Effect of Single-Screw Extruder Die Temperature, Amount of Distillers' Dried Grains With Solubles (DDGS), and Initial Moisture Content on Extrudates[1]

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ABSTRACT

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Corn distillers' dried grains with solubles (DDGS) was extruded with corn meal in a pilot plant single-screw extruder at different extruder die temperatures (100, 120, and 150°C), levels of DDGS (0, 10, 20, and 30%) and initial moisture contents (11, 15, and 20% wb). In general, there was a decrease in water absorption index (WAI), water solubility index (WSI), radial expansion, and *L** value with an increase in DDGS level, whereas *a** value and bulk density increased. Increase in extruder die temperature resulted in an increase in WSI and WAI but a decrease in *L** and bulk density. Peak load was highest at 30% DDGS as compared with 0, 10, and 20% DDGS extrudates. Die temperature of 120°C and initial moisture content of 20% resulted in least peak load. The *a** value remained unaffected by changes in extruder die temperature. Radial expansion was highest at extruder die temperature of 120°C. Maximum WAI, WSI, radial expansion, and *L** value were obtained at 15% initial moisture content. An increase in initial moisture content, in general, decreased *L** value and bulk density but increased *a** value of extrudates.

Corn distillers' dried grains (DDG) and distillers' dried grains with solubles (DDGS) are coproducts of the ethanol industry. The starch fraction of corn is fermented using selected yeasts and enzymes to produce ethanol. The residues remaining after ethanol extraction are dried to produce DDGS, which is high in fiber, fat, and protein.

Extruders have established their position in the food industry and have become irreplaceable. The variety of extruded products ranges from pasta, ready-to-eat breakfast cereal, and snack food to confectionery and pet foods (Harper 1979; Harper and Jensen 1985; Frame 1994). Carbohydrate-based snack foods are usually extruded. Crispness, a typical quality attribute of all snack foods, is strongly related to the expansion that, in turn, is dictated by various extrusion parameters (Chinnaswamy and Hanna 1988). Extrusion cooking conditions and their effect on product qualities have been studied and modeled (Gomez and Aguilera 1984; Owusu-Ansah et al 1984; Bhattacharya and Hanna 1987), and it is known that extrusion variables including ingredient factors and process factors affect extrudate nutritional and functional qualities (Harris et al 1988).

Several groups (Saterlee et al 1976; Breen et al 1977; Walker 1980; Anderson et al 1981) evaluated either corn or wheat DDG in extruded snacks and reported that >20% DDG caused a loss in radial expansion. Extruder barrel temperature affected the expansion of corn starch (Mercier and Feillet 1975). The interaction of temperature and screw speed effects on *L** was reported by Apruzzese et al (2000). They reported that the influence of temperature on the viscosity of melt may cause a great degree of browning at 150°C barrel temperature than at 170°C. Lower moisture contents favored the expansion of materials such as corn grits, corn starch (Mercier and Feillet 1975; Gomez and Aguilera 1984), and corn germ flour (Peri et al 1983). Empirical studies have shown that initial moisture content and extrusion temperature are the most important variables influencing expansion in any particular system (Lawton et al 1972; Merceir and Feillet 1975; Park 1976; Hauck 1981; Holay and Harper 1982). No study, however, has appeared that reports the effect of extruder die temperature at different levels of DDGS and initial moisture content on functional properties of extrudates. Therefore, the objective of this study was to evaluate the effect of extruder die temperature (100, 120, and 150°C) on functional properties of extrudates like hydration properties (WSI and WAI), color properties (*L** and *a**), radial expansion, peak load, and bulk density at varying DDGS levels (0, 10, 20, and 30%) and initial moisture content (11, 15, and 20% wb).

