

Chapter 2

Review of Literature

2.1 Pigmented rice

2.1.1 Nutritional composition

Rice (*Oryza sativa* L.) is a global staple food and is consumed as a whole grain. Although white rice is commonly consumed, there are several rice cultivars containing color pigments and usually known as black, purple and red rice. Pigmented rice has been reported to be an excellent source of phenolic compounds. Therefore, pigmented rice has an impact on human consumption due to its substantial antioxidant content. The North Eastern part of India, which has diverse physiographic and agro climatic landscapes, is considered as the most rice bio diversified rich region. According to Hore⁶⁹ the state of Arunachal Pradesh itself yielded around 616 germplasm collections of rice from 1987 to 2002. The most of rice cultivars grown in Arunachal Pradesh are underutilized and commonly have whitish kernels locally known as ‘*Pungpo ame*’. But there are also some varieties with a colored testa (black, purple or red) that give slightly colored kernels on milling.⁵³ The various types of rice are generally categorized on the basis of amylose content. The proportion of amylose (and amylopectin) in the starch is predominantly responsible for the different physicochemical and cooking properties of the rice kernel. The categories of rice on the basis of amylose content are high amylose, intermediate amylose, low amylose and waxy rice types.²² Functional properties of rice such as gelatinization, rheology and gel consistency are vital for effective use of rice in food systems and depend on the amylose content. Moreover, some of the underutilize rice cultivars of Arunachal Pradesh are pigmented rice. Pigmented rice is rich source of bioactive compounds such as phenolic acid, anthocyanin, flavones, etc. All bioactive compounds are important for human health because of their pharmacological activities as radical scavengers. Recent interest in these substances has been stimulated by the potential health benefits arising from the antioxidant activities of these polyphenolic compounds. Pigmented rice is reported to have a health-promoting potential due to its substantial antioxidant content which inhibits the formation or reduces the concentrations of reactive cell-damaging free radicals.^{7, 105}

Samyor et al. (2017). Pigmented rice a potential source of bioactive compounds: a review. International Journal of Food Science and Technology. doi:10.1111/ijfs.13378. International Journal of Food Science and Technology 2017, 52, 1073–1081

Samyor et al. (2017). In: Value Addition of Underutilized Crops of India by Extrusion Cooking Technology, Innovative Food Science and Emerging Technologies, Published by Apple Academic Press, Taylor & Francis Group (In press)

Table 2.1 Types of pigmented rice

Sl. No.	Types	References
1	Purple rice	Das et al. ⁵⁰
2	Red rice	Shammugasamy et al. ¹³²
3	Blackish purple rice	Nam et al. ¹⁰⁴
4	Black rice	Jha et al. ⁷⁶

Physical, thermal and pasting properties are important to solve problems associated with the design of machines and analysis of the behavior of the product during processing. Physical properties of grain such as shape, size, volume, surface area, thousand grain weight, density, porosity and angle of repose of different grains are important parameters to determine the quality and optimum conditions for processing and safe storage.¹³⁴ The physical properties of various rice grains are also important for design and development of relevant machines and facilities for harvesting, storing, handling and processing. Amin et al.⁶ stated that the bulk density, kernel density and porosity (the ratio of inter granular space to the total space occupied by the grain) can be an important parameters to size the grain hoppers and enhance the storage facilities.



(a)



(b)



(c)



(d)

Fig. 2.1 (a) Rice paddy, (b) Short kernel red rice locally called Umling ame (UA), (c) Long kernel red rice locally called Lingkang ame (LA) and (d) Short kernel white rice locally called Pungpo ame (WR)

2.1.2 Various bioactive compounds of pigmented rice

2.1.2.1 Anthocyanin

Anthocyanins are the primary functional components of pigmented rice.⁴⁵ In nature, anthocyanins are in the form of polyhydroxylated and or methoxylated heterosides which are derived from the flavylum ion or 2- phenyl benzopyrilium. Synthesis of proanthocyanidins and anthocyanins are given in Fig. 2.2. Aglycon (anthocyanidin) is found united to one or various sugars and also in return, acylated with different organic acids.⁵⁶ In rice grain, the pigmentation of pericarp is controlled by three different types of genes *viz.*, R_a, R_c, and R_d. These genes are said to be inherited monogenetically. R_a gene controls purple color and in the absence of the R_d gene, R_c gene produces brown pericarp and when R_c and R_d genes are crossed, red pericarp is produced.¹⁴⁴

2.1.2.2 Proanthocyanidins

Proanthocyanidins (PAs) are high molecular weight polymers. PAs or condensed tannins are complex flavonoid polymers found in some cereals and legume seeds. It comprises of the monomeric unit flavan-3-ol (+) catechin and (-) epicatechin. The reddish colored testa is associated with the presence of a class of polymeric compounds are called the proanthocyanidins. Chen et al.³⁴ revealed that a 4.3-fold variation in the sum of oligomers and polymers content of total proanthocyanidins in the extractable fraction samples was obtained. Furthermore, the concentration of fractions was highly correlated with bioactive compounds like total phenolics, total proanthocyanidins, flavonoids and antiradical capacity, respectively.

