GRAIN QUALITY EVALUATION OF IMPROVED BLACK RICE (*Oryza sativa* L.) GENOTYPES AND ASSESSMENT OF THEIR SUITABILITY FOR PREPARATION OF SOUTH INDIAN FOODS

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B.Sc. (Hons) Community Science

MASTER OF SCIENCE IN HOME SCIENCE
(FOODS AND NUTRITION)

ANGRAU

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BY

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DECLARATION

I, **Ms. PULLAGURA VIJAYA SHAMA**, hereby declare that the thesis entitled **"Grain Quality Evaluation of Improved Black Rice (*Oryza sativa* L.) Genotypes and Assessment of their Suitability for Preparation of South Indian Foods"** submitted to the **Acharya N.G. Ranga Agricultural University** for the degree of **Master of Science in Home Science** is the result of original research work done by me. I also declare that no material contained in the thesis has been published earlier in any manner.

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Ms. **PULLAGURA VIJAYA SHAMA** has satisfactorily prosecuted the course of research and that thesis entitled **"Grain Quality Evaluation of Improved Black Rice (*Oryza sativa* L.) Genotypes and Assessment of their Suitability for Preparation of South Indian Foods"** submitted is the result of original research work and is of sufficiently high standard to warrant its presentation to the examination. I also certify that neither the thesis nor its part thereof has been previously submitted by her for a degree of any University.

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CERTIFICATE

This is to certify that the thesis entitled **"Grain Quality Evaluation of Improved Black Rice (*Oryza sativa* L.) Genotypes and Assessment of their Suitability for Preparation of South Indian Foods"** submitted in partial fulfilment of the requirements for the degree of 'Master of Science in Home Science' of the Acharya N.G. Ranga Agricultural University, Lam, Guntur is a record of bonafide original research work carried out by **Ms. P. VIJAYA SHAMA** under our guidance and supervision.

No part of the thesis has been submitted by the student for any other degree or diploma. The published part and all assistance received during the course of investigations have been duly acknowledged by the author of the thesis.

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LIST OF SYMBOLS AND ABBREVATIONS

% : Percentage
/ : or
< : Less than sign
> : Greater than sign
± : Plus or minus symbol
μg : Microgram
°C : Degree Celsius
°F : Degree Fahrenheit
AAE : Ascorbic acid equivalent
AAS : Atomic Absorption Spectroscopy
AC : Amylose Content
ALP : Alkaline Phosphate
AOAC : Association of Official Analytical Chemists
ARS : Agricultural Research Station
ASV : Alkali Spreading Value
BCCAO : Bilateral Common Carotoid Artery Occlusion
BR : Black rice
BRAE : Black Rice Anthocyanin Extract
BRB : Black rice bran
BRE : Black rice extract
BRF : Black rice flour
C.D : Critical difference
C.V : Coefficient of variance
C3G : Cyanidin-3-glucoside
CF : Crude fiber
CHO : Carbohydrates
db : Dry basis
Df : Degree of freedom
DPPH : 2,2 diphenyl-1-picrylhydrazyl
ER : Elongation ratio

et al.	:	And other people
FAO	:	Food Agricultural Organization
F-Cal	:	F Calculated
Fe	:	Iron
FRAP	:	Ferric Reducing Ability of Plasma
F-Tab	:	F Tabular
g	:	Grams
g/ml	:	Gram per Millilitres
GAE	:	Gallic Acid Equivalent
GC	:	Gel consistency
GI	:	Glycemic index
HCL	:	Hydrochloric acid
HER2	:	Human Epidermal Growth Factor Receptor 2
HPC	:	High Pressure Cooking
HPLC	:	High Performance Liquid Chromatography
HRR	:	Head Rice Recovery
i.e	:	That is
KB	:	Kernel Breadth
KBAC	:	Kerenel Breadth After Cooking
KER	:	Kerenel Elongation Ratio
kg	:	Kilogram
KL	:	Kernel Length
KLAC	:	Kerenel Length After Cooking
KOH	:	Potassium Hydroxide
L/B	:	Length by Breadth
MAPK	:	Mitogen Activated Protein Kinase
mg	:	Milligrams
mg/100g	:	Milligram per 100 grams
mg/dl	:	Milligrams per deciliter
min	:	Minutes
ml	:	Milliliters

mm	:	Millimeters
MSS	:	Mean sum of squares
nm	:	Nano meter
P- value	:	Probability value
ppm	:	Parts per million
q/acre	:	Quintal per acre
QE	:	Quercetin Equivalent
RAF	:	Rapidly accelerated Fibrosarcoma
RAS	:	RAS protein
RDS	:	Rapidly Digestible Starch
RPM	:	Rotations per minute
RS	:	Resistant Starch
SD	:	Standard deviation
SE	:	Standard error
SS	:	Sum of Squares
TAA	:	Total Antioxidant Activity
TE	:	Tocopherol Equivalent
TFC	:	Total Flavanoid Content
TGW	:	Thousand Grain Weight
TPC	:	Total Phenolic Content
UPLC	:	Ultra Performance Liquid Chromatography
VER	:	Volume Expansion Ratio
W/V	:	Weight by volume
W/W	:	Weight by weight
WAC	:	Water Absorption Capacity
WAI	:	Water Absorption Index
WF	:	Wheat flour
WHO	:	World Health Organisation
WSI	:	Water Solubility Index
WU	:	Water uptake
Zn	:	Zinc

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ABSTRACT

Black rice is a speciality rice variety with black bran covering the endosperm. Despite being nutrient-dense, it is not widely consumed by people because of a lack of awareness among public and no preference for its colour. In the present study, six improved black rice varieties including Burma black (control), BPT 2841, BPT 2848, BPT 3136, BPT 3137 and BPT 3145 grown in *Kharif*- 2021 were obtained from the Agricultural Research Station (ARS), Bapatla. These genotypes were investigated for physicochemical, cooking quality, nutraceutical properties, biochemical profile, proximate composition, micronutrients (iron and zinc), glycemic index and correlation among these parameters to identify black rice variety possessing desirable quality and nutritional traits suitable for consumption. Except for the proximate composition of rice genotypes, ANOVA revealed significant differences among all the attributes studied.

All the black rice genotypes along with control had desired parameters such as high hulling, milling and high head rice recovery percentage; medium and long kernel length, medium and long slender grain type; long kernel length after cooking; medium kernel elongation ratio; high volume expansion ratio and good water absorption index. In terms of chemical quality, all the rice varieties differed from control by having intermediate amylose content (20-25) and intermediate alkali spreading value (4-5), which give a soft and flaky texture to the cooked rice, which are the important traits to determine the rice quality.

The proximate composition does not differ significantly among the rice genotypes. The mean values of moisture, protein, fat, ash, fiber, carbohydrates and energy per 100g of the black rice were noted as 10.78g, 10.08g, 1.95g, 0.91g, 1.16g, 75.14g and 358 kcal. Burma black had the highest total anthocyanin content (30.57

mgC3G/100g), followed by BPT 2841 (26.76 mgC3G/100g). The BPT 2841 recorded the highest total phenol content and total antioxidant activity (238.17 mgGAE/100g and 99.52 mgAAE/100g), followed by control (218.89 mgGAE/100g and 97.52 mgGAE/100g). The phytates and oxalates ranged from 351.38 to 410.36 mg/100g and 2.24 to 5.38 mg/100g; the highest values were recorded in Burma black. The Burma black had the highest values for moisture, protein, fat, ash and fiber, followed by BPT 2841, BPT 2848, BPT 3137, BPT 3136 and BPT 3145. Burma black had medium iron and zinc (1.55 mg/100g and 2.05 mg/100g). The black rice genotypes such as BPT 2841, BPT 2848 and BPT 3136 were categorized as medium iron rice varieties. BPT 2848 was categorized under low glycemic index variety; the remaining rice genotypes and control were classified under medium glycemic index varieties (56-69).

Correlation studies revealed a significant positive association among the parameters such as hulling with head rice recovery; thousand grain weight with kernel length and kernel breadth; kernel length after cooking with kernel breadth after cooking, alkali spreading value with gel consistency, water uptake and Iron; kernel elongation ratio with L/B ratio; total phenol content with total anthocyanin content, total antioxidant activity and protein; carbohydrate with volume expansion ratio, bulk density, water solubility index and energy; iron with zinc and ash; fat with energy. Glycemic index showed a non-significant negative correlation with amylose, carbohydrates and energy. Selection of these significantly correlated characters will improve the overall quality of the genotypes.

The suitability of black rice for product development was evaluated for traditional foods like payasam and vadiyalu; baked products like cake; extruded products like vermicelli using the nine point hedonic rating scale. The highest overall acceptability was scored in payasam and cake by BPT 2848 (8.80 and 8.92), in vadiyalu by BPT 3137 (8.72) and in vermicelli by BPT 3136 (8.76). The payasam and cakes of all black rice genotypes were displayed similar values compared to the control. However the vadiyalu and vermicelli made from Burma black (control) scored the lowest in terms of sensory score since the cooked foods became mushy and sticky due to its low amylose content. So, Burma black is not suitable for products like vadiyalu and vermicelli. The highly accepted samples of vermicelli and vadiyalu were assessed with control and white rice products for shelf-life study (30 days), which revealed that all samples were suitable for consumption, since the sensory and nutritional parameters remain unchanged.

On comparison with control, the black rice genotypes had varied traits such as intermediate amylose and alkali spreading values, whereas all the biochemical quality profile, nutritional parameters and glycemic index showed similar trends. So, the black rice genotypes would be preferred over the control for desired eating quality and value added products. In addition to the desired quality characteristics, it had a low and medium glycemic index, antioxidant properties, a high protein content, and a high and medium iron and zinc content. The daily consumption of black rice could reduce several non communicable diseases like diabetes and cancer due to the presence of phytochemicals. Hence, it may be possible to achieve nationwide sustainable nutritional security by including black rice in people's regular meals.

Chapter I

INTRODUCTION

Rice (*Oryza Sativa*. L) is the major cereal food grain and is considered as a staple food by more than half of the globe. *Indica* species are most grown in India and several Asian countries. Worldwide consumption of rice has increased by about 15% in the crop year 2020-2021 as compared to the crop year 2008-2009. About 50% to 75% of the global population has partially or fully adapted to rice as a staple food. Half of the total calorie requirement is fulfilled by the consumption of rice, particularly in the Asian continent (Parida *et al.,* 2022).

Paddy comes in distinct colours with red, brown, purple and even black. These colourful varieties of rice are treated as precious because of its advantages to health and these are known as Specialty rices. “Specialty rices” is a common name for varieties that are have unusual grains with unique characters in grain size, grain shape, aroma and pericarp colour, which have greater amount of nutrients than the ordinary white rice. Most of these rice varieties were consumed on traditional occasions. Now a days public are looking for foodstuff that might benefit the health and provide strength to the body. Functional foods can be made from speciality rices. Scientists and researchers are treating the black rice as the “super food”.

Black rice has a range of rice types of the species *Oryza sativa*. L. The origin of history of black rice was from Asia. It was grown only for imperial households in ancient China. Because it is forbidden for consumption by common Chinese citizens, it has earned the label "Forbidden Rice." Over the time, it has been expanded to the United States, China, Australia, and Europe. It is grown in the north-eastern state of India. It is also known as purple rice, heaven rice, imperial rice, king’s rice and prized rice. The pericarp (outer part) of kernel of this rice colour is black due to a pigment known as anthocyanin, an antioxidant which is stimulated by mutation of the *kala4* gene (Murali and Kumar 2020). This dark purple color predominantly comes from anthocyanins which are flavonoids that perform as antioxidants in the body.

In the world many cultivars of black rice are available. The first is black japonica, which is short-medium in length and has a spicy and sweet in flavour. The second type is waxy glutinous short grain, which is high in branched amylopectin. The third is Italian black long rice with buttery flavor. The fourth is Thai black jasmine rice, which is medium grain rice.

Black rice is known as Chak-hao Ambi in Manipur (Chak-hao means “delicious” and ambi means “black”) and thus refers to delicious black rice. In Odisha it is known as Kalabati (kala means “black” and bati means “rice” in Oriya). In south India, it is found at Keelapoongudi village in karaikudi district of Tamil Nadu and it is called as 'kavuni rice' (Yamuangmorn and Prom-u-Thai 2021 and Murali and Kumar 2020)

Asian nations including China, Korea, and Japan have been consuming black rice for centuries. In Manipur, India, small-scale conventional farmers cultivate black rice. Black rice resources are most abundant in China (62%), Sri Lanka (8.6%), Indonesia (7.2%), India (5.1%), Bangladesh (4.1%), and a small number of countries in Malaysia. They have created 200 kinds thus far, including 52 high yielding variants (Kumari 2020).

Black rice is high in lysine and tryptophan, as well as vitamins like vitamin B1, vitamin B2 and folic acid. It has minerals like iron, zinc, phosphorus, calcium and selenium. It is high in fiber and even it has plant-based protein. A serving of black rice (1/4 cup or 50g) has about 160 calories in it. This variety of rice has 43 g of crabs, 5 g of protein, 1 g of iron and 5 g of fiber per serving, whereas brown rice has 47 g of crabs, 3 g of protein, 2 g of fat and 2 g of fiber per serving (Veni 2019).

Black rice contained lots of fibers which help our body to minimize constipation, assisting weight loss and for the reduction of excess body fat. Black rice doesn't contain gluten, so digestion of food is simple as a result. While it is not as prevalent as the white and brown varieties, it adds more vibrant colour to meals, as well as providing additional health benefits. Black rice extract is an excellent natural food colouring dye. Its pigments can generate different hues of colours from black to purple which results in the black rice bran powder, a good source for natural and healthier alternative to artificial food colorants.

Traditional white rice has high-carbohydrates that raise blood sugar levels. Black rice is one of the coloured rice variants that is particularly rich in nutrients and bioactive substances that have health advantages. It may be used as substitute of white rice in diet plans. As a result, glucose absorption happens relatively slow, which will control the diabetes. It is a good source of dietary fibre and phytochemicals that help combat heart disease and cancer. Research suggests that plant antioxidants, which mop up harmful molecules, that can help to protect from atherosclerosis and also prevents DNA damage that lead to cancer. If it is regularly consumed, it increases the availability of essential amino acids, essential fats, phytosterols, tocopherols, and phytic acid which results in more health benefits. Consuming black rice directly or using its processed products can lower several problems, including hypertension, digestive issues, cancer, neurological diseases, etc. The black rice has become more famous among all the rice varieties since it contains antioxidants. So, it is a good alternative to white rice. (Meena *et al.,* 2021).

