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RESEARCH PAPER

Effect of Composition of Ingredients, Temperature and Screw Speed on Nutritional, Functional and Sensory Properties of Tuber Crop Extrudates

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ABSTRACT

In the present paper tuber crop extrudates has been prepared from Arrowroot flour, Lesser yam flour and Potato flour. Potato flour has been taken as base flour 50% and rest of the two flours varied i.e. Arrowroot flours were (0, 10, 20, 30, 40 and 50%) and Lesser yam flour (50, 40, 30, 20, 10 and 0%). These three flour combinations at 10% MC (db) were extruded using twin screw extruder at screw speed 330, 360 and 390 rpm and barrel temperature 130, 150 and 170°C. The extrudates were analysed for its physico-chemical properties (moisture content, protein, fat, crude fibre, ash content, carbohydrates and colour) and functional properties (water absorption index, water solubility index, expansion ratio, bulk density and hardness). The sensory analysis of the developed extrudates was performed through a panel of 45 trained judges for all 54 samples. The extrudates were optimized for its desirable better functional properties (like lower bulk density, more expansion ratio, lower hardness; protein, fat, fibre, ash and carbohydrates). The optimum extrudates combination was observed at flour combination (Arrowroot: Lesser yam: Potato as 10:40:50) at screw speed 385-390 and temperature 130-135°C. The functional properties at optimum zone was 0.15 g/cm^3, 3.10, 1460g, 4.22g/g and 31.30% bulk density, expansion ratio, hardness, water absorption index and water solubility index respectively. The nutritional properties at optimum zone was 2.80%, 1.40%, 1.96%, 85.01%, 1.20% and 6.0 % (db) protein, fat, ash, carbohydrates, fibers and moisture content respectively. The sensory score was highest at Arrowroot: Lesser yam: Potato (10:40:50) at 390 rpm screw speed and 130°C temperature. The sensory properties at the optimum zone was 7.5, 7.2, 8.5, 7.4, 7.0, 7.3 and 7.5 i.e. appearance, colour, taste, texture, crispiness, expansion and overall acceptability respectively.

Keywords: Tuber crops, arrowroot, lesser yam, potato, extrudates, functional properties, nutritional properties and sensory analysis

The snack foods industry is a vibrant sector and future for the industry looks promising and bright. Global snack foods market is forecast to reach US $334 billion and 48,519 thousand tons in volume terms, by the year 2015. The Indian snack market is worth around US $3 billion and has an annual growth rate of 15-20% (MOFPI, 2005).

Extrudates snacks are generally made from grain based raw materials. Potato offers very large starch

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granules that break down easily with definite flavor, excellent swelling and binding power and could be best utilized for making extruded snack products because of their specific properties like improved taste, texture, gelatinization and shelf life, which influence the higher expansion, natural taste and better crispiness of the end product.

Potato grown in 150 countries is the most important food crop in the world after wheat, rice and maize. It is high yielding short duration crop. The potato ease of cultivation and good nutrient content has made it a valuable cash crop for millions of farmers. India is a second largest potato producer in the world and produced 37.3 million tons of potato during 2009-10 (Singh *et al.* 2011). Once harvested, potato can be used for variety of purposes as a fresh vegetable for cooking, a raw material for processing into food products, food ingredients, starch and alcohol, as a feed for animals and seed tubers for growing the next's season's crop. With phenomenal increase in potato production, recurring gluts have become common in country. Prices crash drastically during the harvesting months leading to panic scale by the farmers and inturn leading to heavy monetary losses. Sometimes, farmers are not able to even cover their cost of production.

Yam (*Dioscorea Spp*) is a traditional food crop of great antiquality that originated in Africa, Asia and America and is now widely distributed throughout the tropics, with a few members occurring in temperature zone (Coursey, 1983). Yams are generally baked, boiled, fried in oil or cooked in stews in similar manner to the potato (O' Hair, 1990). *Dioscorea esculenta (Lour)* Burk is least studied of major staple yam species, although it is widely cultivated in southern Asia and the pacific and is the dominant or co-dominant staple food in parts of India and Papua New Guinea (O'Sullivan and Ernest, 2007). They belong to the Dioscorea genus, which includes 600 spices. Coursey (1967) and Leon (1977) mentioned four distinct centres of origin for the edible yam. World yam production is about 38×10^6 tonns per year (FAO, 2002). Yam serves as a major source of income in countries where they are cultivated. Yam tubers are usually processed into flour by peeling, slicing, parboiling in hot water (40-60°C for 1-3 hr), soaking and sun drying (Onayemi and Potter, 1974). Despite the high levels of yam production noted, it contains high amount of starch (70-80% (db)), these starch resource is not used for starch production on an industrial level (Amani *et al.* 2004).

Arrowroot (*Marantha arundinacea*) is a tropical plant that grows in warm, swampy areas. The plant originated from the caribbean region but is now widespread throughout the tropics. It is an under exploited tuber crops having tremendous potential in food and pharmaceutical industries. The tuber contains about 10% to 25% extractable starch, which from a nutritional point of view is the richest (unenriched) natural starch on the earth (Spennemann, 1992). The starch granules are while having round, polygonal shape and the amylase content ranges between 16-27%. It is popular for its high digestibility and medicinal properties. The starch is often used as a thickner in all kinds of foods, dressings, soups, sauces, candies, cookies and desserts. It posses demulcent properties sooths and protects irritated or inflamed internal tissues of the body and hence is given in bowel complaints (Mathew, 2007). Arrowroot is used as an article of diet in the form of biscuits, puddings, jellies, cakes and hot sauces and so on, and an early digestible food for children and peoples with dietary restrictions. Lack of gluten in arrowroot starch makes it added as a replacement of wheat flour in baking (Jyothi, 2009).

One of the most important technology, which have shows great potential for the development of new snack products is extrusion cooking. Extrusion is a continuous food processing technique classified as a high temperature short time (HTST) operation in which raw food materials are thermo-mechanically cooked in a screw barrel assembly by a combination of moisture, pressure and temperature in order to be mechanically sheared and shaped (Riaz, 2001). It is a low cost and efficient technology that utilizes high temperature, pressure and shear force to produce highly expanded, low density snacks with unique textural properties. Product quality can vary considerably depending on the extrusion variables such as feed composition, screw speed, feed moisture, feed particle size, temperature profile in the barrel, feed rate and die geometry. Extruder type and chemical composition of raw materials also affect product characteristics. These material and process variables determines the extent of macromolecular transformations during extrusion, which inturn influences the rheological properties of food melt in the extruder and consequently, the product characteristics of extrudates. Physical characteristics such as expansion, density, hardness are important parameters to evaluate the consumer acceptability of the final product (Patil *et al.* 2007).

The effect of ingredient properties and processing conditions (such as feed moisture content, screw speed and barrel temperature) on final product quality are also reflected by their influence on process responses or extruder system such as motor torque, die pressure, product temperature and specific mechanical energy (SME).

Extensive work has been done by many researchers on extrusion of cereals such as rice, wheat and corn (Dahlin and Lorenz, 1993; Eerlingen and Others, 1994; Chaudhari and Gautam, 1999; Bryant *et al.* 2001; Pathania *et al.* 2013). However, relatively less work has been done on the extrusion of tubers, their flours and starches.

Badrie and Mellows (1991a, 1991b) have studied the influence of variables on the expansion characteristics, texture and microstructure of cassava flour extrudates. The influence of extruder and processing parameters on the characteristics of cassava flour extrudates was studied by Sheriff (1996). Iwe *et al.* 2000 extruded blends of defatted soy flour and sweet potato flour in a single screw extruder at varying pre-set rotational speeds and their results showed that the whiteness of the extrudates decreased with increase in sweet potato in the blends during extrusion. Taro flour, derived from the corm of cotocasia esculenta cv. Lehua, was extruded with whey protein concentrate, whey protein isolate or lactalbumin to derive high protein blends for incorporation in some weaning foods (Onwulata and Konstances, 2002).

Despite its application in many fields of food industry, no systematic study has been undertaken so far extrusion cooking on Potato, Lesser yam and Arrowroot flour extrudates. Considering the economic importance of Potato, Lesser yam and Arrowroot and its special properties suited for food industry. The present investigation was undertaken to study the effect of combination of ingredients, temperature of extrusion and screw speed on nutritional and functional properties of tuber crops extrudates and its sensory quality.

MATERIALS AND METHODS

Sample preparation

1. Arrowroot flour

Fig. 1 shows the flow chart of preparation of Arrowroot flour.

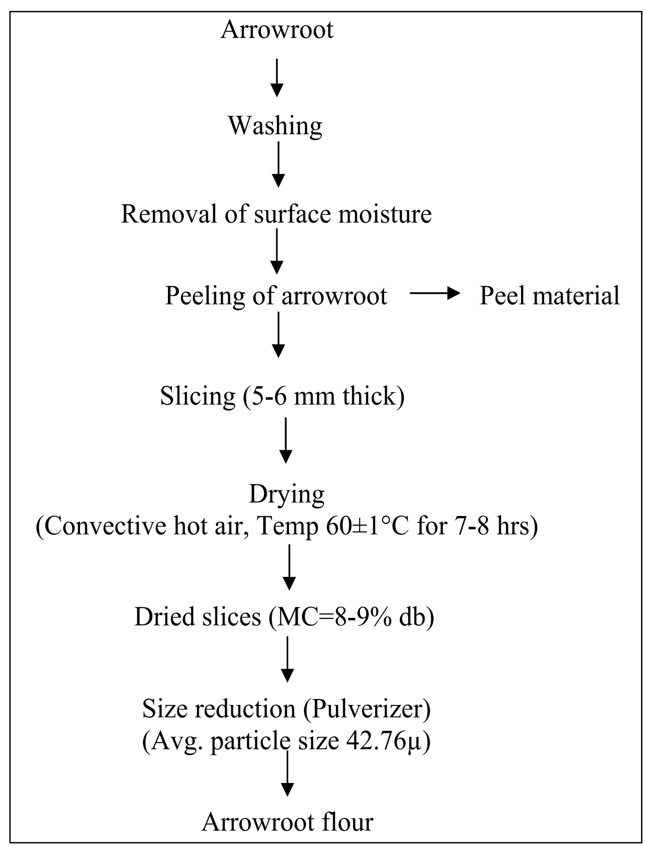


Fig. 1: Flow chart for preparation of Arrowroot flour

The arrowroot washed with clean water, outer layer of the tuber were peeled and sliced (5-6 mm thick). Arrowroot slices were put into convective dryer. The drying was carried out in a tray dryer (Make: M/s Rotex Industries, Pune) having capacity 60 kg. There were 24 no. of trays inside the tray dryer. The size of the tray was 54 cm × 50 cm × 2 cm. The temperature of the drying was kept as 60±1°C for 7-8 hrs upto 8-9 % MC (db). The weight loss during drying was measured by three number of perforated trays placed at three different locations in tray dryer i.e. top, middle and lower side of the dryer. The slices taken out from dryer and allow to cool at ambient temperature and milled using pulverizer (Make: M/s SEW, Kudal) up to average particle size 42.76µ to make flour.

2. Lesser yam flour

Fig. 2 shows the flow chart of preparation of Lesser yam flour. The lesser yam flour were developed as per the procedure described Adegunwa *et al.* 2011.

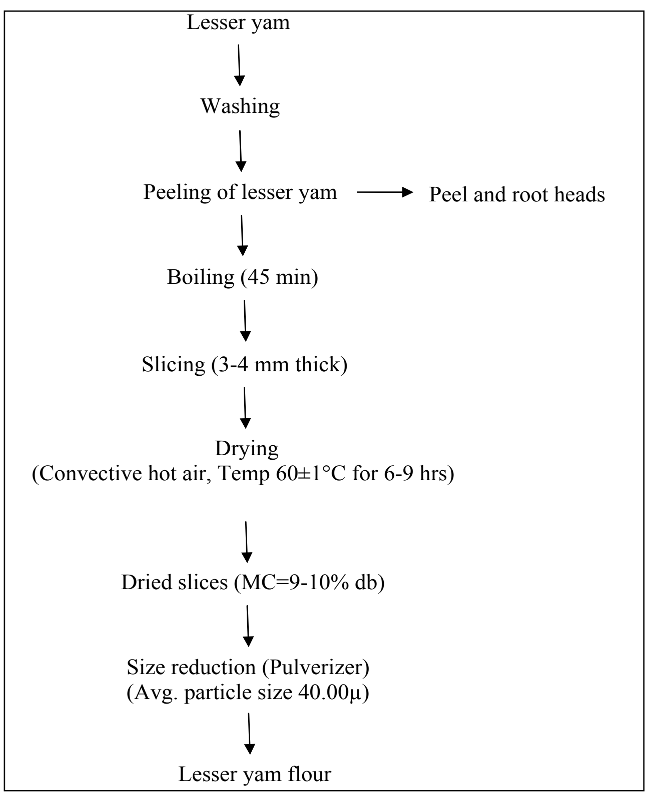


Fig. 2: Flow chart for preparation of Lesser yam flour

The lesser yams were washed and peeled and root heads was removed from the tuber. This peeled yam tubers were boiled in hot water up to 45 min. After boiling, the boiled yam tubers were cut into slices (3-4 mm thick). These slices were placed into the convective dryer as discussed in the above section and dried at temperature 60±1°C for 6-9 hrs upto 9-10 % MC (db) and then slices were taken out from the dryer and allowed to cool at ambient temperature and milled using pulverizer (Make: M/s SEW, Kudal) up to average particle size 40.00µ to make flour (Adegunwa *et al.* 2011).

3. Potato flour

Fig. 3 shows the flow chart of preparation of Potato flour. The potato flour was prepared as per the procedure described by Darvishi *et al.* 2013. Potatoes were washed, peeled, sliced (2-4mm thick).

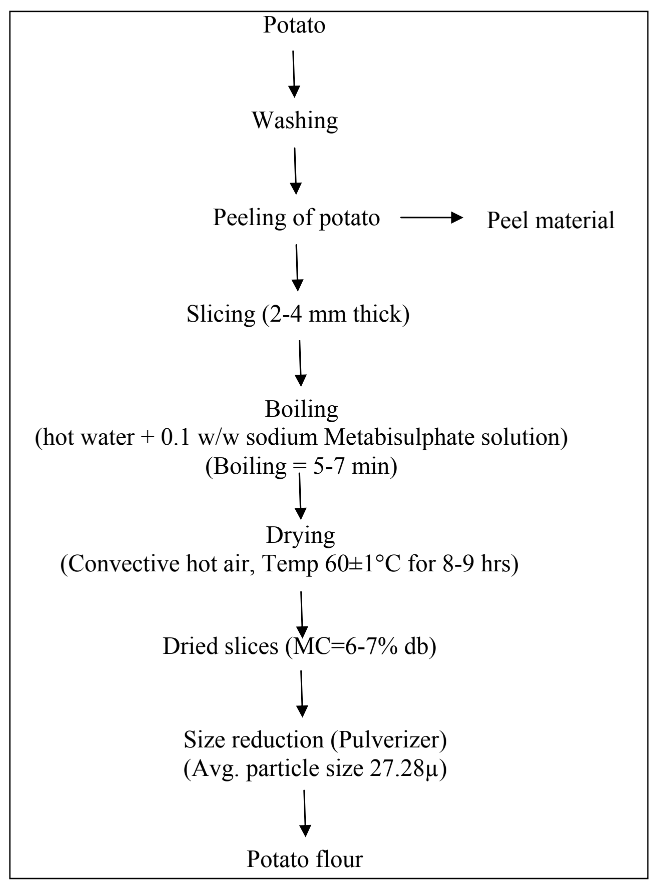


Fig. 3: Flow chart for preparation of Potato flour

These slices were boiled in hot water at temperature of 100°C for 5 min with addition of potatoes were immersed in a sodium meta-bisulphite solution (0.1% w/w) to prevent browning during drying. This blanched slices were dried in convective dryer and drying temperature is 60±1°C for 8-9 hrs upto 6-7 % MC (db) and then slices were taken out from the dryer and allowed to cool at ambient temperature and milled to a particle size 27.28μ using pulverizer (Make: M/s SEW, Kudal) to make flour (Darvishi *et al.* 2013).

