1984; Bhattacharya *et al*., 1986; Bhattacharya and Hanna, 1987; Chinnaswamy and Hanna, 1988; Choudhury and Gautam, 2003). Breaking strength was calculated as per the following equation (Choudhury and Gautam, 2003):

Breaking strength = Peak force / Cross-sectional area

RESULTS AND DISCUSSION

Effects of feed composition on apparent density: Prickly pear fruit solids significantly increased apparent density from 116.07 to 229.66 kg/m^3 (Fig. 1, Table 3). Similar trend in bulk density with increasing levels (from 0 to 20%) of cactus pear fruit solids was reported by El-Samahy *et al*. (2007). This behavior in apparent density seems to be due to an increase in sugar level from 6 to 9.2% as shown in Table 1. This trend in apparent

Table 3: Analysis of variance data for densities (apparent and true), porosity, expansion ratios and breaking strength of the extrudates obtained from the blends of prickly pear pulp and rice flour

		F-values for						
Source	DF	Densities (kg/m^3)		Expansion ratios				Breaking
		Apparent	True	Porosity	Radial	Axial	Overall	strength (kPa)
Solids ratio	2	519.91*	10.73*	678.14*	1289.02*	21.18*	624.91*	1020.19*
Error	60	-	-	-	-	-	-	-

*: Significant at $p \leq 0.05$

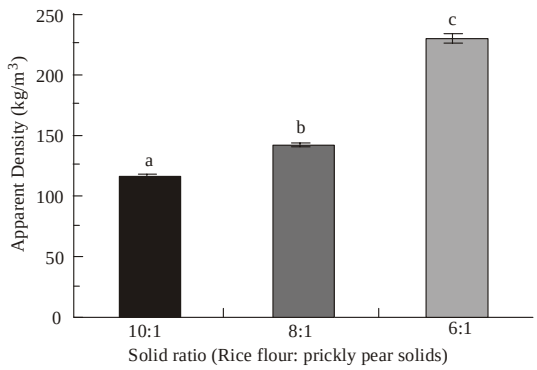

Fig. 1: Effects of rice flour and prickly pear solids ratio on the apparent density of the extrudates. Bars with different letters are significantly different from each other (Tukey's HSD multiple comparison test)

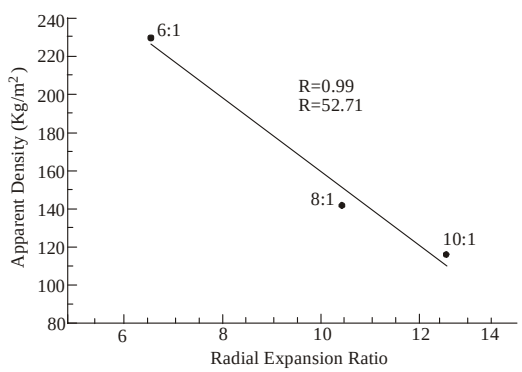

Fig. 2: Relationship between apparent density and radial expansion ratio during extrusion processing of prickly pear fruit solids and rice flour blends

density due to replacement of starch by sugar molecules was also exhibited by numerous authors (Anderson *et al.*, 1981; Moore *et al.*, 1990; Ryu *et al.*, 1993; Jin *et al.*, 1994; Abd El-Hady *et al.*, 1998; Adesina *et al.*, 1998; Abd El-Hady *et al.*, 2002). The prickly pear pulp consist significant amount of monosaccharides such as glucose (35%) and fructose (29%) (El Kossori *et al.*, 1998). Fan *et al.* (1996) has reported that monosaccharides reduce sectional or radial expansion to a greater degree when compared to disaccharides which is responsible for increase in extrudate apparent density. They suggested that a decrease in bubble growth formation and increase in cell shrinkage at die exit were the probable reasons for

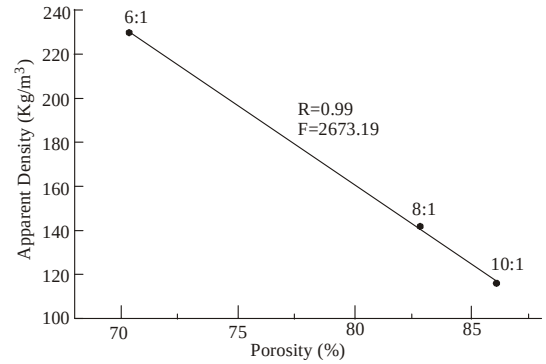

Fig. 3: Relationship between apparent density and porosity during extrusion processing of prickly pear fruit solids and rice flour blends

such an effect. Increasing the fruit solids level in the feed blends also increased the monosaccharide (glucose and fructose) concentration which seems to be responsible for the observed trend. However, an opposite trend in apparent density was reported by Yagci and Gogus (2008) where fruit waste (orange peel, grape seed, tomato pomace) addition reduced apparent density. This opposite trend in apparent density seems to be due to higher level of soluble fiber (pectin) as contributed by the fruit waste. It must be noted that prickly pear fruit solids also has a good amount of pectin (70% of fiber) (El Kossori *et al*., 1998). But our study revealed that sugar levels had a dominant effect on the apparent density of the extrudates as compared to soluble fiber.