Although black rice is known for its medicinal and health benefits in other countries, the knowledge regarding the importance of black rice is not highlighted in India. There is no enough documentation and scientific research on black rice. Efforts are to be made in terms of developing cooking quality, aroma and to disseminate the knowledge regarding its health benefits. On account of the high glycemic index of rice based foods, rice consumption has been affected in the burgeoning prevalence of obesity, diabetes mellitus, cardio vascular disease etc., as the black rice varieties have low and medium glycemic index, anti-inflammatory and antioxidant properties and hence it can be used in the development of functional foods for health promotion and disease prevention (Priya *et al.,* 2019).

Grain quality is also the major concern in rice production and rice palatability, and hence it is an important factor that determines the commercial value of rice. For Asian markets, the hardness and stickiness have been reported as the two most important parameters for determining the palatability of cooked rice. Quality improvement of rice is now increasingly being emphasized in breeding programmes to increase rice consumption and to achieve international competitiveness. The suitability of the black rice products are evaluated for quality to enhance the competitiveness of processed rice foods. Black rice is mainly used in Asian countries for baked products, extruded products and traditional dishes.

Starch is the most important nutrient component of black rice and all the rice, including linear amylose with low molecular weight and amylopection with high molecular weight. The amylose content is less than 2 in waxy rice, 3-9 in very low amylose rice, 10-19 in low amylose rice, 20-24 in intermediate amylose rice and 25-30 in high amylose rice. On cooking, the waxy and very low amylose rices become sticky and mushy whereas intermediate and high amylose rice becomes soft and flaky. Most of the black rice landraces are waxy and very low amylose varieties with poor cooking quality. Hence at ARS, Bapatla breeding programme has been initiated to develop black rice genotypes with good cooking and nutritional traits that are suitable for daily consumption. To satisfy the various demands of different food processing units and customers, a wide variety of rice starch properties are necessary. Also the evaluation of the total antioxidant capacity of cereals is getting more importance, since it has been found that phenolic compounds are the most effective antioxidants.

Therefore, it is essential to evaluate the physiochemical quality traits, biochemical parameters and nutritional composition of the black rice and its value added products to provide a scientific data in order to make it easier to understand its potential uses and applications in food industry, it helps the community in meeting the nutritional problems and food security. In view of these facts, the study is undertaken with the following objectives.

- To evaluate the physico-chemical, cooking quality and nutraceutical properties of improved black rice genotypes.
- To assess the biochemical quality profile of the selected black rice genotypes.
- To study the suitability of black rice genotypes for product development.

Chapter II

REVIEW OF LITERATURE

The relevant literature on the study of 'Grain Quality Evaluation of Improved Black Rice (*Oryza sativa L.*) genotypes and Assessment of their suitability for preparation of south Indian foods' was reviewed and presented under the following headings.

2.1 Scenario of Rice

2.2 Quality Traits of Black rice

2.3 Biochemical Quality Profile of Black rice

2.4 Nutritional Composition of Black rice

  2.4.1 Proximate Composition

  2.4.2 Micronutrients

  2.4.3 Glycemic Index

2.5 Correlation Studies of Rice

2.6 Value-added products

2.7 Health Benefits

2.1 Scenario of rice

Rice (*Oryza sativa* L.) is the second most important cereal in the world and it is the staple food for most Asians and over 90% of the world's rice is produced and consumed in Asia. India is the second-largest rice-producing country in the world and the crop contributes over 42% to the annual food grain production of the country. Black rice is consumed by a very small portion of people in Asia during special occasions. It is a medium-grain, non-glutinous heirloom rice with a deep purple hue and a nutty with a slight sweet flavour. The dark colour of the grain is due to anthocyanin, a powerful antioxidant. The black rice has a deep black colour and usually it turns into deep purple when it was cooked. It is suitable for creating porridge, dessert, cake, bread, kheer, noodles and many other dishes (Saha *et al.,* 2022).

Rice is the most common food in the world since time immemorial. The outer layer of rice kernels contains anthocyanin pigment, which is responsible for the colour of rice bran. Pigmented rice varieties are admired all over the world and have a history of heritage. The black rice is a nutrient-rich variety which is mainly cultivated in Asian countries. The black rice has not only been involved in the field of medicine but also in cooking and in fodder for cattle. It contains high nutrient values and beneficial amino acids like lysine and tryptophan, which possesses lots of health benefits. The benefits of black rice cultivation provide a path of entrepreneurship for many farmers. The black rice cultivation can generate great employment opportunities and producers can earn profit from the sale of black rice (Agrawal 2021).

Black rice has gained popularity in recent times, since consumers have begun realizing its extreme nutritional and health benefits. In India, the north-eastern state of Manipur is known for its traditional cultivars of black rice. Although the yield of black rice is much lower (around 12-15 q/acre) compared to white rice (around 20-25 q/acre), their economic returns is exponentially higher due to its lower cost of cultivation and the much higher price it fetches (around 4 to 5 times or even higher price than white rice). The growing demand for this rice, both at the national and international markets, can be tapped by investing in commercialization avenues and marketing infrastructures through research and development and active participation of the central and state governments (Houmai *et al.,* 2021).

The black rice is called as a unique king of rice which offers a number of promising health advantages. The black rice is a superfood because of its strong antioxidant activity and using it as a component to other food products may produce diets that are incredibly nutrient-dense. Researchers are becoming more interested to study about anthocyanin which is the primary pigment of black rice because of its strong antioxidant activity, health advantages, and natural colouring abilities for use in various culinary applications. The black rice is more useful and innovative ingredient in food processing because it is a high source of tocopherols (vitamin E), iron and antioxidants. Its overall nutritional profile has made it special. The consumption of black rice by individuals those who has allergic symptoms to other cereal grains has proved that it is beneficial to them and also helps in reducing the risk of developing cardiovascular diseases, diabetes and obesity. There is a dire need to include black rice as a novel ingredient in food processing to explore its complete benefits (Murali and Kumar 2020).

Table 2.1 Predominant black rice varieties in different states of India

S.No	State	Variety	Major characteristics
1.	Manipur	Chak-hao	Leaves and husks are light black in colour. Short duration cultivar is grown twice or thrice in a year
2.	Tamil Nadu	Karapu Kavani, Karunguruvai, Kattuyanam, Mappillai Samba	Duration - 140 day. Average yield 1 ton/acre. But few farmers are getting even upto 2 tones/ acre.
3.	Maharashtra	Kalabhat	-
4.	Odisha	Kalabhati	Husk purple in colour, while the rice is black in colour). It grows up to 5 to 6.5 feet in height and changes its colour every week. The total duration of the variety is 150 days (long duration cultivar). Kalabhati is pruned once it reaches 2 to 3 feet to encourage more productive tillers which increase the total yield and productivity per unit area. The average yield potential is 12 to 15 quintal/acre.
5.	Northeast states	Burma Black	Direct seeding – 125 days Transplanting – 135 to 145 days
6.	Other prominent varieties are Kari Munduga, Karingellu, Kari Jeddu and Navaradanta		These varieties have black colour husk and red colour rice. The peculiarity of some varieties of black rice is that its roots, stems, leaves and panicles are all black in colour.

Source: Saha *et al.* (2022)

2.2 Quality Traits of Black rice

Rice varieties must be screened for physicochemical parameters in order to determine their quality and potential applications in the food sector.

Arora *et al.* (2021) studied the changes in the physico-functional and thermo-pasting of roasted black rice (*Oryza sativa* L.). When compared to control, roasting enhanced the physico-functional parameters such as surface area (24.89-72.86 mm^2) and sphericity (0.43-0.73), water absorption index (1.30-3.43 g/g), and oil absorption capacity (1.52-2.05 g/g).

Farooq *et al.* (2021) analyzed the physicochemical properties, swelling power, solubility, and digestibility of flour from four rice varieties (black, brown, white, and waxy rice flour). The results showed that the black and brown rice had high-amylose percentage (21.8% and 20.5%), a relatively low percentage of starch content (68.1% and 79.1%), and lower swelling power (6.6% and 7.6%) and solubility (13.5% and 15.7%), respectively. The black and brown rice flour exhibited lower pasting and viscosity values as compared to waxy rice flour. Brown and black rice flour after cooking have lower digestion rate than white rice and waxy rice flour, probably due to its lower expansion and solubility rates, and higher gelatinization temperature.

Lapcikova *et al.* (2021) evaluated the water binding capacity of selected varieties of rice flours (Fine, Red and Black) as prospective processing parameter for manufacturing gluten-free products. Water retention capability was determined by measuring the water absorption index and water solubility index. It was found that with decreasing particles size of flour the water binding capacity was increasing. This phenomenon was dependent also on the saccharides and proteins content of individual materials. The highest water absorption index was found for Fine, Red and Black rice flours dispersions indicating their ability to associate with water molecules. The water solubility index was the highest for Black rice flour dispersions followed by Red and Fine flours dispersions indicating presence of the high amount of water soluble components in the aqueous phase. This indicates their increased potential to form higher adhesiveness and higher stickiness in the final food product. That is why, for the preparation of the gluten free products the use of the Black and Fine rice flours in the mass ratio of 0.6 : 1 (flour: water) seems to be the most advantageous due to their better ability to retain water in their structure in comparison with the other rice varieties under this study.

Pakuwal and Manandhar (2021) studied the physical characteristics of different rice varieties (Taichung-176, Khumal-4 rice, and Black rice) with Jumli Marsi rice. The kernel length, kernel breadth, 1000 kernel weight, amylose content, amylose content and swelling property were found to be ranged from 4 to 6mm, 3 to 4mm, 17.03 to 19.21g, 5.28 to 27.62% and 1.80 to 3.83g/g.

Ray *et al.* (2021) investigated the morphological characteristics of ten traditional rice varieties among them Burma black had black colour kernels. The kernel length, kernel width and 100 grain wt of Burma black was 6.58mm, 2.45mm and 2.75g.

Sridevi *et al.* (2021) studied 26 rice (pigmented and non pigmented) genotypes for physico-chemical properties. Among the non-pigmented varieties, BPT 5204, BPT 2270, BPT 2595, BPT 2782 and BPT 2776 recorded the desirable quality traits with excellent cooking quality. The coloured rice varieties reported in the present study recorded medium slender grain type and good cooking quality. Black and red rice genotypes *viz.,* BPT 2848, BPT 3140, BPT 3141, BPT 2858, BPT 3111 were recorded desirable physical quality traits.

Rajenan and chanan (2020) studied the grain dimensions of 13 coloured (black and red) rice varieties. The kernel length, kernel breadth and L/B ratio of rice ranged from 6.00-6.30mm, 2.50-3.00mm and 1.88-2.52. Among the 13 coloured rice varieties, Chak hao poreiton (black pericarp) had low concentration of total starch, high concentration of resistant starch and lowermost GI.

Singh *et al.* (2020a) investigated seven red pericarp, eight black pericarp, 17 white rice genotypes and BPT 5204 for physicochemical and cooking characteristics. The HRR, amylose content and alkali spreading value ranged 56.15-69.40 %, 17.53-30.32 % and 2.50-7.00. Among all the genotypes, black pericarp (BPT 2848), red pericarp (BPT 3178), white pericarp (BPT 2615, BPT 2782 and MTU 1281) were identified as high quality genotypes.

Singh and Devi (2020) assessed the physical and cooking quality characteristics of three local aromatic rice cultivars of Manipur. The aromatic rice cultivars of white (Chakhao abngouba), red (Chakhao angangbi) and black (Chakhao amubi) grain samples were studied. All the three aromatic rice varieties were medium slender in L/B ratio. All the three varieties had recorded the maximum hulling and milling percentage than the other land races which were cultivated in the valley of Manipur. Among these varieties, the white get cooked rapidly. Higher grain elongation and volume expansion ratio was observed in all the three varieties.

Sushmitha and Reddy (2020) analyzed the physicochemical properties in extracts of black rice flour (BRF). The functional properties of black and brown rice namely bulk density (68g/100ml and 83 g/100ml), water absorption index (120% and 110%) and fat absorption index (120g/100ml and 200g/100ml) respectively were estimated. The bulk density, water and fat absorption, foaming capacity and emulsifying capacity of the samples were in the order of white rice > Brown rice > Black rice. Although the BRF, physicochemical properties were less than the white rice and Brown rice, the values were comparable.

Devi *et al.* (2019) studied physico-chemical parameters of twenty six coloured rice (7-light brown pericarp, 8-red pericarp and 11 black pericarp) genotypes. All of them were divided into six clusters. The range values of thousand grain wt, water uptake, volume expansion ratio, alkali spreading value, L/B ratio and amylose were 16.16-22.79g, 52.00-111.67, 1.82-3.00, 2.00-4.00, 2.26-3.51 and 21.44-24.24% respectively.

Pal *et al.* (2019) studied the physicochemical properties and consumer preferences of black rice and its products. The Indian black rice cultivars Chakha (CH), Kalobhat (KB), Mamihunger (MA) and Manipuri Black (MN); A popular white rice variety Swarna Sub-1 (SW) (control) were selected for analysis. Significant differences in most of the physicochemical and cooking parameters of raw rice were observed across different cultivars. The head rice recovery, amylose content, elongation ratio (ER) and kernel length after cooking of MA were most satisfactory among the black rice cultivars and are found to be 50.67%, 17.6%, 1.87 and 10.10 mm respectively. With respect to most of the traits, MA showed the good potential for rice Industry as well as for breeding material.

Kumar *et al.* (2018b) studied the physicochemical, functional, pasting and morphological characteristics of paddy (Gurjari variety) and its processed products obtained during flaking. The kernel length, kernel breadth, thousand kernel weight, bulk density, AC, WAI and WSI of rough rice was 9.27±0.07 mm, 2.96±0.29 mm, 36.25±0.51 kg/m^3, 616.80±45.93 kg/m^3, 20.48±1.27, 2.33±0.11g/g and 1.48±0.38% respectively.