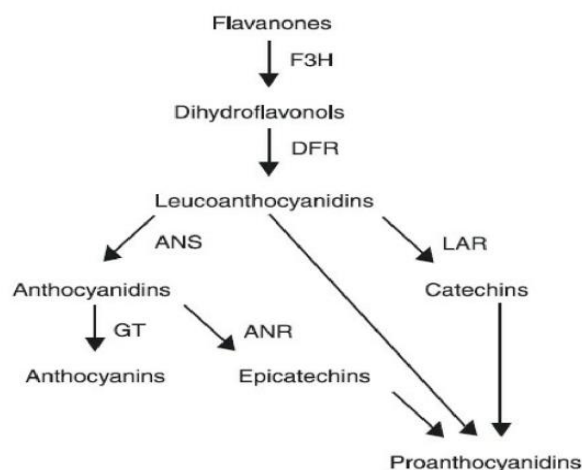


Fig.2.2 Flow chart showing the synthesis of proanthocyanidins and anthocyanins (Source; Xie and Dixon ¹⁴³),

ANS (anthocyanidin synthase); ANR (Anthocyanidin reductase); F3H (Flavones 3-hydroxylase); GT (Glucosyltransferase); DFR (Dihydroflavanol 4-reductase); LAR (Leucoanthocyanidin reductase)

2.1.2.3 Phenolic acids

Phenolic acids are generally classified into two types viz., free and bound phenolic acids.¹¹⁵ Free phenolic acids are soluble in nature and bound acids are insoluble, covalently bound to structural components of cells like cellulose, hemicelluloses (e.g. arabinoxylans), lignin, pectin, and rod shaped structural proteins etc.² Zaupa et al.¹⁴⁵ stated that the main phenolic acids found in pigmented and non-pigmented rice are protocatechuic acid, synapic acid, vanillic acid, *p*-coumaric acid, and ferulic acid. The level of soluble phenolic acids is an important parameter which provides an index of grain resistance. In cell wall especially during the structure formation, insoluble phenolics are actively involved and account for the major part of polyphenols in whole grains.⁹⁸ The amount of soluble form found are 38%⁸ to 60%⁹⁹ of the total polyphenols content in light brown rice grains, and around 81% in color grains particularly in the red and black pericarp.⁹⁹ Laokuldilok et al.⁹⁰ also reported the content of insoluble and total phenolic acids in rice bran.

2.1.2.4 Flavonoids

Flavonoids are the bioactive compounds and synthesized by the phenylpropanoid metabolic pathway. Flavonoids consist of a 15-carbon skeleton which is organized in two aromatic rings (A- and B-rings) and interlinked by a three-carbon chain (structure C6-C3-C6). Flavonoids are known for their ability to donate electrons and to stop chain reactions. Flavonoids can be classified *viz.*, flavones, flavonols, flavanols (flavan-3-ols), flavanonols, isoflavones, and flavanones, which generally occur as O- or C-glycosides. Fig.2.2 shows the flavonoid structure and class of flavonoid. In pigmented rice varieties triclin appears to be the major flavonoid in the bran, covering approximately 77% of all seven flavonoids. Tricin possesses various bioactive compounds which have nutraceutical properties *viz.*, antioxidant effect, inhibition of lipid peroxidation, sparing effect on vitamin E in erythrocyte membrane, antiviral, immunomodulatory, antitubercular, antiulcerogenic, antimutagenic, mildly estrogenic, antiinflammatory and potent anticancer effects etc.⁸¹

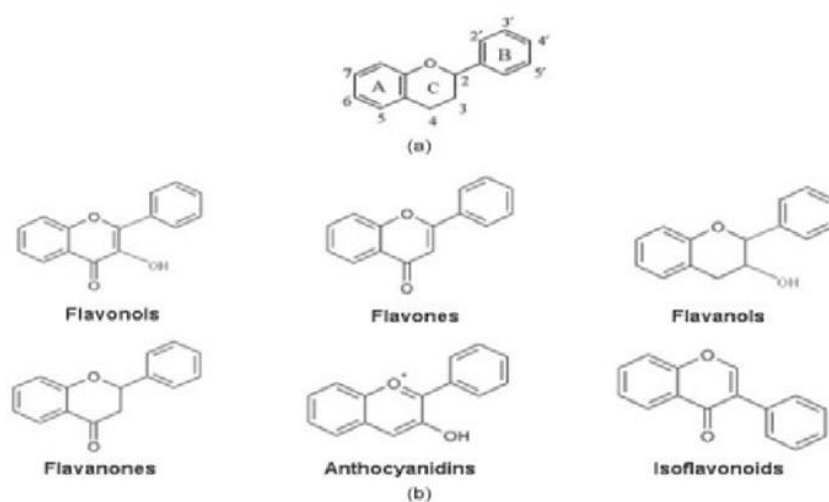


Fig.2.3 (a) Flavonoid structure and (b) Class of flavonoid (Source; Kale et al.⁸³)

2.1.2.5 γ – oryzanol (Steryl ferulate)

γ -oryzanol, a family of ferulic acid esters of unsaturated triterpenoid alcohols, has been characterized in rice bran. It is a class of non-saponifiable lipid and helps in the regulation of elevated LDL. Laokuldilok et al.⁹⁰ reported that γ -oryzanol and phenolic acids were the major antioxidants for pigmented rice bran. In the case of red rice bran, the γ -oryzanol contains 51.8% of the total antioxidant content. γ -oryzanol is a more potent antioxidant than α -tocopherol because of its reducing nature in cholesterol oxidation.¹⁴¹ In a study conducted by Kim et al.⁸² 7 Korean rice varieties *viz.*, 3 white rice (Chucheongbyeo, Kunnunbyeo, Baekjinjubyeo, 3 red rice (Hanyangjo, Chosundo, Jeokjinjubyeo) and 1 purple (Heugjinjubyeo) were obtained from International Rice Research Institute (IRRI) and γ -oryzanol contents and compositions of steryl and triterpene alcohol ferulates proportions in total γ -oryzanol (%) were studied.

