DEVELOPMENT OF FUNCTIONAL EXTRUDED FOOD PRODUCT USING RED RICE (*ORYZA SATIVA* L.) AND PASSION FRUIT (*PASSIFLORA EDULIS* SIMS) AND ITS ANTIDIABETIC POTENTIAL

ABSTRACT

The thesis primarily focuses development of extruded product using red rice (*Oryza sativa* L.) flour and passion fruit (*Passiflora edulis* Sims) foam mat powder of Arunachal Pradesh, India. Physicochemical and phytochemical properties of samples were determined by using different assay and quantification techniques. Foam mat drying of purple passion fruits pulp and characterization of the powder was carried out. Twin extruder was used for product development. Effect of extrusion cooking on the physicochemical and phytochemical properties of passion fruit powder incorporated red rice extrudates, rheology of doughs and sensory evaluation of product was also studied. Moisture sorption isotherm (MSI) of optimized extruded product at three different temperature (25˚C, 35˚C and 45˚C) condition were studied and its antioxidant stability for the period of 120 days was also determined. Further, the bioactivity guided fractionation of the red rice was carried out to determine dipeptidyl peptidase-4 (DPP-4) inhibitory from arsenically safe pigmented red rice (*Oryza sativa* L.) and its product. Determination of glucagon-like peptide-(GLP-1) secretion in raw rice sample and extruded products were also studied.

The thesis is divided into eight chapters which are briefly discussed below:

Chapter 1 highlights the general introduction of underutilized crops like pigmented rice and purple passion fruit in the present work. It also highlights the background information of foam mat drying, extrusion technology, rheology, fuzzy logic etc. Finally, hypothesis and technical objectives were included.

Chapter 2 presents the review of literature for present investigation. Brief introduction about pigmented rice availability, types, various bioactive compounds of pigmented rice, health benefit of pigmented rice are presented. Fruit characteristics of some passiflora species found in India are described. Purple passion fruit availability in Northeastern part of India and health benefits is highlighted. Application of foam mat drying process and extrusion processing were also included. This chapter also includes the illustration of rheology and usage of various rheological models to predict the best fits. Fuzzy logic tool

was also discussed. Importance of moisture sorption isotherm (MSI) of extruded products were also described. Dipeptidyl peptidase-4 (DPP-4) inhibitory activity and glucagon-like peptide-(GLP-1) secretion has been discussed.

Chapter 3 includes the physicochemical properties of three rice cultivars namely red rice: short grain (UA), red rice: long grain (LA) and white rice (WR) and purple passion fruit. Proximate composition, macro and micro mineral analysis, antioxidant activities, quantification of various compounds by RP-HPLC were carried out for rice samples. Physical and thermal attributes varied with difference in cultivars. Moisture and ash content of different rice cultivars varied significantly ($P \leq 0.05$) from 11 to 11.50% (d.b.) and from 0.93 to 1.33% (d.b.). The bulk and true density of the three different rice cultivars (LA, UA and WR) showed no significant differences between the cultivars at the 0.05% probability. Thousand grain weights (g), angle of repose and porosity of LA, UA and WR varied significantly. *L*, *a** and *b** color parameters varied from sample to sample. In addition, pigmented rice cultivars evinced substantial amount of phenolic compounds (UA-349.3 ± 0.02 and LA-262.30 ± 0.01 mg GAE/100 g) compared to white rice (142.90 ± 0.01 mg GAE/100 g) and revealed high antioxidant activity. Seven phenolic acid *viz.*, quinic, salicylic, quercetin, apigenin, gallic, caffeic and ferulic acid were detected and quantified in three rice cultivars. Major amount of phenolic acids were observed in UA (red rice: short length). On the basis of physicochemical analysis and phytochemical quantification among three rice cultivars, UA was selected for further analysis. The pH and total soluble solids (˚Brix) of passion fruit pulp measured were 3.91 ± 0.2 and 16.85 ± 0.4. Color measurement showed that *b** which indicates yellowness were higher than *a** (redness). Phytochemical analysis *viz.*, DPPH scavenging activity (%), total phenolic content (mg GAE/100g) and vitamin C (mg/100g) presented good value of antioxidant property. The vitamins (β carotene, (±)-α-tocopherol and D-α-tocotrienol) and phenolic acids (caffeic, (±) catechin hydrate, chlorogenic, *p*-coumeric, transferulic, 4-hydroxybenzoic, syringic, sinapic and vanillic acid) from pulp were identified and quantified by RP-HPLC, respectively. Some phenolic acid were found in good amount. These data can be useful for further in-depth study in the field of passion fruit powder utilization in food industries.