Masniawati *et al.* (2018) investigated the physicochemical properties from local rice germplasm of Tana Toraja's Regency, South Sulawesi, Indonesia to indicate the cooking quality. Percentage of amylose content ranged from 2 to 18 %. Pare Bumbungan (2.51%) were categorized as waxy rice and Pare Ambo (18.29 %), Pare Bau (17.57%), Pare Kobo (15.91%), Pare Rogon (17.79%), Pare Tallang (17.79%) were categorized as low amylose content. Pare Bumbungan, Pare Kobo, Pare Lalodo, and Pare Rogon were categorized as soft gel consistency (>50 mm). Pare Ambo, Pare Bau and Pare Tallang were categorized as medium gel consistency (36-50m). Pare Rogon and Pare Kobo were two kinds of rice varieties according to the quality of cooking criteria for consumers.

In this study, the cooking properties and retrogradation process of black rice (BR) with high hydrostatic pressure (HHP, 200–400 MPa/15 min) soaking were evaluated. Results showed that the water absorption capacity of BR with HHP soaking was higher than that of control one. The HHP soaking also generated the lower leached amylose and hardness, while the higher springiness, cohesiveness, and resilience for cooked BR. Therefore, HHP soaking is applicable for cooked BR with better palatability as an advantageous technique (Meng *et al.,* 2018).

Ojha *et al.* (2018) concluded that in current decades as human living conditions are being gradually enhanced, people demand for high quality rice is continuously on increase, which entailed in incorporation of preferred grain quality features as the most important objective next to enhancement in yield and also quality characteristics increase the total economic value of rice.

Laishram and Das (2017) studied the water absorption, solubility, cooking characteristics and phytochemical properties of black rice pasta. Water adsorption index and water solubility index of pretreated pasta sample were significantly increased with an increase in temperature or microwave radiation. The cooking losses of pretreated pasta showed an increasing pattern with an increase in temperature or microwave radiation. The pasting properties in terms of the peak, holding, final, breakdown, and setback viscosity were decreased. The conventional treatment also led to the highest DPPH scavenging activity than other pretreatment methods.

Ponnappan *et al.* (2017a) evaluated milling and physical characteristics of pigmented rice -1 followed by black rice. The 1000 grain weight, bulk density and L/B ratio ranged varieties (viz., black rice of Chettinadu origin, red rice varieties TPS-1 and TKM-9) and glutinous white rice (control). The hulling, milling and HRR percent were highest in TPS from 17.50g (black rice) to 22.25g (white glutinous rice), 0.96 g/ml (black rice) to 1.12 g/ml (white glutinous rice) and 2.84 (glutinous rice) to 2.61 (black rice) respectively. The grain type of black rice was long slender whereas red and white glutinous rice were found as medium slender and short slender respectively.

Sahu *et al.* (2017) conducted an experiment to assess the nature and magnitude of variability parameters and descriptive statistics for grain quality traits in 215 indigenous rice landraces of Chhattisgarh, India. The results indicated that direct selection was based on phenotypic performance could be rewarding for all quality traits because they had less influenced by the environment and mostly governed by additive gene action. It has been observed that sixty-nine genotypes had short slender type grain characteristics whereas; forty-seven genotypes had short bold type grains. Thirty genotypes showed more than 80% hulling per cent, fifty-six genotypes showed more than 70% milling per cent and fourteen genotypes showed more than 65 per cent.

Bassuony (2016) evaluated for physical, chemicals and cooking traits of four rice varieties namely Giza 177, Sakha 105, Sakha 106 and Black rice. Rice cultivars indicated that the highest mean values of grain dimension traits were calculated for Black rice and the lowest one for Sakha 106 cultivar, also no significant difference between Black rice and Giza 177 were observed. The hulling percent, milling percent, HRR, grain length, breadth breadth, L/B ratio, amylose content, gel consistency and kernel elongation ranged between 76.67-81.77%, 65.77-71.76%, 58.91-66.80%, 7.40-7.94mm, 3.27-3.62mm, 2.19-2.43, 17.13-20.87%, 86.60-95.67mm and 33.37-53.27% respectively. The lowest hulling percent, milling percent, HRR, L/B ratio, gel consistency, kernel elongation and highest grain length (second highest), grain width, amylose content were found in black rice.

Pathak *et al.* (2016) evaluated the physicochemical characteristics of 22 pigmented glutinous rice varieties and one non-pigmented variety (Memon Bora), and they found that the amylose content was lowest in Kmj Bora-61 (0.05 per cent) and highest in Kola Bora-5 (3.0 per cent), as opposed to 0.4 per cent of non-pigmented-Memon Bora, and the alkali spreading values varied among the genotypes, ranging from 4 to In comparison to 9.7% of non-pigmented Memon Bora.

Ratna *et al.* (2016) investigated the correlation between eight-grain characteristics after cooking and twelve-grain characteristics before cooking on six separate lines of Basmati rice: S1, S2, S5, 42(i), 42(ii), and 44(i). The findings of the correlation investigation showed a highly significant positive link between hulling per cent and milling per cent, HRR per cent, and kernel breadth of milled rice. Cooked rice kernel width and alkali spreading value had a statistically significant positive connection at the genotypic level. Alkali spreading value and water intake showed a significant negative association, although volume expansion per cent and elongation ratio showed an insignificant negative relationship.

Wickert *et al.* (2014) investigated the suitability of cultivation of one red rice variety SCS119 Rubi, one black rice variety SCS120 Onix and one white rice variety Epagri 109 by farmers in order to attend the specific and economically important specialty rices market. The milling percent, HRR, amylose content, grain length, grain breadth, grain L/B ratio and 1000 grain weight of SCS120 Onix were observed as 64.6%,56.5%, 20.5%, 7.41mm, 1.93mm, 3.84 and 19.5g. Both the rices were suitable for marketing in rice producing regions of Santa Catarina State, Brazil.

Thomas *et al.* (2013) studied the physical and cooking qualities and amylose content of six rice cultivars (white, bario, glutinous, black, brown and basmati rice).In the examined rice types, the thousand kernel weight ranged from 16.97 to 19.43 g, the length/breadth (L/B) ratio ranged from 2.09 to 3.75, and the bulk density ranged from 0.8 to 0.86 g/ml.Amylose content was highest (27.71%) in white rice with the lowest recorded for brown rice variety (3.36%). The black rice along with brown rice showed the longest minimum cooking time. The water uptake ratio ranged between 2.33to 3.95 and was low in glutinous rice (2.33), while gruel solid loss (range from3.17 to 6.43 %) was lowest in the Basmati rice variety (3.17%). The minimum cooking time was found to be negatively correlated with amylose content (r = -0.97). Black rice along with brown rice showed a longer cooking time withthe lowest amylose content. A positive correlation was recorded for both amylose content and l/b ratio in relation to elongation of cooked rice. These results highlight the cooking properties of rice to be strongly dependent on their amylose content.

Saikia *et al.* (2012) evaluated the physical dimensions and colour composition of two pigmented aromatic black rice and two nonpigmented aromatic rice. Poreiton chakhao (PC), a purple-coloured variety, and Chak-hao amubi (CA), a scarlet variety, contrast with the non-pigmented Bakul joha (BJ) and Keteki joha (KJ) kinds. In comparison to the fragrant non-pigmented rice, the rice with pigmented kernels had more weight, was longer, and was shaped more slenderly. The bulk density, 1000 kernel wt, kernel length, kernel breadth, L/B ratio, amylose content and gel consistency were ranged from 0.48-0.56 g/cm^3, 11.64-22.32 g, 4.21-6.51 mm, 2.02-2.60 mm, 1.84-3.25, 2.2-28.8 % and 27-144 mm respectively.

The physicochemical qualities and palatability of rice from six premium cultivars in Korea (Chucheongbyeo, Saechucheongbyeo, Mihyangbyeo, Hitomebore, Nampyeongbyeo, and Ilpumbyeo) was studied by Kang *et al.* (2011). All of the samples had 17–18 g/100 g rice starch amylose and were classified as low-amylose rice. The Hitomebore type has the most necessary amino acids, the best palatability (82.9), and the least mineral content. Saturated (21–24 g/100 g rice) and unsaturated (75–78 g/100 g rice) fatty acids were found in nearly equal amounts in the rice samples. The

Mihyangbyeo variety had the most protein (8.10 g/100 g rice), sugar content, pasting temperature (82.75°C), and duration (3.78 min), but the least viscosity. Palatability and breakdown viscosity was shown to have negative associations with ribose, rhamnose, and potassium, indicating that gelatinization properties might be utilised to assess rice eating quality.

Sompong *et al.* (2011) researched the amylose content of ten red rice types and three black rice variants that they had gathered from Sri Lanka, Thailand, and China. The study discovered considerable variations in amylose concentration amongst the different rice cultivars. Niaw Dam Pleuak Khao (PK) and Niaw Dam Pleuak Dam (PD), two varieties of Thai black rice, were categorised as having very low amylose concentrations (8.90 to 9.60 %). High amylose was assigned to China Black Rice (CNB) (25.49 %) Additionally, Thai red rice was shown to have very low amylose levels.

2.3 Biochemical Quality Profile

Putri *et al.* (2022) studied the antioxidant properties of three varieties of Indonesian black rice includes Melik Java, Cempo Ireng, and Toraja variety. The total anthocyanin, total phenolic and DPPH inhibition of these varieties ranged from 93.74-135.07 mg/100g, 1.51-2.11mg GAE/g and 33.51-38.24 %.

Arora *et al.* (2021) studied the changes in the antioxidant, and anthocyanin content of roasted black rice (*Oryza sativa* L.). Roasting significantly ($p < 0.05$) increased the total phenolic content (148.65 to 190.68 mg GAE/100 g) and free radical scavenging activity (80.64 to 87.23%), whereas total flavonoid content (5.4 to 2.41 mg QE/100 g) was reduced. Significant ($p < 0.05$) reduction was observed on anthocyanin (300.94 to 22.53 µg cyanidin/g) with roasting. Overall, roasting led to significant improvement in the various properties of black rice.

Bagchi *et al.* (2021) reported the extractable and free form of phenolic acids and flavonoid profile from different processed products (popped, beaten, puffed and boiled rice) of four black rice cultivars (Chakhao, Kalobhat, Mamihunger. Manipuri Black) along with a white rice variety (Swarna sub-1) as reference. The HPLC-PDA analysis of phenol extracts detected 14 phenolic compounds in most of the products with their higher content in black rice based products than that of reference cultivar. The phytic acid content in boiled rice ranged from 0.14±0.01 to 0.30±0.06%. Among the different products, popped rice ranked first in terms of mean phenolic compounds (467.74 µg/g) of which 54% occurring in free form, vitamin-E, γ-oryzanol and antioxidant activity. Boiled rice had the least amount of all these components. Based on principal component analysis, popped rice of Manipuri Black was identified as a promising product that could contribute to potential health benefits.

Colasanto *et al.* (2021) studied the impact of different cooking techniques (boiling, microwaves oven, under pressure pot and risotto preparation) on phenolic compounds of Artemide black rice. The risotto preparation was the most useful cooking technique to preserve anthocyanins and antioxidant activity. The total phenolic content (86.5±0.9 µg GAE/g), total anthocyanins (3623±126 µg C3G/g) and total antioxidant activity (21.4±0.1 mg TE/g) were estimated in uncooked Artemide rice. The high correlation evidenced between the antioxidant activity and total monomeric anthocyanins content ($p < 0.001$, $r = 0.973$), suggest a significant contribution of this class of phenolic compounds to the antiradical properties of rice.

Moirangthem *et al.* (2021) investigated bioactivity and anthocyanin content of microwave-assisted subcritical water extracts of Manipur black rice (Chakhao) bran and straw. Anthocyanins content of its different fractions displayed a positive correlation with their antioxidant potentials ($r = 0.90$). This study reported the extraction of anthocyanins from black rice straw and presented evidence that the straw, in addition to the bran, contained important bioactive compounds; the extracts of which could further be explored as a natural antioxidant and/or functional ingredients.

Pakuwal and Manandhar (2021) studied the nutritional quality of different rice varieties (Taichung-176, Khumal-4 rice, and Black rice) with Jumli Marsi rice. The highest nutritional factors and phytochemical components were found in the Marsi rice (RR) and Black rice (BR). The highest amount of antioxidant property and phenolic content was found in Black rice which was 61.58±0.02 % and 22.75±0.02 GAE/100g respectively. All the data showed significant difference ($p<0.05$).

Sholikhah *et al.* (2021) analyzed the anthocyanin content of 10 cultivars (9-blackish purple and 1-brown colour grains) in pH difference method. Anthocyanin in black rice is the black pigment found in pericarps and tegmen (skin layers) of rice. Some are also found in all layers of rice. The anthocyanin content ranged from 5.95 mg/g to 21.12 mg/g. The highest anthocyanin content was found in Toraja black rice cultivars of 21.12 mg/g, followed by Banjarnegara of 19.3 mg/g and melik black rice of 19.06 mg/g.

Yamuangmorn and Prom-u-Thai *et al.* (2021) carried out a review of anthocyanin synthesis and accumulation across the entire purple rice plant, from seed to processed end product. Numerous elements, such as genetics, cultivation, management, and post-harvest processing, affect the anthocyanin level of purple rice. The method of rice cultivation has a significant impact on the anthocyanin content of the plants; other important factors include the availability of nutrients in the soil, the quality and quantity of the light, and the availability of water. Due to the low stability of anthocyanins, high temperatures can significantly reduce their effectiveness. Purple rice anthocyanins have been used for a variety of purposes including the development of functional foods.

Singh *et al.* (2020b) investigated seven red pericarp, eight black pericarp, 17 white rice genotypes and BPT 5204 for total phenol content and total antioxidant activity. The recorded mean values of total phenol content and total antioxidant activity were 39.52-267.13 mg/100g and 25.68-109.13 mg AAE/100g. The highest values of iron and zinc were observed in BPT 3165 (black pericarp) and BPT 3136 (black pericarp).