2.1.2.6 Vitamin E

Vitamin E or tocols is a generic term for a group of four tocopherols (a, b, c, and d) and four tocotrienols (a, b, c, and d). Various study supported that the α -tocopherol has the highest biological activity. It is based on an amphiphilic 6-chromanol ring and a terpenoid side chain which is located at position 2 of the ring.⁵⁸ The complex form, the free hydroxyl group on the chromanol ring is responsible for the antioxidant properties. Hydrogen atom from this group can be donated to free radicals which later resulted into a resonance-stabilized vitamin E radical.

2.1.2.7 Minerals

Recently, a study reported that two black rice varieties from Korea *viz.*, Heukjinjubyeo, and Heukgwangbyeo evinced higher amount of Ca and K when compared with a white variety (Heuknambyeo).⁶⁶

2.1.3 Health benefits of bioactive compounds

Various health beneficial bioactive compounds from pigmented rice were reported by several authors which include sterols, γ -oryzanol, tocopherols, tocotrienols, and phenolic compounds that are present in the outer layer of grains such as pericarp and aleurone.¹³³

Antiatherosclerosis activities various researchers have reported that dietary supplementation of pigmented rice such as red or black rice instead of white rice induced significant increase in high-density lipoprotein (HDL) concentrations and the activity of glutathione peroxidase (GPx) in hypercholesterolemic rabbits. These activities reduced the size of atherosclerotic lesions in the hypercholesterolemic rabbits. In addition, supplementation of the outer layer fraction of black rice to these animals showed significant lowering of aortic 8-hydroxy-20-deoxyguanosine (8-OHdG) and the malondialdehyde (MDA) level of serum and aortic artery, respectively.^{35, 91, 92} It was also noted that black rice outer layer extract when fed to rabbits, the level of the compounds in the serum *viz.*, aortic 8-hydroxy-20-deoxyguanosine and malondialdehyde decreased significantly in their body.⁹²

2.1.3.1 Antiallergic activities

Pigmented rice evinced with a wide range of biological activity like antiallergic¹⁴⁰ and also black rice bran's extract showed inhibitory effects on *in vitro* allergic reactions.³⁹ Kim et al.⁸⁰ revealed about antiallergic activity study by using methanol extract of *Oryza sativa* L. subsp. Hsien Ting (OSHT), a variety of Chinese black rice. They conducted a study on Mast cells *in vivo* and *in vitro* in a murine model and tested for the inhibition of histamine release, systemic anaphylaxis and local anaphylaxis after treatment with OSHT. The results showed that OSHT (0.001–1.0 mg g⁻¹ BW) had dose-dependent inhibition against systemic anaphylaxis induced by compound 48/80. Later, local anaphylaxis activated by antidinitrophenyl DNP IgE and serum histamine in rats was found. *In vitro* study also revealed the OSHT inhibited the histamine release from the rat peritoneal mast cells which was activated by the compound 48/80 or anti-DNP IgE in a dose-dependent manner.

2.1.3.2 Antidiabetic activities

Pre-diabetic patients have maximum chances of developing type II diabetes and other complicated health issues.¹⁴⁶ A study conducted by Boue et al.¹³ reported that pigmented rice bran *viz.*, purple and red bran extracts, inhibited α -glucosidase activity. Furthermore, in the red rice bran extract inhibition of α -amylase activity was also found. These inhibition activity of α -amylase and α -glucosidase helped in delaying of digestion and absorption of carbohydrates. These actions ultimately lead to the suppression of postprandial hyperglycaemia in the diabetic person. Rice bran extract was studied for the stimulation

of glucose uptake in 3T3-L1 adipocytes which is a key function in glucose homeostasis. The red and purple bran extracts results revealed that the basal glucose uptake increased between 2.3- and 2.7- fold and between 1.9- and 3.1-fold.

2.1.3.3 Antiinflammatory effects

Black rice is rich in cyanidin-3-b-D-glucoside (C3G) and a number of researchers have reported that C3G possesses antiinflammatory effects.¹⁴² Limtrakul et al.⁹³ conducted a study on antiinflammatory effects of proanthocyanidin-rich red rice extract via the suppression of MAPK, AP-1 and NF- κ B pathways in Raw 264.7 macrophages. It was found that the red rice polar extract fraction exerted anti-inflammatory activities by inhibiting the production of TNF- α , IL-6, and NO in LPS-activated macrophages whereas red rice non-polar extracts fraction had no effect on macrophages.

2.1.3.4 Anticancer activity

Various flora available in the North Eastern region of India, are considered to be a chemo preventive agents. But unfortunately, because of the lack of scientific data the information are still not clear. Many researchers have previously made in vitro and in vivo studies and elucidated that natural products are able to reduce aflatoxicosis, e.g. Korean red ginseng and neem flower Kim et al.⁸⁴ On the other hand, a local pigmented rice cultivar from Thailand called Kum Phayao was found highly cytotoxic to human hepatocellular carcinoma HepG2 cells when compared with other Northern Thai purple rice varieties.¹⁴ Punvittayagul et al.¹⁰⁹ revealed that the alcoholic extract of purple rice (*O. sativa* L. var. indica) grain cultivar Kum Doisaket shown antimutagenic effects against AFB1 in the Ames test.