MATERIALS AND METHODS

Ingredients and Pretreatment

Distillers' dried grains with solubles (DDGS) was obtained from Dakota Ethanol, LLC (Wentworth, SD) and corn meal was obtained from ADM Co. (Milwaukee, WI). Experimental design (3 × 3 × 4) consisted of three levels of die temperature (100, 150, and 120°C), three levels of initial moisture content (11, 15, and 20% wb), and four levels of DDGS (0, 10, 20, and 30%). DDGS and corn meal were mixed in required proportions. The formulations were blended (20 qt. capacity, hub size #12, model A200 with three gears for planetary action, Hobart, Troy, OH) for 15 min. Initial moisture was adjusted to the desired level (Table I) and the formulation was further blended for 5 min. The formulation was stored in an airtight container overnight to attain moisture equilibrium. Three extrusion replicates were conducted.

Extrusion

A single-screw extruder (C. W. Brabender Plasticorder Extruder model PL-2000) with a barrel length-to-diameter ratio of 20:1 and compression ratio of 3:1 was used for all experiments. The PL-2000 had variable screw speed from 0 to 210 and three heating

TABLE I
Experimental Design

Formulation	Die Temperatures (°C)	Initial MC (%, wb)
0% DDGS		
100% Corn meal	100	11
	120	15
	150	20
10% DDGS		
90% Corn meal	100	11
	120	15
	150	20
20% DDGS		
80% Corn meal	100	11
	120	15
	150	20
30% DDGS		
70% Corn meal	100	11
	120	15
	150	20

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sections. The barrel length was 12.5″ and the die assembly was 4″ long. Thermocouples were installed on the die, and 1.5″ and 7.5″ from the die end of the barrel that measured temperature at the end of compression and feed zone, respectively. A uniform-pitch single-flight screw with 0.75″ pitch was used. The screw had 0.15″ flute depth toward the feed zone end and 0.05″ flute depth toward the die zone end as shown in Fig. 1. For all experiments, barrel temperature (feed zone 120°C; compression zone 130°C), the screw and the screw speed (120 rpm) were kept constant. A die with a diameter of 2.7 mm was attached at the outlet with a die L/D of 6.6. Extruder feed and compression zone was electrically heated, and pressurized air-cooling was provided. The die was electrically heated. Pressurized air-cooling was not provided at the die.

Hydration Properties

Hydration properties were measured to study the ability of extrudates to absorb water and solubilize in water. Water solubility index (WSI) is the amount of solubles as percent of the original dry sample when a 2.5-g sample of product is suspended in 30 mL of water at 30°C and shaken intermittently over a period of 30 min, followed by centrifuging at 1,000 × *g*. The ratio between total weight of the pellet and the weight of solids in the pellet is expressed as the water absorption index (WAI). These hydration properties were measured as in Mason and Hoseney (1986).

Color Properties and Bulk Density

Colorimetric properties (L^* and a^* values) were measured using a spectrophotometer (portable model CM-2500d, Minolta, Japan). Bulk density was evaluated by the method suggested by Harris et al (1988).

Radial Expansion and Peak Load

Radial expansion was evaluated by averaging 10 measurements of diameter using a digital vernier caliper (Digimatic, code 500-321, 0.01–150 mm range, Mitutoyo Corp., Japan). Peak load was determined using a Kramer shear cell attached to a Sintech 2/D Universal Testing Machine (MTS System Corp., Eden Prairie, MN). The crosshead speed was 10 cm/min. One extrudate 6 cm long was placed in the shear cell and a load cell of 5 lb was used to shear the extrudates. The test was repeated five times and an average was reported as kgf/m^2. Testworks software on Windows 3.11 was used to indicate peak load.

Statistical Analysis

A three-way interaction and least significant difference (LSD) method were applied. PROC GLM procedure was performed using SAS v. 8 (SAS Institute, Cary, NC). A confidence level of $P < 0.05$ was considered.

