International Food Research Journal 24(4): 1538-1544 (August 2017)
Journal homepage: http://www.ifrj.upm.edu.my

Effect of hydrocolloids and process parameters on the extrusion behavior of pearl millet grits

Maitre, A., Rathod, R. P. and *Annapure, U. S.

Food Engineering and Technology Department, Institute of Chemical Technology, Matunga, Mumbai 400 019, India

Article history

Received: 2 August 2016
Received in revised form: 19 August 2016
Accepted: 21 August 2016

Keywords

CMC, Sodium alginate
Gum acacia
Extrusion
Pearl millet

Abstract

Hydrocolloids are used in food products as thickeners, stabilizer, gelling agents, and emulsifiers for improvement of physical characteristics and texture properties of the products. Pearl millet (*Pennisetum typhoidam*) is a staple food which supplying calories and proteins as well as essential minerals in the diet. The present study was aimed to investigate the effects of addition of different hydrocolloids as carboxymethyl cellulose (CMC), sodium alginate and gum acacia and process parameters as feed moisture and die temperature on the extrusion behavior and product characteristics of pearl millet. The hydrocolloids were added at 1%, 2% and 3% levels. The die temperature has been varied from 160-180°C with screw speed of 170-190 rpm at constant feed rate 14 rpm (70 g/ min) and the feed moisture of the raw material was in the range of 16-21%.The expansion ratio, density, water absorption index (WAI), water solubility index (WSI), and hardness characteristics were analyzed. From the result it was observed that, Expansion ratio and WAI increased with the incorporation of all hydrocolloids whereas, density WSI and Hardness decreased. Increase in die temperature and decrease in feed moisture increased expansion ratio, WAI, WSI and decreased in density and hardness.

Introduction

Pearl millet (*Pennisetum glaucum*) is, also called as bajra in India, grown in semi-arid areas of the world. It is known as a “crop of food security” due to its sustainability at adverse agro-climatic conditions (Malleshi *et al.,* 2007). Pearl millet is a rich source of nutrients as compared to other cereals with regard to protein, fat and mineral contents as studied by Nambiar *et al.,* (2011) and Pilli *et al.*, (2007). Food extrusion is a versatile high temperature short time (HTST) process, which has become established for manufacturing the value-added expanded snacks from numerous raw ingredients. Extrusion cooking applications in food industry cover a wide range of food products based on starches, cereals, confectionary products, macaroni, pasta as well as pet foods. The effects of various process variables and conditions of the extrusion on behavior of different cereals, millets have been studied by various researchers such as Singh *et al.,* (2007) and Plunkett and Ainsworth (2007).

Hydrocolloids are used in food products as thickeners, stabilizer, gelling agents and emulsifiers also used for coating of food material (Izadi *et al.,* 2015). Hydrocolloids have ability to impart viscosity to a fluid system and some hydrocolloids can modify viscosity in such a way as to decrease torque of extruder (Pawar *et al.*, 2015). Hydrocolloids improve the texture of the products and increase water retention while enhancing lower energy value as well as they often employed in low-calorie foods stated by Dickinson (2003), Pahade and Sakhale (2012) and Juszczak *et al.,* (2004). Several studies such as Saha and Bhattacharya (2010), Sakhale *et al.,* (2011) and Manuel *et al.,* (2007) have been reported to clarify the role and potential usefulness of hydrocolloids in controlling rheology and in modifying texture of starch-based food products as well as influences melting, gelatinization, fragmentation, and retrogradation processes. These investigations include addition of hydrocolloids which enhances or modifies the gelatinization and retrogradation behaviour of starches and flours, improves the water holding capacity and freeze-thaw stability. Hydrocolloids also help to improve the thermostability and to provide lubrication during extrusion process.