Treatment combinations

The final moisture content of Arrowroot flour, Lesser yam flour and Potato flour were 5.81, 8.56 and 8.07% (db). The moisture content of the flour was adjusted by adding 3 ml Kokum (*Garcinia Indica*) Liquid Concentrate at 40°B in 7 ml water to make it upto 10 ml. The liquid diluted is added to the flour mixture of 100g to make the moisture content 13-14% (db) for each treatment as shown in Table 1.

Table 1: Flour combinations

Treatment	Arrowroot (%)	Lesser yam (%)	Potato (%)	Total (%)
T1	0	50	50	100
T2	10	40	50	100
T3	20	30	50	100
T4	30	20	50	100
T5	40	10	50	100
T6	50	0	50	100

The flour mixture and the liquid concentrate were well mixed with the help of pan and an agitator. The mixture was sieved through the 2 mm sieve for breaking the lumps formed during mixing. The final moisture content of all the samples was 15% (db). The moisture content of the samples was determined by AOAC, 2000. These samples were used for extrusion cooking.

The Arrowroot flour: Lesser yam flour: Potato flour were mixed at the ratio of 100:00:00, 00:100:00, 00:00:100, 00:50:50, 10:40:50, 20:30:50, 30:20:50, 40:10:50 and 50:00:50 respectively.

Various levels of extruder temperature 130, 150 and 170°C and screw speed 330, 360 and 390 rpm were used to prepare the extrudates from flour combinations of treatment (T1 to T6).

Extrusion cooking of tuber crop based extrudates

Extrusion of samples was performed using a co-rotating twin-screw extruder (M/s Basic Technology Pvt. Ltd., Kolkata, India). The length-to-diameter (L/D) ratio of the extruder was 8:1. The main drive of extruder was provided with a 7.5 HP motor (400 V, 3Φ, 50 cycles). The output shaft of worm reduction gear was provided with a torque limiter coupling. The barrel of the extruder received the feed from a co-rotating variable speed feeder. The barrel was provided with two electric band heaters and two water cooling jackets for circulation of tap water. A temperature sensor was fitted on the front die plate, which was connected to temperature control unit placed on the control panel of barrel. The die was required to be fixed on the face of barrel by a screw nut tightened by a special wrench provided. The twin screw extruder was kept on for 45 min to stabilize the set temperatures and samples were then poured in to feed hopper. The die diameter was selected at 5 mm and shape of opening of die was cylindrical. Length to diameter ratio of die was 2.5cm:5mm. Temperature range was 130, 150 and 170°C, screw speed was 330, 360 and 390 rpm. Direction of rotation of screws was counter rotating. The product was collected at the die end. Collected product was kept at 60±0.5°C in dryer (M/s: Basic Technology Private Ltd., Kolkata, India) for 1 h duration to remove extra moisture from the product. The samples were packed in polythene bags for further analysis.

Functional properties

The functional properties of extrudates are Expansion ratio, Bulk density, Water Absorption Index (WAI), Water Solubility Index (WSI), Colour and Hardness were determined as per the procedures described as below.

1. Expansion ratio

The expansion ratio of extrudates was determined as per the procedure described by (Pathania *et al.* 2013). The ratio of the diameter of the extrudate and the diameter of the die was used to express the expansion of the extrudate. The diameter of the extrudate was determined as the mean of random measurements made with a Vernier caliper (0.01 cm). The extrudates cut into 8-10 cm pieces. The diameter of extrudates were determined at 5 different locations along the length (d) of extrudates and against 90° to that length (d′) as given in Fig 4. The average value of diameter (eq.(1)) at these 5 locations was reported as diameter of extrudates. The experiment was replicated 10 times. The die diameter of extrudates was 5mm. Expansion ratio calculated by Eq. (2);

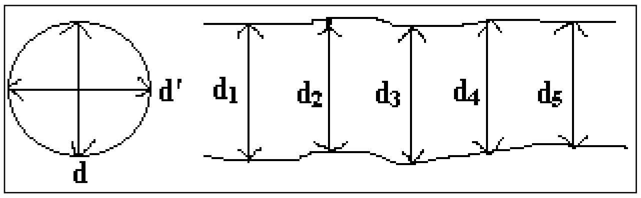


Fig. 4: Diameter of extrudates

Average value (d_{avg}) =

$$\frac{(d_1 + d_1') + (d_2 + d_2') + (d_3 + d_3') + (d_4 + d_4') + (d_5 + d_5')}{10} \quad \ldots(1)$$

$$\text{Expansion ratio} = \frac{\text{Average value } (d_{avg})}{\text{Die Diameter}} \quad \ldots(2)$$

2. Bulk density (g/cm³)

Bulk density (g/cm³) was calculated as per the procedure described by (Stojceska *et al.* 2008). Bulk density was calculated from the mass of extrudates, length of extrudates and average diameter (d_{avg}) of extrudates from eq. (1) as described in eq. 3. Bulk density (g/cm³) determined by using Eq. (3);

$$BD = \frac{4m}{\Pi \times {d_{avg}}^2 \times L} \quad \ldots(3)$$

Where:

m = Mass of extrudates, *g*;

L = Length of extrudates, cm; and

d_{avg} = Avearge diameter of individual extrudates, cm.

3. Water Absorption Index (WAI)

The WAI of extrudates were determined as per the procedure described by (Stojceska *et al.* 2008). The 1 g ground extrudate sample was suspended in 10 ml of water at room temperature for 30 min, the mixture is gently stirred during this period and then centrifuged at 3000 g for 15 min. The supernatant was decanted into an evaporating dish of known weight. The WAI was the weight of water obtained after removal of the supernatant per unit weight of original dry solids. WAI calculated by using Eq. (4);

$$\text{WAI} = \frac{\text{Weight gain by gel, (g)}}{\text{Dry weight of extruded, (g)}} \quad \ldots(4)$$

4. Water Solubility Index (WSI)

The WSI of extrudates were determined as per the procedure described by (Stojceska *et al.* 2008). WSI was determined as per procedure given in section 3. WSI was the weight of dry solids in the supernatant expressed as a percentage of the original weight of sample. WSI calculated by using Eq. (5);

$$\text{WSI (\%)} = \frac{\text{Weight of dry soild in supernatent}}{\text{Dry weight of extruded}} \times 100 \quad \ldots(5)$$

5. Hardness of Extrudates

The peak force as an indication of hardness was measured with Texture Analyzer (Model: Texture Pro CT V1.3, Make: Ametet (main)), M/s Brookfield Engineering Labs, Inc., USA) using TA3/100 probe. The test speed was 0.5 mm/s. The depth of penetration of probe in sample was 4 mm and 50 kg load cell was used. Extruded sample was placed below the probe and compression force was applied on it. Trigger load was provided 6g. After applying the force extruded sample was broken down. Force which was required to break the extruded known as hardness of extruded. The curve was recorded and analyzed by Texture Exponent 32 software program (version 3.0).

Nutritional Properties and colour measurement

The extruded prepared using the various treatment combinations i.e. T1, T2, T3, T4, T5 and T6 of flours, temperature of extrusion 130, 150 and 170°C and screw speed 330, 360 and 390 rpm. The extrudates prepared as per the above treatment combination were used for the nutritional properties analysis. The extrudates prepared using above mentioned treatment combinations was grounded to an average particle size of 1.30μ. The extrudate powders were equilibrated to 8% (db) MC in desiccators by using the saturated solution of salt Nacl at the atmospheric temperature to maintain its RH 75%. These flour samples were used as extruded sample flour.

The nutritional analysis i.e. protein, fat, fibre, ash, moisture and carbohydrates content of the extrudate flour samples of treatments T1, T2, T3, T4, T5 and T6 at 330, 360, 390 rpm screw speed and 130, 150 and 170°C temperature were determined as per the following standard procedures.

1. Moisture content

The initial moisture content of extrudates flour was determined by using hot air oven method (AOAC, 2010). The 10 g flour was taken in the moisture box. The moisture box was kept in hot air oven at 105^0C±1 for 24 h. The final weight of flour after 24 h was recorded. The experiment was recorded 3 times. The average moisture content reading is reported by using following Eq. (6);

$$\text{Moisture Content (db)\%} = \frac{M_2 - M_3}{M_3 - M_1} \times 100 \qquad \ldots(6)$$

Where:

M_1 = Weight of moisture box, *g*;

M_2 = Weight of moisture box + sample before drying, g; and

M_3 = Weight of moisture box + bone dried sample, *g*.

2. Protein

The protein content of extrudates flour was measured by Microkejdhal method (Ranganna, 1986). Around 0.25 g flour was taken for the analysis. 15 ml H_2SO_4 was added in the flour and solution was allowed to predigest for 14 h (overnight). After digestion of sample 5 ml H_2O_2 was added to it and mixture was shaken up to colour of sample change to colour less sample. Colour less sample was makeup up to volume 25 ml. The makeup sample (25 ml) was taken as volume of aliquot. After digestion procedure was complete, the sample was allowed for distillation was done in automatic distillation unit provided with receiver flask contained 20 ml boric acid indicator. The mixture of 10 ml colourless sample solution (aliquot) and 10 ml water was taken for distillation with flushing the NaOH as 25 ml in nitrogen distillation unit. The outlet tube of distillation unit assembly was properly submerged into the indicator. Mixing chamber of the assembly was heated for 6 minute or until the colour of indicator solution was changed from pink to green. The experiments were replicated for 3 times. The distillate sample was titrated against 0.01N H_2SO_4 and % protein content was calculated by Eq. (7);

$$\% \text{ Protein} = \frac{\left(\begin{array}{c}\text{(Sample titre} - \text{Blank titre)} \times \text{Normality of } H_2 2SO_4 \times \\ 0.014 \times \text{vol. of aliquot} \times 6.25 \times 100\end{array}\right)}{\text{Weight of sample taken}} \qquad \ldots(7)$$

3. Fat

Fat content of extrudates flour was determined using soxhlet fat extraction system (AOAC, 2010) by Soxhlet apparatus (Make: Elico, Hyderabad). In this method, initially weight of empty flask was weighed. 2 g flour was wrapped in filter paper. The sample with filter paper was kept in siphoning tube and condenser was fixed above it and siphoned for 9-12 times with the petroleum ether in soxhlet apparatus. After removing assembly, evaporation of petroleum ether was allowed by heating round bottom flask. Residue remained at the bottom of the flask and was reweighed with flask. The quantity of residue was determined as fat content of flour. The experiments were replicated for 3 times. Fat content was calculated by using Eq. (8);

$$\text{Fat content} = \frac{\text{Final wt.} - \text{Initial wt}}{\text{Wt. of sample}} \times 100 \qquad \ldots(8)$$

4. Crude fibre

The fibre content of extrudates flour was determined from the fat free sample available in filter paper from fat extraction method (Ranganna, 1986). The filter paper and fat free residue was kept in the oven for 105º C for 5-6 hours. Around 2 g sample from oven was taken into 600 ml beaker and boiled; to it 200 ml of 1.25% H_2SO_4 was added. The beaker containing solution was placed on hot plate for 30 minute. After heating residue from beaker was filtered through filter paper and rinsed beaker with 50 to 75 ml boiling water for three times. The filtered residue from filter paper was dried by convective hot air drying for 2-3 h at 130±1°C. The dried residue from convective hot air dryer was transferred to 600 ml beaker and boiled, 200 ml 1.25 % NaOH was added to it and boiled for 30 minutes on hot plate. After heating the residue from beaker was filtered through filter paper and rinsed beaker with 50 to 75 ml boiling water for three times. The filtered residue from filter paper was dried by convective hot air drying at 130^0 C for 2 h. The dried residue was weighed after cooling and weight was noted. The weighed residue was transferred to crucible in hot air oven and ignited for 30 minutes at 600^0 C and reweighed after cooled in dessicator and weight was recorded. The experiments were replicated for 3 times. The fibre content of extrudates flours were calculated by Eq. (9);

$$\% \text{ Fibre} = \frac{\text{weight of residue with crucible} - \text{weight of ash with crucible}}{\text{weight of sample}} \times 100 \quad \dots(9)$$

5. Ash content

Ash content of extrudates flour was calculated using muffle furnace. Five gram of flour was taken in a crucible. Weight of crucible and flour was recorded and kept in muffle furnace at 650°C for 4-5 h till constant weight was achieved. It was observed for three constant readings. The crucible was cooled in desiccators and final weight of ash and crucible was recorded. The experiments were replicated for 3 times. Ash content was calculated by using Eq. (10);

$$\text{Ashcontent}, \% = \frac{W_2 - W}{W_1 - W} \times 100 \quad \dots(10)$$

Where,

W = weight of crucible, g;

W_1 = weight of crucible and flour, g; and

W_2 = weight of crucible with ash, g.

6. Carbohydrates

Carbohydrate content was determined by subtracting the total sum of protein, fibre, ash and fat from the total dry matter (Vengaiah *et al.* 2013). Carbohydrates were calculated by using Eq. (11);

$$\text{Carbohydrates} = 100 - (\text{protein} + \text{fat} + \text{fibre} + \text{ash} + \text{moisture content}) \quad \dots(11)$$

7. Colour

A colour co-ordinate of flour was measured under Hunter Lab calorimeter. The equipment was calibrated by using standard white and black tiles. The extrudates sample (60 g) was ground into flour with help of grinder. 5 g ground sample of the extrudates was taken into a glass sample holder of the color meter. The sample holder was kept on the aperture of the colour measuring device in such a way that light should not pass through it and the colour was measure in *L*, *a* and *b* values, the equipment given the colour values in terms of yellowness index.

Yellowness index (*YI*) of *L*, *a* and *b* values was determined (Pankaj *et al.* 2012). Yellowness index was determined by using Eq. (12);

$$\text{YI} = \frac{142.87\text{b}}{\text{L}} \quad \dots(12)$$

Where:

L = Degree of lightness or darkness

a = Redness to greenness

b = Yellowness to blueness

Sensory evaluation

The extrudates for all the treatments (Flour combinations (T1 to T6); Temperature (130, 150 and 170°C); screw speed (330, 360 and 390 rpm)) were mixed with spices (100 g extrudates sample, 10 g chat masala and 5 g vegetable oil) the extrudates were dried in a convective hot air drying at 50°C for 1 h. These samples for each treatment were cut into uniform length 2-3 cm size pieces and placed in the paper dish. These samples were organoleptically tested for different quality attributes like appearance, taste, colour, texture and overall acceptability.

Sensory evaluation was performed by a panel of 45 trained judges of various age groups consisted of students, staff and faculty members from the CAET, Dr. BSKKV, Dapoli (MS). Samples were coded using random code A to C11 (54 samples). Panelists were served with salted potato chips, water to break the monotony in taste of the extrudates. Mean sensory scores for quality attributes (appearance, taste, colour, texture) and overall acceptability were recorded in individual sheet and average scores are reported.

Optimization of Responses for Functional and Nutritional properties of tuber crops extrudates

The effect of temperature of the extruder barrel and screw speed on various parameters of functional properties i.e. expansion ratio, bulk density, water absorption index, water solubility index, hardness and colour of the extrudates were assessed by response surface methodology (RSM) as described by Myers (1971). The variables which were found to influence the extrusion process were termed as regression or factors (X_k). The dependant variables were considered as Response Parameters (Y_k). Y_k and X_k were assumed to be correlated with a second order polynominal in the following form. The second order quadratic model was chosen assuming it will provide a good approximation of the relationship Eq. (13);

$$Y_k = \beta_{ko} + \sum_{i=1}^{n} \beta_{ki} X_i + \sum_{i=1}^{n} \beta_{ki} X_i^2 + \sum_{i=1}^{n} \sum_{j=i+1}^{n} \beta_{ki} X_i X_j \quad \ldots(13)$$

Where,

β_{ko} and β_{ki} are the regression coefficients.

The values of independent variables were coded within -1, 0 and +1. The coading of X_i (actual value of independent variable) in to E_i (coded value) was done by following Eq. (14);

$$E_i = \frac{X_i - X_{i(mean)}}{X_{i(mean)} - X_{min}} \quad \ldots(14)$$

Where,

X_i = Actual value of factor, *i*;

$X_{i(mean)}$ = The mean of high and low levels of the factor, *i*; and

$X_{i(min)}$ = Minimum value of factor, *i*.

The most desirable parameters of the extrudates were to obtain, product of lower bulk density, more expansion ratio, lower hardness, higher water absorption index and higher water solubility index.