RESULTS AND DISCUSSION

Hydration Properties

Hydration properties indicate the ability of extrudates to absorb water and dissolve in water. Similar trends were obtained for WAI and WSI with a change in factors and levels. WAI decreased significantly from 1.082 to 1.053 with an increase in DDGS from 10 to 30% as shown in Table II. Control formulation with no DDGS resulted in significantly lower WAI (1.074) when compared to 10% DDGS level (1.082) but was significantly higher than 20 and 30% DDGS (1.054 and 1.053, respectively). This result suggests that the extrudates with 10% DDGS can absorb liquid and solubilize easily broadening its use in liquid products or suspensions. An increase in extruder die temperature from 100 to 150°C resulted in a significant increase in WAI from 1.065 to 1.067. The effect of die temperature on WAI at different levels of DDGS and initial moisture contents is shown in Fig. 2. Highest WAI/WSI was observed at 15% initial moisture (Table II). A range of initial moisture content from 13.5 to 15% is optimum for

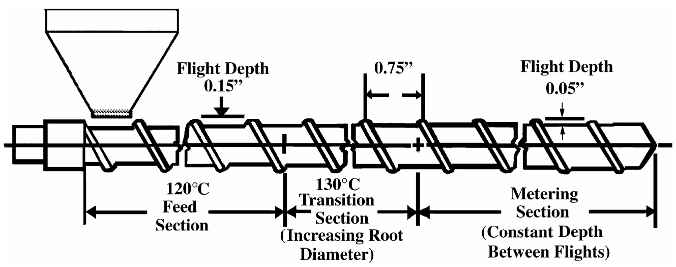

Fig. 1. Extruder screw design.

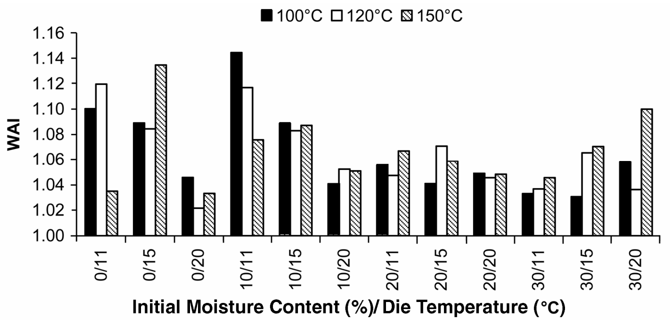

Fig. 2. Effect of die temperature on water absorption index (WAI) at varying DDGS levels (%) and initial moisture contents.

TABLE II
Effect of DDGS (%), Die Temperature (%), and Initial Moisture Content (IMC, %) on Water Absorption Index (WAI) and Water Solubility Index (WSI) of Extrudates[a]

	DDGS (%)				Die Temperature (°C)			Initial Moisture Content (IMC, %)		
Parameter	**0**	**10**	**20**	**30**	**100**	**120**	**150**	**11**	**15**	**20**
WAI	1.074b	1.082a	1.054c	1.053d	1.065c	1.066b	1.067a	1.073b	1.075a	1.049c
WSI	6.75b	7.53a	5.09c	4.99d	5.99c	6.04b	6.24a	6.71b	6.96a	4.60c

[a] Values followed by the same letter in the same row for a factor are not significantly different ($P < 0.05$). Average values across all other factors have been reported.

TABLE III
Effect of DDGS (%), Die Temperature (%), and Initial Moisture Content (IMC, %) on Brightness (L^* value) and Redness (a^* value) of Extrudates[a]

	DDGS (%)				Die Temperature (°C)			Initial Moisture Content (IMC, %)		
Parameter	**0**	**10**	**20**	**30**	**100**	**120**	**150**	**11**	**15**	**20**
L^* value	63.92a	56.19b	52.94b	51.65c	59.32a	56.95a	52.27b	58.87a	57.37a	52.30b
a^* value	2.46c	6.26b	8.31a	8.05a	6.35a	6.33a	6.13a	6.18b	5.22c	7.41a

[a] Values followed by the same letter in the same row for a factor are not significantly different ($P < 0.05$).

corn starch expansion (Owusu-Ansah et al 1984; Chinnaswamy and Hanna 1988). Optimum expansion of extrudate could result in easier absorption of water because of a thinner surface membrane, eventually resulting in higher solubility.