Two rice paddy plants, Limnophila aromatica (phak-kha-yaeng khao) and Limnophila geoffrayi, were evaluated by Wanyo *et al.* (2020) for their effects on drying methods and changes after cooking in oxalate concentrations (phak-kha-yaeng daeng). The entire, soluble and insoluble oxalate contents of the cooked samples were also evaluated. With the exception of hot-air dried phak-kha-yaeng daeng, dried samples' soluble oxalate concentration was substantially higher than that of fresh samples, although their total and insoluble oxalate amounts were significantly lower. After boiling, soluble oxalates that were 30% and 46%, respectively, in fresh phak-kha-yaeng khao and daeng can be greatly decreased. In comparison to other samples examined, heating of both hot-air dried phak-kha-yaeng samples revealed increased oxalate losses. In order to lessen the oxalates in phak-kha-yaeng, hot-air drying should be taken into consideration. The information from the current study is helpful for drying vegetables or plant meals to lower the risk of ingesting plant foods that are rich in oxalates.

Devi *et al.* (2019) studied biochemical quality parameters of twenty six coloured rice (7-light brown pericarp, 8-red pericarp and 11 black pericarp) genotypes. All of them were divided into six clusters. The range values of Total antioxidant activity and Total phenol content were 59.72-108.83 mg AAE/100g and 56.36-214.34 mg/100g respectively. The highest values of TAA and TPC were found in cluster VI, which had black pericarp genotype.

Meera *et al.* (2019) studied the nutrient composition of pigmented rice cultivars namely kattuyanam (brown), red kavuni, black kavuni and karudan samba (white). Kattuyanam had comparatively higher content of protein, amylose, total phenol, total flavonoid, DPPH and reducing power followed by red and black kavuni. The total phenol content, total flavonoid, DPPH and total tannins content in black kavuni was 3.33 mg GAE/g, 44.08 mg CE/g, 95.48% and 0.34 mg TAE/g.

Chuchird (2018) investigated the effects of cooking on antioxidant properties in black glutinous rice (*Oryza sativa* L. cv. Shaw Mai Pai 49). Phenolic compounds, anthocyanin, cyadinin-3-glucoside and antioxidant activity were examined. This investigation found that phenolic compound, anthocyanin, cyadinin-3-glucoside and antioxidant activity were 0.27 ± 0.01 mg GAE/100g crude, 46.12 ± 2.24, 57.27 ± 6.00 mg/l and 5.32 ± 0.88 mg/ml, respectively. The antioxidant properties of black glutinous rice changed after cooking in an electric cooker for 35 minutes. It was found that the phenolic compound, anthocyanin, cyadinin-3-glucoside and antioxidant activity were 1.30 ± 0.02 mg GAE/100g crude, 33.25 ± 0.52, 9.00 ± 0.40 mg/ml and 0.13 ± 0.16 mg/ml, respectively. Cooking affected the antioxidant properties by reducing anthocyanin, cyadinin-3-glucoside whereas total phenolic compounds and antioxidant activity were increased.

The total phenolic content of 15 rice genotypes was evaluated using the Folin-Ciocalteu method. The genotypes included 5 non-pigmented brown rice, 5 red rice, and 5 black pigmented rice. Moreover, they noted that compared to non-coloured rice genotypes (0.79-3.21 mg/100 g), coloured rice genotypes (red rice: 6.55-51.86 mg/100g and black rice: 4.31-23.72 mg/100 g) had the highest total phenolic content (Shao *et al.,* 2018).

Batubara *et al.* (2017) investigated the antioxidant effects of extracts from three varieties of rice, namely white, red, and black rice. Three different solvents were used to extract the rice *viz.,* n-hexane, ethyl acetate, and methanol. The ethanol extract of black rice (IC50) has the highest antioxidant activity (290 g/ml) as determined by the 1,1-diphenyl-2picrylhydrazyl method.

Chay *et al.,* (2017) studied the comparison of antioxidant activity and total phenolic content of waxy pigmented and non-pigmented rice varieties. They found that the total polyphenol content of the waxy pigmented rice was 2074gGAE/g, which was substantially greater than the 134gGAE/g db of the waxy non-pigmented rice. Along with the rise in total phenol concentration, the percentage of DPPH inhibition (antioxidant activity) rose. More inhibition was present in waxy pigmented rice types (75.37 per cent) than in non-pigmented rice variants (6.72 per cent).

Kumar *et al.* (2017a) investigated the effect of soaking on phytic acid contents and iron availability in six rice varieties. Minimum phytic acid measured in the Sarjoo-52 was 5.61 g/kg and maximum phytic acid measured in the Swarna was 9.12 g/kg followed by NDR-359 was 8.05 g/kg. After processing in case of after soaking minimum phytic acid content measured in the Sarjoo-52 was 3.63 g/kg and maximum phytic acid content in parents after soaking measured in Swarna was 6.76 g/kg. Minimum phytic acid content after germination measured in the Sarjoo-52 was 3.08 g/kg and maximum phytic acid content in parents after germination measured in Swarna was 6.05 g/kg. The soaking treatment reduced the inherent phytic acid content in seeds of rice. The highest iron was obtained in sarjoo-52 (24.15 ppm) and lowest obtained in Swarna (12.48 ppm).

The anthocyanins, γ-oryzanols, and vitamin E content of glutinous black rice are better preserved by sun drying than by hot air drying. After ten months of storage as paddy, rice contains 16.3 per centfewer anthocyanins, 20.9 per centfewer γ-oryzanols, and 45.1 per cent fewer vitamin E. During six months of storage, both packing methods and storage period had a substantial influence on certain phytochemicals and fragrance quality in unpolished black aromatic rice. The most efficient strategy to delay the reduction of the major aroma component, anthocyanin, and total phenolic contents, as well as the formation of several common off-flavour compounds, is to store unpolished black rice in nylon pouches containing N_2 (Norkaew *et al.,*2017).

Ponnappan *et al.* (2017a) studied two of red pigmented (TPS-1and TKM-9), one white (glutinous rice) and black pigmented rice varieties for polyphenol content and antioxidant acivity. The anthocyanin content was very high in black rice than other variety contents up to 244.45mg/100 g. Polyphenol compound were varied significantly within the compared varieties. Highest polyphenol compound content (463.05 mg/100g) was found in the black rice and also showed rich antioxidant properties. Black rice had the highest amount of lutein when compared to other varieties. Antioxidant activity of selected pigmented rice varieties was highest in black rice at 15.81 per cent in terms of DPPH value followed by TPS-1 (13.42%), TKM-9 (12.68%) and lowest in glutinous rice (10.48%).

Pathak *et al.* (2017) evaluated the total phenol content, antioxidant activity, and flavonoid content of fourteen pigmented hill rice cultivars as well as a non-pigmented cultivar. In comparison to Vandana (33.23 mg GAE/100 g), the total phenolic content of 14 pigmented hill rice cultivars ranged from 67.89 to 89.43 mg GAE/100 g. Meanwhile, the flavonoid content of pigmented rice cultivars ranged from 57.75 to 78.74 mg QE/100 g, whereas Vandana had 24.58 mg QE/100 g. In contrast to Vandana, a non-pigmented rice cultivar, the DPPH scavenging activity of 14 pigmented hill rice cultivars ranged from 19.56 to 29.29 per cent. According to their findings, there is a positive correlation between phenol content, antioxidant activity, and flavonoid content.

Chemical reactions after thermal treatment may lower the nutritional value of black rice. Heat treatment can dramatically reduce these bioactive molecules (p 0.05). Furthermore, two alternative thermal processing methods resulted in different results for those functional molecules. In particular, black rice porridge has substantially higher antioxidant content (such as phenolics). As a result, rice porridge was the suggested way of cooking black rice, may have greater health-promoting effects to retain the bioavailability of active components. Before eating black rice, it must always be cooked. In other words, due to the heat loss of phenolic components, we cannot extract all bioactive chemicals in raw black rice (Tang *et al.,* 2016).

Wickert *et al.* (2014) investigated the suitability of cultivation of one red rice variety SCS119 Rubi, one black rice variety SCS120 Onix and one white rice variety Epagri 109. The SCS119 Rubi (2.5 flavonoids) and SCS120 Onix (0.2 flavonoids) showed highest amount of anthocyanins than Epagri 109. The black pericarp SCS120 Onix showed almost five more times phenolic compounds than white pericarp Epagri 109.

Pereira-Caro *et al.* (2013) found and measured the anthocyanins in the dehusked black purple rice seed. Anthocyanins were discovered to be concentrated in the pericarp of the black-purple rice, where a total of 1.4 mg/g fresh weight in the form of seven distinct anthocyanin species was observed. In addition to five minor components (less than 2 per cent), which were cyanidin, peonidin, and pelargonidin derivatives, the two primary anthocyanins were cyanidin-3-O-glucoside (89.0 per cent of total anthocyanins) and peonidin-3-O-glucoside (9.3 per cent). It has lutein (3.05 ± 0.22 μg/g), zeaxanthin (0.65 ±0.01 μg/g), lycopene (0.11 ±0.01 μg/g) and β-Carotene (0.14 ± 0.01 μg/g) and γ-Oryzanol (279 μg/g).

Saikia *et al.* (2012) investigated the total phenols, flavonoids, and antioxidant activity of two pigmented (purple and red colour) and two nonpigmented aromatic rice types. The non-pigmented one had more amylose than the pigmented one. In comparison to purple-coloured and non-pigmented rice varieties, the red rice variety Chak-Hao-Amubi had the highest total phenolic content (579.00 mg GAE 100-1g) and flavonoid concentration (220.5 mg QE 100-1g). The DPPH radical scavenging activity of the purple and red types was 94.19 per cent and 96.43 per cent, respectively.

2.4 Nutritional Traits

2.4.1 Proximate Composition

Colasanto *et al.* (2021) studied the impact of different cooking techniques (boiling, microwaves oven, under pressure pot and risotto preparation) on proximate composition of Artemide black rice. Different cooking methods had significant and different impact on rice composition. Proximate composition was not affected by cooking, except for moisture which was increased and fiber content which was decreased. The proximate composition (d.w) of uncooked Artemide black rice was moisture (11.7±0.4 %), protein (10.5±0.2 %), ash (1.95±0.09 %) and total dietary fiber (10.8±1.4 %).

Farooq *et al.* (2021) analyzed the protein content of four rice varieties (black, brown, white, and waxy rice). The protein and fat content ranged from 6.8±0.5% (brown rice) to 8.4±0.3% (black rice) and 1.3±0.2% (waxy rice) to 3.5±0.4% (brown rice).

Pakuwal and Manandhar (2021) studied the proximate composition of different rice varieties (Taichung-176, Khumal-4 rice, and Black rice) with Jumli Marsi rice. The moisture, ash, carbohydrate and reducing sugar were found to be ranged from 7.91 to 12.15%, 0.74 to 1.70%, 65.3 to 82.5% and 1.12 to 2.74%. The data showed statistical significance.

Rajenan and chanan (2020) studied the grain nutritional properties of 13 coloured (black and red) rice varieties. The protein concentration of almost all the rice samples is less than 20%. High concentration of protein (16%) was observed in chak hao poreiton (black pericarp) variety. Rice varieties with high concentration of proteins decrease the access of enzyme for starch hydrolysis. As the concentration of protein was high in Chak hao poreiton, the hydrolysis index and GI are also low in the same variety.

Devi *et al.* (2019) studied nutritional parameters of twenty six coloured rice (7-light brown pericarp, 8-red pericarp and 11 black pericarp) genotypes. All of them were divided into six clusters. The range value of protein content was 8.21-13.24%. The highest range was found in cluster III, which has all the black rice genotypes.

Veni (2019) reviewed on nutritional profile of different coloured rice varieties namely brown rice, purple rice, red rice and black rice. Among all the varieties, black rice has the highest amount of protein (11.9%), lipids (3.87%), ash (1.98%), dietary fiber (5.67%) and energy (362 kcal).

Yenrina *et al.* (2019) studied the nutritional and energy values of various processed black glutinous rice. The results showed that the highest water content was found in boiled black glutinous rice (75.61%), the highest ash content in roasted black glutinous rice (1.19%), the highest fat content in puffing black glutinous rice (10.51%), the highest protein content in puffingblack glutinous rice (11.09%), the highest starch digestibility in roasted black glutinous rice (80.12%), the highest amylose content and the lowest amylopectin in roasted black glutinous rice (10.32% and 89.67% respectively), the highest starch digestibility in puffing black glutinous rice (75.61%), the highest antioxidant activity in raw black glutinous rice (60.75%), and the highest energy content (408 kcal) in puffing black glutinous rice.

Nine non-pigmented rice (NPR) and eleven pigmented red rice (PRR) landraces of Assam were investigated by Dasgupta and Handique (2018) for their nutritional properties. Considerable variation was observed among and between PRR and NPR landraces. Among PRR crude protein content varied from 8.20% to 13.96% while corresponding range of NPR was 8.70% to 11.18%. Total carbohydrate for PRR varied from 64% to 80%. While the corresponding range for NPR varied from to 62% to 69%. Lipid content varied within the narrow range of 1.72% to 3.75% for PRR while the corresponding range of NPR was 2.17% to 3.46%. Total mineral in the form of Ash content also varied within a narrow range of 0.83% to 1.40% for PRR, while the corresponding range of NPR was 0.35% to 1.43%. Calorific values in case of PRR vary from 314.79 kcal to 379.19 kcal, while in NPR 314.06 kcal to 349.51 kcal.

Ramelan *et al.* (2018) aim is to provide details information on the proximate composition of the third generation of gamma irradiated black rice (*Oryza sativa* L. cv. *Cempoireng*) with a dose of 200 Gy and 300 Gy. In comparison to the control, both gamma irradiated black rice showed no significant changes in moisture, lipids, proteins, carbs, or fibres. The nutritional value of the 200-BR, however, is somewhat higher than the 300-BR and the control. When compared to non-gamma irradiation black rice, the mineral content of 200-BR rose by approximately 35%.

Verma *et al.* (2018) evaluated nutritional quality of different rice cultivars. The study concluded that some of the chemical and nutritional characteristics were desired by consumers based on their grain quality and nutrients composition. The variation between the chemical and nutritional quality of rice cultivars was due to several responsible factors such as environmental factors, agronomical conditions, genetic factors, and postharvest operations.