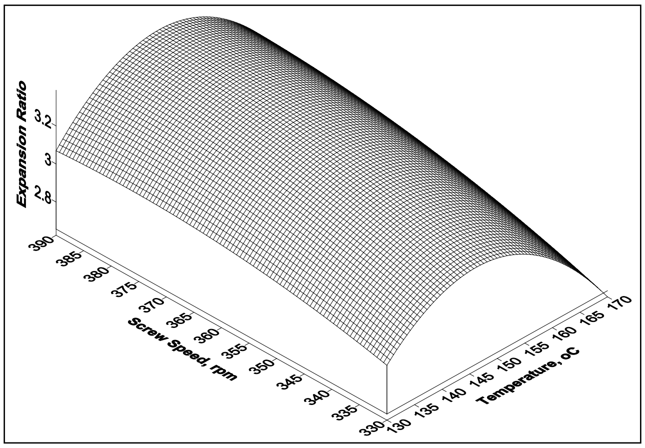
The product obtained with the above procedure should have better nutritional properties (protein, fat, fibre and ash) and more overall acceptability by the panelist.

RESULTS AND DISCUSSION

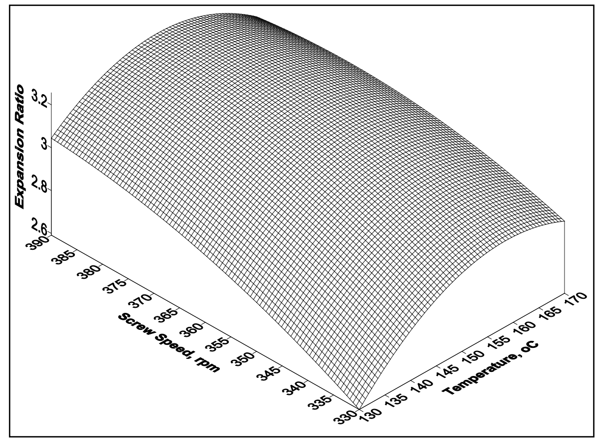
Functional properties

1. Expansion ratio

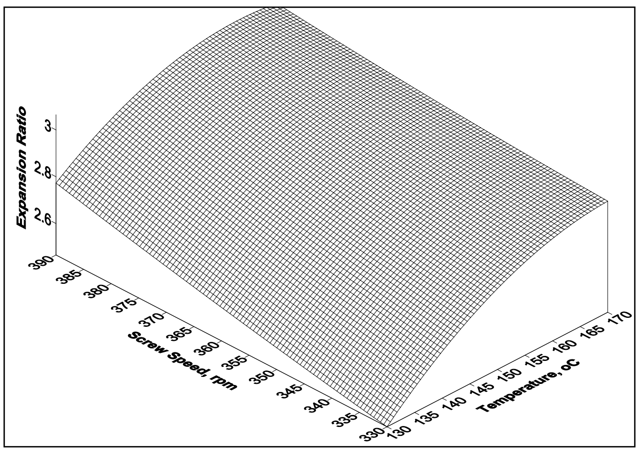
Fig. 5 (a)-(f) shows the surface plots of effect of temperature of extrusion (°C) and screw speed (rpm) on the expansion ratio of the extrudates for treatment (a) T1, (b) T2, (c) T3, (d) T4, (e) T5, (f) T6. The expansion ratio for tuber crops extrudates were in the range of 2.12-3.35 for all the treatments (T1 to T6), temperature of extrusion (130 to 170°C) and screw speed (330 to 390). Expansion ratio for treatment T1 ranges from 2.45-3.35, for T2 from 2.55-3.18, for T3 from 2.38-3.06, for T4 from 2.19-3.01, for T5 from 1.96-2.99 and for T6 from 2.12-3.06 respectively. As the temperature of extrusion increases from 130°C to 170°C the expansion ratio of extrudates increases for all treatments i.e. T2 to T6. However in treatment T1 the expansion ratio increases gradually from 130°C to 145°C followed by decreasing trend up to 170°C, which can be observed from contour plots Fig. (6) (a)-(f). Similarly if the screw speed of the extruder



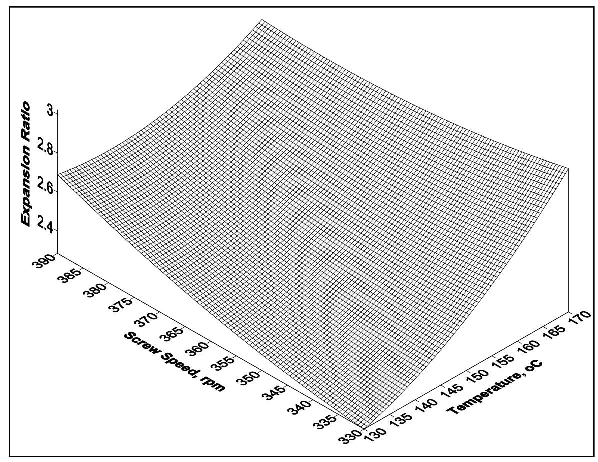
(a) T1



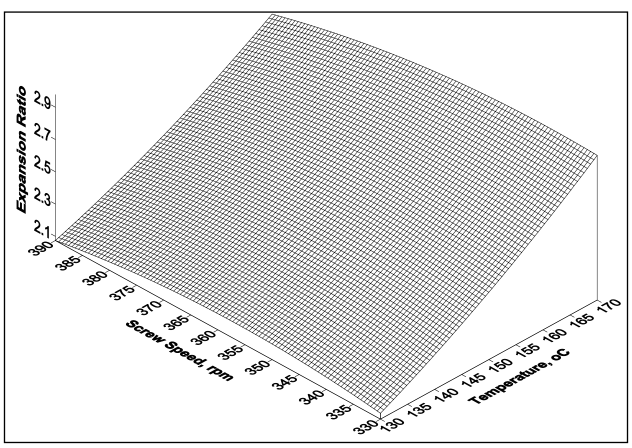
(b) T2



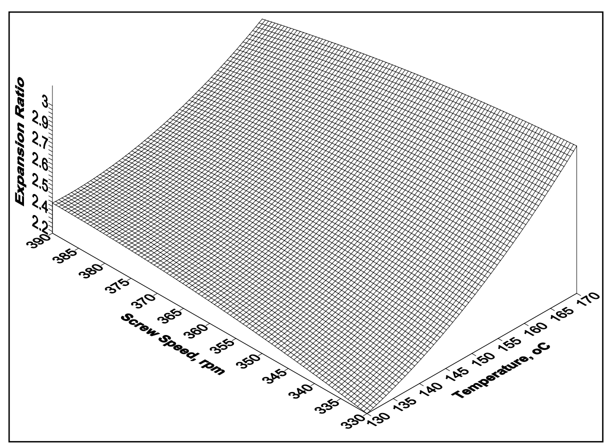
(c) T3



(d) T4



(e) T5



(f) T6

Fig. 5: Surface plots of Effect of Temperature of Extrusion, Screw Speed on Expansion Ratio of Tuber Crops based extrudates **(a)** For Treatment *T*1; **(b)** For Treatment T2; **(c)** For *T* For Treatment *T*3; **(d)** For Treatment *T*4; **(e)** For Treatment *T*5; **(f)** For Treatment *T*6

increases from 330 rpm to 390 rpm the expansion ratio increases for treatments T1, T2, T3, T4, T5 and T6. In treatment T5 as the screw speed increases from 330 rpm to 390 rpm the expansion ratio increases up to 360 rpm followed by a decreasing trend.

During the extrusion cooking lesser yam flour play significant role in expansion of extrudates. In extrusion cooking, if lesser yam proportion increases in flour combination then the expansion ratio of extrudates also increases and vice versa. In treatments T1, T2, T3, T4, T5 and T6 expansion ratio decreases with decrease the proportion of lesser yam in flour combination from T1 to T6 during extrusion cooking which is shown in Table 2.

The second order polynomials equation shows the effect of temperature of extrusion (°C) and screw speed (rpm) on the expansion ratio of tuber crop extrudates for treatments T1, T2, T3, T4, T5 and T6 are given in eq^{n}. (15), (16), (17), (18), (19) and (20) respectivally.

$$ER_{T1} = -24.826 + 0.047S - 7.611 \times 10^{-5} S^2 + 0.255T + 7.708 \times 10^{-5} ST - 9.587 \times 10^{-4} T^2 \quad \ldots(15)$$

$$ER_{T2} = -29.858 + 0.093S - 9.648 \times 10^{-5} S^2 + 0.198T - 1.299 \times 10{-}5\ ST - 4.920 \times 10^{-4} T^2 \quad \ldots(16)$$

$$ER_{T3} = -8.717 + 7.129 \times 10^{-3} S + 1.203 \times 10{-}5\ S^2 + 0.120T - 8.208 \times 10{-}5\ ST - 2.70 \times 10^{-4} T^2 \quad \ldots(17)$$

$$ER_{T4} = 2.197 - 0.012S + 6.685 \times 10^{-5} S^2 + 0.016T - 2.258 \times 10^{-4} ST + 2.541 \times 10^{-4} T^2 \quad \ldots(18)$$

$$ER_{T5} = 12.922 + 0.075S - 9.074 \times 10^{-5} S^2 + 0.011T - 8.125 \times 10^{-5} ST + 1.233 \times 10^{-4}) T^2 \quad \ldots(19)$$

$$ER_{T6} = -10.283 + 0.063S - 4.611 \times 10^{-5} S^2 + 6.783 \times 10^{-3} T - 2.075 \times 10^{-4} ST + 2.787 \times 10^{-4} T^2 \quad \ldots(20)$$

Where;

T = Temperature of barrel (extrusion) °C

S = Screw speed (rpm)

ER_{T1}, ER_{T2}, ER_{T3}, ER_{T4}, ER_{T5} and ER_{T6} = Expansion ratio at treatment T1, T2, T3, T4, T5 and T6 respectivaly.

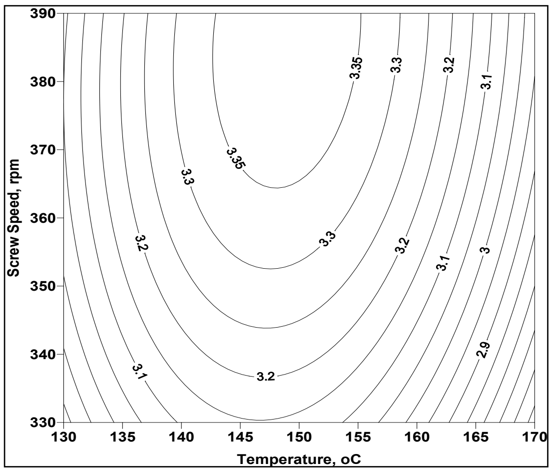
Table 2 and 7(a) shows the ANOVA for the effect of flour composition (T1-T6), temperature of extrusion (130-170°C) and screw speed (330-390 rpm) on expansion ratio of the tuber crops extrudates at $p \leq 0.01$. It is clear from the table, all the quadratic effects from barrel temperature, screw speed and ingredient composition were significant with ER. The interaction effect between barrel temperature and screw speed, screw speed, ingredient composition and barrel temperature were significant ($p \leq 0.01$) with ER. In expansion ratio, individual effect of screw speed and temperature were significant effect on the ingredients composition. The effect of temperature at constant screw speed along with flour composition on expansion ratio was a non significant ($p \leq 0.01$).

The combined effect of increase of barrel temperature (130-170°C) and increase of screw speed (330-390 rpm) increases the expansion ratio for all the treatments i.e. T1 to T6. Increase in barrel temperature with increase in screw speed increased the expansion ratio of extrudates. Similar observations observed in barley grape pomace, carrot rice pulse, carrot pomace powder, broken rice flour: pineapple waste pulp powder: red gram powder, wheat: mungbean: groundnut (Kumar *et al.* 2010; Altan *et al.* 2008; Upadhyay, 2009; Ding *et al.* 2006; Pathania *et al.* 2013; Kothakota *et al.* 2013) have been reported.

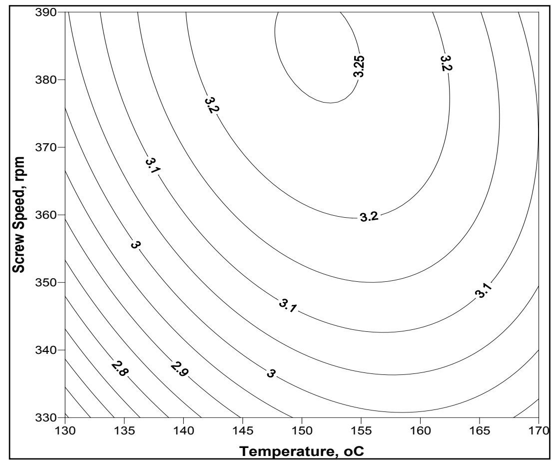
The expansion ratio increased with increases in screw speed, which may be due to high mechanical shear resulting in higher expansion. The expansion ratio rapidly increased with increase in temperature which may be due to higher degree of superheating of water in the extruder encountering the bubble formation consequently resulting in higher expansion (Ding *et al.* 2006).

2. Bulk density (BD)

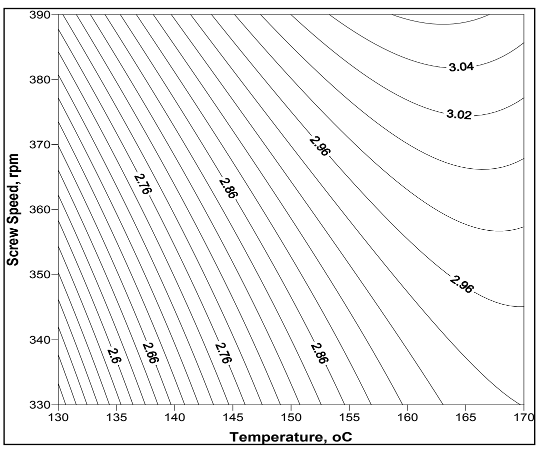
Fig. 7 (a)-(f) shows the surface plots of effect of temperature of extrusion (°C) and screw speed (rpm) on the bulk density of extrudates for treatment (a) T1, (b) T2, (c) T3, (d) T4, (e) T5 and (f) T6. The bulk density