2.1.3.5 Antitumor Activities

In body, reactive oxygen species (ROS) are produced by some tumour promoter in the development of cancer. An in vitro studies using flow cytometry, 70% ethanol-water extracts of bran (outer layer) from seeds of five pigmented rice cultivars viz., Jumlocal-1, DZ 78, Elwee, LK1-3-6-12-1-1, and LK1A-2-12-1-1 revealed their antitumour-promoting activities by measuring the inhibition of Epstein-Barr virus early-antigen activation (EBV-EA) which was later induced by the tumor promoter 12-O-

tetradecanoylphorbol-13-acetate (TPA) ¹⁰⁴ The results reported that pigmented varieties strongly inhibited phorbol ester-induced tumor promotion in marmoset lymphoblastoid cells B95-8 in vitro than non-pigmented variety.

2.1.3.6 Alleviating gallstones

Tsai et al. ¹³⁵ reported that those women who are eating foods which are rich in insoluble fibre like brown rice gained more protection against gallstones. In addition, the reduction of gallstone in women by 17% was noted particularly whose diets were incorporated with brown rice.²⁵

2.1.3.7 Internal rejuvenation

Pigmented rice comprises of almost all essential amino acids in proportions *viz.*, tryptophan, valine, threonine, isoleucine, lysine, leucine, phenylalanine, histidine, and methionine. Vitamins *viz.*, thiamine, riboflavin, and niacin are present in brown rice which reduces the health problems and important chemical constituents help to maintain internal fluid balance. Rice contains iron which enriches the bloodstream and phosphorus and potassium are another two important minerals which maintain internal water balance along with other nutrients. Thus, the presence of these important nutrients makes rice a vital grain in restoring the internal harmony of the human body system.¹³⁹

2.1.3.8 Other bioactivities

Hu ⁶⁷ reported that black rice pigment had significant effects on the anti-fatigue and hypoxia tolerance of mice. Anthocyanins extracted from pigmented rice such as black rice may be a strong candidate to protect mouse brain neuron against death at low concentration ⁴⁶ and can be incorporated in the production of value-added products to combat certain deficiency and lifestyle diseases.

2.1.4 Passion fruit (*Passiflora edulis*)

Passion fruit (*Passiflora edulis*) is an exotic tropical fruit native to Brazil belongs to Passifloraceae family. In Latin America, the cultivation of passion fruit became dominant due to the favorable weather condition and its processed products became popular widely

in European countries. In India, initially passion fruit was cultivated in South India. Cultivation extended to the North Eastern part of India due to the suitable climatic condition.⁸⁸ The genus *Passiflora* reported between 500 to 700 species.^{38, 108} As per the record, *Passiflora* species are found highest in tropical regions (despite some records of species in India, China, Australia and the Pacific islands).^{38,40} The most popular edible passion fruits reported are namely purple passion fruit (*Passiflora edulis* Sims), granadilla, (*Passiflora ligularis* Juss.), gulupa (*Passiflora edulis* Sims. fo *edulis*), sweet passion fruit (*Passiflora alata* Curtis), banana passion fruit (*Passiflora mollissima* (Kunth) Spreng.) and yellow passion fruit (*Passiflora edulis* var. *flavicarpa* Degenerer).⁴² Geographically, yellow passion fruit favored lowland tropical conditions, whilst, the purple type tends to be favored by subtropical areas or at higher altitudes in the tropics. The purple passion fruit is native from southern Brazil through Paraguay to northern Argentina and yellow one perhaps from native to Amazon region of Brazil.⁷⁵ Passion fruit is consumed as fresh fruit or juice. It is popular and is very well known for its possession of exotic, flowery and fruity aroma.⁴⁴