Chapter 4 conducts foam mat drying of purple passion fruits and characterization of the powder. Foam mat drying is a simple process of drying liquid - solid foods. The central

composite design (CCD) was used to optimize experimental conditions of foam mat drying. Methyl cellulose was used as a foaming stabilizer. The ranges of experimental parameters were selected based on preliminary trials. The optimum process conditions of foam mat drying of passion fruit pulp were whipping temperature (WT) 2.58 min, methyl cellulose (MC) 2.58 %, and temperature (Temp) 44.05˚C. CCD data was further successfully used to predict the experimental outcome using artificial neural network (ANN). For total phenolic content (TPC), the best ANN model was obtained with one hidden layer and ten hidden neurons with (R^2=0.94. Similarly, for vitamin C (R^2=0.96) and hygroscopicity (R^2=0.89). The co-efficient of determination (R^2) for vitamin C, total phenolic content and hygoscopicity values were higher than response surface methodology (RSM) which inferred that ANN has the higher ability to predict the experimental outcome than the RSM model. In the RP-HPLC, three vitamins *viz.,* β-carotene, (±)-α-tocopherol and D-α-tocotrienol and phenolic acids (caffeic, (±) catechin hydrate, chlorogenic, *p*-coumeric, transferulic, 4-hydroxybenzoic, syringic, sinapic and vanillic acid) were quantified in the foam mat powder respectively. RP-HPLC of vitamins and phenolic compounds revealed that even after foam mat drying, compounds were present in the powder.

Chapter 5 discusses about the effect of extrusion parameters on the physicochemical and phytochemical properties of red rice and passion fruit foam mat powder incorporated red rice product. The extrusion process was performed using a twin screw extruder and optimized using central composite design. The effect of process parameters such as temperature (80-150˚C), screw speed (200-400rpm), feed moisture content (20-30 %) and passion fruit powder (0-15%) on product quality were also investigated. Response variables were expansion ratio (ER), water absorption index (WAI), total phenolic content (TPC) and DPPH scavenging activity (DPPH). The optimum conditions of extrusion process were temperature 97.50˚C, screw speed 250 rpm, feed moisture content 25.20% and passion fruit powder 11.25 %. A comparison between optimized and control extruded product indicated that thermal, crystallinity and morphological properties differed significantly. FT-IR was also conducted for both the extrudates and revealed presence of various functional groups in the spectrum. It also discusses about rheological properties of extrudates. The incorporation of powder in red rice dough showed significant effect on the dough rheology. The flow behavior of red rice and foam mat passion fruit powder incorporated red rice doughs can be explained by the Mizrahi and Berk model (R^2=0.83)

and (R^2=0.87). The storage modulus (G´) and loss modulus (G´´) of both the samples revealed a linear viscoelastic behaviour and showed lower dependence of moduli on frequency. This present chapter also discusses about quality attributes *viz.*, appearance, color, taste, texture and mouthfeel and ranking of extruded samples. The observed ranking order were appearance >taste> color > mouthfeel >texture. The difference in the ranking of two products were almost negligible control (X_C 37.61) > optimized (X_O 37.28). Similarity values for extruded samples showed that both samples were satisfactory.