In recent years, the demand for snacks with improved nutritional and functional properties as well as economical has been increased. Among these, expanded product has gained preference among both consumers and producers. Extrusion cooking is used worldwide for the production of

*Corresponding author.
Email: udayannapure@gmail.com
Tel. no.: +91 (022) 33612507
Fax no. +9122 3361 1020

expanded snack foods, as there is a huge demand of healthy and nutritious ready-to-eat products from all age groups of consumer. Krokida and Lazou (2010) studied that for consumer acceptability structural and textural properties as well as quality of expanded products proven to be more vital. And hydrocolloids help to improve the thermostability, dispersibility and wettability to provide lubrication during extrusion process which assists to enhance the structural and textural charecteristics of extruded product. Therefore efforts have also been made in most studies to improve the extrudate properties using various hydrocolloids. Smith *et al.,* (1982) and Imeson *et al.,* (1985) studied the effect of different polysaccharides on the extrusion behavior of soy and observed decrease in dough viscosity, expansion ratio and die temperature on addition of sodium alginate. The effect of various process variables and addition of sodium alginate on extrusion behavior of nixtamalized corn grit has been studied by Singh and Singh (2004). But there is no report on the effect of hydrocolloids on extrusion behavior and properties of pearl millet grits. Therefore the objective of present study was to study the effects of addition of different hydrocolloids as CMC, sodium alginate and gum acacia and process parameters as feed moisture and die temperature on the extrusion behavior and product characteristics of pearl millet.

Materials and Methods

Raw material

Pearl millet (*Pennisteum glaucum*) grains of "Shraddha" variety were procured from local market of Vashi, New Mumbai. The pearl millet grains first cleaned and then ground to grits to pass through 20 mesh sieves in a laboratory mill. The grits were packed in polyethylene bags and stored in desiccator till further analysis.

Proximate composition

Moisture content, ash, protein, fat, starch, fiber content were carried out by AOAC (1980, 2006) and Carbohydrate was calculated by difference.

Preparation of samples

The Pearl millet grits were blended with sodium alginate (alginic acid), CMC, sodium salt and gum acacia at 1%, 2% and 3% levels and thoroughly mixed in a laboratory blender. To obtain desired moisture content viz. 16%, 20% and 24% calculated amount of distilled water were sprayed on to the blends and mixed thoroughly to assure uniform moisture distribution. The blends were then packed in polyethylene bags and allowed to equilibrate for 24 h prior to extrusion (Rathod and Annapure, 2015).

Extrusion processing

Extrusion cooking of different conditioned blends was carried out using Brabender single screw extruder (Model No. 823500, Germany), with 20:1 barrel length to diameter ratio and a screw with compression ratio of 2:1. The extruder was fitted with a die nozzle of 4 mm diameter. The feed zone temperature was kept at 100^0C, and the compression and die zone temperature was kept at either 150^0C or 170^0C. The extruder screw speed was maintained at 125 rpm and feed rate of the grits into the extruder was controlled at 70 g/min using a feeder. The extrudates were dried for a period of 2 h to a final moisture content of 4%. After drying to the desired moisture content, they were sealed in polyethylene bags and stored in a desiccator till further analysis as describe by Rathod and Annapure (2015).

Expansion ratio

The expansion ratio was calculated as the ratio of diameter of extrudates to the diameter of die. The diameter of extrudates was measured using a vernier caliper with least count of 0.1 mm. Ten readings were taken for each sample and their average was taken as the mean diameter of the extrudate as explained by Rathod and Annapure (2015).

Density

Extrudate density was calculated as suggested by Ding et al. (2006) and Rathod and Annapure (2015).

$$\text{Density} = 4 \times m / (\pi \times D2L)$$

Where m is the mass of a length L of cooked extrudate with diameter D. Ten replicates of extrudates were randomly selected and a mean value was considered.

Water absorption index (WAI) and water solubility index (WSI)

The WAI and WSI were measured using a technique developed for cereals as per accordance with Ding *et al.,* (2006) and Rathod and Annapure (2015). 2.5 g ground extrudate sample was suspended in 25 mL water at room temperature for 30 min, with intermediate stirring, and then centrifuged at 3000 rpm for 15 min. The supernatant was decanted into an evaporating dish with a known weight. The WAI is the weight of gel obtained after removal of the supernatant per unit weight of original dry solids whereas WSI is the weight of dry solids in the supernatant expressed as a percentage of the original weight of sample. It is given as follows,

Table 1. Effects of extrusion process variables and hydrocolloids on expansion ratio of extrudates