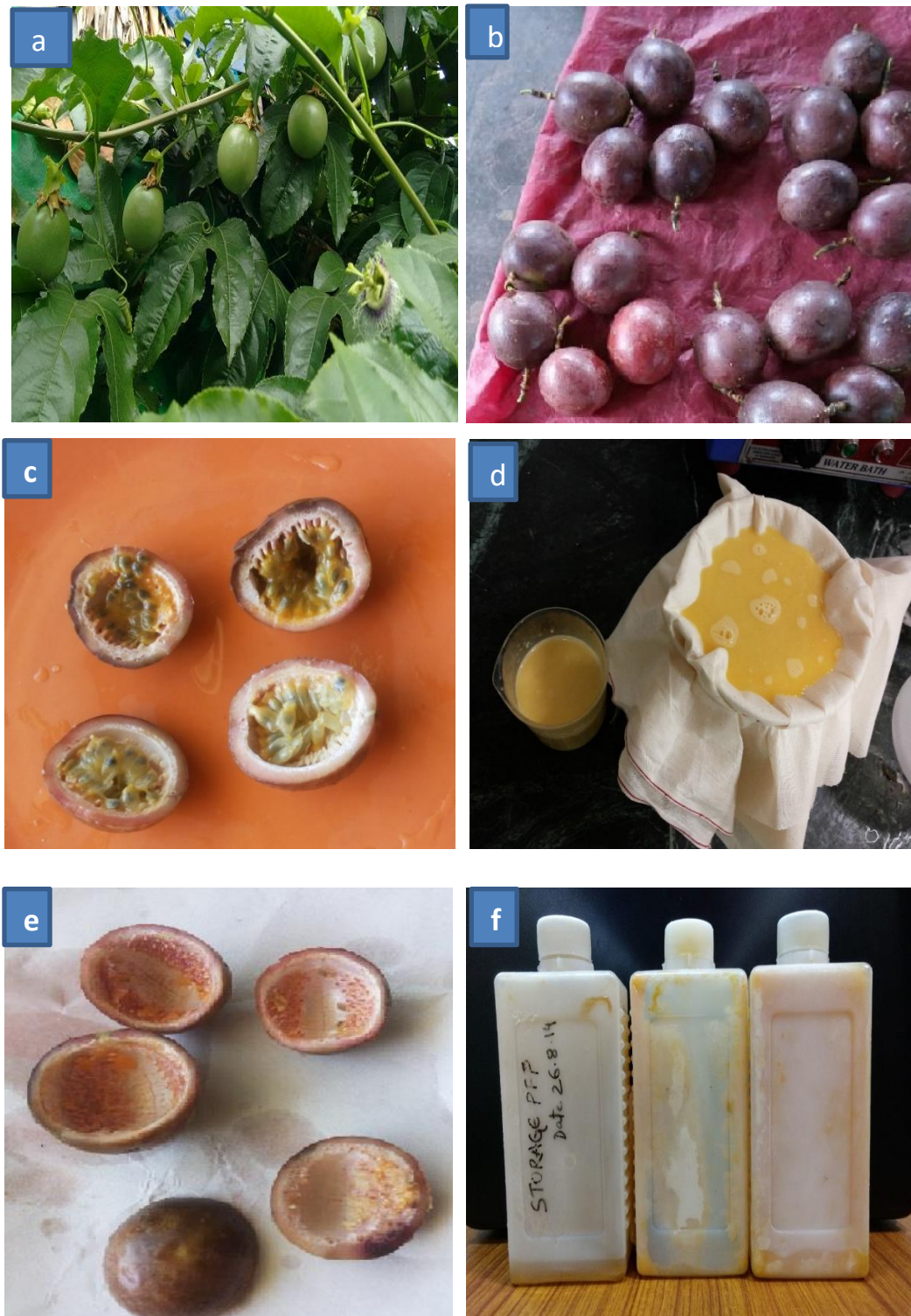


Fig. 2.4 Passion fruit samples (a) unripe passionfruit and (b) ripe passionfruit (c) pulp with seed (d) pulp (e) rind of fruit and (f) storage of pulp in container

Table 2.2 Fruit characteristics of some passiflora species found in India

Sl. No.	Common name	Characteristics	Reference
<i>Passiflora edulis</i> Sims	Purple Passion Fruit/Mountain Sweet Cup	Color: purple Shape: Round to ovoid fruit (5-8 cm long and 4-8 cm diameter) Appearance : tough, waxy smooth rind and orange yellow colored pulpy juice with pleasant and sub-acidic flavored arils	Sema and Maiti, ¹²⁸
<i>Passiflora edulis</i> Sims f. <i>flavicarpa</i> Degener	Yellow Passion Fruit/Golden passion fruit	Color: yellow Shape: Round to ovoid fruit, larger in size(8-10 cm long and 4-10cm diameter) Appearance: Smooth, glossy, light and airy thick (3-4mm) rind of yellow to light orange pulp having highly aromatic and acidic juice.	
<i>Passiflora quadrangularis</i> Medic	Giant Granadilla	Color: Greenish-white to pale yellow color Shape: Oblong-ovoid fruit of very large size (20-30 cm long and 12-15 cm diameter) Appearance: thick skin, whitish to yellowish sweet acid arils having mild flavor.	

2.1.4.1 Health benefits

Various researcher has claimed that exotic tropical fruits are abundantly rich in bioactive constituent's viz., phenolic compounds, carotenoids, vitamins and fibers. Recently, surge of research has been carried out to explore recovery technologies and new applications to utilized by products of these fruits.⁹⁵ Passion fruit constitutes a powerful house of various bioactive compound like vitamins A, C and D¹² alkaloids, carotenoids and flavonoids.³⁸ Also found to be a good source of nicotinic acid, riboflavin and meagerly mineral. Due to presence of polyphenol, antioxidant properties like anti-inflammatory and antipyretic properties.^{102, 126} Apart from its tremendous health benefits of pulp, the infusions made with the leaves is also well recognized. In the countries like America and Europe the leave is used as sedative or tranquilizer^{38, 54, 114} and the tea prepared by the infusion of the leaves is reported with anti-inflammatory potential.¹⁰²

The purple passion fruit extracts is used widely in folk medicine in South America to treat various ailments like anxiety, insomnia, bronchitis, and asthma.¹⁴⁸ Zibadi et al.¹⁴⁹ stated that the purple passion fruit peel (PFP) extract contains 3 major components: cyanidin-3*O*-glucoside, quercetin-3*O*-glucoside, and edulilic acid, and also used in treatment of hypertensive rats (modeling human essential hypertension with increased expression and activity of iNOS) results in significantly attenuated blood pressure through NO modulation. Also found reduced systolic and diastolic blood pressure in hypertensive patients.

