Development of multigrain breakfast cereal using extrusion technology

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ABSTRACT
Designed experiments were conducted to prepare extrudates from different cereals blends using twin screw extruder. Linear model was developed using Response Surface methodology (RSM) to study the effect of the variables (rice, wheat, maize) on SEI (sectional expansion index), WAI (water absorption index), WSI (water solubility index), texture and color. Maize had a significant positive linear effect on the SEI and a significant negative effect on the texture of the extrudate. Rice had a positive linear effect on the WAI and WSI Combination of maize and wheat had a significant effect on the color of the extrudates. Maximum desirability of 0.659 was recorded at the 45.4% rice, 27.3% maize and 27.3% wheat levels. The predicted responses in terms of SEI, WAI, WSI, texture and color were 5.14, 5.27g/g, 11.24 per cent, 44.81N, 28.65 respectively. The predicted values registered non-significant difference from the experimental values.

Key words: Extrusion cooking, Maize, Rice, Response Surface methodology, Wheat.

INTRODUCTION
Rice (Oryza sativa), wheat (Triticum aestivum) and maize (Zea mays) are the major cereals grown around the world. They are responsible for satisfying the hunger quest of a major chunk of the world’s population. These cereals serve as the major source of carbohydrates and proteins. There consumption pattern varies according to the area, culture, climate and lifestyle. Traditionally wheat is consumed in the form of bread as roti, chappati, pita, poori, upma, flakes, porridge and rice as cooked/boiled rice, noodles, and flat noodles. With the world becoming a busy place the people have shifted from traditionally cooked food in the kitchen to the convenient foods on the shelf, rich in nutrients, with standard taste and economically viable. Convenience foods include a large variety of Ready-to-eat (RTE) meals, break-fast cereals, special foods, frozen products and snacks.

Breakfast is the most important meal of the day and should be nutritionally balanced and wholesome. Breakfast cereals are gaining importance at a fast pace in the world market as they are the best source of daily iron and B vitamins. Children consuming RTE cereals have lower plasma cholesterol concentrations in comparison to those eating other type of breakfast (Gretchen, 1995). The impact of such a consumption pattern on long term health is extremely important. Extrusion technology has replaced the conventional method of boiling and then drying the products and is a popular technique to make ready to eat products. Research has been done on the extrusion based products from various cereals, pulses, vegetables and fruits and there combination thereof (Yadav et al, 2014, Sharma et al, 2015). In the present study the development of a multi-grain product has been done by optimizing the ingredients i.e. wheat, rice and maize and process parameters using Response Surface Methodology (RSM). Response surface methodology (RSM) involves design of experiments, selection of levels of variables in experimental runs, fitting mathematical models and finally selecting variables’ level by optimizing the responses (Myers and Montgomery, 2002).

MATERIALS AND METHODS
Materials: Commercially available milled rice (PR 116), wheat (PBW 343) and maize (PMH 1) were used as key ingredients for the research work. These were procured from the Department of Plant Breeding and Genetics, Punjab Agricultural University, Ludhiana. Grains were milled using lab mill model 3303 (Perten, Sweden) through 200 ìm sieve. Proximate analysis: The proximate parameters like moisture, protein, crude fat, ash and crude fiber were determined using the standard methods (AACC, 1995). The carbohydrate content of sample was estimated by subtracting the sum of moisture, protein, fat, ash and total dietary fiber from 100 (Merrill and Watt, 1973). All the chemicals used were of analytical grade and procured from S D Fine chemicals, Mumbai, India.

Extrusion cooking: A laboratory scale co-rotating twin-screw extruder with intermeshing screws (Model BC21;Clextral, Firminy Cedex, France) was used for the extrusion study. The barrel diameter and L/D ratio were 25mm and 16:1 respectively. Material was fed into the extruder inlet port by a screw feeder, motor (DS and M, Modena, Italy).The screw installed in the barrel performs the function of mixing and grinding. The sample was conditioned at 15 % moisture content in the first zone of the
barrel by manually adjusting the pre-calibrated water feed pump. The feeder speed and screw speed were maintained at 60 rpm and 400 rpm respectively. Temperature in the four barrel section was set at 40, 70, 100 and 160ºC. The extruded samples were dried in the tray drier @ 70ºC for 1 hour and sealed in a LDPE bag and stored at room temperature for further analysis.