Bassuony (2016) evaluated for physical, chemicals and cooking traits of four rice varieties namely Giza 177, Sakha 105, Sakha 106 and Black rice. The moisture, protein, fat, ash and carbohydrates ranged from 12.63-14.29%, 6.59-10.67%, 0.914-1.187%, 0.648-1.130% and 73.72-78.61% respectively. Black rice variety had the highest value in protein and ash while recorded the lowest values in fat and carbohydrate content.

Chanu (2015) studied proximate composition of three black rice varieties (Poreiton Chakhao, Chakhao amubi and Burma black), Kemp akki (red rice), white parboiled rice and Sona Masuri. The moisture, protein, fat, ash, crude fiber and carbohydrates ranged from 9.2- 12.1%, 6.5-11.4%, 0.63-3.2%, 0.60-2.8%, 0.55-1.18% and 72.5-75.3% respectively.

Laokuldilok and Kanha (2015) investigated how milling affected the colour and nutritional qualities of glutinous black rice. After milling, the grains and the flour's redness grew, reaching its peak after 20 seconds. The dehulled rice kernel had an uneven distribution of protein, fat, and crude fibre. After milling the rice for 60 seconds, only 76.95, 32.79, 20.24, and 36.57 per cent of the protein, fat, crude fibre, and ash were retained, respectively.

Thomas *et al.* (2015) examined the nutritional composition of six distinct rice kinds (white, brown, bario, black, glutinous, and basmati rice) sold in Penang, Malaysia. The moisture percentage of the different rice cultivars ranged from 10.04 to 12.88%. Black rice had the lowest fat content and the highest protein content (8.16 per cent) (0.07 per cent). The black rice type also had the highest percentage of ash and coarse fibre.

Wickert *et al.* (2014) investigated the suitability of cultivation of one red rice variety SCS119 Rubi, one black rice variety SCS120 Onix and one white rice variety Epagri 109. The proximate composition viz., protein (11.2 g/100g), lipids (3.6 g/100g), ash (1.7 g/100g), soluble alimentar fiber (1.2 g/100g) and insoluble alimentar fiber (4.4

g/100g) were recorded in black rice. The red and black rice varieties showed similar values compared to white rice which showed lesser values.

The chemical composition of rice bran, rice bran layer, and rice germ from waxy and non-waxy varieties of Thai rice, including Kao Dok Mali 105 (KDML) and Red rice, was studied by Moongngarm *et al.* (2012). The findings show that the bran layer had the lowest level of fat content whereas the rice germ had the greatest amount of fat across all cultivars, ranging from 20.16 to 22.56 per cent. Similarly, all of the cultivars' rice germ fractions had the greatest protein levels (15 to 20 per cent), whereas pigmented rice had the highest crude fibre values. Ash and carbohydrate concentrations were higher in the bran layer portion.

Saikia *et al.* (2012) evaluated the nutritional composition of two pigmented aromatic black rice and two nonpigmented aromatic rice. The moisture, protein, fat, ash, crude fiber and carbohydrates ranged between 11.6-13.7%, 6.6-9.9%, 1.0-2.1%, 0.5-0.8%, 0.2-0.3% and 76.4-78.0% respectively. In comparison to aromatic non-pigmented rice, aromatic pigmented rice (Poreiton Chakhao) contained more fat (2.1%). Protein content was found highest in non-pigmented keteki joha rice (9.9%).

Sompong *et al.* (2011) analysed nine red and three black rice varieties from Thailand, China and Sri Lanka to determine the proximate composition. The proximate composition of black rice varieties ranged from 11.26-12.59% (moisture cotent), 8.17-10.85% (protein), and 2.85-3.72% (fat), 1.42-1.74% (ash), 3.41-4.08% (total dietary fiber), 71.99-74.09% (total carbohydrates) and 362.25-364.22 kcal/100 g (energy). Ash levels were highest in the Chinese black rice (1.7%) and lowest in the two kinds of red rice from Sri Lanka (0.8% and 1.0%). The highest fat level was found in the Thai black rice cultivars Niaw Dam Pleuak Khao and Niaw Dam Pleuak Dam in particular. Similar to this, Thai red rice Sung Yod Phatthalung and black rice Niaw Dam Pleuak Dam were discovered to contain the most protein (10.9% and 10.4%). The majority of varieties ranged from 3 to 4 per cent in total dietary fibre content.

Savitha and Singh (2011) examined the dietary fibre content of four rice varieties, one pigmented and one non-pigmented; both before and after parboiling. Rice with pigment was shown to provide more dietary fibre (9–10 g/100 g) than rice without pigment (6 g/100 g). The soluble fibre content of coloured head rice and pigmented broken rice was 1 to 1.5 g/100 g and 0.45 to 1.45 g/100 g, respectively. The percentage of dietary fibre in parboiled rice was only about 1%. The total fibre content and soluble fibre content in parboiled rice of coloured kinds ranged from 7.95 to 9.05 g/100 g and

0.7 to 0.9 g/100 g, respectively. Compared to milled raw rice, parboiled rice had more soluble dietary fibre.

Yodmanee *et al.* (2011) investigated the proximate composition of eight types of coloured rice cultivated in Southern Thailand. All types had moisture levels that ranged from 5.96 to 8.19 g/100 g. (db). All of the varieties had protein levels ranging from 6.63 to 8.46 g/100g (db). These rice types had crude fibre and ash values that ranged from 0.16 to 0.35 g/100g (db) and 1.35 to 2.15 g/100 g (db), respectively.

By using high-performance liquid chromatography, gas chromatography, and thin layer chromatography, Yoshida *et al.* (2011) examined the lipid components of black and red rice. The major tocopherols were discovered to be γ-tocotrienol and α-tocopherol, followed by α-tocotrienol (red) and γ-tocopherol (black), with considerably lower levels of β-, δ- tocopherol, and δ-tocotrienol. Triacylglycerol (76.4–80.5%), free fatty acids (7.2–9.8%), and phospholipids (3.5–3.6%) made up the majority of the lipids in these rice. Other components were found in low amounts (0.1–4.1%). The three main fatty acids were palmitic (16:0), oleic (18:1n–9), and linoleic (18:2n–6) acids.

2.4.2 Micronutrients (Iron and Zinc)

Singh *et al.* (2020b) investigated seven red pericarp, eight black pericarp, 17 white rice genotypes and BPT 5204 for iron and zinc. The recorded mean values of iron and zinc were 6.46-19.25 ppm and 12.15-30.16 ppm. The highest values of iron and zinc were observed in BPT 3165 (black pericarp) and BPT 3136 (black pericarp).

Devi *et al.* (2019) studied Iron and Zinc of twenty six coloured rice (7-light brown pericarp, 8-red pericarp and 11 black pericarp) genotypes. All of them were divided into six clusters. The range values of Fe and Zn content were 9.69-13.40ppm and 18.13-25.90 ppm respectively.

Pathak *et al.,* (2016) evaluated the physicochemical characteristics of 22 pigmented glutinous rice varieties and one non-pigmented variety. Narul Bora (10.17%) had the highest protein content and Til Bora-2 (8.32%) had the lowest. Kmj Bora-50 had the highest Zn concentration (4.42 mg/100 g), whereas Pakhori Bora had the lowest (3.14 mg/100 g), and non-pigmented Memon Bora had 3.902 mg/100 g. Kmj Bora-21 had the highest Fe concentration (4.21 mg/100 g), whereas Narul Bora had the lowest (3.12 mg/100 g), compared to Memon Bora's non-pigmented 2.70 mg/100 g.

Chanu (2015) investigated mineral composition of three black rice varieties (Poreiton Chakhao, Chakhao and Burma black), Kemp akki (red rice), white parboiled rice and Sona Masuri. The zinc, manganese and copper contents were significantly higher in black rice varieties and iron content was found significantly higher in parboiled rice than the black rice varieties. The iron and zinc content in black rice ranged from 2.66 to 3.53 mg/100g and 4.30 to 5.20 mg/100g.

Thomas *et al.,* (2015) conducted an analysis of the mineral content of several types of rice, including brown, white, Bario, black, glutinous, and basmati in Malaysia. Black rice had 21.38 mg/100g of calcium and 0.58 mg/100g of iron. Magnesium and potassium content was found to be high in black (K, 186.54 mg/100g and Mg, 107. mg/21 100g) and brown rice varieties (K, 197.41, mg/100g and Mg, 95.09 mg/100g).

Meng *et al.* (2005) evaluated the iron content in different cereal foods (black rice, rice, red rice, sticky rice and millet) and different rice seeds as well as in the milling products, and the iron bioavailability of different forms. The data show that the iron content in black rice is higher than in the other rice types, and in rice chaff and husk the content is still fairly high. The iron and zinc values in black rice were 116.1µg/g and 37.4 µg/g.

2.3.3 Glycemic Index

Karuppasamy and Latha (2020) estimated the glycemic index (GI) of three rice varieties namely, TRY-3, Black Kavuni and Karungkuruvai. the Glycemic index of black kavuni (53.10) is lesser than karunkuruvai (55.50) which are in the low Glycemic foods. TRY-3 has a GI of 68.20 which is higher Glycemic index than traditional varieties. The estimated glycemic index of traditional varieties (Black Kavuni and Karungkuruvai) was lower compared to TRY 3 Variety because the traditional varieties contained higher dietary fibre which exerts a hypoglycemic effect.

Devi *et al.* (2019) studied Glycemic index of twenty six coloured rice (7-light brown pericarp, 8-red pericarp and 11 black pericarp) genotypes. All of them were divided into six clusters. The GI values ranged from 57.12-69.25. All the varieties were classified under medium GI category.

Meera *et al.* (2019) studied the glycemic potential of pigmented rice cultivars namely kattuyanam (brown), red kavuni, black kavuni and karudan samba (white) and found to have immense nutrient potentials. Amylose content (27.28–30.03%) correlated inversely with the glycemic index ($r = -0.713$; $p \leq 0.01$) and glycemic load ($r = -0.574$). The glycemic index in black rice variety black kavuni was 56.27.

Kumar *et al.* (2018a) studied the effect of pulses and cooking oils on cooked rice in lowering glycemic response. The three rice genotypes Swarna, Manipuri black and Pusa basmati were used in the study. Rice genotypes varied widely with respect to GI (57.9 to 75.9), resistant starch (RS) (0.4% to 2.7%) and amylose content (AC) (4% to 26.5%). A significant negative correlation ($r = -0.778$) was observed between GI and RS. Addition of pigeon pea to rice lowered its GI and increased RS compared to other pulses, while ghee (clarified butter) showed more GI lowering and RS increasing effect compared with vegetable oils, when added during cooking. The GI of rice food can be further reduced by combining with suitable pulses and oil/fat.

2.5 Correlation studies

Ray *et al.* (2021) studied the colour-based nutritional properties of six coloured and four non-coloured indigenous rice varieties based on antioxidant potential, total phenol and flavonoid content along with secondary metabolites profiling by high performance liquid chromatography. A strong positive relationship ($r = 0.856$) was also obtained between Total Phenol Content and Total Flavonoid Content. Hence, the antioxidant potentiality is highly influenced by the presence of TPC and TFC. All the correlation values are highly significant at $P < 0.05$. The coloured rice landraces (B09, B72, B56, K69, P23, SH01) had higher antioxidant potential than the non-coloured rices.

Sridevi *et al.* (2021) studied 26 rice (pigmented and non pigmented) genotypes for antioxidant properties. Black and red rice genotypes *viz.,* BPT 2848, BPT 3140, BPT 3141, BPT 2858, BPT 3111 were recorded high antioxidant activity. The results of correlation studies revealed that total phenol content, flavonoid content, total antioxidant activity were positively associated with each other and also with protein content, Zn and Fe content, hence simultaneous improvement of all these traits was anticipated.

Singh *et al.* (2020b) studied correlation path studies of seven red pericarp, eight black pericarp, 17 white rice genotypes and BPT 5204. The results revealed that Akali spreading value correlated positively with iron; test weight with kernel breadth, protein content, total phenol content, total antioxidant activity, iron and zinc; Kernel length with L/B ratio, total phenol content and iron content; protein content with total phenol content, total antioxidant activity, zinc and iron content.

Lum *et al.,* (2017) assessed the physicochemical properties of five rice cultivars (white, red, black, brown, and aroma rice). According to the study, black rice had the lowest L/B ratio, 1000 grain weight, cooking duration, highest water uptake ratio, highest elongation ratio, and most loss of gruel solids whereas red rice had the highest L/B ratio. The highest amylose concentration and thousand-grain weight were found in white rice. The starch and amylose contents of aromatic rice were the greatest. In comparison to other milled or polished rice, brown rice demonstrated the lowest water uptake ratio and cooking time. The L/B ratio and the elongation and water uptake ratios both had positive correlations with rice cooking characteristics. The water uptake ratio and elongation ratio had a significant negative correlation with the cooking time for the different rice cultivars.

The physical, milling, and cooking characteristics of four new rice varieties (FARO 44, FARO 52, FARO 60, and FARO 61) were compared in a study conducted in Nigeria. The different types were made into white rice and then their individual qualities were examined. According to the findings, there were significant differences between all of the varieties in terms of paddy length, paddy length to width ratio, equivalent diameter, sphericity, grain volume, aspect ratio, thousand paddy grain weight, milled rice length, milled rice width, milled rice length to width ratio, milling 39 recovery, head milled rice, broken milled rice, elongation ratio, cooked rice length to breadth ratio, water uptake ratio, and cooking time. While cooking time and milling recovery showed a negative association, the percentage of heads of rice that were milled showed a strong positive correlation (r = 0.824). This information could be exploited by rice processors in the post-harvest processing of the varieties (Sanusia *et al.,* 2017).

Chowdhury *et al.,* (2016) analysed 65 different rice germplasm samples to investigate the relationship between different parameters. According to studies, there was a significant positive correlation of amylose content with elongation ratio and alkali spreading value, as well as between the elongation ratio and gel consistency. Amylose content and gel consistency had a significant negative correlation. There is a strong positive correlation between the zinc and iron contents of grains. However, protein content was unaffected by zinc and iron concentration.