2.1.4.2 Foam mat drying

Foam-mat drying is a simple process of drying liquid - solid foods. Addition of stabilizing agent or foaming agent *viz.*, proteins, gums and various emulsifiers (e.g., glycerol monostearate, propylene glycerol monostearate, carboxymethyl cellulose [CMC], trichlorophosphate) acceleration¹⁵ and drying at 50-80°C^{86,52} Foam mat drying is carried out at relatively low temperatures to obtain a thin porous honeycomb sheet to get a free-flowing powder. The main cause of moisture removal acceleration is larger surface area.¹⁵ Sankat and Castaigne¹³⁰ reported that capillary diffusion is the main reason for the moisture movement or displacement within the sample during drying.

There are various drying methods such as belt/tray drying method but it changes the color of sample, protein denaturation and poor rehydration quality has reported. Freeze-drying of liquids product is popular for its excellent product quality with good rehydration and color but costly affairs. Foam mat drying is also cheaper than vacuum drying, relatively simple and cost effective.^{79,129}

The various food items such as soy milk,⁴ star fruit⁸⁵ cowpea,⁵⁷ apple juice,¹¹⁶ mango,¹²¹ banana,¹³⁷ tomato juice,⁷⁸ bael,¹⁸ shrimp⁴ has been used for foam mat drying. Though, there is scanty of research on foam mat drying of purple passion fruit.

2.1.4.3 Foam generating methods

According to Eisner et al.⁵¹ in liquid sample foaminess is characterized by the volume of foam which is either bubbling air through liquid or by using any mixing method. Foam generation classifications is term as the static method and most common methods are whipping, shaking and bubbling.

2.1.4.3.1 Whipping

Whipping or beating are done by using different devices such manual and automatic blenders, vortex mixers, and homogenizers, which agitate the liquid into a gas and while vortex mixers can only be used for liquid suspension.¹¹³ During incorporation of air foam usually increases with an increase of beating intensity.¹

The final size of bubbles is defined by speed of the agitator, the geometry of the apparatus and rheological properties of the liquid respectively.¹

2.1.4.3.2 Shaking

Shaking method is another foam generation method but rarely used method. More the amplitude of shaking more the formation of bubbles. Volume of foam formed is meagre.¹

2.1.4.3.3 Bubbling

Bubbling involves injection of gas through narrow openings into a known quantity of liquid, produces uniform bubble sizes. Size of bubbles is depends on the viscosity of the liquid.¹

2.1.5 Extrusion cooking technology

In the food industry, extrusion cooking has been continuously developed since its invention.^{96,19} Olden days, the extruder was engaged in the production of macaroni and ready to eat cereal pellets only but now ingredients are transformed into various modified intermediate and finished products respectively.^{28,32,127,122} Extrusion cooking techniques are preferable than other techniques due to its high productivity and significant nutrient retention, owing to the high temperature and short time required.⁵⁹ This technology also reported in the reduction of microbial contamination increase the shelf life of extrudates product which has a water activity of 0.1 to 0.4.²³

In the recent year, high temperature-short time (HTST) extrusion cooking has been used successfully in the food industry. Products like nutritious ready-to-eat meals such as a protein-rich instant porridge were available in the markets^{110,127}. Extruders come in various design depending on the utility. Two broad categories are single screw extruder and twin extruder.

2.1.6 Rheology

Rice flour is hypoallergenic, colorless, and bland taste in nature but one of the most suitable flour for the preparation of gluten-free products and properties.⁶² Rheology is a science which deal with the deformation and flow of matter. Rheology has a very important role in food manufacture and marketing sector *viz.*, design of handling systems, quality control and evaluation of sensory stimuli associated with oral and non-oral evaluation of viscosity.¹¹⁷ Basic concepts of stress (force per area) and strain (deformation per length) are keys to all rheological evaluations. Stress (σ) is always a measurement of force per unit of surface area and is expressed in units of Pascals (Pa). The direction of the force with respect to the impacted surface area determines the type of stress. Normal stress occurs when the force is directly perpendicular to a surface and can be achieved during tension or compression. Shear stress occurs when the forces act in parallel to a surface. Various food show different rheological behavior and categorized into solid and liquids stages. It basically means that food varies their characteristic in viscous and elastic behaviors commonly known as viscoelasticity of food cause by entanglement of long chain molecules with other molecules.⁵

Dynamic oscillation test is the very convenient and suitable test for rheological property of viscoelastic food material. The elastic nature is measured by dynamic storage modulus (G') which is a measure of the energy stored in the food material and recovered from it per cycle of sinusoidal deformation while viscous nature i.e. the loss modulus (G'') is a measure of the energy dissipated or lost per cycle.^{138, 127}

Table 2.3 Various rheological models

Sl. No.	Model name	Equation	Reference
1	Power law	$\sigma = k(\gamma)^n$	Holdsworth ⁶⁸
2	Bingham model	$\sigma - \sigma_0 = n' \gamma$	Bingham ²⁴
3	Herschel –Bulky model	$\sigma = K_H \gamma^{n_H} + \sigma_{OH}$	Barnes and Walters ²⁶
4	Casson model	$\sigma^{0.5} = K_{oc} + K_c (\gamma)^{0.5}$	Casson, ³³
5	Mizrahi and Berk	$\sigma^{0.5} = K_M \gamma^{n_M} + \sigma_{OM}$	Mizrahi and Berk ¹⁰³

The Casson model is a used for structure-based model and used for food dispersions which include cooked rice flour dispersions²⁹ and rice starch dispersions.

