ABSTRACT

Bori, a popular traditional conical shape pulse nugget used in the Indian sub continent, is made manually from aerated batter prepared from soaked black gram pulse (*phaseolus mungo*). An array of these nuggets placed on oil-smeared surface are usually dried under the sun. Texture and structure of nuggets are largely dependent on rheological and spreading characteristics which are function of both moisture and air content in the batter. The rheology of the batter with varied amount of moisture content (62.11-72.42 % wb) and air incorporation (14.06-18.17 % v/v) was measured at 22±2°C with a co-axial rotational Brookfield viscometer using cylindrical spindle. The Herschel-Bulkley model adequately fitted the data ($r^2 \geq 0.976$: $p \leq 0.05$). Flow behaviour indices varied in the range from 0.321 and 0.485, which increased with the increase in volume of air incorporation and water content in the batter. The consistency index varied in the range from 80.28 to 18.54 Pa s^n, and decreased with increase in either water content or level of air incorporation in the batter. Density of the batter decreased (903-818 kg/m^3) as the level of air incorporation or water addition to the batter increased. The spreadability of the batter was tested on a galvanized iron sheet by measuring the radial growth rate. This was directly proportional to the water content but inversely related to the air incorporation in the batter. The radial growth decreased linearly with increase in apparent viscosity of the batter ($r^2 \geq 0.810$: $p < 0.05$).

A continuous extrusion system with intermittent discharge mechanism has been developed for preparing conical shape nuggets from semi-solid pulse batter. The system is comprised of a barrel and plunger, a piston and a receiving tray. All operates in synchronized manner with gear and chain drive mechanism to discharge an array of nuggets one after another on the receiving tray with the manual rotation of a handle. The speed of the plunger inside the barrel could be regulated by using interchangeable lead screws having different pitches.

Irrespective of the speed (displacement/time) of the plunger inside the barrel continuous operation of the extrusion showed a constant force (steady state) zone followed by an increasing trend. However, the length of this zone (duration) decreased with the increase in either speed of the plunger or L/D ratio of the extruder die. Average extrusion force at the steady state region varied from 3.9 to 5.9 N, 5.7 to 8.1 N and 9.9 to 14.8 N for L/D ratios of 2/12, 2/10 and 2/8, respectively for plunger speeds from 1.67 to 5.00 mm/s. At the same

plunger speed, the force-time profile for discontinuous (intermittent) extrusion showed similar trend to that of continuous extrusion, however, the peak values of forces were higher for the former for the entire range of plunger displacement. For a particular set of operation uniform product formation was ensured from the least variation of the diameter of the discharged nuggets over the respective mean values. Whole extrusion system consumes 45 W power for formation of array of nuggets.

Adsorption-desorption behaviors of *bori* nuggets prepared from black gram pulse were studied at different relative humidity (*ERH)* ranging from 0 to 85% and temperatures at 25, 35, 45 and 55°C following the static equilibriation technique using the saturated solutions of various salts. These data were analysed and fitted to Guggenheim-Anderson-de Boer (GAB) sorption model. The temperature dependence of the respective coefficients revealed that GAB model is acceptable ($r \geq 0.99$; $M_{RES} \leq 0.481$) in describing the EMC-ERH relationships of the nuggets. M_0, C and K values of the GAB equation were in the range of 8.35 to 8.24, 82.28 to 41.04 and 0.74 to 0.72 for adsorption. The corresponding values for desorption were 9.52 to 8.77, 107.83 to 39.68 and 0.74 to 0.73. The net isosteric heats of sorption estimated from the Clausius-Clapeyron equation, decreased exponentially from 5.94 to 2.52 kJ mol^{-1} with the increase in moisture content of the sample from 5 % to 24% (db) for adsorption. The corresponding values were 8.42 to 3.42 kJ mol^{-1} for desorption.

Experiments on open air sun drying of *bori* nuggets prepared from black gram batter having different initial moisture content of 62 to 72% (wb) and air incorporation of 14.14 to 18.12% (v/v) showed an initial constant rate period followed by a falling rate period. The drying rate was found to increase with the increase in air incorporation and initial moisture content in the batter. With the increase in either initial moisture content or volume of air incorporation into the batter, the drying time decreased. This decrease in drying time is attributed to larger surface area with spreading of batter and more porous structure in the nuggets respectively for higher initial moisture content and air incorporation in the batter.

Response surface analysis reveals that initial moisture content of 67.10 to 67.95% (wb) and air incorporation of 16.81 to 17.43% (v/v) was found to be optimum with respect to lower values of yellowness index, hardness and optimum cooking time of the finished product with less drying time.

Drying characteristics of *bori* nuggets, was studied using hot air temperature of 30, 50 and 70°C and air flow rates of 0.6, 1.0 and 1.4 m/s. The drying constants obtained from Lewis equation decreased from 0.457 to 0.139, 0.514 to 0.324 and 0.735 to 0.487 ($r \geq 0.975$; MSE$\leq$0.0082) for 30, 50 and 70°C respectively, while the air velocity decreased from 1.4 to 0.6 m/s in each case. The correlation among drying constant, air velocity and air temperature for the drying was found to best described by Arrhenious equation ($r=0.995$; MSE=0.0029). Statistical analysis (ANOVA) revealed that effects of both air temperature and air velocity on yellowness index, hardness and cooking time of the nugget as well as on drying time were significant ($p \leq 0.01$ or 0.05). Superimposed contour plots of air temperature and air velocity for different dependent variables suggest optimum drying air temperature between 59 and 63°C and air velocity between 0.8 and 1.0 m/s for attaining minimum values for yellowness index (44), hardness (9.0 –9.5 N), cooking time (8.0 – 8.4 min) and drying time (250 – 275 min).

Key Words: rheology; spreadability; pulse; sorption isotherms, extrusion, pulse product, shape-product, drying.