Ngamdee *et al.* (2016) studied the correlation between phytochemical and mineral contents and antioxidant activity of black glutinous rice bran, and its potential chemopreventive property in five black glutinous rice cultivars (MS, SK, PY, PC and

KK) from Thailand. Rice bran extract of cultivar KK had the highest TAC, of SK the highest TFC and of PC the highest TPC. Overall TAC, TFC and TPC had a combinatorial effect on the antioxidant activities of all extracts; none of them dominated. Minerals may not play a role in the antioxidant activity of the extracts because most correlations between them and the antioxidant activity were unpredictable.

During kharif 2013, 92 rice genotypes (*Oryza sativa* L.) were assessed to determine the genetic diversity, heritability, and correlation coefficients for 14 physicochemical and cooking quality variables. A total randomised block design with three replications was used to perform the experiment. For all 14 of the quality, characteristics examined, highly significant differences ($P < 0.01$) were found (Nirmaladevi *et al.,*2015).

Surh and Koh (2014) found no substantial loss of anthocyanins during the cooking of black rice. Roasting resulted in the largest reduction (94%) followed by steaming (88%), pan-frying (86%), and boiling (77%). After cooking, the number of phenolic compounds in the rice fell dramatically, with much lower retention in the black rice varieties with greater amylose concentration. After heating, black rice's DPPH radical-scavenging activity was reduced. Metal-chelating activity, on the other hand, rose dramatically after cooking. Anthocyanins had a strong positive connection (r2 = 0.936) with total phenolic compounds, but a substantial negative correlation (r2 = 0.6107) with metal chelating activity.

Thirty rice crosses were examined by Kumar *et al.* (2010) in order to understand the relationships between the different parameters of grain quality. Following milling percent, brown rice length had the strongest positive direct effect on head rice recovery. While hulling percent exhibited a positive indirect effect on head rice recovery through milling percentage, kernel length had the most negative direct effect on head rice recovery.

2.6 Value-added products

The Burma black rice-based instant beverage mix (BBIBM) was created utilising the flour of Burma black rice (*Oryza sativa* L. indica), lentils (*Lens culinaris*) and sweet potatoes (*Ipomoea batatas*), and mulberries (*Morus nigra*), and its chemical and functional qualities were assessed. The crude fat level of 3.10±0.2 g/100g, the crude protein content of 14.34±0.08g, crude fibre content of total mineral content of

2.43±0.02 g/100g, the total carbohydrate content of 11.34±0.22 g/100g, and total fat content of 58.54±1.33 g/100gm, 319±0.9 kcal of calories, and 10.25 g/100gm of moisture were compared to other commercially available health drink powder. The developed Burma black rice-based instant beverage mixis rich in nutrients and had excellent functional characteristics indicating a quality product for consumer acceptability (Singh *et al.,* 2021).

Yamuangmorn and Prom-u-Thai (2021) reviewed the usage of anthocyanin extracted from black rice in different value added products. Anthocyanin applications were divided into functional and other purposes as presented in Table 2.2.

Table 2.2 Application of black rice anthocyanin in functional food and other purposes

Functional Food
Bread made from anthocyanin-rich purple rice improved postprandial plasma glucose and antioxidant status in healthy subjects
Anthocyanin-rich purple rice flour can be used as a gluten-free ingredient in bread providing FRAP antioxidant activity
Bread fortified with 1–4% of anthocyanin-rich rice powder has a low digestion rate that provides health benefits
Anthocyanin-rich rice beverage added with xanthan gum has high thermal stability
Germinated purple rice that retains anthocyanins has good sensory characteristics
Crispy rice bar made purple rice provides high anthocyanin
Fresh germinated purple rice noodles provide total anthocyanin and DPPH and FRAP antioxidant capacity
15% of anthocyanin-rich purple rice extract supplemented pasta contains high anthocyanins and antioxidant capacity (DPPH and FRAP)
Purple rice sprouts present high total anthocyanin and could be developed for natural health products
0.25% of anthocyanin-rice purple rice extract supplemented yogurt suppresses postprandial glucose level and improved plasma antioxidant capacity in healthy volunteers
0.06% of purple rice anthocyanin extract inhibited lipid and protein oxidation in whey-protein-stabilized food emulsions

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Purple rice sprouts present high total anthocyanin and could be developed for natural health products
0.25% of anthocyanin-rice purple rice extract supplemented yogurt suppresses postprandial glucose level and improved plasma antioxidant capacity in healthy volunteers
0.06% of purple rice anthocyanin extract inhibited lipid and protein oxidation in whey protein-stabilized food emulsions
Other Purposes
Anthocyanin extract used in cream exhibited in vitro antioxidant activity and in vivo anti-ageing activity on human skin
Rice bran extracts containing anthocyanins have been investigated as ingredients in the cosmetic formulations that exhibit antioxidant capacity
Purple rice anthocyanin is used in the colorimetric sensing of Aluminium (Al^{+3})
Packaging film based on oxidized chitin nanocrystals/gelatin incorporating purple rice bran anthocyanins has potential in freshness monitoring
3% of purple rice bran anthocyanins added in oxidized-chitin nanocrystals/chitosan matrix are able to monitor the spoiling of seafoods
1% of purple rice anthocyanins incorporated into chitosan packing films can be used to monitor pork spoilage
Anthocyanin dye increased the performance of dye-sensitized solar cells

A research was conducted to study the effect of replacement wheat flour with various levels of black rice flours on the quality characteristics of prepared noodles. The obtained results revealed that black rice (BR) variety had a higher level of crude protein, crude fat, ash and fiber contents than wheat flour. Black rice contained the highest values of vitamins B complex group content. From the obtained results, BR could be considered as a good source of anthocyanin and antioxidant activity. The protein, fat and ash of noodles increased as the amount of black rice flour increased. Sensory evaluation of noodles showed that supplemented of 5 and 10% black rice flour had the best overall preference compared with 15 and 20%. Generally, black rice has been added to noodles in place of wheat flour to obtain healthier trends (Bedier *et al.,* 2020).

Bhavika (2020) developed antioxidant rich black rice kheer and formulated ready to cook (RTC) black rice kheer. The physiochemical analysis of optimized product revealed that it comprised of 6.5±0.04% moisture, 1.84±0.05% ash. , 5.11±0.26% fat, 13.54±0.36% protein, 1.65±0.05 mg/100g zinc and 3.44±0.05 mg/100g iron. A total carbohydrate was found to be 72.57± 0.51. The pH of the optimized product was found to be 6.81± 0.44. It could be concluded that TPC and DPPH activity of Kheer made from Black rice was much more than that of normal conventional kheer made from white rice.

Kanabur and Kamath (2020) developed and evaluated the nutritional composition of black rice fryums. In this study, the white rice was replaced by Burma black rice (*Oryza sativa*) to the extent of 50 per cent (variation one), 75 per cent (variation two) and 100 per cent (variation three). Variation one and two which were used in a combination of white rice and black rice received low sensory scores compared to variation three. Variation three was found to be closest to the basic recipe in terms of sensory properties. The sun dried hundred per cent Black rice fryums provide 290.5 kcals of energy, 72.25 g of carbohydrates and 8.71 g of protein per 100 g. The evaluation by Food Action Rating Scale, revealed that it was overall acceptable.

Fiqri and Anggraeni (2019) developed macaron cake with black rice flour. The panelists used in this study were 2 trained panelists, 30 semi-trained panelists, and 60 untrained panelists. Macaron Cake's development products were included in the preferred category with a score of 3 and above on all characteristics. The total carbohydrates, protein, fat and calories per 50g were 25g, 4g, 14.5g and 250 kcal respectively. Nutritional analysis shows that Macaron Cake products were classified as high-fat products. Finally, it was concluded that black rice flour could be one of the local food ingredients that could replace wheat flour. Although it couldn’t replace all wheat flour in a recipe, it could at least reduce the use of wheat flour in the food industry.

Mangaleima *et al.,* (2019) investigated on preparation of papad (papadum) using black rice flour, white rice flour and potato paste by standardizing the recipe. Four treatments were developed and the results indicate that carbohydrate % varies from {T0 (83.91)-T3 (83.38)}, protein {T0 (8.52)-T3 (8.03)}, fat {T0 (2.53)-T3 (1.53)}, ash {T0 (1.02)-T3 (2.03)}, TS {T0 (95.98)-T3 (94.98)} and moisture {T0 (4.02)-T3 (5.02)} in papad formulations. The most acceptable fortified papad was analysed for organoleptic analysis. The analysis of papad has colour & appearance {T0 (8.39)-T3 (7.65)}, flavour & taste {T0 (8.30)-T3 (7.46)}, body & texture {T0 (8.35)-T3 (7.12)} and overall acceptability {T0 (8.35)-T3 (7.41)} of product.

Mau *et al.* (2017) assessed the Physicochemical, antioxidant and sensory characteristics of chiffon cake prepared with black rice as replacement for wheat flour. Black rice (BR) powders were used to substitute 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, and 100% (w/w) of wheat flour to manufacture chiffon cakes, assigned as BR10, BR20, BR30, BR40, BR50, BR60, BR70, BR80, BR90, and BR100, respectively. The specific gravity in cake batter, and crumb a value, hardness, cohesiveness, adhesiveness, gumminess and chewiness of baked cakes increased with increased black rice powder levels. However, the moisture in cake batter, and cake volume, crust color and crumb L and b values, springiness, and resilience of baked cakes showed a reverse trend. Total phenols, anthocyanins and scavenging ability of baked cake extracts increased with increased black rice powder levels. The hedonic sensory results of control and 10% to 60% substituted cakes were comparable but 70% to 100% substituted cakes showed lower sensory results. Altogether, black rice chiffon cake could be developed as a novel food with more bioactive components and effective antioxidant activity.

Ronge *et al.* (2017) studied the physico-chemical properties of vermicelli prepeared by using skim milk powder. Vermicelli was prepared by using skim milk powder at three different treatment levels of 0, 5, 10 and 15%, respectively. It was observed that as the level of skim milk powder increased, moisture content of *vermicelli* increased from 7.21 to 6.90 %, fat content decreased from 0.53 to 0.61%, protein content increased from 9.70 to 14.63%; ash content increased from 0.55 to 1.44%; crude fiber content decreased from 2.06 to 1.67%; carbohydrate content deceased from 79.95 to 74.68% for treatments T1, T2, T3 and T4, respectively. The experimental results revealed that with increase in SMP, cooked *vermicelli* weight increased from 353.10 to 274.95 g/25 g, cooking solid loss increased from 2.18 to 5.10% and swelling index decreased from 3.67 to 3.36 under the selected experimental ranges. The 10% skim milk powder with 90% refined wheat flour was highly accepted.

Ahmed *et al.* (2016) studied processing and quality evaluation of six varieties of rice noodles. The proximate composition included protein (6.92-8.65%), fat (0.63-2.17%) and ash (0.55-0.77%) was analyzed. Rice based noodles were made from rice flour having appropriate protein and amylose concentration and lower ash concentration. Compositional differences and lower starch concentration influence the functional, thermal, pasting, cooking, eating and sensory properties of rice noodles. Protein concentration and amylose concentration had a positive correlation with the firmness and brightness of the noodle strands. Higher level of starch causes excessive surface swelling and cooking loss. On the other hand, ash concentrations negatively affected the brightness of noodle.

Bhusnar *et al.* (2016) studied the chemical composition of kheer prepared from cow milk blended with sweet potato. Kheer prepared from five different combinations of cow milk and sweet potato paste i.e 97.50 per cent cow milk with 2.50 per cent rice T1 (control), 95:05(T2), 90:10(T3), 85:15(T4) and 80:20 (T5) was analyzed for chemical composition and it was found that maximum fat, protein, total sugar, ash and total solids content was recorded in kheer prepared from 97.50 per cent cow milk with 2.50 per cent rice T1 (control) i.e 7.50, 6.31, 15.80, 1.42 and 49.44 per cent, respectively. While maximum moisture content (53.16 %) was recorded in kheer prepared from 80:20 (T5).

Black rice flour was used as a substitution for wheat flour in bread making with 2 percent and 4 percent and it was discovered that the sensory quality of 2 percent was equivalent to the control. At 4 percent, the crumb structure became thick and the elasticity decreased. When the digestion rates of the two samples were compared, it was discovered that the bread containing black rice flour required more time to digest, leading to the conclusion that it could be used as a functional food for diabetics by slowing down the digestion of starch and lowering blood sugar levels (Sui *et al.,* 2016).

Chemical reactions after thermal treatment might lower the nutritional value of black rice. Heat treatment could dramatically reduce these bioactive molecules ($p<0.05$). Furthermore, two alternative thermal processing methods resulted in different results for those functional molecules. In particular, black rice porridge had substantially higher antioxidant content (such as phenolics). As a result, rice porridge, as a way of cooking black rice, might have greater health-promoting effects to retain the bioavailability of active components. Before eating black rice, it must always be cooked. In other words, due to the heat loss of phenolic components, we cannot extract all bioactive chemicals in raw black rice (Tang *et al.,* 2016).

Chanu (2015) studied nutritional and functional quality of black rice varieties and value added products. Two aromatic black rice varieties namely Poireiton chakhao and Chakhao amubi were procured from Manipur and Burma Black rice from Dharwad market. Among them the kheers prepared from Poreiton Chakhao and Chakhao amubi had moisture, protein, fat, ash and crude fiber content as 6.61% and 6.84%, 13.49% and 8.54%, 5.08% and 4.32%, 1.58% and 1.52%, 1.88% and 1.51% respectively. The protein, fat, ash, crude fiber, dietary fiber, polyphenol, phytate content, DPPH radical scavenging activity, zinc, manganese were higher in black rice when compared to normal white rice, parboiled rice and red rice. Traditional foods like *kheer* and *kabok* (black rice laddoo) were found to be rich in minerals especially iron and zinc.

Saravanan (2014) evaluated grian quality and developed black rice products. Selected rice varieties. *viz*., glutinous white rice, black rice, TPS-1 and TKM-9 were analaysed for their physicochemical and nutraceutical characteristics to develop their suitability for different traditional and extruded food products. The suitability of black rice for product development was evaluated for traditional foods (payasam, pongal, pittu and porridge) and for extruded foods (idiappam and noodles) using the nine point hedonic rating scale.