Power law

Power law model describes the data of shear-thinning and shear thickening fluids or material

$$\sigma = k(\dot{\gamma})^n \quad \text{eq. (1)}$$

where, $\dot{\gamma}$ is the shear rate, K is the consistency coefficient with the units and n is the viscosity of the fluid.

Bingham model

Bingham model exhibits a yield stress,

$$\sigma - \sigma_0 = \eta' \dot{\gamma} \quad \text{eq. (2)}$$

where η' is called the Bingham plastic viscosity, $\dot{\gamma}$ is the shear rate and σ_0 is the yield stress

Herschel –Bulky model

$$\sigma = K_H \dot{\gamma}^{n_H} + \sigma_{OH} \quad \text{eq. (3)}$$

σ_0 is the yield stress, $\dot{\gamma}$ is the shear rate, K_H is the consistency index, n_H is the flow behavior.

Casson model

Casson model is used in characterization of various number of food dispersions

$$\sigma^{0.5} = K_{oc} + K_c(\gamma)^{0.5} \quad \text{eq. (4)}$$

Where $(\sigma)^{0.5}$ is the square root of shear stress, γ is the shear rate, K_c is the slope and K_{oc} is intercept.

Mizrahi and Berk model

Mizrahi and Berk model is a three-parameter viscoplastic model which also exhibits yield stress (Mizrahi and Berk) ¹⁰³ and eq. is given below

$$\sigma^{0.5} = K_M \gamma^{n_M} + \sigma_{OM} \quad \text{eq. (5)}$$

Where K_M = Apparent viscosity or consistency coefficient, σ_{OM} = Yield stress and n_M = Flow behavior index

2.1.7 Fuzzy logic tool

Value addition of underutilised crops is growing in the food markets. Incorporation of various ingredients add varieties in the items and enhance their textural or nutritional quality. Extrusion cooking, popularly known as high temperature/short time (HTST) is an important and popular food processing technique classified as a process to produce a fiber-rich product.⁶⁰ The process is not only popular for developing ready to eat food items but nutritionally to some extent may improve the bioavailability of bioactive compounds.²⁷

The *fuzzy* model can be used to determine the importance of individual factors to the overall quality of a product. In the model another important parameter is ‘weighting subset’, which tailored a product for specific consumer groups or geographic regions respectively^{147,138} Various food products such as mango drink⁷⁷ black rice wine⁷⁶ gluten free pasta,¹²⁵ risk dependency chain model of dairy agro-industry supply chain¹²⁴ but no study has been reported on ready to eat product develop rom underutilized crops such as red rice and purple passion fruit.

2.1.8 Moisture sorption isotherm

Water plays a crucial role in food processing and, food quality preservation depends on various aspects *viz.*, moisture content, moisture migration or moisture uptake by the

material during storage. Adsorption (refers weight gain of dry material because of water intake from atmospheres of increasing relative humidity) or desorption (refers weight loss (wet material) under the same relative humidity) state of a food product depends on vapor pressure of water present in the sample and of surroundings. The state of moisture content at which vapor pressure of water present in sample equals that of the surroundings termed as equilibrium moisture content (EMC).¹⁰⁰ Moisture sorption isotherm (MSI) is a relationship between total moisture content and the water activity of the food at constant temperature. According to Brunauer et al.²¹ stated that on the basis of the van der Waals adsorption of gases on various solid substrates, Moisture sorption isotherm adsorption can be categorized into 5 types *viz.*, Type I (Langmuir) and Type II (sigmoid shaped adsorption isotherm) and no specific name has been reported yet for others, Types III, Types IV and V. But later, Ricardo et al.¹¹⁷ reported that MSI characteristics are of five types *viz.*, Type 1: Langmuir or similar isotherm, Type 2 : sigmoidal sorption isotherm, Type 3 : Flory-Huggins isotherm, Type 4 : described the adsorption of a swellable hydrophilic solid until a maximum of site hydration is reached, and type 5: Brunauer-Emmett-Teller (BET). Mostly, MSI of foods are sigmoidal in shape (non-linear) i.e. Type II isotherms. Caurie⁴¹ stated that water content in fresh food exerts a vapour pressure near of pure water, i.e. unity. In food, this vapour pressure is maintain to attend 22% moisture content. In unity, vapour pressure will starts dropping which in dehydrated food showed sigmoidal shape of water sorption isotherms. The food products during storage and processing at different range of temperature, showed the mobility of water molecules and the dynamic equilibrium between the vapour and adsorbed phases in food. Iglesias and Chirife⁷¹ reported that the storage of food items in different increasing temperature make it less hygroscopic. Palipane and Driscoll¹¹¹ also stated that due to higher temperatures, water molecules are activated to energy levels and break away the sorption sites causing decrease in the equilibrium moisture content.