Color Properties

The brightness of extrudates, measured as *L** value, decreased significantly from 63.92 to 51.65 as the level of DDGS increased from 0 to 30%. The color of DDGS ranged from a bright orange to dull golden; therefore, the higher addition of DDGS would further reduce the brightness as shown in Fig. 3. Increasing extruder die temperature from 100 to 150°C caused a significant decrease in brightness from 59.32 to 52.27 (Table III). Higher processing temperature could cause browning; burning decreased the extrudate brightness. Initial moisture content of 20% resulted in a significantly darker product as compared to 11 and 15% as shown in Table III. A combination of either DDGS or initial moisture content with die temperature does not significantly affect brightness of the product as shown in the interaction table (Table IV). Redness (*a**) increased significantly from 2.46 to 8.31 when the DDGS level was increased from 0 to 20% (Table III). Extruder die temperature had no significant effect on redness of the product. The color of DDGS might be responsible for increase in *a** value with an increase in DDGS level. Initial moisture content of 20% resulted in highest *a** value of 7.41 and lowest *L** value of 52.30. Water might dull color, improving *a** value.

Radial Expansion and Bulk Density

The effect of various factors on radial expansion is shown in Table V. DDGS is a protein-rich product (≈26%) with significantly less carbohydrate (≈48.47%) than corn meal (≈7% protein and 80% carbohydrates). Radial expansion decreased significantly from 7.72 to 4.08 mm when the DDGS level was increased from 0 to 30%. Highest expansion of 6.94 mm resulted with 15% initial moisture content, and 6.27 mm resulted at the 120°C die temperature. Processing above or below that would result in a significant decrease in radial expansion. Decreased radial expansion resulted in extrudates with increased bulk density. Bulk density increased significantly from 176 kg/m^3 to 397 kg/m^3 with an increase in DDGS from 0 to 30% (Table VI). This corresponds well with a decrease in radial expansion. On the other hand, bulk density decreased significantly with increases in extruder die

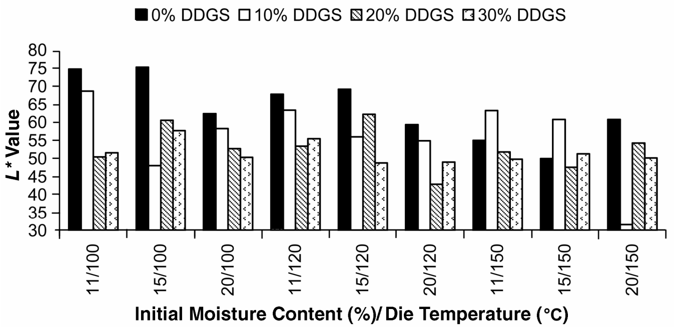

Fig. 3. Effect of DDGS levels (%) on *L** value of extrudates.

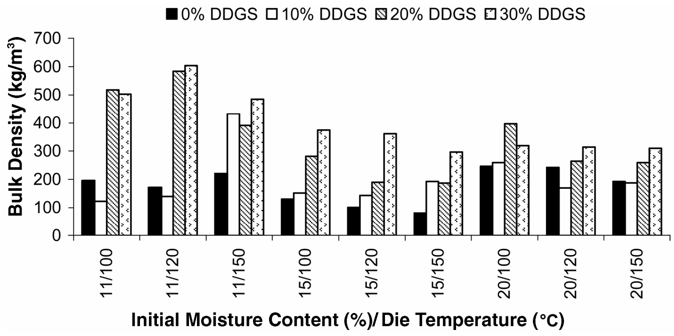

Fig. 4. Effect of DDGS levels (%) on bulk density of extrudates.

TABLE IV
Interaction Results for DDGS, Die Temperature (DT), and Initial Moisture Content (IMC)[a]

Interactions	WSI	WAI	Expansion	Peak Load	*L**	Bulk Density	*a**
DDGS	*	*	*	*	*	*	*
IMC	*	*	*	*	*	*	*
DT	*	*	*	*	*	*	ns
DDGS × IMC	*	*	*	*	*	*	*
DDGS × DT	*	*	*	*	ns	*	*
IMC × DT	*	*	*	*	ns	*	ns
DDGS × IMC × DT	*	*	*	*	*	*	*

[a] Significant difference indicated by *; no significant difference indicated by ns.