Kim *et al.* (2012) investigated the antioxidant activity and fermentation properties of black rice wine. Black rice wine had stronger antioxidant activity than the control, and DPPH radical scavenging activity was linked to anthocyanin concentration in rice wine. The pH dropped dramatically until the third day of fermentation, and then progressively dropped. Due to enzyme activity, the decreasing sugar and free sugar levels peaked after one day of fermentation. During the fermentation process, the amount of organic acids, particularly lactic acid, increased. The number of lactic acid bacteria and yeast grew with the duration of time and the amount of black rice consumed. Regardless of treatment, the L colour value increased throughout fermentation, while the 'a' colour value increased with the percentage of black rice owing to anthocyanin. As a result, colour received a good score in black rice wine. However, rice wine prepared with less than 20 per cent black rice received a lot of attention.

The primary ingredient of noodles, an extruded product, is refined wheat flour. Because components like proteins, fibre, and vitamins are lost during the refining of wheat, noodles are not regarded as a particularly nutrient-dense diet. As a result, the demand for healthy noodles has grown. Black rice bran (BRB) powder was added to wheat flour at substitution levels of 0, 2, 5, 10 and 15% in order to establish its qualitative attributes. Addition of BRB (5%, 10% and 15%) significantly decreased the cohesiveness of noodles in texture evaluation. Protein, fat, minerals, and antioxidants all increased, according to the analysis. The antioxidant activity of BRB noodles was increased compared to the control (Kong *et al.,* 2012).

Lee *et al.* (2008) prepared puffed rice cakes from a blend of ground black rice (GBR) and medium-grain brown rice (GMBR). The specific volume of black rice cakes showed an increasing trend with increasing tempering moisture, heating temperature and heating time. The hardness of puffed black rice cake decreased as tempering moisture and heating time increased, and was influenced more by GMBR content than heating temperature. In general, the black rice cake lightness and yellowness decreased steadily with increasing GBR content, while tempering moisture, heating temperature and heating time did not significantly affect the colours of black rice cake. On the contrary, the redness increased with increasing GBR contents.

2.7 Health Benefits

Rahim *et al.* (2022) studied the photochemistry, functional characteristics, dietary uses, and health potential of black rice. Black rice comes in many distinct kinds across the world. This product has Asian roots, according to research. The names forbidden rice, emperor's rice, and royal's rice are also used to describe this rice. The nutrients in black rice include fibre, protein, carbohydrates, potassium, and vitamin B complex. Tocopherols and an antioxidant called anthocyanin are also present. Foods that are black or dark purple tend to be high in antioxidants. Black rice is a superior option to white and brown rice because of its high nutrient density, high fibre content, and high antioxidant content. Utilizing black rice in various foods can enhance the nutritional value of food and be transformed into functional food items. Many noncommunicable diseases (NCDs) can be prevented by eating black rice daily, including cancer cells, atherosclerosis, hypertension, diabetes, osteoporosis, asthma, digestive health, and stroke risk.

Qi *et al.,* (2020) found eight weeks of black rice cyanidin-3-glucoside supplementation prevented the pathological changes inkidneys in diabetic nephropathy rats. Black rice cyanidin-3-glucoside inhibited renal fibrosis and glomerulosclerosis by reducing blood glucose, alleviating insulin resistance, anti-oxidative stress, antiinflammation, and inhibiting Transforming growth factor (TGF-β1)/phosphorylated Smad expression act as signalling pathway in renal fibrosis and accumulation of the extracellular matrix. Black rice cyanidin-3-glucoside could be used as a nutrient to prevent diabetic nephropathy, as well as diabetes diet control.

Han *et al.* (2018) Exposure of the skin to ultraviolet (UV) radiation causes extracellular matrix (ECM) collapse in the dermis, owing to an increase in matrix metalloproteinase (MMP) production in both the epidermis and dermis and a decrease in type I collagen expression in the dermis. BRE inhibits UV-induced ECM degradation via regulating mitogen-activated protein kinase and AP-1 signalling, and it might be employed as a skin photoaging preventative agent.

The effects of black rice (*Oryza sativa L.*, Poaceae) extract (BRE) on ischemic-induced hippocampus neuronal damages were examined by Hwang *et al.,* (2018). Adult male C57BL/6 mice were given 300 mg/kg of BRE orally once a day for 21 days. On the eighth day of BRE or vehicle administration, bilateral common carotid artery occlusion (BCCAO) was conducted for 23 minutes. When compared to vehicle treatment, giving BRE significantly reduced neuronal cell death, suppressed reactive astrogliosis, and prevented loss of glutathione peroxidase expression in the hippocampus on the 22nd day. Furthermore, BRE significantly reduced BCCAO-induced memory deterioration. These results indicate that chronic administration of BRE is potentially beneficial in cerebral ischemia.

HPLC-MS/MS was used to identify five anthocyanin monomers in black rice extract, and preparative HPLC (PreHPLC) was used to extract the primary anthocyanin monomer (cyanidin-3-glucoside, C3G). By measuring the media pH, bacterial populations, and metabolic products, the proliferative effects of anthocyanins on Bifidobacteria and Lactobacillus were studied. Not only was the pH of the medium containing C3G lower than that of the extract of black rice anthocyanin (BRAE) after anaerobic incubation at 37°C for 48 hours, but the populations of both Bifidobacteria and Lactobacillus were also dramatically enhanced. The anthocyanins and anthocyanin monomers from black rice showed prebiotic action, and they were metabolised by Bifidobacteria and Lactobacillus into numerous small compounds (Zhu *et al.,* 2018).

Krisbianto *et al.* (2016) assessed the antihyperglycemic effect and antioxidant properties of black rice and anthocyanin extract on health and histopathology of hyperglycemic rats. Black rice cereal supplemented with soybean (RSC) was prepared as isocaloric feed for three groups of hyperglycemic rats. The first group (F0) was treated only with RSC, while the other two groups also received 40 ppm (F4) and 80 ppm (F8) black rice bran anthocyanin extract (BRE). Non-hyperglycemic and hyperglycemic rats were fed with standard feed which was used as control and hyperglycemic group respectively. After 6 weeks experiments, blood glucose level, insulin resistance and MDA value were decreased in treatment groups, which were more significant in F4 and F8 than F0. RSC and BRE alleviated inflammatory and steatosis in pancreas, liver and kidney.

Chen *et al.* (2015) investigated the molecular processes behind the chemopreventive effects of black rice anthocyanins (BRACs) extract in HER2+ breast cancer cells and identified their molecular targets. In 30% of breast cancer patients, over expression of the human epidermal growth factor receptor 2 (HER2) drives biology. The RAS/RAF/MAPK pathway plays a critical role in the development of breast cancer as a transducer of HER2 signalling. BRACs inhibit breast cancer cell metastasis by suppressing the RAS/RAF/MAPK pathway.

Extracts of black rice (*Oryza sativa* L.) were discovered to be osteogenic inducers. In both C3H10T1/2 and primary bone marrow cells, BRE increased the activity of alkaline phosphatase (ALP). In OVX rats, oral treatment of BRE prevented bone density and strength declines. BRE, on the other hand, blocked adipocyte development of mesenchymal C3H10T1/2 cells and prevented increases in body weight and fat mass in obese mice fed a high-fat diet, indicating that BRE has both anti-adipogenesis and pro-osteogenesis actions. The anti-adipogenic effectors cyanidin-3-O-glucoside and peonidin3-O-glucoside were identified by UPLC analysis. These findings imply that BRE might be a beneficial element for preventing age-related osteoporosis and diet-induced obesity (Jang 2015).

Jiang *et al.,* (2013) observed the inhibitive effects of black rice pericarp extracts on cell proliferation of human prostate cancer cell PC-3. A dose-dependent and time-dependent proliferation inhibition of black rice pericarp extract was demonstrated in PC-3. The most prominent experiment condition was inhibitory concentration with 300microg/ml and treated for 72 h. Black rice pericarp extract could inhibit proliferation, change the cell cycle distributions and induce apoptosis in human prostatic cancer cell PC-3. These results suggested that black rice pericarp extract had an inhibitory effect on prostatic cancer.

In a high-fat diet-fed mouse model of NAFLD, Jang *et al.,* (2012) investigated the effects of black rice extract (BRE) on hepatic steatosis and insulin resistance. Dietary BRE supplementation dramatically improved serum lipid profiles and mRNA expression levels of fatty acid metabolism-related genes, largely through β-oxidation and ω-oxidation in the liver. The data showed that a BRE-supplemented diet might help to reduce the risk of hepatic steatosis and associated diseases, such as hyperlipidemia and hyperglycemia. It increased insulin production and decreased the digestion of sugars in the small intestine which helps to lower blood glucose.

Min *et al.,* (2010) investigated the anti-inflammatory effects *in vivo* and *in vitro* on mice and found that the main constituent in black rice was cyanidin-3-O-β-D-glycoside (C3G), which was metabolized by intestinal microflora to protocatechuic acid via cyanidin. When C3G was orally administered, the metabolites, cyanidin and protocatechuic acid were observed in the blood, which showed potent anti-inflammatory effects.

Salgada *et al.,* (2010) investigated lipidemic parameters in hyper-cholesterolemic rats had given either black rice variety IAC 600 or unprocessed rice in their diets. The animals were divided into four groups: the first received a control casein diet, the second received a hypercholesterolemic diet, and the other two groups received the test diets, the first containing 20% black rice and the second containing 20% unrefined rice for 30 days after induction of hypercholesterolemia. It was discovered that eating a diet rich in black rice lowers plasma cholesterol, triglycerides, and low-density lipoprotein. The black rice diet was found to boost high-density lipoprotein levels. When compared to the whole rice diet, the black rice diet was more successful in reducing lipidemia.

Chapter III

MATERIAL AND METHODS

In this chapter, the details of the materials used and methods adopted during the investigation are described below.

3.1 Details of the experimental material

3.2 Experimental details and methods

3.3 Standardization of the value-added products

3.4 Sensory Evaluation

3.5 Storage studies

3.6 Statistical Analysis

3.1 Details of the experimental material

The experiment material consists of six black rice varieties collected from Agricultural Research Station (ARS), Bapatla district, Andhra Pradesh, India. The salient features of genotypes are mentioned here in Table 3.1 and genotypes are shown in Plate 3.1.

Table 3.1 Rice varieties selected for the study

S.No	Name of the variety	Grain Type
1.	Burma Black (control)	Long Bold
2.	BPT 2841	Medium Slender
3.	BPT 2848	Medium Slender
4.	BPT 3136	Long Bold
5.	BPT 3137	Medium Slender
6.	BPT 3145	Long Bold

3.2 Experimental details and methods

Seven physical quality traits *viz*., hulling percent, milling percent, head rice recovery (HRR), kernel length (mm), kernel breadth (mm), kernel length / breadth ratio (L/B ratio) and 1000 kernel weight (g), three chemical quality traits *viz*., amylose content (AC) (g%), gel consistency (GC)(mm) and alkali spreading value (ASV), five cooking quality traits *viz.*, kernel length after cooking (mm), kernel breadth after cooking (mm), kernel elongation ratio (mm), volume expansion ratio and water uptake (ml), eight nutritional traits like iron(mg%), zinc(mg%), moisture(g %), protein (g %), fat (g %), fiber (g %), carbohydrate (g %) and energy (K.cal), three nutraceutical properties *viz.*, bulk density, water solubility index and water absorption index, five biochemical quality traits *viz.*, total anthocyanin content, total phenol content, total antioxidant activity, phytic acid, oxalates and glycemic index were recorded. The standard procedures for physico-chemical, cooking and nutritional traits are discussed below.

Burma black **BPT 2841** **BPT 2848**

BPT 3136 **BPT 3137** **BPT 3145**

Plate 3.1 Black rice genotypes

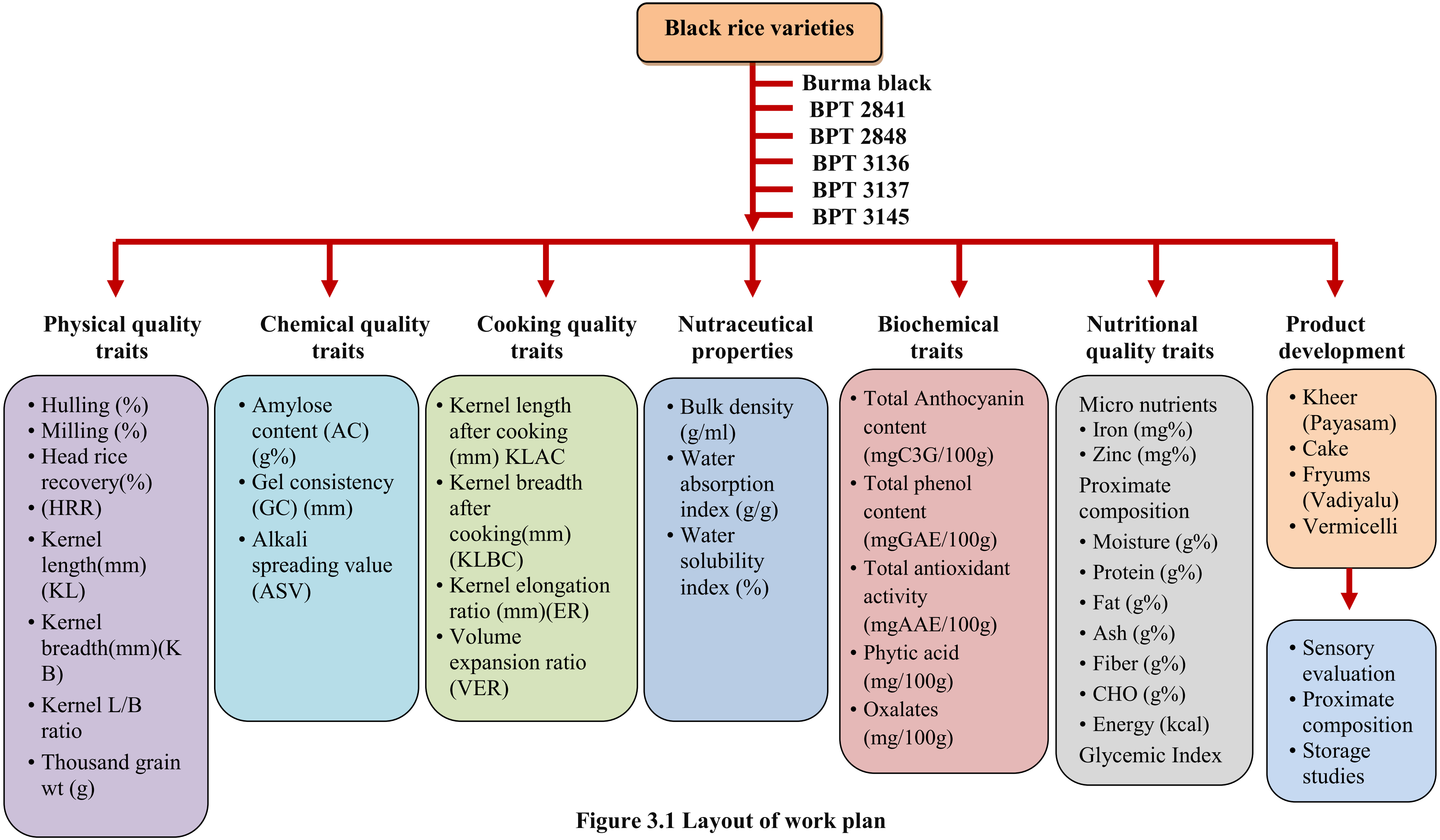


Figure 3.1 Layout of work plan

Burma black **BPT 2841** **BPT 2848**

BPT 3136 **BPT 3137** **BPT 3145**

Plate 3.2 Cooked black rice genotypes

3.2.1 Methods

After threshing and cleaning, the seed from individual varieties was dried under shade until moisture content reaches 14%. These seed varieties are dehusked in a satake laboratory huller. The unpolished rice was then utilized for analysis of seed quality traits at the quality laboratory of ARS, Bapatla.