Apparent density was found to correlate negatively with radial expansion ratio (Fig. 2). This relationship is in agreement with the data of Onyango *et al*. (2004) where they observed similar increase in apparent or bulk density and decrease in sectional or radial expansion index with increase in sugar level from 0 to 20% in maize millet feed blends. Apparent density exhibited a significant negative correlation with extrudate porosity (Fig. 3).

Effects of feed composition on true density: The true density decreased gradually from 838 to 776 kg/m^3 with increasing fruit solids level, a trend opposite to that of apparent density (Fig. 4). This effect of fruit solids on true density of the extrudates was statistically significant ($p \leq 0.05$) (Table 3). Tukey's HSD multiple comparison test revealed that true density of the blend with the highest

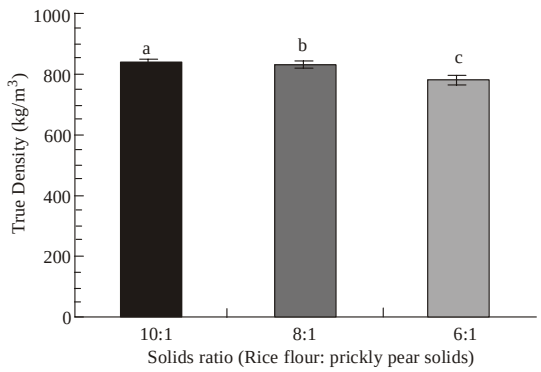

Fig. 4: Effects of rice flour and prickly pear pulp solids ratio on the true density of the extrudates. Bars with different letters are significantly different from each other (Tukey's HSD multiple comparison test)

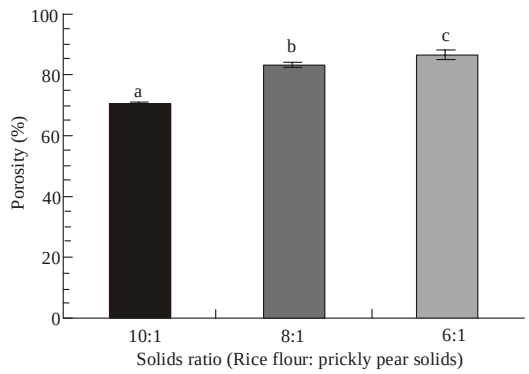

Fig. 5: Effects of rice flour and prickly pear pulp solids ratio on the porosity of the extrudates. Bars with different letters are significantly different from each other (Tukey's HSD multiple comparison test)

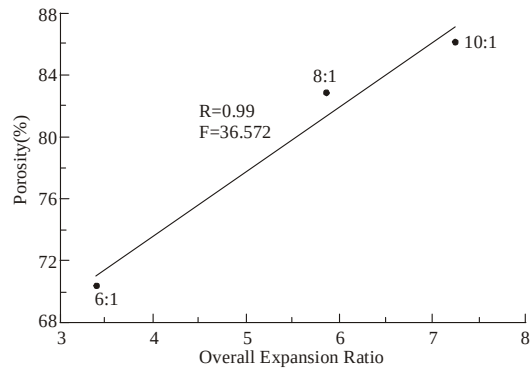

Fig. 6: Relationship between porosity and overall expansion ratio during extrusion processing of prickly pear fruit solids and rice flour blends

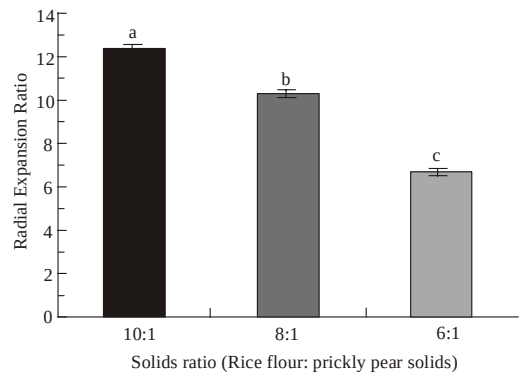

Fig. 7: Effects of rice flour and prickly pear pulp solids ratio on the radial expansion ratio of the extrudates. Bars with different letters are significantly different from each other (Tukey's HSD multiple comparison test)

fruit solids level was significantly different from the other two feed mixes.