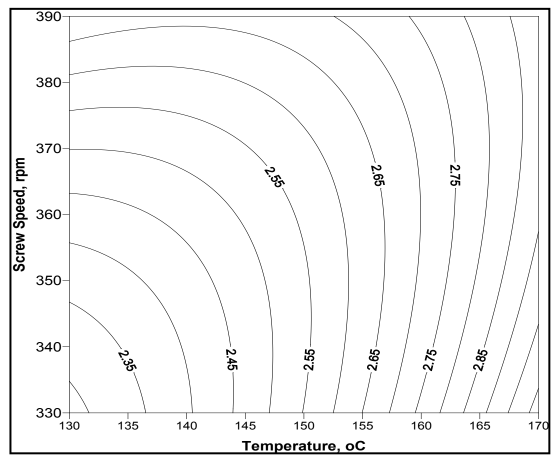
(a) T1



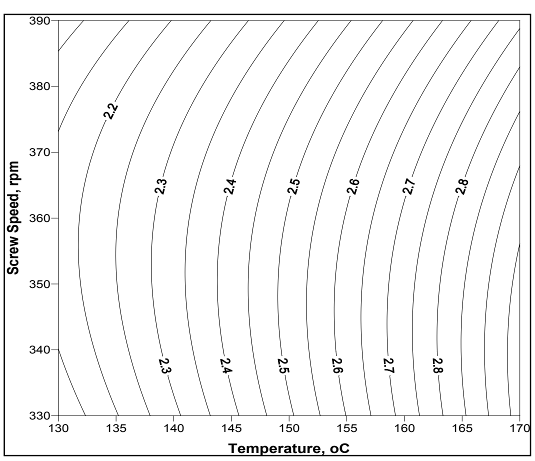
(b) T2



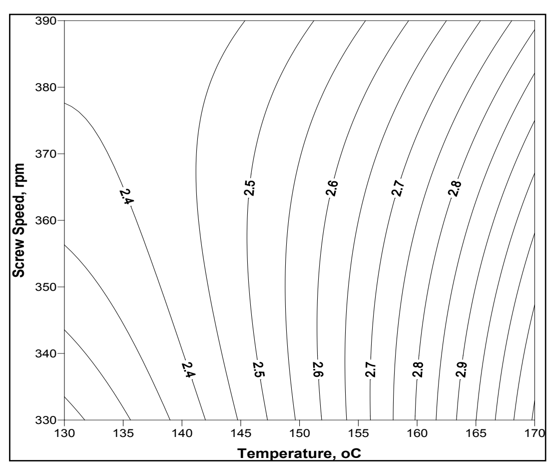
(c) T3



(d) T4

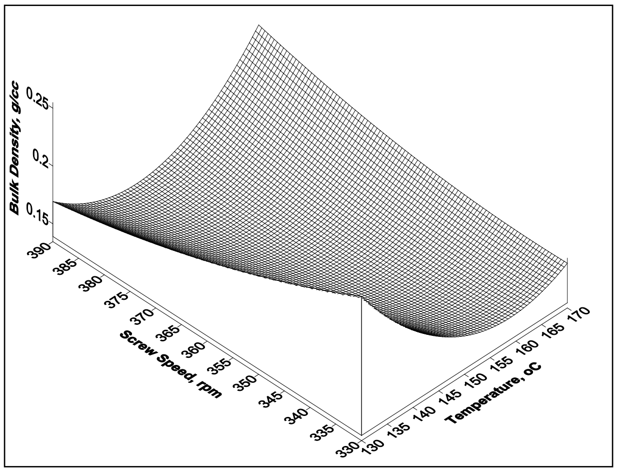


(e) T5

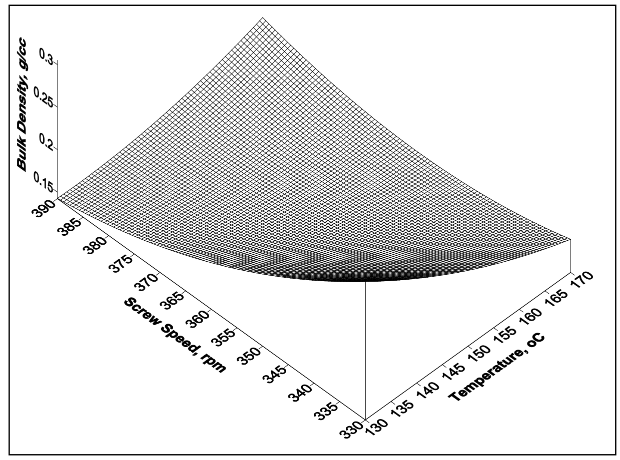


(f) T6

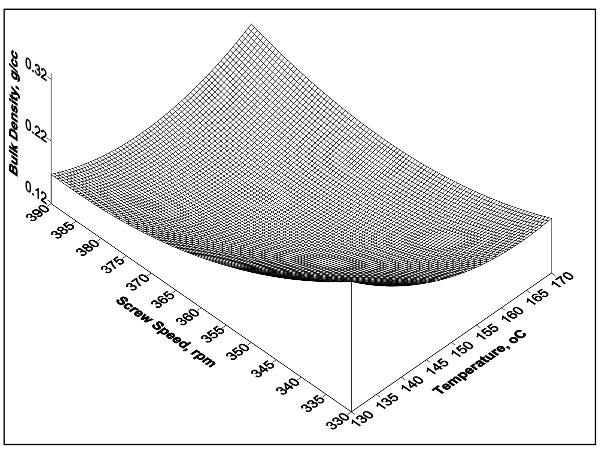
Fig. 6: Contour plots of Effect of Temperature of Extrusion, Screw Speed on Expansion ratio of Tuber Crops based Extrudates **(a)** For Treatment T1; **(b)** For Treatment T2; **(c)** For T For Treatment T3; **(d)** For Treatment T4; **(e)** For Treatment T5; **(f)** For Treatment T6



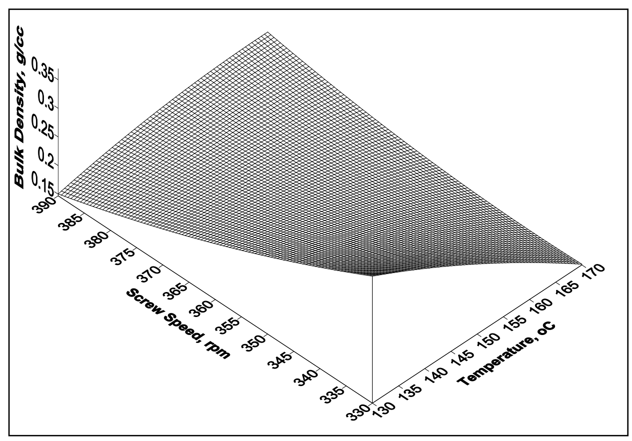
(a) T1



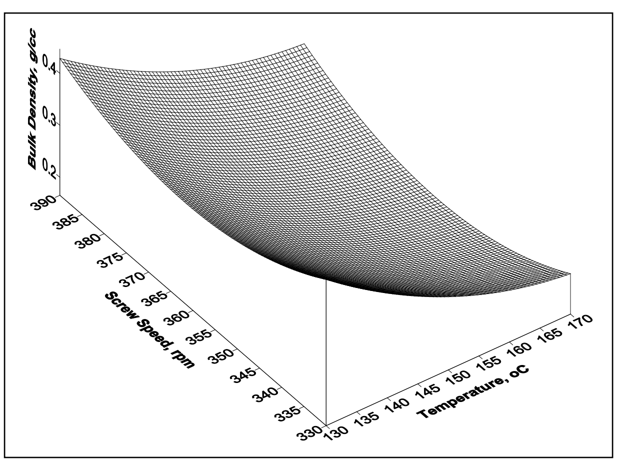
(b)T2



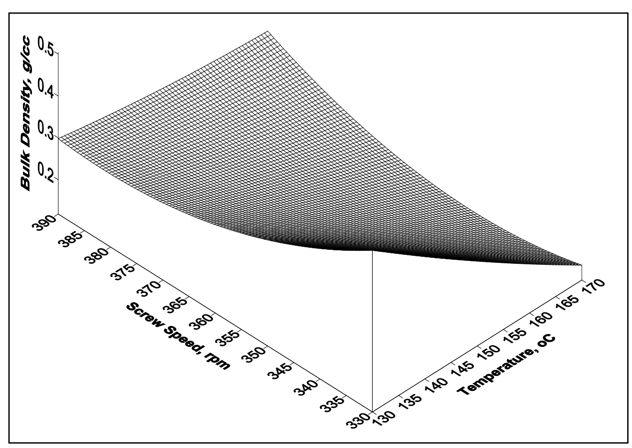
(c) T3



(d) T4



(e) T5



(f) T6

Fig. 7: Surface plots of Effect of Temperature of Extrusion, Screw Speed on Bulk Density **(a)** For Treatment T1; **(b)** For Treatment T2; **(c)** For T For Treatment T3; **(d)** For Treatment T4; **(e)** For Treatment T5; **(f)** For Treatment T6

for tuber crops extrudates were in the range of 0.553-0.123 g/cm^3 for treatments (T1 to T6), temperature of extrusion (130 to 170°C) and screw speed (330 to 390 rpm). Bulk density for treatment T1 ranges from 0.122-0.279g/cm^3, for T2 from 0.134-0.315g/cm^3, for T3 from 0.123-0.351g/cm^3, for T4 from 0.127-0.380g/cm^3, for T5 from 0.198-0.459g/cm^3 and for T6 from 0.148-0.553g/cm^3 respectively for all treatments (T1 to T6), temperature of extrusion (130 to 170°C) and screw speed (330 to 390 rpm). As the temperature of extrudates increases from 130°C to 170°C the bulk density of the extrudates decreases for treatments T2 to T6. However in treatment T1 the bulk density decreases gradually form 130°C to 150°C followed by increasing trend up to 170°C which can observed from counter plots Fig.8 (a)-(f). Similarly as the screw speed of the extruder increases from 330 to 390 rpm bulk density decreases for treatments T1, T2, T3, T4 and T6. In treatment T5 as the screw speed increases from 330 to 390 rpm the bulk density decreases up to 350 rpm followed by a increasing trend upto 90 rpm.

During extrusion cooking, lesser yam play a significant role in bulk density of the extruded products. As the composition of lesser yam increases in flour composition, bulk density of extrudates decreased and vice versa. For treatment T1 to T6 proportion of lesser yam decreased from 50% to 00% and bulk density of extrudates also increased shown in Table 3.

The second order polynomials equation shows the effect of temperature of extrusion (°C) and screw speed (rpm) on the bulk density of tuber crop extrudates for treatments T1, T2, T3, T4, T5 and T6 are given in eq^n. (21), (22), (23), (24), (25) and (26) respectively.

$$BD_{T1} = 7.473 - 0.016S + 1.185 \times 10^{-5} S^2 - 0.055T + 5.166 \times 10{-}5\ ST + 1.2 \times 10^{-4} T^2 \quad \ldots(21)$$

$$BD_{T2} = 9.005 - 0.033S + 2.981 \times 10^{-5} S^2 - 0.034T + 6.791 \times 10^{-5} ST + 2.958 \times 10^{-5} T^2 \quad \ldots(22)$$

$$BD_{T3} = 13.447 - 0.048S + 5.351 \times 10^{-5} S^2 - 0.055T + 5.874 \times 10^{-5} ST + 1.091 \times 10^{-4} T^2 \quad \ldots(23)$$

$$BD_{T4} = 8.542 - 0.029S + 1.685 \times 10{-}5\ S^2 - 0.033T + 1.091 \times 10^{-4} ST - 2.708 \times 10^{-5} T^2 \quad \ldots(24)$$

$$BD_{T5} = 14.714 - 0.063S + 8.592 \times 10^{-5} S^2 - 0.036T + 7.083 \times 10^{-6} ST + 9.708 \times 10^{-5} T^2 \quad \ldots(25)$$

$$BD_{T6} = 18.764 - 0.076S + 8.018 \times 10^{-5} S^2 - 0.055T + 1.216 \times 10^{-4} ST + 2.041 \times 10^{-5} T^2 \quad \ldots(26)$$

Where;

T = Temperature of barrel (extrusion) °C

S = Screw speed (rpm)

BD_{T1}, BD_{T2}, BD_{T3}, BD_{T4}, BD_{T5} and BD_{T6} = Bulk density at treatment T1, T2, T3, T4, T5 and T6 respectivaly.

Table 3 and 7(b) shows the ANOVA for the effect of flour composition, temperature of extrusion and screw speed on the bulk density of the tuber crops extrudates. It is clear from the table, flour composition, screw speed and temperature have a significant effect ($p \leq 0.01$) on bulk density. The interaction between the flour compositions, screw speed and temperature has also a significant difference ($p \leq 0.01$) on the bulk density.

The trend of bulk density was inversely related to the expansion ratio. Decrease in bulk density with increase in temperature, which may be due to increasing the pressure inside the extruder barrel. Decrease in bulk density with increases in screw speed, which may due to the starch gelatinization decreases (Hagenimana *et al.* 2006).

The combined effect of increase in barrel temperature (130-170°C) and screw speed (330-390 rpm) decreases the bulk density for all the treatments i.e. T1 to T6 of tuber crops extrudates. Increase in barrel temperature with increase in screw speed decreases bulk density of the extruded products. These results are in agreement with extrudates prepared from corn/soybean feed, texturized rice, broken rice flour:pineapple waste pulp powder: red gram powder, rice:sweet potato: yam, carrot pomace: rice flour: pulse powder, rice flour, wheat, mungbean and groundnut (Sahagun and Harper, 1980; Ding *et al.* 2006; Kothakota *et* *al.* 2013; Hazarika *et al.* 2013; Kumar *et al.* 2010; Hagenimana *et al.* 2006 and Pathania *et al.* 2013)

3. Water Absorption Index (WAI)

Fig. 9 (a)-(f) shows the surface plots of effect of temperature of extrusion (°C) and screw speed (rpm) on the water absorption index of extrudates for treatment (a) T1, (b) T2, (c) T3, (d) T4, (e) T5 and (f) T6. The water absorption index for tuber crops extrudates were in the range of 5.87-3.00 g/g for all the treatments (T1 to T6), at varied temperature of extrusion (130 to 170°C) and screw speed (330 to 390 rpm). Water absorption index for treatment T1 ranges from 3.00-4.93g/g, for T2 from 3.53-4.53g/g, for T3 from 2.73-5.53g/g, for T4 from 3.20-5.87g/g, for T5 from 3.40-5.00g/g and for from T6 3.00-4.87g/g respectively for all the treatments (T1 to T6), temperature of extrusion (130 to 170°C) and screw speed (330 to 390 rpm). The temperature of extrudates increases from 130°C to 170°C the water absorption index of the extrudates decreases for treatments T2, T3, T5 and T6. However in treatment T1 the water absorption index increases gradually form 130°C to 170°C. Similarly in treatment T4 water absorption index increases gradually from 130 to 170°C, which can observe from counter plots Fig. 10 (a)-(f). Similarly as the screw speed of the extruder increases from 330 to 390 rpm water absorption index decreases for treatments T1, T3 and T6. In treatment T2, T4 and T5 as the screw speed increases from 330 to 390 rpm the water absorption index increases up to 390 rpm, which can observe from counter plot Fig. 10 (a)-(f).

During extrusion cooking, lesser yam play important role in water absorption index of extrudates. As the lesser yam composition decreases in flour combination, water absorption index does not significantly change or it does not vary. Flour composition varied from T1 to T6 with decreasing the proportion of lesser yam. Water absorption index was shown in Table 4.

The second order polynomials equation shows the effect of temperature of extrusion (°C) and screw speed (rpm) on the water absorption index of tuber crop extrudates for treatments T1, T2, T3, T4, T5 and T6 are given in eq^n. (27), (28), (29), (30), (31) and (32) respectively.

$$WAI_{T1} = -76.931 + 0.276S - 3.086 \times 10^{-4} S^2 + 0.467T - 5.000 \times 10^{-4} ST - 9.444 \times 10^{-4} T^2 \quad \ldots(27)$$

$$WAI_{T2} = 34.713 - 0.129S + 1.419 \times 10^{-4} S^2 - 0.101T + 2.083 \times 10^{-4} ST - 6.944 \times 10^{-5} T^2 \quad \ldots(28)$$

$$WAI_{T3} = 34.713 - 0.129S + 1.419 \times 10^{-4} S^2 - 0.101T + 2.083 \times 10^{-4} ST - 6.944 \times 10^{-5} T^2 \ldots(29)$$

$$WAI_{T4} = -17.388 - 0.036S + 3.641 S^2 + 0.352T + 1.111 \times 10^{-4} ST - 1.247 \times 10^{-3} T^2 \quad \ldots(30)$$

$$WAI_{T5} = 75.050 - 0.317S + 13.827 \times 10^{-4} S^2 - 0.190T + 3.333 \times 10{-}4\ ST + 1.944 \times 10^{-4} T^2 \quad \ldots(31)$$

$$WAI_{T6} = 119.051 - 0.565S + 6.296 \times 10^{-4} S^2 - 0.182T + 7.500 \times 10^{-4} ST - 2.916 \times 10^{-4} T^2 \quad \ldots(32)$$

Where;

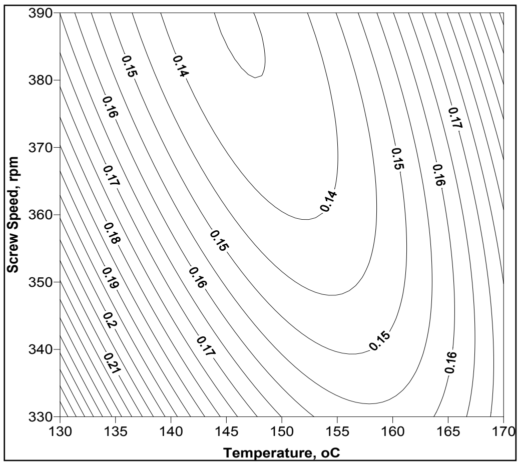
T = Temperature of barrel (extrusion) °C

S = Screw speed (rpm)

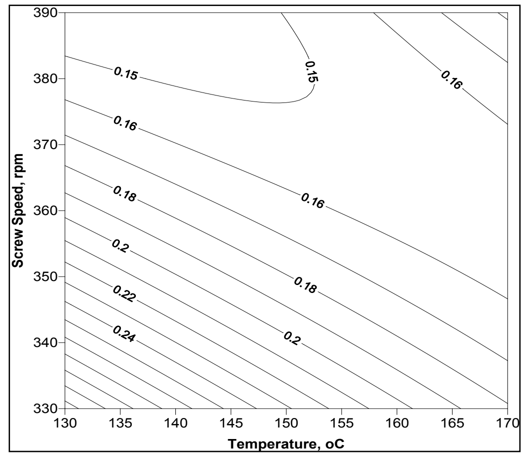
WAI_{T1}, WAI_{T2}, WAI_{T3}, WAI_{T4}, WAI_{T5} and WAI_{T6} = Water absorption index at treatment T1, T2, T3, T4, T5 and T6 respectively.