**Experimental design and data analysis:** The central composite rotatable design (CCRD), a powerful tool was selected for the study as it drastically reduces the number of experiments for study when more than two variables are involved. In present study CCRD was used to design the experiments without any blocking comprising three independent variables (at three different levels). The Statistical software package design expert ® 8.08(Stat ease Inc., Minneapolis, USA) was used to plan the experimental design and to analyze the data. Different combinations of cereals were formulated, as per the RSM model design. Ground sugar was incorporated uniformly @15 % to all the samples and packed in LDPE bags. The bags were allowed to equilibrate overnight at 5ºC.

In the present study, an attempt was made to understand the effect of variations in the blend ratio (rice, wheat and maize) on the properties of the extrudates. The experimental design, with coded and actual values of variables in specific range, is tabulated in Table 1. The values in the design outside the ranges were selected for rotatability of the design. In all, 20 experiments were conducted (Table 2) with six experiments at centre point to calculate the repeatability of the method (Montgomery, 2001).

**TABLE 1-** Experimental ranges and levels of independent variables using RSM in terms of actual and coded factors of multi grain cereal breakfast

<table>
<thead>
<tr>
<th>Variables(g)</th>
<th>Range of levels</th>
<th>Actual/Coded</th>
<th>Actual/Coded</th>
<th>Actual/Coded</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (Rice)</td>
<td>30/-1</td>
<td>40/0</td>
<td>50/1</td>
<td></td>
</tr>
<tr>
<td>B(Wheat)</td>
<td>10/-1</td>
<td>20/0</td>
<td>30/1</td>
<td></td>
</tr>
<tr>
<td>C (Maize)</td>
<td>10/-1</td>
<td>20/0</td>
<td>30/1</td>
<td></td>
</tr>
</tbody>
</table>

The mathematical model fitting and selection of variables was done on the basis of optimization of response. The coding of the variable values was done using the following equation.

\[ A = \frac{(\text{Rice} - 40)}{10} \quad \ldots \quad (1) \]

\[ B = \frac{(\text{Wheat} - 20)}{10} \quad \ldots \quad (2) \]

\[ C = \frac{(\text{Maize} - 20)}{10} \quad \ldots \quad (3) \]

**Product responses**

**Sectional Expansion Index (SEI):** Expansion of extrudates was evaluated as sectional expansion. The diameter of 5 pieces of extrudates taken at random was measured with a digital caliper and average was calculated. SEI was determined by dividing the cross sectional area (mean of five measurements) of the extrudates by the cross sectional area of the die nozzle (Alvarez-Martinez et al., 1988). The die had a diameter of 3.5 mm.

\[ \text{SEI} = \frac{S_e}{S_d} \quad \ldots \quad (4) \]

where \( S_e \) and \( S_d \) are the cross sectional areas of the extrudates and the die.

**TABLE 2-** Experimental design and values of quality parameters of extruded multi grain breakfast cereal

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>SEI</th>
<th>WAI</th>
<th>WSI</th>
<th>Hardness(N)</th>
<th>Colour</th>
</tr>
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<tr>
<td>-1.00</td>
<td>-1.00</td>
<td>1.00</td>
<td>4.95</td>
<td>4.38</td>
<td>21.0</td>
<td>32.3</td>
<td>28.7</td>
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<td>0.00</td>
<td>4.67</td>
<td>4.94</td>
<td>8.9</td>
<td>48.7</td>
<td>32.4</td>
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<td>-1.00</td>
<td>1.00</td>
<td>-1.00</td>
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<td>5.01</td>
<td>17.2</td>
<td>46.7</td>
<td>27.8</td>
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<td>0.00</td>
<td>0.00</td>
<td>5.1</td>
<td>5.46</td>
<td>14.3</td>
<td>47.8</td>
<td>26.9</td>
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<tr>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>5.28</td>
<td>5.42</td>
<td>13.9</td>
<td>47.7</td>
<td>28.2</td>
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<tr>
<td>1.00</td>
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<td>-1.00</td>
<td>4.65</td>
<td>5.47</td>
<td>13.6</td>
<td>54.5</td>
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<td>0.00</td>
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<td>4.62</td>
<td>20.1</td>
<td>66.3</td>
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<td>0.00</td>
<td>4.77</td>
<td>5.55</td>
<td>10.8</td>
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<td>18.6</td>
<td>53.9</td>
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<td>-1.00</td>
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<td>4.49</td>
<td>17.7</td>
<td>56.7</td>
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<td>35.6</td>
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<td>43.7</td>
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<td>0.00</td>
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<td>6.15</td>
<td>10.3</td>
<td>51.3</td>
<td>26.1</td>
</tr>
</tbody>
</table>