Effects of feed composition on porosity: Cactus pear fruit solids addition significantly decreased extrudate porosity from 86 to 70% ($p \leq 0.05$) (Fig. 5, Table 3). Hsieh *et al*., (1993) reported an increase in specific volume (decrease in extrudate apparent density) from 6.4 to 11 mL/g with increasing sugar level in rice flour from 0 to 8%. Jin *et al.* (1995) suggested that the decrease in apparent density and expansion ratio was due to reduction in extrudate air cell size and increase in cell thickness. The gradual decrease in porosity seems to be due to an increased amount of sugar contributed by the fruit solids (Table 1).

However, soluble dietary fibers such as pectin were found to increase porosity of the extrudates (Yanniotis *et al.*, 2007; Yagci and Gogus, 2008). Prickly pear fruit solids contains considerable amount of pectin (70% of total fiber) (El Kossori *et al.*, 1998) but the effect of the soluble fiber was not dominant when compared to that of sugar. Further research will be needed to understand the effects of pectin in combination with sugar on the porosity of extruded products. Porosity was found to exhibit a linear positive correlation with overall expansion ratio (Fig. 6).

Effects of feed composition on radial expansion ratio: The radial expansion decreased significantly upon addition of cactus pear fruit solids from 12.37 to 6.60 (Fig. 7, Table 3). Similar detrimental effects on the radial expansion of cactus pear concentrate based extrudates were observed by El-Samahy *et al.* (2007). This decreasing trend in radial expansion seems to be due to increase in viscosity with increase in sugar level in the feed mixes (Table 1). Sugar competes for the moisture in the feed, thus making it unavailable for complete starch gelatinization and extrudate expansion at the die exit as

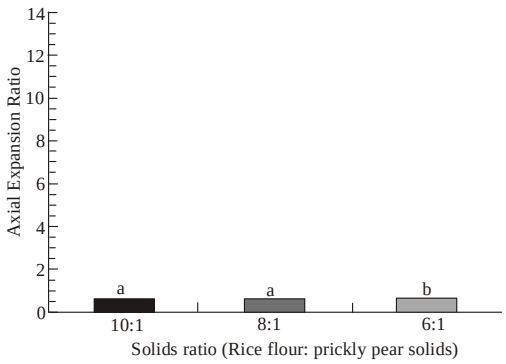

Fig. 8: Effects of rice flour and prickly pear pulp solids ratio on the axial expansion ratio of the extrudates. Bars with different letters are significantly different from each other (Tukey's HSD multiple comparison test)

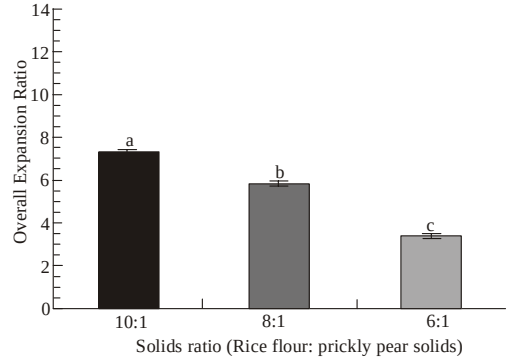

Fig. 9: Effects of rice flour and prickly pear pulp solids ratio on the overall expansion ratio of the extrudates. Bars with different letters are significantly different from each other (Tukey's HSD multiple comparison test)

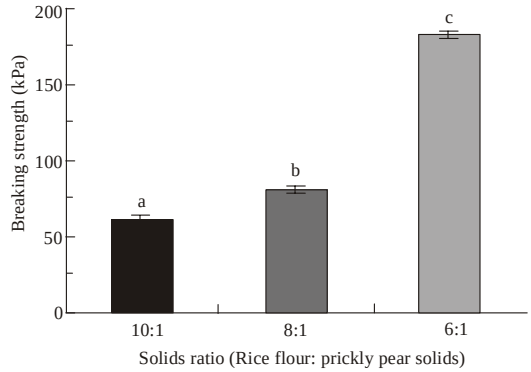

Fig. 10: Effects of rice flour and prickly pear pulp solids ratio on the breaking strength of the extrudates. Bars with different letters are significantly different from each other (Tukey's HSD multiple comparison test)

suggested by El-Samahy *et al.* (2007). Fan *et al.* (1996) have confirmed that monosaccharides such as fructose reduce radial expansion to a greater degree compared to disaccharides. Higher cell contraction and reduced growth in bubble size were the major reasons cited for decrease in radial expansion. Therefore, with higher levels of monosaccharides in fruit solids (fructose: 29%, glucose: 35%) (El Kossori *et al*., 1998), the radial expansion ratio exhibited a declining trend with an increase in the sugar content (Table 1). Similar effect of sugar (sucrose) on radial expansion ratio was observed by others (Onyango *et al.*, 2004; Jin *et al.*, 1994; Carvalho and Mitchell, 2000; Fan *et al.*, 1996; Camire *et al.*, 2002; Ryu *et al*., 1993).