TABLE V
Effect of DDGS (%), Die Temperature (°C), and Initial Moisture Content (IMC, %) on Radial Expansion (RE) of Extrudates[a]

	DDGS (%)				Die Temperature (°C)			Initial Moisture Content (IMC, %)		
Parameter	0	10	20	30	100	120	150	11	15	20
RE, mm	7.72a	6.89b	4.91c	4.08d	5.71b	6.27a	5.71b	5.01c	6.94a	5.74b

[a] Values followed by the same letter in the same row for a factor are not significantly different ($P < 0.05$).

TABLE VI
Effect of DDGS (%), Die Temperature (°C), and Initial Moisture Content (IMC, %) on Peak Load (PL), and Bulk Density (BD) of Extrudates[a]

	DDGS (%)				Die Temperature (°C)			Initial Moisture Content (IMC, %)		
Parameter	0	10	20	30	100	120	150	11	15	20
PL × 10^3 kgf/m^2	2.69b	1.93c	3.03ab	3.43a	3.39a	2.36c	2.85b	2.97b	2.24c	3.52a
BD, kg/m^3	176d	200c	341b	397a	292a	274b	270c	364a	208c	264b

[a] Values followed by the same letter in the same row for a factor are not significantly different ($P < 0.05$).

temperature and initial moisture content. Bulk density of 292 kg/m^3 was highest at 100°C die temperature and 364 kg/m^3 at 11% initial moisture content as shown in Table VI. Low moisture extrusion resulted in rope-like extrudates with significantly low radial expansion and high bulk density as shown in Fig. 4. Reduced expansion and higher moisture retention could have added to the weight of the extrudate, resulting in significantly high bulk density.

Peak Load

Decrease in die temperature and increase in initial moisture content increased the peak load as shown in Table VI. Peak load was highest (3.43×10^3 kgf/m^3) at 30% DDGS level. Radial expansion in 30% DDGS extrudate was the least, leading to the most compact texture. This compact structure indicates that higher force is required to break the extrudate of the same radial cross-section when compared with other extrudates. Least peak load was observed in the case of 10% DDGS (1.93×10^3 kgf/m^2). There was no significant difference in peak load between the 20 and 30% DDGS levels. Die temperature of 120°C resulted in highest expansion and least extrudate peak load of 2.36×10^3 kgf/m^2 in the group. The trend of highest expansion extrudate resulting in least extrudate peak load of 2.24×10^3 kgf/m^2 continued when initial moisture content was grouped.

CONCLUSIONS

This study was conducted with a broad intention of increasing the value of DDGS and utilizing DDGS in extruded foods. This study clearly demonstrated that extruder die temperature affects functional properties of extrudates. Studying additional factors like initial moisture content and amount of DDGS gave a broader view of the effect of die temperature on extrudates. An increase in die temperature resulted in a decrease in L^* and bulk density and an increase in WAI and WSI. Change in die temperature did not affect a^* value significantly. Increased die temperature can darken the extrudates without changing the redness of the product and increasing the solubility of the product in liquid. WAI was highest at the 10% DDGS level with 1.082 and 15% initial moisture with 1.075. Initial moisture of 15% and die temperature of 120°C resulted in significantly higher radial expansion (6.94 and 6.27 mm, respectively, in their respective groups) and L^* value (57.37 and 56.95). Results of expansion from 15% initial moisture support the studies of similar researchers. Increase in DDGS resulted in a decrease in WAI, WSI, radial expansion, peak load, and L^* value, whereas a^* value and bulk density increased. A decrease in WAI, WSI, L^* value, and bulk density was observed with an increase in initial moisture content but resulted in increased peak load and a^* value. Effect of change in extruder die temperature is evident from this study.

Further studies on effect of DDGS on hydration properties of extrudate need to be conducted. Similar study on large-scale single-screw extruder and twin-screw extruder may provide broader understanding of the effect of die temperature in combination with other optimized factors.

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