Table 4 and 7(c) shows the ANOVA for the effect of flour composition, temperature of extrusion and screw speed on the water absorption index of the tuber crops extrudates. It is clear from the table, water absorption index have a significant effect ($p \leq 0.01$) between the flour composition, screw speed and temperature. The interaction between the flour compositions, screw speed and temperature has a significant difference in the water absorption index. The interactions among independent variables significantly affected the WAI values ($P \leq 0.01$).

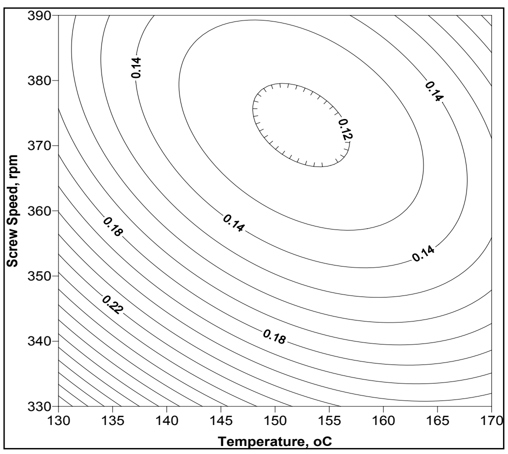
Increase in temperature resulted in decrease in water absorption index. Whereas further increase water absorption index may be due to dextrinization of starch molecules at higher temperature, similar



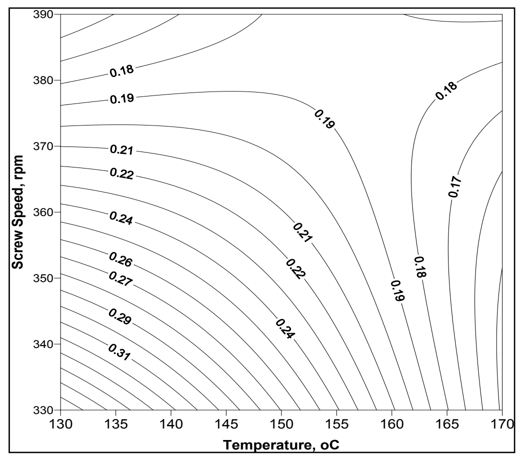
(a) T1



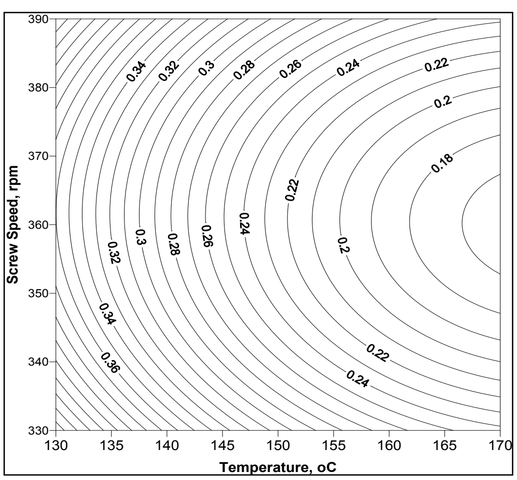
(b) T2



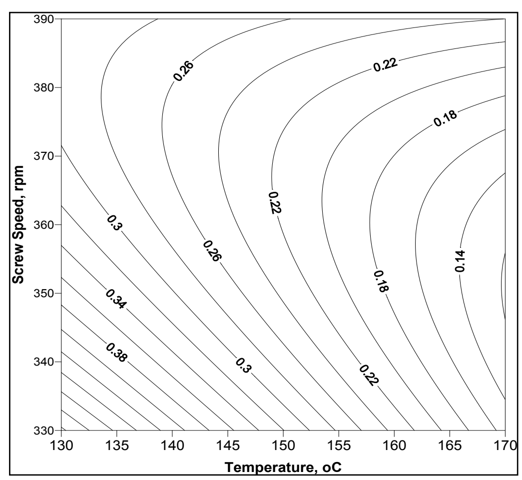
(c) T3



(d) T4



(e) T5



(f) T6

Fig. 8: Contour plots of Effect of Temperature of Extrusion, Screw Speed on Bulk Density of Tuber Crops based Extrudates **(a)** For Treatment T1; **(b)** For Treatment T2; **(c)** For T For Treatment T3; **(d)** For Treatment T4; **(e)** For Treatment T5; **(f)** For Treatment T6

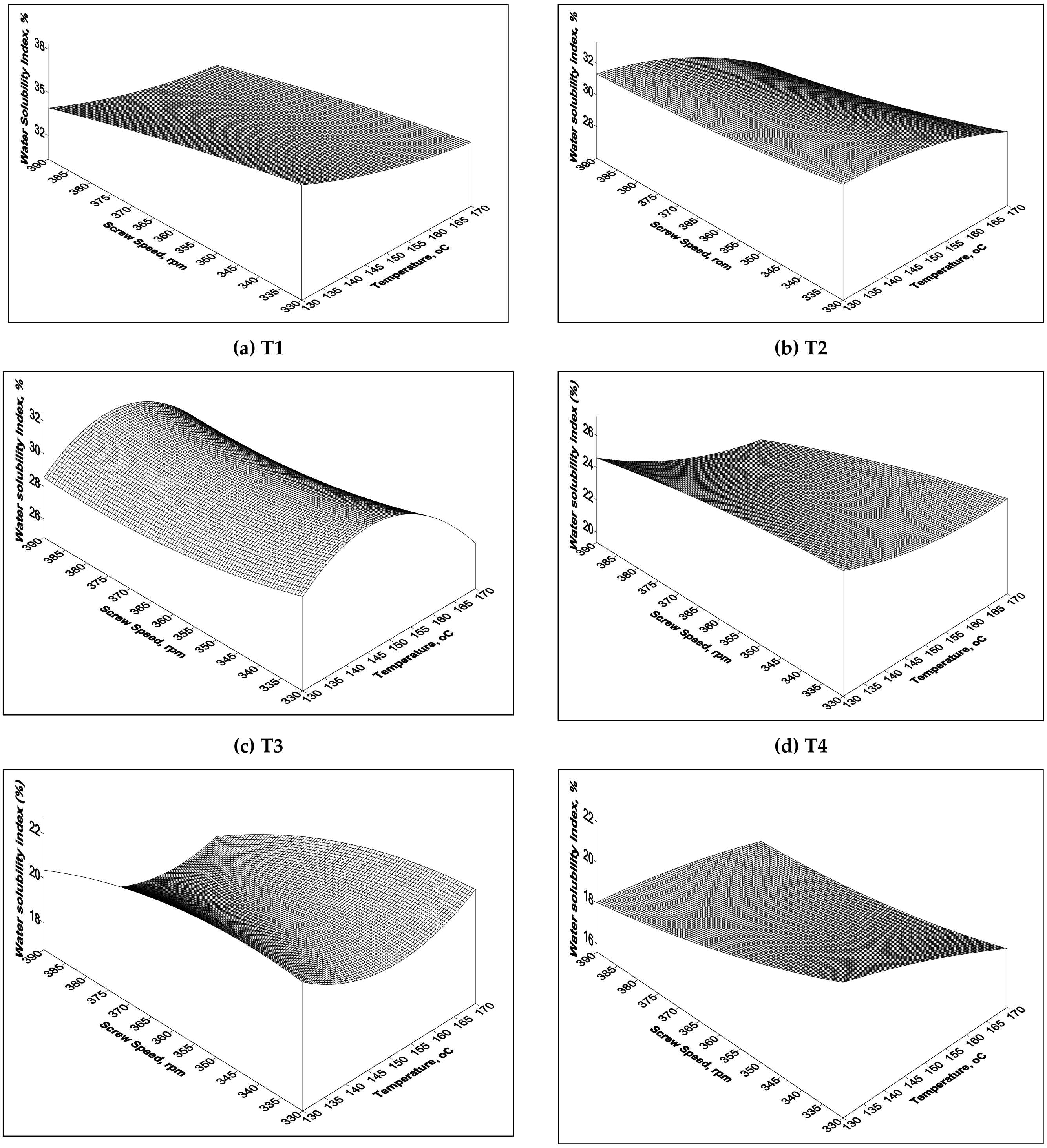


Fig. 9: Surface plots of Effect of Temperature of Extrusion, Screw Speed on Water solubility Index of Tuber Crops based extrudates **(a)** For Treatment T1; **(b)** For Treatment T2; **(c)** For T For Treatment T3; **(d)** For Treatment T4; **(e)** For Treatment T5; **(f)** For Treatment T6

observations were reported by Mercier and Feillet (1975) for cereal products. Water absorption index increased with increase in screw speed, may be attributed to high mechanical shear and higher expansion due to gelatinization of starch molecules. Whereas further decrease water absorption index may be because of plasticization of melt at higher moisture content (Ding *et al.* 2006; Kumar *et al.* 2010).

The combined effect of increase in barrel temperature (130-170°C) and screw speed (330-390 rpm) decreases the water absorption index for all the treatments i.e. T1 to T6 of tuber crops extrudates. These results are in consistant with the extruded products prepared from for broken rice flour: pineapple waste paste powder: red gram powder, pomace: rice flour: pulse powder, wheat: mungbean: groundnut, barley-tomato pomace (Kothakota *et al.* 2013; Kumar *et al.* 2010; Pathania *et al.* 2013; Altan *et al.* (2008)).

4. Water solubility index (WSI)

Fig. 10 (a)-(f) shows the surface plots of effect of temperature of extrusion (°C) and screw speed (rpm) on the water solubility index of extrudates for treatment (a) T1, (b) T2, (c) T3, (d) T4, (e) T5 and (f) T6. The water solubility index for tuber crops extrudates were in the range of 38.00-15.33% for all treatments (T1 to T6), varied temperature of extrusion (130 to 170°C) and screw speeds (330 to 390 rpm). Water solubility index for treatment T1 was ranges from 30.66-38.00%, for T2 from 26.00-33.33%, for T3 from 22.66-32.00%, for T4 from 19.33-27.33%, for T5 from 16.00-23.33% and for T6 from 15.33-21.33% respectively. The temperature of extrudates increases from 130°C to 170°C the water solubility index of the extrudates decreases for treatments T1, T2, T3, T4, T5 and T6, which can observe from counter plots Fig. 12 (a)-(f). Similarly as the screw speed of the extruder increases from 330 to 390 rpm water solubility index decreases for treatments T1, T2, T3, T4, T5 and T6, this can observe from counter plots Fig. 12 (a)-(f).

During extrusion cooking, lesser yam play an important role in water solubility index. As the lesser yam proportion decreases in flour composition from T1 to T6 the water solubility index of the extrudates decreases and vice versa. If lesser yam composition increases in flour composition then water solubility index also increases in extruded an product which was shown in Table 5.

The second order polynomials equation shows the effect of temperature of extrusion (°C) and screw speed (rpm) on the water solubility index of tuber crop extrudates for treatments T1, T2, T3, T4, T5 and T6 are given in eq^n. (33), (34), (35), (36), (37) and (38) respectivally.

$$WSI_{T1} = 66.924 + 0.105S - 2.487 \times 10^{-4}\, S - 0.422T - 1.293 \times 10^{-15}\, ST + 1.111 \times 10^{-4}\, T^2 \quad ...(33)$$

$$WSI_{T2} = 16.436 - 0.155S + 3.691 \times 10{-}4\, S^2 + 0.795T - 1.106 \times 10^{-3}\, ST - 1.656 \times 10^{-3}\, T^2 \quad ...(34)$$

$$WSI_{T3} = -26.500 - 0.622S + 8.654 \times 10^{-4}\, S^2 + 2.433T - 2.749 \times 10^{-4}\, ST - 8.061 \times 10^{-3}\, T^2 \quad ...(35)$$

$$WSI_{T4} = -23.304 + 0.0.405S - 3.722 \times 10^{-4}\, S^2 - 0.088T - 1.387 \times 10^{-3}\, ST + 1.662 \times 10^{-3}\, T^2 \quad ...(36)$$

$$WSI_{T5} = -57.601 + 0.496S - 9.851 \times 10^{-4}\, S^2 - 0.733T - 1.108 \times 10^{-3}\, ST + 3.608 \times 10^{-3}\, T^2 \quad ...(37)$$

$$WSI_{T6} = 132.571 - 0.496S + 4.907 \times 10^{-4}\, S^2 - 0.111T + 5.583 \times 10^{-4}\, ST - 5.583 \times 10^{-4}\, T^2 \quad ...(38)$$

Where;

T = Temperature of barrel (extrusion) °C

S = Screw speed (rpm)

WSI_{T1}, WSI_{T2}, WSI_{T3}, WSI_{T4}, WSI_{T5} and WSI_{T6} = Water solubility index at treatment T1, T2, T3, T4, T5 and T6 respectivaly.

Table 5 and 7(d) shows the ANOVA for the effect of flour composition, temperature of extrusion and screw speed on the water solubility index of the tuber crops extrudates. It is clear from the table, water solubility index have a significant effect ($p \leq 0.01$) between the flour composition, screw speed and temperature. The interaction between the flour compositions, screw speed and temperature

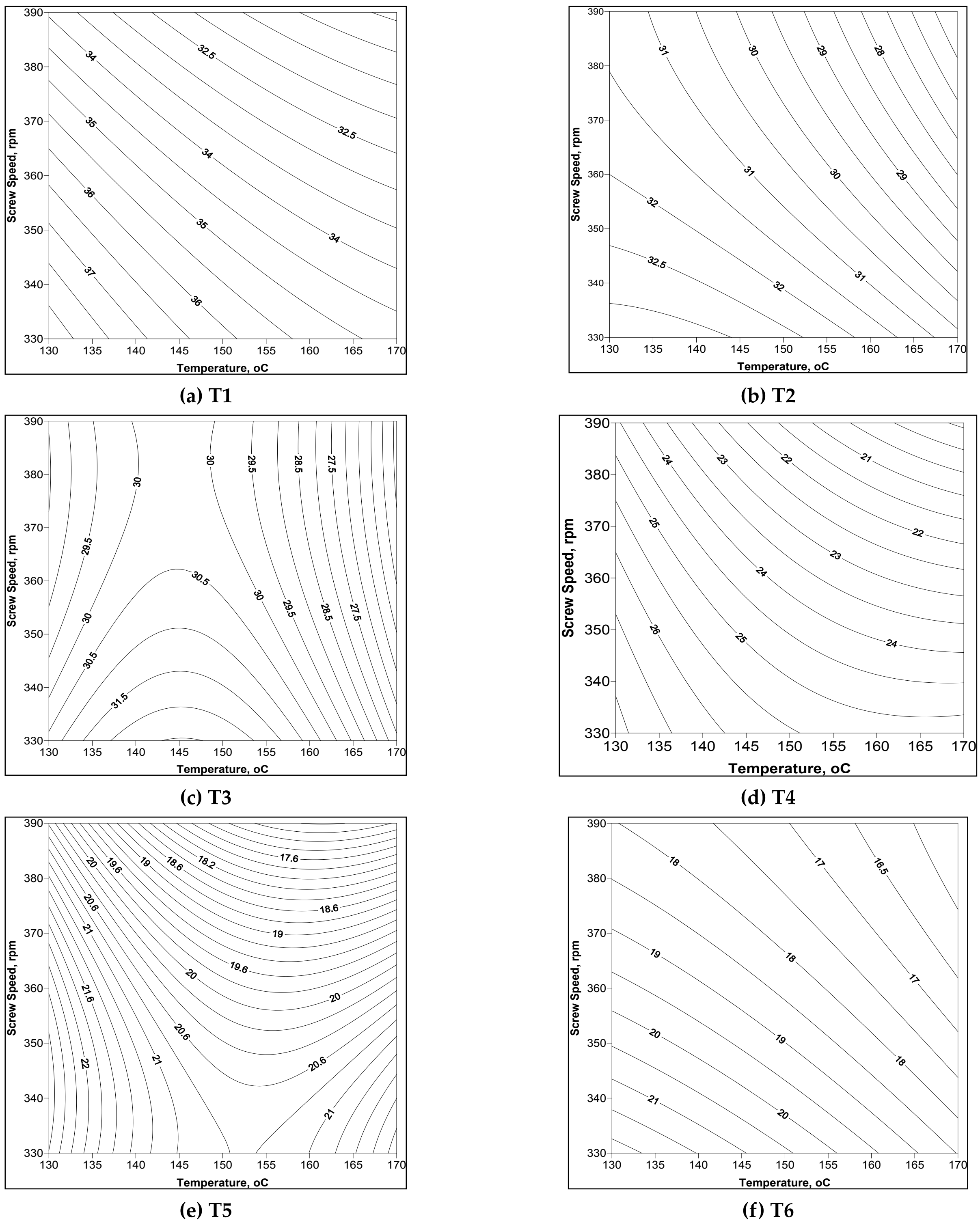


Fig. 10: Contour plots of Effect of Temperature of Extrusion, Screw Speed on Water solubility Index of Tuber Crops based Extrudates (a) For Treatment T1; **(b)** For Treatment T2; **(c)** For T For Treatment T3; **(d)** For Treatment T4; **(e)** For Treatment T5; **(f)** For Treatment T6

has indicated that water solubility index have a significant difference at ($p \leq 0.01$). The interactions among independent variables significantly affected the WSI values ($p \leq 0.01$)

Higher WSI of extrudate with increasing screw speed may be related to increasing specific mechanical energy with screw speed. The high mechanical shear caused breakdown of macromolecules to small molecules with higher solubility. The increase in WSI with increasing screw speed was consistent with the results reported by other researchers (Dogan and Karwe, 2003; Guha, 1997) for quinoa extrudates and rice flour extrudates. Increasing temperature would increase the degree of starch gelatinization that could increase the amount of soluble starch resulting in an increase in WSI. Positive relationship of WSI and temperature was also achieved by Ding et al. (2005) in extruded products. Water solubility index decreased initially and increased further with increase in temperature, which may be attributed to increased dextrinization at higher temperature and it causes more solubility due to change in the starch granule structure (Mercier and Feillet, 1975). Water solubility index increases with increase screw speed due to high mechanical shear exerted on extrudates. Similar observations were reported by Ding *et al.* (2005) for rice based expanded snacks.