A fundamental property of a biomaterial is the water sorption characteristics.³⁰ The moisture sorption isotherm (MSI) predicts the possible changes in food item and also used to find out the storage study method and selection of packaging material for food products.¹⁶ These parameters helps to optimize or maximize retention of color, flavor, texture, nutrients, biological stability¹¹⁹ and also crucial for design, modelling and optimization of different processes like aeration, drying and storage.²⁰

Table 2.4 Mathematical models used to fit the equilibrium MSI of extruded products

Sl. No.	Model	Mathematical equation	Reference
1	Oswin	$M_w = A\left(\frac{a_w}{1-a_w}\right)^B$	Andrade et al. ⁹
2	Smith	$M_w = A + B \ln(-a_w)$	Andrade et al. ⁹
3	Curie	$M_w = \exp(A + Ka_w)$	Curie ⁴¹
4	Peleg	$M_w = Aa_w^c + Ba_w^k$	Basu et al. ¹⁶
5	Langmuir	$\frac{1}{CM_o} = a_w \left(\frac{1}{M_w} - \frac{1}{M_o} \right)$	Langmuir ⁹⁴
6	Brunauer-Emmett-Teller (BET)	$\frac{M_w}{M_o} = \frac{Ca_w}{(1-aw)[1+(C-1)a_w]}$	Brunauer et al. ²²

M_w and M_o are equilibrium and monolayer moisture content, respectively (g water/100 g dry matter); a_w is the water activity (decimal); A, B, C and M are respective model constants.

2.1.9 Dipeptidyl peptidase-4 (DPP-4) inhibitory activity and GLP-1 secretion

2.1.9.1 Diabetes mellitus

India is reported to be largest number of diabetics in the world, 3.8% in rural and 11.8% in urban adults.¹²³ Diabetes mellitus are of two types namely type 1 and type 2^{74,10}. Type 2 diabetes mellitus (T2DM) showed 90 % cases of diabetes (approx.) and soon going to be declared as global epidemic of the twenty-first century.⁷²

2.1.9.2 Incretin System

The incretin a gastrointestinal hormones namely glucose-dependent insulintrophic polypeptide (GIP) and glucagon-like peptide-1 (GLP-1), are insulintropic i.e. stimulate insulin secretion.⁶³ As soon as the meal is taken GLP-1 (7-36 amide) i.e. 30 amino acid polypeptide cause the release of insulin from from β -cells of the Islets of Langerhans and inhibit glucagon release from the α -cells of the Islets of Langerhans. Half-life of glucagon-like peptide (GLP) which secreted from L- cell is 1- 1.5 minutes total but abruptly

degraded by dipeptidyl peptidase-4 (DPP-IV) enzyme and get cleaved in two N-terminal residues of GLP-1^{47,31}. Another intestinal hormone i.e. glucose-dependent insulinotropic polypeptide (GIP) secreted from K cells of the duodenum released GIP after meal is taken. Half-life of GIP secreted have reported to be 5-7 minutes^{101,48,120,49}

2.1.9.3 Dipeptidyl peptidase-4 (DPP-4) inhibitory activity

In record, dipeptidyl peptidase IV (DPP IV) was identified by Hopsu-Hovu and Glenner⁷⁰ as glycylproline naphthylamidase. Later, in the year 1967 and 1968, it was purified from rat liver and pig kidney respectively. The first inhibitor characterization was stated in the late 1980s and 1990s.¹³¹ DPP4 is present in various organ *viz.*, kidney, spleen, lungs, pancreas, and prostate.⁶¹ Highly expressed at high levels on various cells such as endothelial, differentiated epithelial, and immune cells such as T cells, dendritic cells, and macrophages. Kirino et al.⁸⁷ and Andrieu¹¹ stated that altered expression of soluble DPP4 is commonly ascertain in various disorders such as solid tumors, autoimmune diseases, hepatitis C, type 2 diabetes (T2DM), and obesity. Pharmacological involvement and clinically approved strategies *viz.*, glucagon-like peptide-1 (GLP-1), inhibitors of dipeptidyl peptidase-4 (DPP-4) which act to halt the physiological breakdown of glucagon-like peptide-(GLP-1) and glucose-dependent insulinotropic polypeptide (GIP), which is the need of hour to cease the rate of diabetic people in the world specially in the developing countries.^{56,64,65,89}

2.1.9.4 GLP-1 secretion

Glucagon-like peptide (GLP-1) is a type of incretin which is secreted from enteroendocrine L cells, and also a part of lower small intestine and large intestine. GLP-1 stimulates insulin secretion in a blood glucose concentration dependent manner which results in reduction of pancreatic cell exhaustion, hypoglycemia, and weight gain etc. GLP-1 is reported with various diabetes-suppressing actions and considered as an important and effective molecule for treating type 2 diabetes.¹⁰⁶ Review of literature has showed various studies *viz.*, administration of lipase inhibitor (Orlistat) in type 2 diabetes patients to validate GLP-1 and GIP secretion during glucose and oil intake, showed lowered glucose tolerance,¹⁰⁷ whey protein stimulates the secretion of GLP-1 during mashed potato intake and helps in postprandial hyperglycemia⁹⁷ alcohol consumption after a meal helps in

suppressing the increase of GLP-1 concentration⁴³ healthy subjects who consume sandwich (containing bread, butter, and dried meat) was stated with strong GIP secretion and effective incretin, when compared to a meal consisting of dried meat or butter,³⁶ increase intake of fish (polyunsaturated fatty acids, such as docosahexaenoic acid and eicosapentaenoic acid) in Japanese type 2 diabetes patients reported effectiveness of glycated hemoglobin reduction.⁷³

2.1.9.5 Mechanism of action

In the body, DPP-IV inhibitors helps in inhibition of DPP 4 enzyme which degrade incretin GLP-1 and GIP after meal. GLP-1 and GIP increases the secretion of insulin and prevent the release of glucagon by the pancreas to maintain blood glucose in normal. Once the normal level is attained in the body, insulin released and glucagon suppression declined, prevents hypoglycemia in oral hypoglycemic agents.¹¹²

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