A; Rice,B; Wheat, C; Maize, SEI; Sectional Expansion Index, WAI; Water Absorption Index, WSI; Water Solubility Index
**Water Absorption and Water Solubility Indices:** Water Absorption Index (WAI) was determined according to the method of Kaur and Singh (2006). Water solubility index (WSI) was determined by the method given by Nyombaire, Siddiq and Dolan (2011).

**Texture:** The hardness of samples was measured using Texture Analyzer, model TA-XT2i (Stable Micro-Systems, Surrey, England) with a compression plate p75. The tests were conducted at pre—test speed of 1.0 mm/sec, test speed of 1mm/sec, post test speed of 5 mm/s, distance of 2.5mm, trigger force of 25 g and load cell of 250 kg. The value of the first peak obtained during the compression cycle was recorded as hardness (N). An average of five replicates was recorded.

**Colour:** Samples were ground to pass through 200ìm sieve. For each sample, average of three measurements was taken. Color of extruded samples was measured using a Hunter Laboratory Instrument Model CIE 1996 (Hunter Associates Laboratory, Inc., Reston, Virginia, U.S.A.) and expressed in terms of the ‘L’ (lightness (100) or darkness (0)), ‘a’ (redness (+) or greenness (–)), and ‘b’ (yellowness (+) or blueness (–)). A white calibration plate (L = 91.08, a = –1.25 and b = 1.43) was used as a standard for the measurements (Altan et al, 2008). AE, which signifies the total color difference, was calculated (Matthey and Hanna, 1997) as:

\[ \Delta E = (\Delta L^2 + \Delta a^2 + \Delta b^2)^{1/2} \]  

where, \( \Delta L = L_{\text{sample}} - L_{\text{standard}} \), \( \Delta a = a_{\text{sample}} - a_{\text{standard}} \), and \( \Delta b = b_{\text{sample}} - b_{\text{standard}} \).

**OPTIMISATION**

Optimum values of the cereal combinations were obtained with the help of numerical optimization technique of the Design – Expert software. It necessitates assigning goals to the processing variables when kept within the range while responses were maximized, minimized or kept in range. Water absorption index, water solubility index, texture, specific expansion index and color are considered to be dependent directly on the specific composition of the product. The regression analysis of the responses was conducted by fitting suitable models represented by Y in equation (6). Where \( \alpha \) was the value of the fitted response at the center point of the design, i.e. point (0, 0, 0), \( \alpha_{ii} \) and \( \alpha_{ij} \) were linear and cross product (interaction effect) regression terms and \( n \) denoted the number of independent variables (n=3). The numerical optimization finds a point that maximizes the desirability function.

\[ Y_i = \beta_k \alpha + \sum_{i=1}^{3} (\beta_k \alpha X_i) + \sum_{i=1}^{3} \sum_{j=1}^{3} (\beta_{kj} \alpha X_iX_j) \]  

In order to search a solution satisfying the imposed constraints the goals are combined into an overall composite function, D(x) called desirability factor (Myers and Montgomery, 2002) represented in equation (7)

\[ D(x) = (d_1 \times d_2 \times d_3 \ldots \ldots \ldots d_k)^{1/k} \]  

where, \( d_1, d_2, \ldots, d_k \) are desirability values.

**RESULTS AND DISCUSSION**

**Proximate analysis:** The wheat, rice and maize were analyzed for their proximate composition. The moisture content varied between 12.0-13.8%. Wheat grains showed a maximum protein content of 12.3% followed by maize (8.9%) and rice (7.5%). Maize had the highest fat content (3.9%) followed by rice (1.9%) and wheat (1.8%) whereas wheat had the highest fiber content (2.3%) and ash content (1.2%).