There was a slight decrease with the increase in screw speed which may be because of high mechanical shear exerted on extrudates, whereas further decrease in water soluble index with the increase in screw speed may be the result of higher expansion of the product. Water solubility index decreased initially and increased further with increase in temperature, which may be attributed to the similar variation of lateral expansion of the extrudates with increase in temperature. The results obtained for water solubility index are in line with the results obtained for lateral expansion (Kumar *et al.* 2010) for carrot pomace, rice flour and pulse power blend.

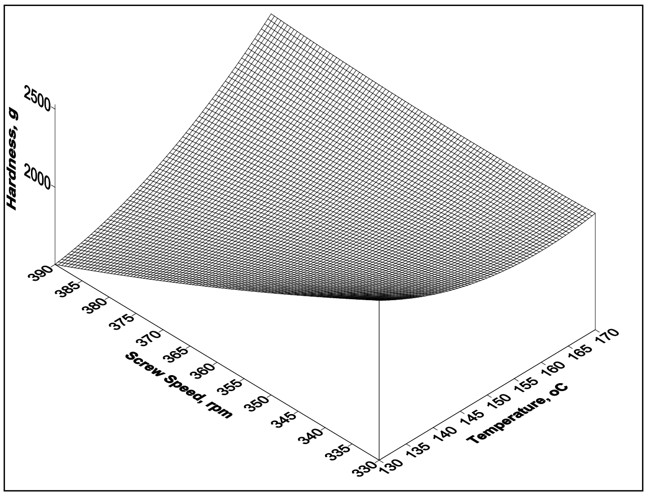
The combined effect of increase in barrel temperature (130-170°C) and screw speed (330-390 rpm) decreases the water solubility index for all the treatments i.e. T1 to T6 of tuber crops extrudates. Increase in barrel temperature with increase in screw speed decreases water solubility index of the extruded products for broken rice flour:pineapple waste paste powder:red gram powder, pomace:rice flour:pulse powder, wheat:mungbean:groundnut, barley-tomato pomace (Kothakota *et al.* 2013; Kumar *et al.* 2010; Pathania *et al.* 2013; Altan *et al.* (2008)).

5. Hardness (HR)

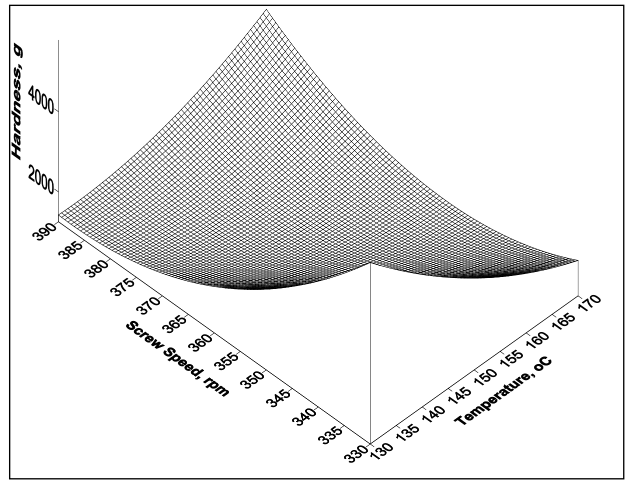
Fig. 11 (a)-(f) shows the surface plots of effect of temperature of extrusion (°C) and screw speed (rpm) on the hardness of extrudates for treatment (a) T1, (b) T2, (c) T3, (d) T4, (e) T5 and (f) T6. The hardness for tuber crops extrudates were in the range of 1080.00-19976.67 g for all treatments (T1 to T6), at varied temperature of extrusion (130 to 170°C) and screw speeds (330 to 390 rpm). Hardness for treatment T1 was ranges from 1080.00-2785.88g, for T2 from 1250.00-6051.67g, for T3 from 1085.00-7920.00g, for T4 from 1561.67-14855.00g, for T5 from 3553.33-11945.00g and for T6 from 2275.00-19976.67g respectively. The temperature of extrudates increases from 130°C to 170°C the hardness of the extrudates decreases for treatments T2, T3, T4, T5 and T6. Similarly in screw speed of the extruder increases from 330 to 390 rpm hardness decreases for treatments T1, T2, T3, T4, T5 and T6 which can be observed from counter plots fig. 14 (a)-(f) .

During extrusion cooking, lesser yam play important role in hardness of the extrudates. As the lesser yam decreases in flour combination from T1 to T6, hardness of extrudates increases during extrusion cooking and vice versa. Increases proportion of lesser yam with decreases hardness of extruded which was shown in Table 6.

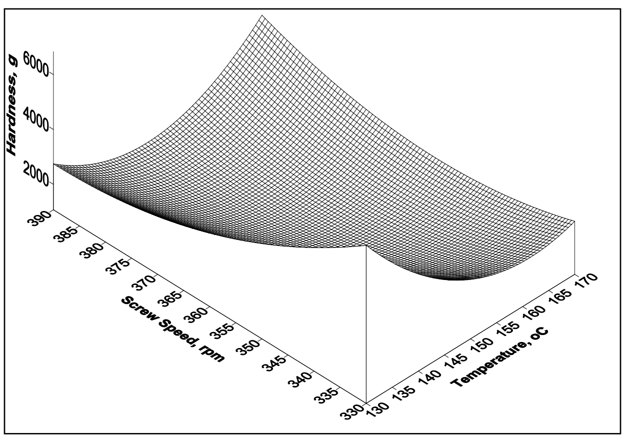
The second order polynomials equation shows the effect of temperature of extrusion (°C) and screw speed (rpm) on the hardness of tuber crop extrudates for treatments T1, T2, T3, T4, T5 and T6 are given in eq^{n}. (39), (40), (41), (42), (43) and (44) respectively.



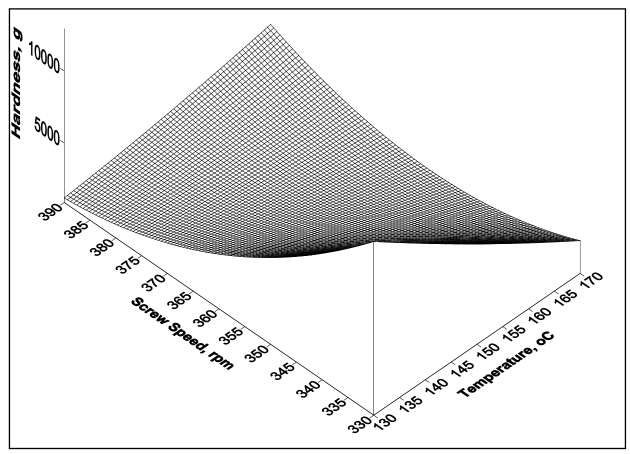
(a) T1



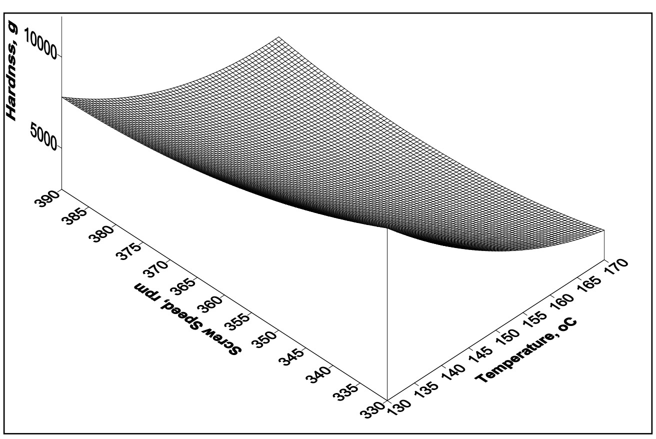
(b) T2



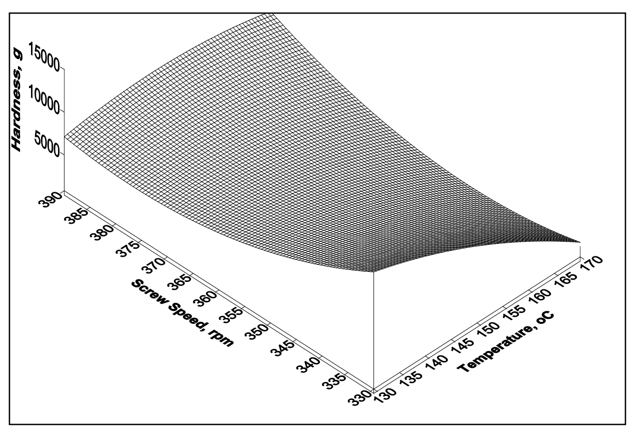
(c) T3



(d) T4



(e) T5



(f) T6

Fig. 11: Surface plots of Effect of Temperature of Extrusion, Screw Speed on Hardness of Tuber Crops based extrudates **(a)** For Treatment T1; **(b)** For Treatment T2; **(c)** For T For Treatment T3; **(d)** For Treatment T4; **(e)** For Treatment T5; **(f)** For Treatment T6

$$HR_{T1} = 39888.601 - 99.849\,S + 0.036\,S^2 - 252.083\,T + 0.435ST + 0.338\,T^2 \quad \ldots(39)$$

$$HR_{T2} = 325623.971 - 1300.819S + 1.325\,S^2 - 1100.111T + 2.114\,ST + 1.037\,T^2 \quad \ldots(40)$$

$$HR_{T3} = 365303.667 - 1149.668\,S + 1.160\,S^2 - 21982.863\,T + 1.892\,ST + 4.209\,T^2 \quad \ldots(41)$$

$$HR_{T4} = 676760.462 - 2758.975S + 2.658\,S^2 - 22043.055\,T + 4.993\,ST + 0.502\,T^2 \quad \ldots(42)$$

$$HR_{T5} = 342467.103 - 1115.104S + 1.189S^2 - 1566.529\,T + 01.423\,ST + 3.002\,T^2 \quad \ldots(43)$$

$$HR_{T6} = 703055.177 - 3405.033S + 03.715\,S^2 - 879.811T + 4.668\,ST - 3.244\,T^2 \quad \ldots(44)$$

Where;

T = Temperature of barrel (extrusion) °C

S = Screw speed (rpm)

HR_{T1}, HR_{T2}, HR_{T3}, HR_{T4}, HR_{T5} and HR_{T6} = Hardness at treatment T1, T2, T3, T4, T5 and T6 respectively.

Table 6 and 7(e) shows the ANOVA for the effect of flour composition, temperature of extrusion and screw speed on the hardness of the tuber crops extrudates. It is clear from the table, hardness have a significant effect (p≤0.01) on the flour composition, screw speed and temperature. The interaction between the flour compositions, screw speed and temperature has a significant difference in the hardness. The interactions among independent variables significantly effect on the hardness values (p≤0.01). As the lesser yam decreased in flour composition from T1 to T6 which increased hardness of extruded products which was significantly (p≤0.01) affected on hardness.

It may be observed that hardness decreased with the increase in screw speed. Similar decrease in hardness with increased screw speed due to lower melt density was observed by Ding *et al.* (2006) for wheat based expanded snacks.

The combined effect of increase in barrel temperature (130-170°C) and screw speed (330-390 rpm) decreases the hardness for all the treatments i.e. T1 to T6 of tuber crops extrudates. Increase in barrel temperature with increase in screw speed decreases hardness of the extruded products for wheat:mugbean:groundnut, pomace:riceflour:pulse powder, broken rice flour:pineapple waste pulp powder:red gram powder (Pathania *et al.* 2013; Kumar *et al.* 2010 and Kothakota *et al.* 2013).

Nutritional Properties

1. Protein Content

Table 8 shows the effect of flour composition, temperature of extrusion and the screw speed on the protein content (%) of the tuber crops extrudates. The protein of extrudates varied between 4.67 and 1.52 % for all treatments (T1 to T6), at varied temperature of extrusion (130 to 170°C) and screw speeds (330 to 390 rpm). Protein content for treatment T1 was ranges from 2.86-4.67%, for T2 from 2.45-4.55%, for T3 from 2.33-4.43%, for T4 from 2.04-4.03%, for T5 from 1.87-2.63% and for T6 from 1.52-2.16% respectively. It was maximum (4.67 %) at 130°C barrel temperature, screw speed is 330 rpm and feed composition level is T1 and was minimum (1.52 %) at 170°C barrel temperature, screw speed is 390 rpm and feed composition level is T6. As the proportion of lesser yam decreased in feed composition which may result in decreased protein content of extruded in extrusion cooking and vice versa.

Table 7 and 12(a) shows the ANOVA for the effect of flour composition, temperature of extrusion and screw speed on the protein content of the tuber crops extrudates. It is clear from the table that protein content has a significant effect (p≤0.01) on the flour composition, screw speed and temperature. The interactions among independent variables significantly affected the protein content values of extrudates (p≤0.01). As the lesser yam decreased in flour composition from T1 to T6 which decreased protein content of extruded products which was significantly (p≤0.01) affected.

