Abstract

The traditional production of black-gram nuggets (BGN) is done manually by a skilled or semi-skilled worker and finally sun-dried, which is a tedious, cumbersome, unhygienic and time-consuming process. This work aimed to develop a suitable low-cost nugget-formation machine for continuous production of peculiar conical-shaped nuggets under a fully mechanized and hygienic condition, and to study the drying characteristics of BGN. The model prototype was developed to obtain optimum operating parameters. Experiments were conducted on this model by varying the crank-throw distance ranging from 20-45 mm to regulate the volume of nuggets; nugget clearance varying between 10-20 mm to adjust the height and diameter of nuggets and die used with diameters ranging from 5-12 mm. A D-optimal experimental design was applied for statistical analysis. Numerical optimization of operating parameters was carried out to obtain the height and diameter of nuggets in the ranges of 15-25 mm and 20-30 mm, respectively. The optimum ranges of crank throw, die diameter, and nugget clearance were found to be 22-40 mm, 6-12 mm, and 10-18 mm, respectively. The nugget-formation machine was designed and fabricated based on these ranges. Experiments were conducted on the fabricated machine for validation. The highest production capacity of the nugget-formation machine was found to be around 17 kg/h. The experiments have shown that the fabricated nugget-formation machine is capable of continuous production of peculiar conical-shaped nuggets of various sizes. The machine is easy to operate, has low operational and maintenance costs and no skilled labor is required for its operation.

The BGN were dried using microwave drying (MD) and combined hot air with microwave drying (CHMD) system. Drying kinetics, quality characteristics, and optimization for BGN using MD and CHMD with the variation of microwave power densities (MPD, 4-6 W/g) for MD; and MPD (1.33-2 W/g) and air temperatures (T, 40-70°C) for CHMD were studied. For both drying methods, at the initial period, the drying rate (DR) of BGN was found to increase significantly and attain a peak value followed by a falling rate period. Toward the end of the drying period, a very slow DR was observed. Ten models were fitted to experimental data of drying using non-linear regression; Midilli-Kucuk was found to be the best suitable model to describe the trends of BGN drying. The highest R^2 and the lowest RMSE, χ^2, and Akaike information criterion (AIC) values were 0.9999, 0.0031, 0.0002, and –252.489, respectively for MD; and corresponding values were 0.999, 0.0054, 0.0007, and –226.050, respectively for CHMD. Effective moisture diffusivity of BGN varied between 1.08×10^{-7} and $2.58 \times 10^{-7} m^2/s$ for MD; and 1.257×10^{-7} and 3.602×10^{-7} m^2/s for CHMD. Increasing MPD in MD, and T and MPD in CHMD, increased yellowness index, cooking time and effective moisture diffusivity but decreased the hardness and drying time of BGN. Optimum MPD for MD; and T and MPD for CHMD were obtained at 5.18 W/g; and 1.627 W/g and 58.2°C, respectively by applying the desirability function. The CHMD required a minimum time for drying of BGN than the other methods. The hardness and yellowness index of the sun-dried BGN were high and the cooking time was higher for CHMD than the other methods.

Keywords: Nugget formation machine; continuous multiple-outlet; black-gram nuggets; drying characteristics; hybrid drying; numerical optimization; modeling.