Feed Moisture (%)	Die temperature (^{0}C)	Control	CMC (%)			Sodium alginate (%)			Gum acacia (%)		
			1	2	3	1	2	3	1	2	3
16	150	1.76	1.82	2.06	2.06	2.19	2.56	2.64	2.17	2.38	2.43
20	150	1.75	1.81	1.92	1.91	2.11	2.47	2.50	1.83	1.95	2.01
24	150	1.54	1.59	1.6	1.61	2.04	2.32	2.35	1.62	1.74	1.76
16	170	1.60	1.74	1.98	1.99	2.09	2.28	2.34	2.13	2.24	2.27
20	170	1.51	1.69	1.89	1.90	1.88	1.96	2.13	1.79	1.82	1.84
24	170	1.43	1.54	1.58	1.59	1.52	1.83	1.88	1.52	1.59	1.62

CMC-Carboxymethyl cellulose

WAI = weight of sediment / sample dry weight

WSI = (weight of dry dish – weight of empty dish / sample dry weight) x100

Hardness

Hardness of the extrudate was determined using TAXT2i texture analyzer (Serial No.4650, TEE version no.2.64 UK). 2 mm cylindrical probe was used for the measurement of hardness of the extrudates. The force required for a cylindrical probe to penetrate the sample was measured in grams (g). Five randomly collected samples of each extrudate were measured and a mean value was taken as explained by Rathod and Annapure (2015).

Statistical analysis

The experiments were conducted in three replications. The results were expressed as a mean (±SD) for each analysis and the data were statistically analyzed by one-factor analysis.

Results and Discussion

Proximate composition analysis

Proximate composition of pearl millet flour is as mean values (± standard deviation) of at least three replicates and the mean values are expressed as per 100 g of sample (dry and wet weight basis). Pearl millet contains 11.26% moisture, 5.56% fat, 13.68% protein, 64.71% carbohydrate, 62.72% starch, 3.0% total fiber and 1.78% ash content respectively.

Expansion ratio

The expansion index of extrudates is vital parameter which seeks to describe the degree of puffing undergone by the dough as it exits the extruder. Higher expansion index is favorable as an industrial point of view because of the consumer demand. The effect of hydrocolloids, die temperature and feed moisture on expansion ratio of pearl millet grits is shows in Table 1. Incorporation of sodium alginate, CMC and gum acacia showed that increased in the expansion ratio of the extrudates. Expansion ratio of extrudates was increased with decreased in feed moisture and die temperature. This may be attributed to restriction of flow of the material and increase shearing rate and residence time, which might increase the degree of gelatinization and expansion. The expansion of extruded food material depends on the difference in pressure inside the barrel before die and outside atmosphere. Foods with lower moisture tend to be more viscous than those with higher moisture and, therefore, the pressure difference would be smaller for higher moisture foods, leading to a less expanded product. A number of studies have observed the inverse relationship between expansion of extrudates and the feed moisture from different raw materials, results was agreement with Singh et al. (2007) and Singh and Singh (2004). Expansion ratio of extrudates increased with the addition of CMC, sodium alginate and gum acacia. Expansion ratio of extrudate increased from 1.61 to 2.06, 2.35 to 2.64 and 1.76 to 2.43 respectively when feed moisture decreased from 24% to 16% at 150^{0}C extrusion temprature with the addition of CMC, sodium alginate and gum acacia at 3% level. From the result it was observed that addition of sodium alginate is most effective to increase the expansion ratio as compare to the CMC and gum acacia. The increase in expansion ratio with the addition of hydrocolloids may be attributed to the changes in visco-elastic properties of starch. The similar effects of addition of hydrocolloids on expansion have been observed by Kaur *et al.,* (1999).