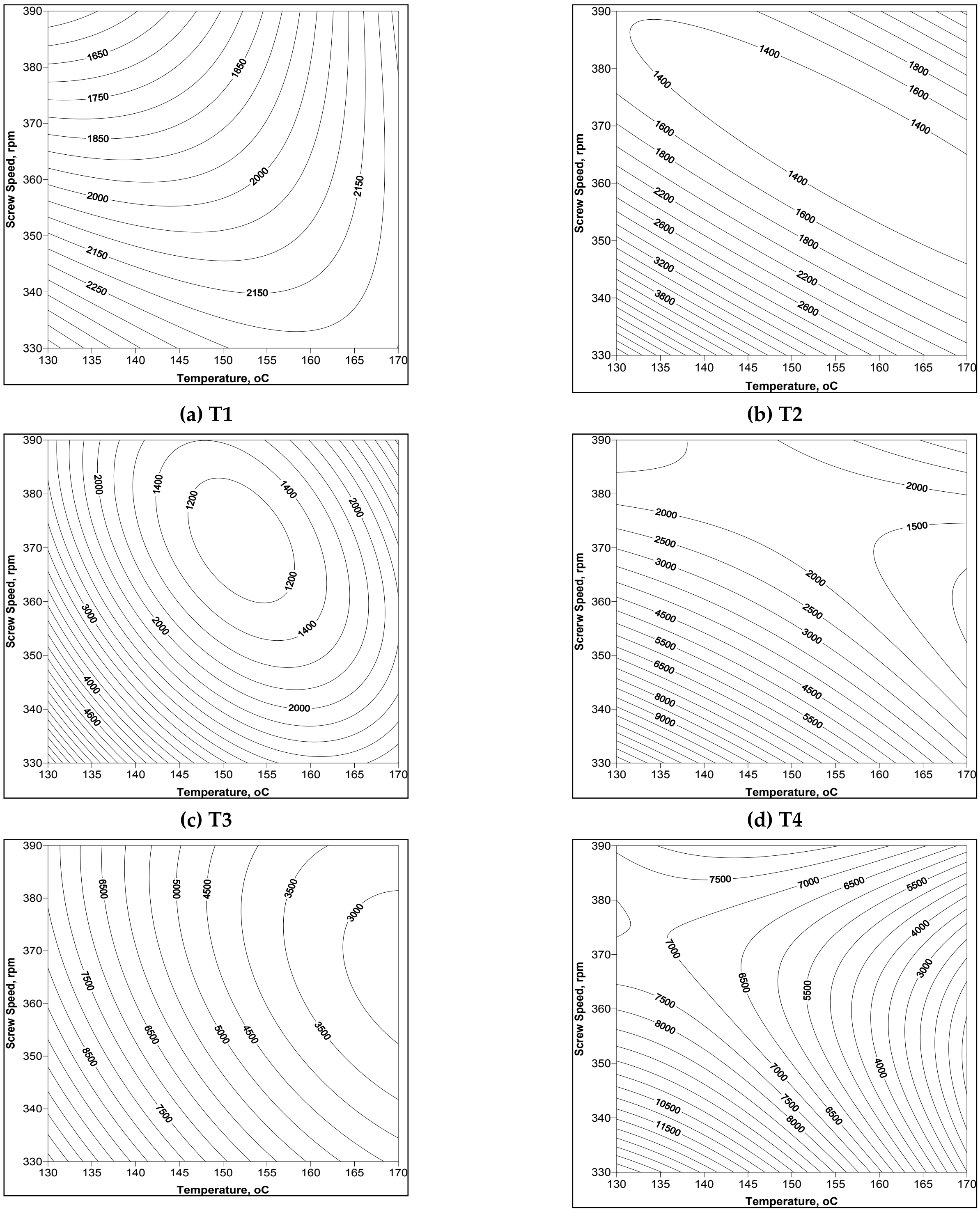


Fig. 12: Contour plots of Effect of Temperature of Extrusion, Screw Speed on Hardness of Tuber Crops based Extrudates **(a)** For Treatment T1; **(b)** For Treatment T2; **(c)** For T For Treatment T3; **(d)** For Treatment T4; **(e)** For Treatment T5; **(f)** For Treatment T6

Protein nutritional value is dependent on the quality, digestibility and availability of essential amino acids. Protein digestibility value was of the extrudates s higher than non extruded products. The possible cause might be the denaturation of proteins and inactivation of antinutritional factors that inpair digestion (Singh *et al.* 2007).

Among the process variables, the feed ratio has the maximum effect on protein digestibility, followed by process temperature in the extrusion of fish–wheat flour blend. Increase in extrusion temperature (100-140°C) enhances protein digestibility values are increased. Increased screw speed may have decreased the protein digestibility these results are in agreement with of extrudates of corn-gluten, because the increase in shear forces in the extruder denatures the proteins more easily, thus facilitating enzyme hydrolysis (Bhattacharya and Hanna, 1985). Similar result was also reported by Liceti *et al.* (1995) in rice and soybean blend.

2. Fat

Table 9 shows the effect of flour composition, temperature of extrusion and the screw speed on the fat content (%) of the tuber crops extrudates. The fat content of extrudates varied between 1.51 and 1.18% for all treatments (T1 to T6), at varied temperature of extrusion (130 to 170°C) and screw speeds (330 to 390 rpm). Fat content for treatment T1 was ranges from 1.35-1.51%, for T2 from 1.30-1.49%, for T3 from 1.28-1.47%, for T4 from 1.22-1.45%, for T5 from 1.21-1.41% and for T6 from 1.18-1.38% respectively. It was maximum (1.51%) at 130°C barrel temperature, screw speed is 330 rpm and feed composition level is T1 and was minimum (1.18%) at 170°C barrel temperature, screw speed is 390 rpm and feed composition level is T6. The proportion of lesser yam decreased in feed composition which may result in decreased fat content of extruded. The screw speed and temperature increased during extrusion significantly affected on the fat content of extruded. Fat content was decreased with increased temperature and screw speed of extrusion.

Table 8 and 15(b) shows the ANOVA for the effect of flour composition, temperature of extrusion and screw speed on the fat content of the tuber crops extrudates. It is clear from the table, fat content have a significant effect ($p \leq 0.01$) on the flour composition, screw speed and temperature. The interaction between the flour compositions, screw speed and temperature has a significant difference on the fat content. As the properties of lesser yam decreased in flour composition from T1 to T6 which decreased fat content of extruded products which was significantly ($p \leq 0.01$) affected.

There was reduction in the fat content of the extrudate from 1.51 to 1.18 %. Extrusion cooking has been reported to aid oil extraction since oil is freed during cooking and shearing operations which break fat globules (Nelson *et al*. 1978). The chance for lipid oxidation that significantly affect product sensory attributes and nutritional quality is reduced during extrusion. This could be attributed to high temperature that inactivates lipolytic enzymes; low residence time of the feed material in the barrel due to increase in speed and the formation of starch-lipid complex. However, air cells in expanded products and the release of pro-oxidants by screw wear favour lipid oxidation (Leszek, 2011).

3. Fibre

Table 10 shows the effect of flour composition, temperature of extrusion and the screw speed on the fibre content (%) of the tuber crops extrudates. The fibre content of extrudates varied between 1.39 and 1.09 % for all treatments (T1 to T6), at varied temperature of extrusion (130 to 170°C) and screw speeds (330 to 390 rpm). Fibre content for treatment T1 was ranges from 1.09-1.23%, for T2 from 1.13-1.27%, for T3 from 1.17-1.29%, for T4 from 1.20-1.33%, for T5 from 1.22-1.35% and for T6 from 1.28-1.39% respectively. It was maximum (1.39%) at 130°C barrel temperature, screw speed is 330 rpm and feed composition level is at T6 and was minimum (1.09%) at 170°C barrel temperature, screw speed is 390 rpm and feed composition level is T1.

Table 10 and 15(c) shows the ANOVA for the effect of flour composition, temperature of extrusion and screw speed on the fibre content of the tuber crops extrudates. It is clear from the table, fibre content have no significant effect ($p \leq 0.01$) between the flour composition, screw speed and temperature. The interaction between the flour compositions, screw speed and temperature has a significant difference on the fibre content. As the lesser yam decreased in flour composition from T1 to T6 which increased fibre content of extruded products which was significantly ($p \leq 0.01$) affected.

As the proportion of lesser yam decreased in feed composition which may result in increased fibre content of extruded. The screw speed and temperature increased during extrusion non significantly affected on the fiber content of extruded. Fibre content was decreased with increased temperature and screw speed of extrusion. Extrusion cooking did not significantly affect the crude fibre content. As with starch, larger fragments of fibre molecules may be sheared off during extrusion (Leszek, 2011).

4. Ash content

Table 11 shows the effect of flour composition, temperature of extrusion and the screw speed on the ash content (%) of the tuber crops extrudates. The ash content of extrudates varied between 2.32 and 1.42% for all treatments (T1 to T6), at varied temperature of extrusion (130 to 170°C) and screw speeds (330 to 390 rpm). Ash content for treatment T1 was ranges from 1.87-2.32%, for T2 from 1.70-2.12%, for T3 from 1.65-2.07%, for T4 from 1.55-1.95%, for T5 from 1.46-1.87% and for T6 from 1.42-1.77% respectively. It was maximum (2.32%) at 170°C barrel temperature, screw speed is 390 rpm and feed composition level is T1 and was minimum (1.42%) at 130°C barrel temperature, screw speed is 330 rpm and feed composition level is T6. As the proportion of lesser yam decreased in feed composition which may result in decreased ash content of extruded. The screw speed and temperature increased during extrusion significantly affected on the ash content of extruded. Ash content increased with increased temperature and screw speed of extrusion.

Table 11 and 15(d) shows the ANOVA for the effect of flour composition, temperature of extrusion and screw speed on the ash content of the tuber crops extrudates. It is clear from the table, ash content have a significant effect ($p \leq 0.01$) between the flour composition, screw speed and temperature. The interaction between the flour compositions, screw speed and temperature has a significant difference in the ash content. As the lesser yam decreased in flour composition from T1 to T6 which decreased ash content of extruded products which was significantly ($p \leq 0.01$) affected.

Extrusion cooking significantly increased the ash content of the extrudates from 1.42 to 2.32 %. This could be attributed to high barrel temperature and high shear rate involved during the cooking process (James and Nwabueze, 2013).

5. Moisture content

Table 12 shows the effect of flour composition, temperature of extrusion and the screw speed on the moisture content (%) of the tuber crops extrudates. The moisture content of extrudates varied between 6.10 and 7.40 % for all treatments (T1 to T6), at varied temperature of extrusion (130 to 170°C) and screw speeds (330 to 390 rpm). Moisture content for treatment T1 was ranges from 6.55-7.40%, for T2 from 6.52-7.27%, for T3 from 6.45-7.13%, for T4 from 6.35-7.08%, for T5 from 6.30-6.90% and for T6 from 6.10-6.83% respectively. It was maximum (7.40%) at 130°C barrel temperature, screw speed is 330 rpm and feed composition level is 61 and was minimum (6.10%) at 170°C barrel temperature, screw speed is 390 rpm and feed composition level is T1.

Table 12 and 13(e) shows the ANOVA for the effect of flour composition, temperature of extrusion and screw speed on the moisture content of the tuber crops extrudates. It is clear from the table, moisture content have a significant effect ($p \leq 0.01$) between the flour composition, screw speed and temperature. The interaction between the flour compositions, screw speed and temperature has a significant difference in the moisture content.

As the proportion of lesser yam decreased in feed composition which may result in decreased moisture content of extruded. The screw speed and temperature increased during extrusion significantly affected on the moisture content of extruded. Moisture content decreased with increased temperature and screw speed of extrusion.

6. Carbohydrates

Table 13 shows the effect of flour composition, temperature of extrusion and the screw speed on the carbohydrates (%) of the tuber crops extrudates. The carbohydrates content of extrudates varied between 83.32 and 88.16 % for all treatments (T1 to T6), at varied temperature of extrusion (130 to 170°C) and screw speeds (330 to 390 rpm). Carbohydrates content for treatment T1 was ranges from 86.01-83.32%, for T2 83.71-86.48%, for T3 83.98-86.70%, for T4 84.50-87.34%, for T5 86.16-87.73% and for T6 86.70-88.16% respectively. It was maximum (88.16 %) at 170°C barrel temperature, screw speed is 390 rpm and feed composition level is T1 and was minimum (83.32%) at 130°C barrel temperature, screw speed is 330 rpm and feed composition level is T6. As the proportion of lesser yam decreased in feed composition which may result in increased carbohydrates content of extruded. The screw speed and temperature increased during extrusion significantly affected on the carbohydrate content of extruded. Carbohydrates content was increased with increased temperature and screw speed of extrusion.

Table 13 and 15(f) shows the ANOVA for the effect of flour composition, temperature of extrusion and screw speed on the carbohydrate content of the tuber crops extrudates. It is clear from the table, carbohydrate content have a significant effect ($p \leq 0.01$) on the flour composition, screw speed and temperature. The interaction between the flour compositions, screw speed and temperature has a significant effect in the carbohydrate content. As the lesser yam decreased in flour composition from T1 to T6 which increased carbohydrate content of extruded products which was significantly ($p \leq 0.01$) affected.

Conditions that increase temperature, share and pressure tend to increase the rate of gelatinization. Complete gelatinization may not occur but, digestibility is improved on the other hand (Wang *et al.* 1993). In essence extrusion may predigest starch depending on the composition of the feed material and operating conditions.

7. Yellowness Index (YI)

Table 14 shows the effect of flour composition, temperature of extrusion and the screw speed on the yellowness index of the tuber crops extrudates. The yellowness index of extrudates varied between 5.87 and 4.51 for all treatments (T1 to T6), at varied temperature of extrusion (130 to 170°C) and screw speeds (330 to 390 rpm). Yellowness index for treatment T1 was ranges from 4.79-5.86, for T2 from 4.70-5.87, for T3 from 4.53-5.83, for T4 from 4.53-5.50, for T5 from 4.54-5.53 and for T6 from 4.57-5.37 respectively. It was maximum (5.87) at 150°C barrel temperature, screw speed is 390 rpm and feed composition level is T6 and was minimum (4.51) at 130°C barrel temperature, screw speed is 330 rpm and feed composition level is T1.

Table 14 and 15(g) shows the ANOVA for the effect of flour composition, temperature of extrusion and screw speed on the yellowness index of the tuber crops extrudates. It is clear from the table, yellowness index have a significant effect ($p \leq 0.01$) between the flour composition, screw speed and temperature. The interaction between the flour compositions, screw speed and temperature has a significant difference in the yellowness index. As the lesser yam decreased in flour composition from T1 to T6 which decreased yellowness index of extruded products which was significantly ($p \leq 0.01$) affected.

Sensory characteristics

Sensory evaluation of the tuber crops extrudates shown in Table 15. Overall score of sensory characteristics ranged from 6.07 to 7.46 for all treatments (T1 to T6), at varied temperature of extrusion (130 to 170°C) and screw speeds (330 to 390 rpm). Therefore, increase in arrowroot proportion may reduce the sensory score. Maximum acceptability was observed either at the minimum level of arrowroot proportion and vice

Table 15: Sensory Evaluation of Tuber of the Tuber crops extrudates

Sample Code	Flour composition (Arrowroot: Lesser Yam: Potato)	Temperature, ºC	RPM of Screw	Sensory Parameters						
				Appearance	Colour	Taste	Texture	Crispiness	Expansion	Overall Acceptability
A	0:50:50	130	330	6.5	6.4	6.1	6.5	6.6	6.6	6.5
B	10:40:50	130	330	6.1	6.1	6.2	6.2	6.4	6.5	6.3
C	20:30:50	130	330	6.4	6.3	6.3	6.4	6.6	6.7	6.5
D	30:20:50	130	330	6.5	6.5	6.6	6.5	6.5	6.4	6.5
E	40:10:50	130	330	6.1	6.2	6.4	6.3	6.3	6.4	6.3
F	50:0:50	130	330	6.4	6.4	6.3	6.3	6.4	6.2	6.3
G	0:50:50	130	360	6.4	6.1	6.0	6.2	6.1	6.2	6.2
H	10:40:50	130	360	6.5	6.2	6.1	6.3	6.3	6.3	6.3
I	20:30:50	130	360	7.5	7.5	6.9	7.4	7.1	7.0	7.2
J	30:20:50	130	360	7.5	7.4	6.7	7.4	6.8	6.5	7.0
K	40:10:50	130	360	6.5	7.5	7.3	7.1	7.4	7.4	7.2
L	50:0:50	130	360	7.6	7.4	7.2	7.5	7.1	7.3	7.4
M	0:50:50	130	390	7.3	7.7	7.4	7.3	7.3	7.4	7.4
N	10:40:50	130	390	7.5	7.2	8.5	7.4	7.0	7.3	7.5
O	20:30:50	130	390	7.3	7.6	7.4	7.4	7.2	7.3	7.4
P	30:20:50	130	390	6.9	7.5	7.0	7.3	7.5	7.5	7.3
Q	40:10:50	130	390	7.5	7.5	7.0	7.6	7.0	7.1	7.3
R	50:0:50	130	390	7.1	7.5	7.4	7.2	7.4	7.5	7.3
S	0:50:50	150	330	5.8	5.6	6.3	8.0	6.5	6.4	6.4
T	10:40:50	150	330	6.2	5.7	6.1	6.3	5.7	6.4	6.1
U	20:30:50	150	330	5.9	6.1	6.0	6.5	7.3	6.8	6.4
V	30:20:50	150	330	6.0	6.5	7.0	6.7	6.4	7.3	6.7
W	40:10:50	150	330	5.6	5.9	6.1	8.0	6.4	6.8	6.5
X	50:0:50	150	330	6.1	6.6	7.3	6.8	6.6	7.0	6.7
Y	0:50:50	150	360	5.8	5.9	6.2	6.2	6.7	6.9	6.3
Z	10:40:50	150	360	6.0	6.3	6.5	6.6	7.0	7.3	6.6
A1	20:30:50	150	360	6.5	6.2	6.5	6.5	6.4	6.2	6.4
B1	30:20:50	150	360	7.0	6.7	6.8	6.6	6.7	6.8	6.8
C1	40:10:50	150	360	5.3	5.8	6.2	6.5	6.4	6.6	6.1
D1	50:0:50	150	360	5.4	5.9	6.5	6.6	6.5	5.6	6.1
E1	0:50:50	150	390	7.1	7.8	6.8	7.3	6.9	7.3	7.2
F1	10:40:50	150	390	7.4	7.4	6.7	7.5	7.0	7.0	7.2
G1	20:30:50	150	390	6.9	7.4	6.8	6.9	7.3	7.5	7.1
H1	30:20:50	150	390	6.7	6.3	7.4	7.3	7.1	7.0	6.9