Chapter 6 deals with moisture sorption isotherm (MSI) and antioxidant content (total phenolic content (mg GAE/100 g dry matter)). Total eight saturated electrolytes solution *viz.*, lithium chloride (LiCl), magnesium chloride ($MgCl_2$), potassium carbonate (K_2CO_3), magnesium nitrate ($Mg(NO_3)_2$), potassium iodide (KI), sodium chloride (NaCl), potassium chloride (KCl) and potassium sulfate (K_2SO_4) were used. Relative humidity (RH %) range from 11 to 97 % were used. Initially, the total phenolic content of product was 105.54 (mg GAE/100 g dry matter). After 120 days, the amount reduced to 101.13 (mg GAE/100 g dry matter). It was observed that there was slow degradation of total phenolic content over the period of time. The equilibrium moisture content (EMC) values were obtained from experimental data of control and optimized extruded products at three different temperatures (25-45˚C) and water activity (a_w) ranged 0.11 to 0.97 were fitted to six MSI models. Mathematical models used were Oswin, Smith, Curie, Peleg, Langmuir and Brunauer-Emmett-Teller (BET). The model constants and statistical parameters were also illustrated to predict the best fit. Sigmoid shape resembling type II isotherm was observed which is very typical of food material. At 25 ˚C, among six mathematical models Langmuir model showed the best fit. And at 35 ˚C and 45 ˚C Peleg model predicted as most suitable model to practice MSI study of optimized extruded product.

Chapter 7 assesses the DPP-4 inhibitory activity and GLP-1 secretory ability of pigmented red rice and its extruded product secretion using STC-1 pGIP/Neo cell culture. The bioactivity guided fractionation of the samples using three different solvents (*n* - hexane, 50:50 ethanol and water and water) were used to determine DPP4 inhibitory activity and GLP-1 secretion. Rice bran (RB) was the most potent at inhibiting DPP-4 activity by 70.48±1.06 %, followed by red rice (UA: 42.55±0.84 %), polished red rice (PRR: 35.91±1.27 %), white rice (WR: 29.14±1.23 %), optimized extrudate (O: 25.49±1.86 %), then control extrudate (C: 13.55 ±3.97 %). Extracts from O containing

passion fruit powder, had greater inhibitory activity than the control extrudate, suggesting that passion fruit may possess its own anti-diabetic activities. *n*-hexane extracts were able to potently stimulate GLP-1 secretion. In particular, PRR, C and O enhanced secretion of GLP-1 3.14-fold ($p<0.01$), 3.48-fold ($p<0.001$) and 6.06-fold ($p<0.001$), respectively when compared to buffer control. Ethanol: water extracts of WR and O also significantly stimulated GLP-1 secretion 3.33-fold and 4.19-fold, respectively. None of the water extracts had any effect on incretin secretion. The ICP-MS study revealed that dimethyl arsenic acid (DMA) content was highest in (UA0.010mg/kg) > (WR; 0.005 mg/kg) > (RB),(PRR),(O;0.003mg/kg)> (C;0.002mg/kg). Arsenic V (i-As) content was found in significantly higher proportions and was highest in RB > C > UA > O > WR > PRR, ranging from 0.026 – 0.176 mg/kg.

Chapter 8 concludes the study carried out with specific objectives, salient findings and future scopes of the present investigations. It includes that underutilized pigmented rice from the state of Arunachal Pradesh is an excellent source of many functionally important nutrients and bioactive compounds which could be potentially utilized for the benefit of local people in terms of health and nutrition by delivering energy dense product products. It is concluded that the foam mat drying of passion fruit pulp into powder has a significant effect on powder quality. Effect of extrusion processing it was observed and illustrated elaborately. Incorporation of foam mat powder in red rice dough showed significant changes in morphological structure of products. Assessment of the antidiabetic potential of red rice and rice based products were also carried out successfully. Rice bran (RB) was the most potent at inhibiting DPP-4 activity when compared with other samples. In the extruded products, significant levels of DPP-4 inhibitory activity and GLP-1 secretion was still retained even after food processing. The ICP-MS study revealed the ranges of dimethyl arsenic acid (DMA) and arsenic V (i-As) content in the rice and extruded products.