**Sectional Expansion Index (SEI):** The SEI index is considered one of the most important parameter in the evaluation of extruded cereals. The regression equation for the experiment is given in the equation (8)

\[ \text{SEI} = 4.76 + 0.031 \times A + 0.11 \times B + 0.24 \times C \]  

where A: Rice, B: Wheat and C: Maize

The predicted model is described by linear equation with \( p^2 = 0.05 \) and correlation coefficient, \( r^2 = 0.49 \) with an adequate precision 7.301. Maize showed a positive effect on the SEI with the increase in maize content the SEI increased. It could be due to lower protein content in maize (8.9%) in comparison to wheat (12.3%). The increased level of starch and gluten reduced the SEI up to 11% (Mathew, et al. 1999). Rice and maize showed a non-significant effect on SEI Fig 1. The SEI ranged from 4.22 – 5.54.

**FIG 1:** Response surface plot for sectional expansion index(SEI) as a function of Maize and Rice.

Maximum SEI of 5.54 was recorded for sample 18 which had maize and rice 27.3% each. The fiber concentration also affects the expansion; SEI is maximum at optimum levels of fiber. The radial and axial expansion was maximum at 10 % rice bran and decreased with its increase to higher levels (20 % and 30 %) (Grenus, et al. 1993).

**Water Absorption Index:** WAI is an important parameter for the evaluation of the breakfast cereals. It measures the volume occupied by granules or starch polymer after swelling in excess water. The predicted model is described by linear equation in terms of coded values as in equation (9)

\[ \text{WAI} = 5.04 + 0.28 \times A + 0.16 \times B - 0.21 \times C \]  

where A: Rice, B: Wheat and C: Maize.
The model is highly significant with $p \leq 0.05$, $r^2 = 0.43$ with the precision of 7.11. The presence of rice showed a significant positive linear effect. With the increase in rice and wheat content the WAI increased but it decreased with the increase in maize content (Fig 2). Minimum WAI was recorded for sample 10 with a value of 3.93 having 33.3% maize, 44.5% rice and 22.2% wheat. With the increase in maize content the starch and protein content of the extrudate decreased resulting in lower WAI. Similar results were reported (Artz, et al., 1990), when the ratio of fibre/corn starch was increased in extrusion of corn fibre and corn starch blend. Deshpande and Poshadri (2011) reported that with increase in chick pea, cow pea flour which have higher protein, WAI increased. Similarly, addition of pumpkin and canola protein to wheat increased WAI (Nwabueze, 2006).

**Water Solubility Index:** The predicted model for WSI is described by linear equation in terms of coded values as shown in equation (10)

$$\text{WSI} = 14.92 - 1.75\times A - 1.49\times B - 1.23\times C + 2.20\times A\times B + 0.27\times A\times C - 1.67\times B\times C$$

where A; Rice, B; wheat and C; maize

The model is significant with $p \leq 0.05$, $r^2$ value of 0.577 with an adequate precision 6.14. Rice showed a significant negative effect. Increase in rice content decreased the WSI as shown in Fig 3. It could be due to gelatinisation of starch during the extrusion reducing the solubility of solids. Maximum WSI was recorded for sample 1 having 42.9% rice, 14.2% wheat and 42.9% maize. Reduction in wheat decreased WSI which could be due to high protein content capable of forming better bonds thus reducing WSI. Nwabueze (2006) reported with the increase in percentage of bread fruit and corn flour the WSI decreases, due to formation of insoluble water compounds.

**Texture:** The texture is normally defined by the hardness, the force required to break the product. The linear model for the hardness (H) is shown in equation (11). The higher value of maximum peak force required in N, which means more force required to breakdown the sample, the higher the hardness of the sample to fracture (Li et al., 2005). The equation in terms of coded levels variables was developed with $r^2=0.43$ and adeq precision 6.821.

$$\text{Hardness} = 49.76 - 0.56\times A + 1.23\times B - 5.61\times C$$

where A;Rice, B;wheat and C;maize

Maize had a significant negative effect as shown in Fig 4. The minimum hardness was recorded for sample 1 with 20% wheat, 20% rice and 60% maize. Protein rich extrudates produce less expandable products and more rigid network resulting in higher resistance to shear (Li et al., 2005). Maize is naturally low in protein content so the extrudates developed with higher content of maize are less rigid resulting in low hardness values.