Sample Code	Flour composition (Arrowroot: Lesser Yam: Potato)	Temperature, °C	RPM of Screw	Sensory Parameters						
				Appearance	Colour	Taste	Texture	Crispiness	Expansion	Overall Acceptability
I1	40:10:50	150	390	6.8	6.3	7.3	7.1	7.0	7.0	7.0
J1	50:0:50	150	390	6.7	6.2	7.2	7.0	7.0	7.0	6.9
K1	0:50:50	170	330	6.2	5.7	5.8	6.3	6.6	6.6	6.2
L1	10:40:50	170	330	6.2	6.3	7.7	6.4	6.2	6.4	6.5
M1	20:30:50	170	330	6.7	6.6	6.4	6.5	6.5	6.4	6.5
N1	30:20:50	170	330	6.9	6.7	6.5	6.7	6.5	6.6	6.6
O1	40:10:50	170	330	6.7	6.5	6.4	6.5	6.7	6.5	6.6
P1	50:0:50	170	330	6.4	6.2	6.2	6.2	6.1	6.5	6.3
Q1	0:50:50	170	360	7.0	6.0	6.5	6.6	7.0	6.9	6.7
R1	10:40:50	170	360	6.5	6.5	6.8	6.7	6.4	6.8	6.6
S1	20:30:50	170	360	5.7	6.4	6.4	6.7	5.9	6.7	6.3
T1	30:20:50	170	360	6.6	6.5	5.7	6.8	7.7	7.4	6.8
U1	40:10:50	170	360	5.7	5.9	6.5	6.2	6.5	6.9	6.3
V1	50:0:50	170	360	6.5	6.1	6.5	6.7	6.5	7.0	6.5
W1	0:50:50	170	390	6.5	8.3	7.2	7.3	6.6	7.4	7.2
X1	10:40:50	170	390	6.0	6.5	6.5	6.8	7.0	7.1	6.6
Y1	20:30:50	170	390	6.1	6.3	6.5	6.5	6.8	7.0	6.6
Z1	30:20:50	170	390	6.0	5.9	6.4	7.0	7.3	7.4	6.7
A11	40:10:50	170	390	7.5	7.2	6.7	7.4	6.9	7.2	7.1
B11	50:0:50	170	390	7.5	7.3	6.7	7.4	6.9	7.0	7.1
C11	**CONTROL**			**7.2**	**6.9**	**6.8**	**7.1**	**6.9**	**6.4**	**6.9**

Table 16: ANOVA for the sensory analysis of the scores obtained for extrudates at each treatment combinations

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	F_{crit}
Rows	61.56902	53	1.16168	10.35588	7.05E-44	1.380984
Columns	4.336667	6	0.722778	6.443259	2E-06	2.127128
Error	35.6719	318	0.112176			
Total	101.5776	377				

versa. The sensory analysis of extrudates indicated that the overall acceptability of the extrudates were highest at treatment T2 (sample code 'N') at which the appearance, colour, taste, crispiness, expansion and overall acceptability was 7.5, 7.2, 8.5, 7.4, 7.0, 7.3 and 7.5 respectively. The treatment at which the flour composition at which Arrowroot: Lesser yam: Potao (10:40:50) at extrusion temperature 130°C and screw speed at the extrusion was 390 rpm. Table 16 shows the ANOVA for the sensory analysis of the scores obtained for extrudates at each treatment combinations.

Table 17: Treatment wise optimim zone of lower bulk density, more expansion ratio, lower Hardness, higher water absorption capacity, higher water solubility index

Treatments	Optimum Temperature, °C	Optimum RPM	Bulk Density, g/cc	Expansion ratio	Hardness, g	Water Absorption capacity (%)	Water Solubility index (%)
T1	145-155	375-385	0.14	3.35	1710-1870	3.89-4.2	32.5 -33.7
T2	130-135	385-390	0.15	3.06-3.13	1420-1500	4.22	31.0-31.6
T3	145-155	370-380	0.12-0.13	2.88-3.01	1200-1310	3.8-3.92	29.10-30.0
T4	165-170	370-380	0.18	2.75-2.85	1500-1800	4.75-5.03	22.8-23.9
T5	165-170	355-365	0.18	2.79-2.9	3000-3300	3.9-4.07	11.6-20.8
T6	165-170	355-365	0.13-0.16	2.81-3.00	2300-2800	3.68-3.78	16.7-17.5

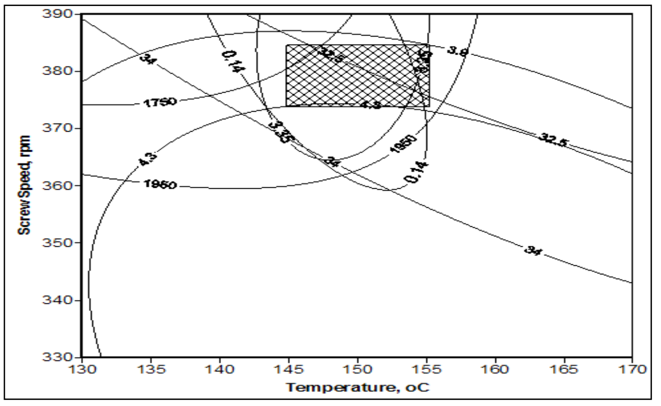
Table 18: Treatment wise optimum zone for nutritional properties

Treatments	Optimum Temperature, °C	Optimum RPM	Proteins %	Fat, %	Ash,%	Moisture, %	Carbohydrates, %	Fibres, %
T1	145-155	375-385	2.98-3.81	1.38-1.41	2.11-2.22	6.50-6.72	85.65-85.68	1.13-1.14
T2	130-135	385-390	2.80-2.81	1.40-1.42	1.96-1.98	6.0-6.70	85.01-85.23	1.20-1.21
T3	145-155	370-380	2.48-2.67	1.32-1.34	1.88-1.95	6.38-6.52	86.24-86.12	1.21-1.24
T4	165-170	370-380	2.0-2.1	1.27-1.30	1.79-1.85	6.35-6.39	87.72-87.34	1.24-1.25
T5	165-170	355-365	1.85-1.90	1.24-1.26	1.72-1.77	6.25-6.33	87.44-87.45	1.27-1.29
T6	165-170	355-365	1.64-1.72	1.22-1.25	1.58-1.59	6.20-6.25	87.89-87.92	1.30-1.31

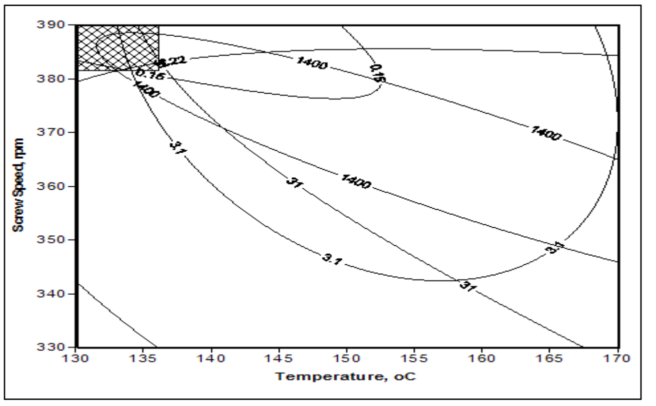
Optimization of extrudates

Table 17 and 18 shows the treatment wise optimum zone for functional and nutritional properties of tuber crop extrudates respectively. Fig. 15 (a)-(f) shows the optimum zone for extrudates. The extrudates were optimized based on its desirable functional properties like lower bulk density, more expansion ratio, lower hardness, higher water absorption index, higher water solubility index. Fig. 15 (a)-(f) shows the optimum zones obtained for the desirable functional properties of these extrudates prepared for treatments T1, T2, T3, T4, T5 and T6 respectively at extrusion temperature 130 to 170°C and screw speed 330 to 390 rpm

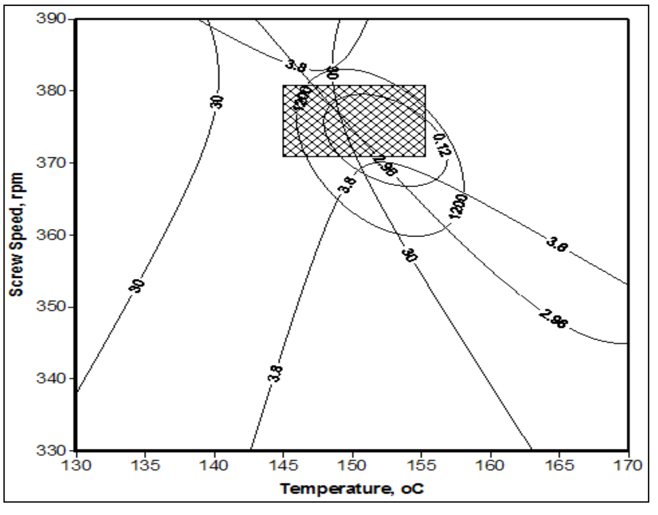
The optimum zones for treatment T1, T2, T3, T4, T5 and T6 are observed at extrusion temperature and screw speeds i.e. 145-155°C, 375-385 rpm; 130-135°C, 380-390 rpm; 145-155°C, 370-380 rpm; 165-170°C, 370-380 rpm; 165-170°C, 355-365 rpm and 165-170°C, 355-365 rpm respectively. Table 16 shows that the nutritional properties at the optimum zone at T1, T2, T3, T4, T5 and T6. The optimum product has best retention of functional properties, nutritional properties and highest sensory scores. Comparing Table 15, 16 and 17, the treatment T2 at which the product has best functional properties i.e. bulk density, expansion ratio, water absorption index and water solubility index are 0.15 g/cm^3, 3.13, 1460 g, 4.22%, 31.3 % respectively. The nutritional properties of extrudates at the optimum products are protein 2.8%, fat 1.40 %, ash 1.96 %, moisture 6.0 %, fiber 1.20 % and carbohydrate 85.01 % respectively. The treatment T2 receives a highest sensory score i.e. higher overall acceptability i.e. 7.5 out of 9 (appearance, colour, texture, crispiness, expansion, overall acceptability were 7.5, 7.2, 8.5, 7.4, 7.0, 7.3 and 7.5 respectively).



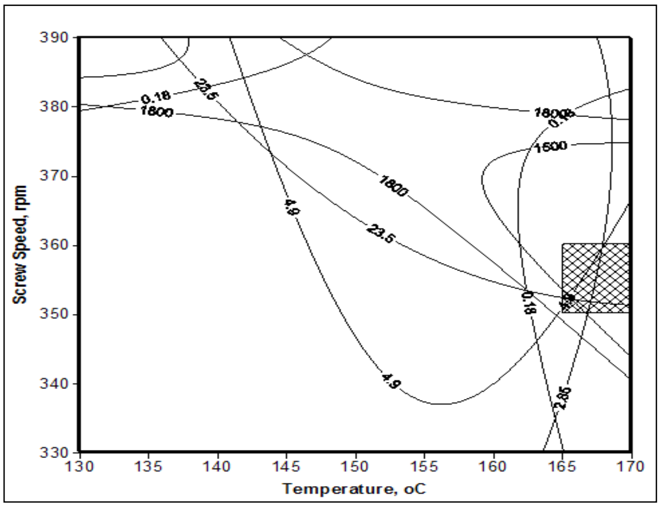
(a) Optimum zone for the Treatment T1



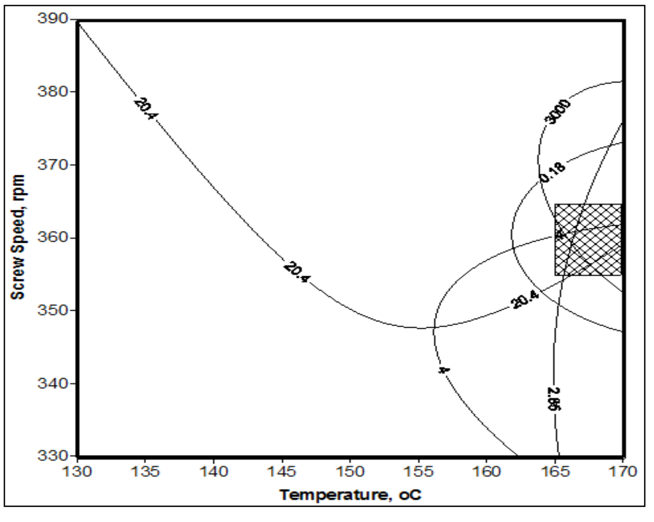
(b) Optimum zone for the Treatment T2



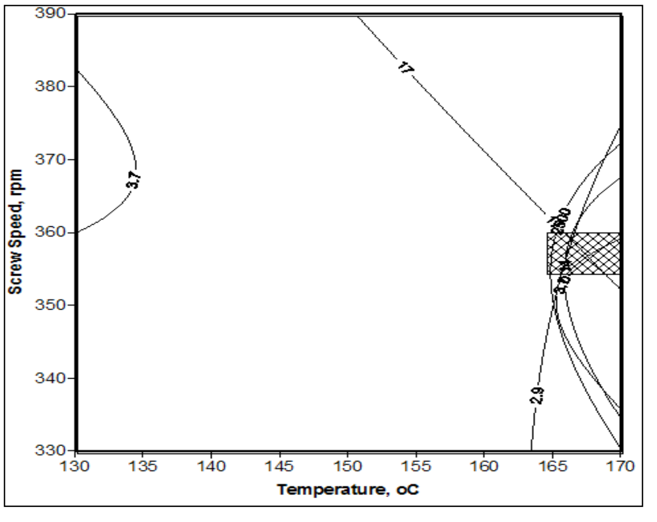
(c) Optimum zone for the Treatment T3



(d) Optimum zone for the Treatment T4



(e) Optimum zone for the Treatment T5



(f) Optimum zone for the Treatment T6

Fig. 13: Optimum zone Treatments wise

CONCLUSION

Following conclusion can be drawn from the present study:

1. Lesser yam incorporation in the extrudates flour composition has significant influence on the functional nutritional and sensory properties of the extrudates ($p \leq 0.01$).

2. Optimum combination of flour composition (treatment T1 to T6), temperature of extrusion (130, 150 and 170°C) and screw speed (330, 360 and 390 rpm) is based on the desirable functional properties of extrudates i.e. lower bulk density, more expansion ratio, higher water absorption index, higher water solubility index and lower hardness.

3. Extrudates prepared at treatment T2 (Arrowrrot: Lesser yam: Potato (10:40:50)) at 130°C extrusion temperature and 390 rpm screw speed has received desirable functional properties i.e. bulk density 0.15 g/cm^3, expansion ratio 3.13, hardness 1460 g, water absorption capacity 4.22 % and water solubility index 31.3 % respectively.

4. Extrudates at treatment T2 has optimum nutritional properties i.e. protein 2.8 %, fat 1.4 %, ash 1.9 %, fiber 1.20 % and carbohydrate 85.01 % respectively.

5. The treatment T2 receives the highest sensory scores i.e. appearance 7.5, colour 7.2, texture 8.5, crispiness 7.4, expansion 7.0 and overall acceptability 7.5 out of 9.

6. Considering better functional, nutritional and sensory scores, treatment T2 flour combination (Arrowroot: Lesser yam: Potato (10:40:50)) extruded at 130°C extrusion temperature and at 390 rpm at screw speed is the best treatment.

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