However, a few authors have reported increase in radial expansion ratio of corn meal and rice flour based extrudates with increase in sugar level in feed mix (Hsieh *et al*., 1990, 1993). This opposite trend in radial expansion seems to be due to the presence of the disaccharide sucrose in the feed blends which reduces expansion to a lesser degree compared to that of monosaccharides (Fan *et al*., 1996). It seems that the role of disaccharides such as sucrose is not clear on extrudate radial expansion. Therefore more research will be needed to fully understand the contradictory effects of sucrose on expansion properties of extruded products.

Effects of feed composition on axial expansion ratio: Cactus pear fruit solid incorporation decreased axial expansion ratio of the extrudates from 0.58 to 0.51 (Fig. 8, Table 3). The extrudates obtained from blends with solid ratios 8:1 and 10:1 were significantly different from the 6:1 blend extrudate. The decrease in the axial expansion seems to be due to the effects of sugar on extrudate expansion, as discussed above. Jin *et al*. (1994) also observed a decrease in the axial expansion ratio of corn meal based extrudates with an increase in sugar level from 0 to 12%. An opposite trend was reported by Hsieh *et al*. (1990) who observed an increase in axial expansion with an increase in sugar level from 0 to 8% in the corn meal based feed blends. This reverse trend also seems to be due to the effect of disaccharides (sucrose) as explained by Fan *et al*. (1996).

Effects of feed composition on overall expansion ratio: Effect of fruit solid on the overall expansion ratio of extrudates was similar to that of radial expansion ratio. Prickly pear solid incorporation to the blends significantly affected the overall expansion ratio of the extrudates (Fig. 9, Table 3).

Effects of feed composition on breaking strength: Breaking strength increased significantly with the increase in fruit solids level in blends from 58.5 to 178.63 kPa (Fig. 10, Table 3). This trend is in agreement with the data of El-Samahy *et al*. (2007) who reported a significant increase in breaking strength with an increase in cactus

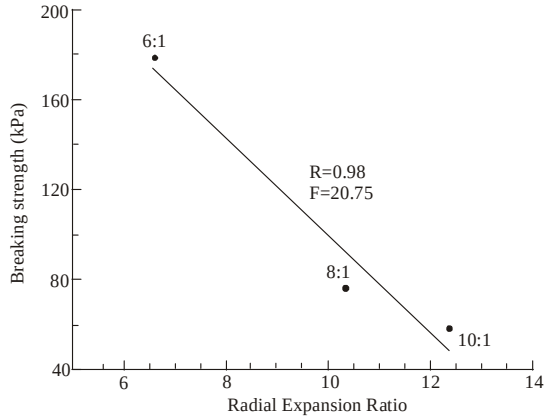

Fig. 11: Relationship between breaking strength and radial expansion ratio during extrusion processing of prickly pear fruit solids and rice flour blends

pear pulp level from 10 to 20% (total weight basis) in rice flour based extrudates. The fruit solids level in our feed blends ranged between 40 to 50% (total weight basis). It seems that breaking strength exhibits an increasing trend at the higher range of prickly pear solids in cereal flours. Jin *et al*. (1995) reported an increase in the breaking strength of corn meal extrudates with an increase in sugar level from 0 to 12%. Similar increase in breaking strength due to increase in sucrose level was also reported by Ryu *et al*. (1993) during extrusion processing of certain baking ingredients.

Breaking strength was found to correlate negatively with radial expansion ratio (Fig. 11). Similar trend between breaking strength and radial expansion ratio have also been reported by (Hsieh *et al*., 1990, 1993; Jin *et al*., 1995; Rinaldi *et al*., 2000; Choudhury and Gautam, 2003).

CONCLUSION

The addition of prickly pear pulp solids demonstrated significant effects on physical and textural properties of the extrudates. Increase in cactus fruit solids level in the blends increased apparent density and breaking strength of the extrudates. Reverse trend was observed for true density, porosity, radial expansion and overall expansion ratios. Breaking strength of extrudates exhibited a strong negative linear correlation with radial expansion ratio. The results of this study indicated that peeled prickly pear can be effectively utilized as a food ingredient for production of expanded extruded food products and increase the overall fruit utilization.

ACKNOWLEDGMENT

This research was carried out at Center for Food Science and Nutrition Research, Jordan College of Agricultural Sciences and Technology, California State University, Fresno. The study was funded by the California State University-Agricultural Research Institute and the United States Department of Agriculture (USDA), Parlier, CA, USA.

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