**Color:** Color is an important quality factor related to consumer acceptability. A regression was carried out to fit mathematical models to the experimental data. The predicted model is described by quadratic equation (12) in terms of coded values.

$$\text{Colour} = 29.28 - 0.12\times A - 0.41\times B + 1.29\times C - 1.76\times A\times B - 0.80\times A\times C + 1.17\times B\times C$$

where A;Rice, B;wheat and C;maize

**FIG 2:** Response surface plot for Water absorption index (WAI) as a function of Maize and Rice

**FIG 3:** Response surface plot and perturbation graph for water solubility index (WSI) as a function of Maize and Rice.

**FIG 4:** Response surface plot and perturbation graph for texture as a function of Maize and Wheat
The r^2 values for the model was 0.6211 indicated the model to be significant with F value 0.0263 <0.05, and high adequate precision of 8.334 as shown in Table 3. The color variation was mainly due to maize and wheat Fig 5. Natural color of maize and wheat are yellow and brown respectively. Maize (C) had a significant positive effect with p <0.05 and significant negative effect was recorded for wheat and rice combination. The ÄE value varied from 26.12-35.58. Sample 18 recorded the maximum value with 33.3% rice, wheat and maize. Changes in the yellowness during extrusion cooking of yellow maize was induced by the effects of two different reactions: non-enzymatic browning and pigment destruction (Ilo and Berghofer, 1999) where the caratenoids might have been damaged by thermal treatment and some browning might have made up the colour loss.

Optimisation: The desirable maximisation of the polynomials was performed by numerical techniques using mathematical optimisation procedure by design experts. The response optimisation was achieved as per the desirable criteria of maximum SEI and WAI, minimising WSI and color and texture values within the range. Maximisation of SEI and WAI are the most important parameter in the development of extruded breakfast cereals. The optimised variable levels and importance of responses were also taken into account. The cuboid represented in Fig 6 shows the variation of desirability with respect to composition of cereals. Maximum desirability of 0.659 was recorded with a composition of 45.4% rice, 27.3% wheat and maize each respectively. Minimum value of 0.00 for desirability was predicted at 2 different composition levels with 55.6% rice in each and 11.2% wheat ,33.2% maize along with 33.3% wheat and 11.1% maize respectively.

FIG 5: Response surface plot for color as a function of Maize and wheat

FIG 6: Cuboid representation of effect of variation of wheat, rice and maize on the desirability

### TABLE 3-ANOVA and model statistics for the extruded multi grain breakfast cereal

<table>
<thead>
<tr>
<th>Term</th>
<th>SEI</th>
<th>WAI</th>
<th>WSI</th>
<th>Texture(N)</th>
<th>Color</th>
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<tbody>
<tr>
<td>F-value</td>
<td>5.21</td>
<td>4.02</td>
<td>2.96</td>
<td>3.96</td>
<td>3.55</td>
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<tr>
<td>P&gt;F</td>
<td>0.0106</td>
<td>0.0261</td>
<td>0.0475</td>
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<td>0.0263</td>
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<tr>
<td>S.D</td>
<td>0.24</td>
<td>0.41</td>
<td>2.95</td>
<td>6.19</td>
<td>1.76</td>
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<tr>
<td>Mean</td>
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<td>5.04</td>
<td>14.92</td>
<td>49.73</td>
<td>29.28</td>
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<tr>
<td>C.V</td>
<td>5.14</td>
<td>8.15</td>
<td>19.77</td>
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<td>R- squared</td>
<td>0.4942</td>
<td>0.4299</td>
<td>0.577</td>
<td>0.4262</td>
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<tr>
<td>Adjusted R- Squared</td>
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<td>0.3230</td>
<td>0.3828</td>
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<td>0.4462</td>
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SEI; Sectional Expansion Index, WAI; Water Absorption Index, WSI; Water Solubility Index

### TABLE 4-Predicted Response Vs Actual Response

<table>
<thead>
<tr>
<th>Values</th>
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<th>WAI</th>
<th>WSI</th>
<th>Texture</th>
<th>Color</th>
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<td>5.04</td>
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SEI; Sectional Expansion Index, WAI; Water Absorption Index, WSI; Water Solubility Index

### CONCLUSION

The composition of wheat and maize at 27.3% each and rice 45.4% gave the best results with WAI 5.27g/g, WSI 11.24% and SEI 5.14, color 28.65 and texture 44.81N. The maximum desirability of 0.659 was recorded with linear model fitting. The predicted values registered non-significant difference from experimental values.

### ACKNOWLEDGEMENTS

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