SUMMARY
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Extrusion is a multivariable unit operation i.e. mixing, shearing, cooking, puffing and drying in one energy efficient rapid continuous process. Extrusion has become an important technique in an increasing variety of food processes and it has many benefits, including the inactivation of anti nutritional factors, versatility, high productivity, low cost, product shapes, high product quality and production of new food and there are no effluents. Extrusion cooking is a popular means of preparing snack foods and ready-to-eat breakfast cereals using starch-based raw materials (Harper, 1981). Snacks contribute an important part of many consumers in daily nutrient and calories intake (Teethweiler, 1991). Extrusion cooking is capable of converting soluble globular legume proteins into material having fibrous and chewy texture (Harper, 1981).

Grain legumes are an important source of protein, minerals and vitamins for millions of people in the world, particularly in the developing countries (Singh and Singh, 1992). Proteins are essential for growth and carbohydrates are the source of energy for our body. In addition to these, pulses also possess B-complex vitamins and minerals. This necessitates the consumption of pulses in some form or the other. Pulses are grown in appreciable amount in the Bundelkhand region; the milling process yields a sizeable amount of pulses in the form of brokens from the pulse mills. The brokens do not find good market and are listed as losses of pulse processing, generally disposed of cheaply, only to be used as animal feed or to act as raw material for manufacture of other complementary products. Extrusion has been reported to have caused biggest effect in reduction of protein anti-nutritional factors and appeared to be the most effective,
improving both *in-vitro* protein digestibility and *in-vitro* starch digestibility (Alonso, 2000).

Millets are small seeded annual cereal grains. They are not only nutritionally comparable but are also superior to major cereals with respect to protein energy, vitamins and minerals. Besides they are rich source of dietary fibre, phytochemicals, micro-nutrients, nutriceuticals, and hence now-a-days they are rightly termed as nutricereals (Desikachar, 1977). However, the utilization of millets for foods is still mostly confined to the traditional consumers and population of lower economic strata, partly due to non availability of these grains in ready to use or ready to eat forms (Malleshi and Desikachar, 1985).

In the extrusion of snacks and other food products, proper control of the extrusion process is of vital importance to the quality of the final product. In cereal-based products, the degree of starch processing is all-important for major quality aspects such as taste, digestibility, texture and appearance. However, the effect of various operational and processing parameters and their interaction on extrudates quality for millets and pulse-brokins blend was yet to be studied and established. Review of literature has revealed that extrusion cooking process parameters such as feed moisture content, blending ratio, die head temperature, barrel temperature and screw speed play an important role in quality of the extruded product. Combine effect of various operational and processing parameters in relation to product quality have not been investigated and standardized so far for millets and pulse-broken. In the present study a systematic and integrated approach was applied to consider the effect of various operational and processing
parameters, in order to develop models for the extrusion process which were then optimized for obtaining the best quality of ready-to-eat snack food product.

5.1 Summary

Designed experiments were conducted following Response Surface Methodology (RSM) (Myres, 1976). This is a combination of mathematical and statistical techniques that are useful for the modeling and analysis of problems, in which response of interest is influenced by several variables and objective is to optimize the response. In the present study, Central Composite Rotatable Design (CCRD) of five independent variables with five levels of each was used. In this study the effect of processing parameters i.e. moisture content (w.b.) of feed (12, 15, 18, 21 and 24 %), blend ratio i.e. pulse – brokens and millet (12:88, 16:84, 20:80, 24:76 and 28:72), die head temperature (160, 170, 180, 190 and 200°C), barrel temperature (100, 110, 120, 130 and 140°C), and screw speed (100, 110, 120, 130 and 140 rpm) was optimized against the following responses,- mass flow rate, specific length, sectional expansion index, longitudinal expansion index, volumetric expansion index, density, bulk density, crispness, hardness, and cutting strength of extrudates. Prediction models were developed for each of the response, followed by model analysis which included checking the validity of the model with the help of various relevant statistical aids. Optimum values were obtained for all the processing variables by keeping the response either in range, at minimum, or at maximum. Response surface graphs and the contour plots were generated to illustrate the effect of variables on the responses. Overlapping of the contour plots were also done to find out the range of the processing variables which would yield desirable response.
5.2 Conclusions

The following conclusions can be elicited from the present study:

(i) Ready-to-eat snack can be made out of pulse-broken and millet blends.