Density

The physical properties and density of extruded

Table 2. Effects of extrusion process variables and hydrocolloids on density of extrudates

Feed Moisture (%)	Die Temperature (^{0}C)	Control	CMC (%)			Sodium alginate (%)			Gum acacia (%)		
			1	2	3	1	2	3	1	2	3
16	150	0.417	0.415	0.412	0.409	0.407	0.401	0.395	0.412	0.409	0.403
20	150	0.431	0.419	0.416	0.412	0.418	0.412	0.399	0.424	0.418	0.414
24	150	0.445	0.424	0.426	0.419	0.427	0.421	0.413	0.435	0.427	0.421
16	170	0.454	0.429	0.428	0.417	0.419	0.413	0.409	0.442	0.436	0.432
20	170	0.461	0.438	0.434	0.426	0.428	0.423	0.418	0.451	0.445	0.440
24	170	0.468	0.449	0.439	0.432	0.435	0.431	0.424	0.459	0.452	0.449

CMC-Carboxymethyl cellulose

Table 3. Effects of extrusion process variables and hydrocolloids on WAI of extrudates

Feed Moisture (%)	Die temperature (^{0}C)	Control	CMC (%)			Sodium alginate (%)			Gum acacia (%)		
			1	2	3	1	2	3	1	2	3
16	150	6.006	6.384	7.001	7.210	6.235	6.872	7.002	6.125	6.391	6.763
20	150	6.312	7.146	7.532	8.260	6.841	7.323	7.940	6.532	7.002	7.441
24	150	7.037	7.825	8.308	8.913	7.615	8.107	8.629	7.224	7.432	7.931
16	170	6.719	7.126	7.639	7.950	7.937	7.462	7.723	6.841	7.143	7.325
20	170	6.972	7.327	7.929	8.431	7.125	7.728	8.284	7.003	7.421	7.943
24	170	7.335	7.712	8.527	9.213	7.584	8.373	9.001	7.432	8.002	8.523

CMC-Carboxymethyl cellulose

snack products have an important role in the acceptability of the final product. . Density is a major physical property of the extrudate products. Density is inversely proportion to the expansion ratio. Increase in expansion ratio decreases density and vice versa. Density and expansion are the indices of degree of puffing of extrudates. Lower the bulk density and higher expansion ratio, leads to greater degree of puffing of the extrudates. The effect of hydrocolloids, die temperature and feed moisture on density of pearl millet grits is given in Table 2. The densities of extrudates increased with the increases in moisture and temperature and decreased with the addition of CMC, sodium alginate and gum acacia. Densities of extrudates decreased from 0.419 g/cm^3 to 0.409 g/cm^3, 0.413 g/cm^3 to 0.395 g/cm^3, 0.421 g/cm3 to 0.403 g/cm^3 respectively when feed moisture decreased from 24% to 16% at 150^{0}C extrusion temprature with the addition of CMC, sodium alginate and gum acacia at 3% level. From the results it was observed that intensity of reduction in density was highest with sodium alginate, followed by CMC and gum acacia. Increased in feed moisture content during extrusion may reduce the elasticity of the dough through plasticization of the melt, resulting in reduced specific mechanical energy and therefore reduced gelatinization hence decreased the expansion and increased the density of extrudate. Kaur et al. (1999) studied similar effects of feed moisture and barrel temperature on the density of extrudates from rice grits. Increase in density of extrudates of defatted soy flour with the addition of CMC and sodium alginate has been reported by Boison *et al.,* (1983).

Water absorption index

WAI measures the amount of water absorbed by starch and can be used as an index of gelatinization. The effect of hydrocolloids, die temperature and feed moisture on water absorption index of pearl millet grits is given in Table 3. Feed moisture and die temperature showed significant effect on WAI of pearl millet extrudates. WAI of pearl millet extrudates increased with the increase in feed moisture, temprature and the level of hydrocolloids. At higher moisture and

Table 4. Effects of extrusion process variables and hydrocolloids on WSI of extrudates

Feed Moisture (%)	Die Temperature (⁰C)	Control	CMC (%)			Sodium alginate (%)			Gum acacia (%)		
			1	2	3	1	2	3	1	2	3
16	150	5.625	5.315	5.103	4.979	5.225	5.101	4.982	5.521	5.325	5.006
20	150	5.434	5.019	4.872	4.518	5.085	4.705	4.677	5.314	5.136	4.932
24	150	5.018	4.729	4.125	3.629	4.700	4.020	3.525	5.002	4.725	4.325
16	170	5.818	5.534	5.325	5.000	5.421	5.293	5.007	5.725	5.524	5.490
20	170	5.735	5.412	5.221	4.962	5.223	5.008	4.728	5.527	5.319	5.124
24	170	5.529	5.363	5.109	4.229	5.004	4.629	4.126	5.319	5.000	4.615