(ii) The observations made during the research work readily fit in a second order polynomial model with reasonable statistical validity for all the responses.

(iii) The mass flow rate of the extrudates varied between 1.609 and 4.694 kg/hr. Increase in moisture content blend ratio, barrel temperature and die head temperature would result in an increase in the mass flow rate of the extrudates, while increase in screw speed would result in decrease of the mass flow rate. All the processing parameters were significantly affecting the mass flow rate.

(iv) The specific length of the extrudates varied between 19.24 and 66.01 mm/g. The process variables, - moisture content, blend ratio, die head temperature and barrel temperature had a positive effect upon the specific length, i.e. an increase in the value of any of these variables would result in an increase of the specific length, and however the screw speed had a negative effect. The moisture content, blend ratio, and screw speed were more effective than the die head temperature and barrel temperature.

(v) The sectional expansion index of the extrudates varied between 1.825 and 5.457. All the processing variables were significantly affecting the sectional expansion index in linear, interactive and quadratic terms. The individual effect of all the processing parameters was also significant. The sectional expansion index would decrease with increase of screw speed, where as with rest of the processing variables the effect was positive.
(vi) The longitudinal expansion index of the extrudates varied between 0.325 and 0.706. The moisture content and blend ratio, had a positive effect upon longitudinal expansion index, i.e. an increase in the value of any of these variables would result in an increase of the longitudinal expansion index. The die head temperature, barrel temperature and screw speed had a negative effect upon longitudinal expansion index. Individually all the processing variables were significantly effecting the longitudinal expansion index, however the effect of barrel temperature was less significant.

(vii) The volumetric expansion index of the extrudates varied between 0.585 and 3.774. Increase in moisture content and blend ratio resulted in an increase in the volumetric expansion index, while increase in any other processing variable resulted in the decrease of volumetric expansion index. All the processing factors were significantly affecting the volumetric expansion index; however, the barrel temperature and die head temperature were less significant.

(viii) The density of the extrudates varied between 0.232 and 0.523 kg/m³. The density increased with the increase of moisture content, blend ratio, barrel temperature and decreased with the increase of the rest of the process variables. All the processing variables were significantly affecting the density.

(ix) The bulk density of the extrudates varied between 0.140 and 0.302 kg/m³. The bulk density showed all the trends similar to density, the only difference being that the effect of barrel temperature and die head temperature was less significant than the other process variables.
(x) The crispness of the extrudates varied between 22 and 50. However, die head
temperature had less effect on the crispness of the extrudates. The crispness
would increase with increase of moisture content, blend ratio, and barrel
temperature.

(xi) The hardness of the extrudates varied between 2.15 and 5.40 kg. The
extrudate became harder if the moisture content, blend ratio, and barrel
temperature was increased.

(xii) The cutting strength of the extrudates varied between 3.15 and 9.00 kg. The
increase of screw speed would result in a decrease of the cutting strength. The
cutting strength would increase if rest of the process variables were increased.

(xiii) The process parameters were optimized with respect to the responses, the
optimum values obtained for process parameters were, moisture content
(w.b., %) – 20.49, blend ratio(% pulse) – 23.79, die head temperature (°C) –
169.78, barrel temperature (°C) – 126.18, and screw speed (rpm) – 107.08.
The corresponding values of the responses were, mass flow rate (kg/hr) - 4.69,
specific length – 64.10 mm/g, sectional expansion index – 5.46, longitudinial
expansion index – 0.66, volumetric expansion index – 3.68, density (kg/m³) –
0.52, bulk density (kg/m³) – 0.31, crispness – 50.00, hardness (kg) – 5.39,
cutting strength (kg) – 8.77.

(xiv) The contour plots generated out of the models for the various responses were
overlapped to obtain range of input variables that would fit the optimization
criteria. This range of input variables formed a region in the contour plots that
were plotted between any two input variable at-a-time while the rest of the
input variables were kept at centre point. All the pairs of input variable yielded a compromised region represented in white (Fig. 4.11) except die head temperature-screw speed and barrel temperature-screw speed.