CMC-Carboxymethyl cellulose

Table 5. Effects of extrusion process variables and hydrocolloids on hardness of extrudates

Feed Moisture (%)	Die temperature (⁰C)	Control	CMC (%)			Sodium alginate (%)			Gum acacia (%)		
			1	2	3	1	2	3	1	2	3
16	150	1345	1214	1110	980	1305	1238	1100	1268	1182	1093
20	150	1503	1422	1348	1198	1428	1356	1228	1432	1364	1184
24	150	1815	1689	1420	1258	1725	1662	1549	1603	1589	1391
16	170	1182	1102	1056	928	1096	1005	954	1097	1005	934
20	170	1378	1243	1190	986	1285	1168	1041	1222	1108	1048
24	170	1568	1338	1255	1075	1453	1387	1192	1382	1271	1137

CMC-Carboxymethyl cellulose

temperature, starch granule is disrupted and more water is bound to the starch molecule resulting in increased WAI. WAI of extrudates increased from 6.006% to 6.384%, 7.001% and 7.21% with the addition of CMC, 6.006% to 6.235%, 6.872% and 7.002% with addition of sodium alginate, 6.006% to 6.125%, 6.931% and 6.763% with addition of gum acacia at the level of 1%, 2% and 3% respectively with 16% moisture content and 150⁰C extrusion temprature. From the result it was observed that CMC improve more WAI as compare to sodium alginate and gum acacia. Increase in WAI has been reported by Arambula *et al.,* (1999) during extrusion cooking of corn masa with various hydrocolloids. Singh and Singh (2004) also reported that increase in WAI with the addition of sodium alginate during the extrusion of nixtamalized pearl millet grit. Increase in WAI of with the addition of sodium alginate may be attributed to its interaction with the starch components of the pearl millet grits during extrusion. The higher WAI values with the addition of various hydrocolloids may also be attributed to water retention capacity providing better interaction with the components of pearl millet as starch, proteins, and lipids. Gum acacia showed the lower rate of WAI increment that may be attributed to partial degradation of its protein component same result was observed by Kaur *et al.,* (1999). Die temperature also showed significant effect on WAI of pearl millet extrudates. The extrudates at 170⁰C die temperature showed higher WAI values than 150⁰C with the same feed moisture and hydrocolloids levels. The increase in WAI at high temperature may be due to solubility of carbohydrates and increased in the level of damaged starch, similar result was found by Singh *et al.*, (2007).

Water solubility index

WSI used as an indicator of degradation of molecular components. It measures the amount of soluble components released from the starch after extrusion. The effect of hydrocolloids, die temperature and feed moisture on water solubility index of pearl millet grits is given in Table 4. All the hydrocolloids and feed moisture showed significant effect on WSI of extrudates as well as die temperature also showed greater effect on WSI under lower feed moisture conditions. Feed moisture in interaction with die temperature and different hydrocolloids also showed significant effect. WSI of pearl millet extrudates increased with the increase in die temperature and decreased with the increase in the level of various hydrocolloids and feed moisture. WSI of pearl millet extrudates decreased with the increase in feed moisture and the level of hydrocolloids. WSI of extrudates decreased from 5.652% to 5.315%, 5.103% and 4.979% with the addition of CMC, 5.652% to 5.225%, 5.101% and 4.982% with the addition of sodium alginate, 5.652% to 5.521%, 5.325% and 5.006% with the addition of gum acacia at the level of 1%, 2% and 3% respectively with the 16% feed moisture and 150^0C extrusion temprature. These effects of various hydrocolloids on WSI may be attributed to their high water retention capacity and interaction with starch components, which result in the increase in the viscosity. Decrease in WSI may also have resulted because hydrocolloids compete with water during thermal processing and reducing the degree of starch gelatinization, Christianson (1982) agreement with these results. The effect of feed moisture may be attributed to higher degradation of starch at lower feed moisture and of higher die temperature to greater gelatinization of starch. WSI of pearl millet extrudates increased with the increase in die temperature with the same feed moisture and levels of hydrocolloids. WSI of extrudates at 170^0C die temperature higher than the extrudates at 150^0C with 16% feed moisture, it increased from 5.315%, 5.103% and 4.979% to 5.534%, 5.325% and 5.000% with the addition of CMC, from 5.225%, 5.101% and 4.982% to 5.421%, 5.293% and 5.007% with the addition of sodium alginate and from 5.521%, 5.325% and 5.006% to 5.725%, 5.524% and 5.490% with the addition of gum acacia at the level of 1%, 2% and 3% respectively. Higher WSI may be attributed to more fragmentation at high temperature than a lower temperature. The results are in agreement with the study of Singh and Singh (2004).

Hardness

The textural properties of extruded products are generally described by the hardness and crispness. The hardness of an expanded extrudate is a perception of the human being and is associated with the expansion and cell structure of the product. For extruded foods, it was desirable to have low values for hardness as consumer as well as industrial point of view. The effect of hydrocolloids, die temperature and feed moisture on hardness of pearl millet grits is given in Table 5. The quality of extruded snacks is judged from its crispness, which in turn is determined by expanded volume. Crisp texture is the most important quality indicator of extruded snacks. The hardness is determined by the average force required for a probe to penetrate the extrudate. Feed moisture in interaction with die temperature and different hydrocolloids showed significant effect on the hardness i.e. textural characteristics of extrudates. Increasing feed moisture content significantly increased the hardness of the extrudates. An increase in temperature resulted to decrease in hardness. Hardness of pearl millet extrudates decreased with the increase in die temperature and level of hydrocolloids and increased with the increase in feed moisture. Hardness of extrudates decreased from 1345 g to 1214 g, 1110 g and 980 g with the addition of CMC, 1345 g to 1305 g, 1238 g and 1100 g with the addition of sodium alginate, 1345 g to 1268 g, 1182 g and 1093 g with the addition of gum acacia at the level of 1%, 2% and 3% respectively with 16% feed moisture and 150^0C die temperature. Hardness of extrudates was found to higher with increased in feed moisture content. It might be due to the reduced expansion, similar observed by Rathod and Annapure (2015). Christianson (1982) and Singh and Singh (2004) stated that the decrease in hardness of the extrudates may be attributed to the retention of water and inhibition of retrogradation of the gelatinized starch granules, which improved the textural properties of the extrudates. Hardness of pearl millet extrudates decreased with the increase in die temperature at same feed moisture and levels of hydrocolloids. Hardness of extrudates at 170^0C die temperature decreased than that of extrudates at 150^0C from 1214 g, 1110 g and 980 g to 1102 g, 1056 g and 928 g respectively, with the addition of carboxymethyl cellulose (CMC) at 1%, 2% and 3% at 16% feed moisture against an decrease from 1305 g, 1238 g and 1100 g to 1096 g, 1005 g and 954 g with sodium alginate and from 1268 g, 1182 g and 1093 g to 1097 g, 1005 g and 934 g with gum acacia. Decrease in hardness of extrudates may be attributed to decrease in melt viscosity that would favour bubble growth, resulting in increased expansion and low density, giving a softer extrudate.

Conclusion

The effects of addition of various hydrocolloids and process parameters on the extrusion behavior and product characteristics of pearl millet were studied. The physicochemical properties of pearl millet-based extrudate were highly dependent on process variables that are feed moisture content and die temperature. Expansion ratios and WSI of extrudates increased and densities, WAI and hardness decreased with the decrease in feed moisture and die temperature as well as expansion ratios and WAI increased while densities, WSI and hardness decreased with the addition of different hydrocolloids. The overall best quality product was obtained at 16% moisture and 150^0C die temperature with the addition of 3% sodium alginate. Thus, results indicate that pearl millet may be the good candidate to be used as an industrial raw material for the production of extruded snacks with great nutritional value at low cost.

Acknowledgment

The authors gratefully acknowledge University Grant Commission (UGC) for financial support in carrying out this work.

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