3.2.1.1 Physical Quality Traits

3.2.1.1.1 Hulling percent (%)

A hundred grams of paddy from each variety were weighed and the character was determined after dehusking was done using Satake huller from each replication by using the following formula.

$$\text{Hulling (\%)} = \frac{\text{Weight of dehusked grain or brown rice (g)}}{\text{Weight of paddy (g)}} \times 100$$

3.2.1.1.2 Milling percent (%)

The dehusked brown rice was passed through the Satake grain testing mill for one minute to obtain uniformly 5% polish. Total polished kernels were weighed and the milling percent was calculated by the following formula.

$$\text{Milling (\%)} = \frac{\text{Weight of the polished kernel (g)}}{\text{Weight of the paddy (g)}} \times 100$$

3.2.1.1.3 Head Rice Recovery (HRR) (%)

The milled samples were passed through a rice grader to separate whole kernels from the broken ones. Small proportions of whole kernels which passed along with the broken grains were separated by hand**.** Whole and three-fourth length kernels were considered and weighed. Head rice recovery (HRR) was calculated in percent as below.

$$\text{Head rice recovery} = \frac{\text{Weight of whole polished grain (g)}}{\text{Weight of paddy (g)}} \times 100$$

3.2.1.1.3 Kernel Length (KL) (mm)

Ten grains at random from each sample from each replication were dehusked by hand and the length in millimeters was recorded using a Dial micrometer.

3.2.1.1.4 Kernel Breadth (KB) (mm)

Ten grains at random from each sample were dehusked by hand from each replication and the breadth in millimeters was recorded using a Dial micrometer.

3.2.1.1.5 Kernel Length/Breadth (L/B) ratio

The kernel L/B ratio was calculated by using the formula of Murthy and Govindaswamy (1967).

$$\text{L/B ratio} = \frac{\text{Mean length of grain in millimeters}}{\text{Mean breadth of grain in millimeters}}$$

Classification of grain length and shape of milled rice was carried out as per Ramaiah, 1985.

Table 3.2 Classification og grain length and shape of rice

Grain type	Length	L/B ratio
Long Slender (LS)	6 mm and above	3 and above
Medium Slender (MS)	< 6 mm	2.5 – 3.0
Short Slender (SS)	< 6 mm	3 and above
Long Bold (LB)	6 mm and above	< 3.0
Short Bold (SB)	< 6 mm	< 2.5

3.2.1.1.6 1000 Grain Weight (g)

Ten panicles were threshed, a thousand seeds were randomly picked, counted and weighed in the electronic balance and their weight was recorded to the nearest milligram at 14% moisture.

3.2.1.2 Chemical Quality Traits

3.2.1.2.1 Amylose Content (g %)

Amylose is the linear fraction of starch in the non-glutinous genotypes. Amylopectin, the branch fraction makes up the remainder of the starch. Amylose content has a major influence on the texture of cooked milled rice. Amylose content in the rice samples was estimated as per the procedure given by Juliano (1971).

Principle

The iodine is absorbed within the helical coils of amylose to produce a blue-colored complex which is measured colorimetrically at 590 nm.

Reagents

1. IN NaOH

2. 0.1% Phenolphthalein indicator

3. Distilled ethanol

4. Iodine reagent: Dissolve 1g of iodine and 10g of KI in water and makeup to 500ml.

5. Standard amylose: 100mg amylose in 10ml of IN NaOH and makeup to 100ml with water (1mg/ml)

Method

1. To 100mg of powdered sample add 1ml of distilled ethanol, mix well and add 10ml of IN NaOH. Leave it overnight and make up the volume to 100ml.

2 To 2.5ml of extract, add about 20ml of water, three drops of phenolphthalein indicator and mix.

3. Add 0.1N HCI drop by drop until the pink colour just disappears.

4. Add Iml of iodine reagent and make up the volume to 50ml and read the absorbance at 590nm.

5. Calculate the amount of amylose in the sample using the standard curve prepared from amylose (range 0.2-1mg) against a blank for which dilute 1ml of iodine reagent to 50ml with water.

Calculation

Absorbance corresponds to 2.5 ml of test solution = 'x' mg amylose in test solution.

$$\text{100ml contains} = \frac{x}{2.5} \times 100 = \%\ \text{amylose}$$

3.1.2.2 Gel Consistency (mm)

The gel consistency test is based on the consistency of the rice paste and the following steps were followed in its estimation as per Cagampang *et al.* (1973).

Step 1 Rice powder (100 mg) was placed into 13 x 100-mm test tubes and wetted with 0.2 ml 95 % ethanol containing 0.025 % thymol blue.

Step 2 The tube was shaken to suspend the starch, 2.0 ml of 0.2 N-KOH was immediately added and the mixture was dispersed using a Vortex.

Step 3 The tubes were covered with glass marbles and placed for 8 min into a vigorously boiling water bath to reflux.

Step 4 The samples were then removed from the water bath, set at room temperature for 5 min, and then cooled in an ice-water bath for 15 min.

Step 5 The tubes were then laid horizontally over ruled paper graduated in millimeters and the length of the gel was measured from the bottom of the test tube to the gel front 60 min later. Each test was conducted in triplicate.

Table 3.3 Categorization of rice according to gel consistency

Gel length (mm)	Type of gel consistency
26 – 40	Hard
41 – 60	Medium
61 – 100	Soft

3.2.1.2.3 Alkali Spreading Value

The time required for cooking is determined by the gelatinization temperature. Gelatinization temperature, a physical property of starch, is the range of temperature within which the starch granules begin to swell irreversibly in hot water. Six milled grains per replication were spread evenly in transparent plastic boxes containing 10 ml of 1.7 percent KOH. These boxes were kept undisturbed in an incubator at 23- 30°C for 23 hours. Rice with low gelatinization temperature disintegrates completely, whereas, rice with intermediate gelatinization temperature shows only partial disintegration. Rice with high gelatinization temperature remains largely unaffected in the alkali solution.

Table 3.4 Alkali spreading scale

ASV Score	Kernel spreading
1	Kernel not affected
2	Kernel swollen
3	Kernel swollen, collar incomplete and narrow
4	Kernel swollen, collar complete and wide
5	Kernel split or segmented, collar complete wide
6	Kernel dispersed, merging with collar
7	Kernel completely dispersed and intermingled

The gelatinization temperature ranges from 55 to 79°C and is divided into three main groups: low (< 70°C), intermediate (70-74°C) and high (75-79°C). Gelatinization temperature is estimated by the extent of alkali spreading and clearing of milled rice soaked in 1.7% KOH for 23 hours at room temperature. The alkali spreading of kernels was noted on a 7-point scale following the protocol of Little *et al.,* (1958)

The gelatinization temperature of the entries was further classified into four groups based on alkali spreading score.

Table 3.5 Classification of gelatinization temperature (GT) according to alkali spreading score

Classification	ASV Rating	GT
1-2	Low	High
3	Low Intermediate	High
4 – 5	Intermediate	Intermediate
6 – 7	High	Low

3.2.1.3 Cooking Quality Traits

3.2.1.3.1 Kernel Length after Cooking (KLAC) (ml)

For determining the length of grains after cooking and elongation ratio simultaneously, the standard method of Juliano *et al.,* (1965) was followed. Five grams of whole grain milled rice was soaked in 15 ml of water for 10 minutes in a 50 ml centrifuge tube. Then the test tubes were placed in beakers containing water and heat for 20 minutes. Then the cooked rice was transferred to a petridish. Then the average lengths of 10 randomly selected cooked kernels were measured to the nearest millimeter on a graph sheet.

3.2.1.3.2 Kernel breadth after Cooking (KLAC) (ml)

For determining the breadth of grains after cooking and elongation ratio simultaneously, the standard method of Juliano *et al.,* (1965) was followed. Five grams of whole grain milled rice was soaked in 15 ml of water for 10 minutes in a 50 ml centrifuge tube. Then the test tubes were placed in beakers containing water and heat for 20 minutes. Then the cooked rice was transferred to a petridish. Then the average breadths of 10 randomly selected cooked kernels were measured to the nearest millimeter on a graph sheet.

3.2.1.3.3 Kernel elongation ratio (ER) (mm)

The length of rice grains of each sample was measured before and after cooking and the kernel elongation ratio was worked out following the standard method of Verghese (1950) as modified by Murthy (1965).

$$\text{ER} = \frac{\text{Mean length of cooked kernels in millimeters}}{\text{Mean length of raw kernels in millimeters}}$$

3.2.1.3.4 Volume Expansion Ratio (VER)

The volume expansion ratio was determined as suggested by Verghese (1950). Five grams of rice sample was soaked in 15 ml of water for 5 minutes in a 50 ml graduated centrifuge tube. The volume of water was recorded after adding rice samples (Y-15). Rice cooked for 20 minutes in a water bath was dipped in a 100 ml measuring cylinder (X) containing 50 ml water. The volume raised was recorded (X-50) and was computed by using the formulae mentioned below.

$$\text{Volume expansion ratio (VER)} = \frac{\text{Increase in volume after cooking} \quad (X\text{-}50)}{\text{Increase in volume before cooking } (Y\text{-}15)}$$

3.2.1.3.5 Water uptake (WU) (ml)

Two grams of each rice sample were kept in 10 ml water and soaked for 30 minutes followed by boiling for 45 minutes at 77°C - 80°C in a constant temperature water bath. Another 2-3 test tubes with 10 ml water were also kept as control along with the test samples in the water bath. After boiling, the tubes were taken out and cooled. The supernatant water was poured into a graduated cylinder to note the water level. The actual amount of water absorbed during cooking was calculated by subtracting the supernatant water from the water used for cooking after considering the evaporation loss (Beachell and Stansel, 1963).

$$\text{Water uptake (ml)} = \frac{100 \text{ g}}{2 \text{ g}} \times \text{Actual water absorbed during cooking}$$

3.2.1.4 Nutraceutical properties

The Nutraceutical properties were estimated according to Kumar *et al.,* 2018b.

3.2.1.4.1 Bulk density (g/ml)

The ratio of sample weight to its total volume was determined by filling a 10 ml graduated cylinder with a known quantity of sample. The cylinder was gradually tapped a few times and recorded for its volume.

3.2.1.4.2 Water Absorption Index (WAI)

One gram sample taken in a centrifuge tube was added with 10 ml distilled water and agitated for 30 min followed by its centrifugation at 3000 rpm for 25 min.

The decanted centrifuged tube with settled gel at the base was weighed and used in the calculation of WAI.

$$\text{WAI(g/g)} = \frac{\text{Weight of gel}}{\text{Dry weight of the sample}}$$

3.2.1.4.3 Water Solubility Index (WSI)

The supernatant obtained during WAI estimation was used to determine WSI by decanting it into a pre-weighed evaporating dish whose final weight after oven drying at 103 °C was recorded and used in the calculation of WSI.

$$\text{WSI(\%)} = \frac{\text{Weight of dry solid in the supernatant}}{\text{Dry weight of the sample}} \times 100$$

3.2.1.5 Biochemical quality profile

3.2.1.5.1 Estimation of Anthocyanin Content

Anthocyanins are intensely coloured water-soluble pigments which give colouring matter to plants. The following steps are done according to Nicoue *et al.,* 2007.

Principle

The alcohol extract of the sample is treated with HCl in aqueous methanol followed by an anthocyanin reagent. The colour intensity is measured colorimetrically at 525 nm.

Reagents

1. Methanol
2. 0.5N HCl in 80-85% methanol (HCI in aqueous methanol)
3. Anthocyanin reagent: Mix 1 ml of 30% H_2O_2 with 9ml of methanolic HCl (5:1, 3N).
4. Standard Anthocyanin: dissolve 1mg of cyanin hydrochloride in 10ml methanol.

Method

Step 1 Grind 1g of fresh rice sample in 10ml of methanol.

Step 2 Centrifuge at 5000 rpm for 20 min and filter the sample extract.

Step 3 Pipette 1ml of the alcohol extract into the test tube and add 3ml of HCl in aqueous methanol.

Step 4 Add 1ml of anthocyanin reagents to the samples.

Step 5 Prepare the blank in the same manner by adding 1ml of methanol- HCI instead of anthocyanin reagent.

Step 6 Pipette out 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1.0ml of working standard and make up to 1ml with methanolic HCl.

Step 7 Measure the absorbance at 525 nm against the blank.

Step 8 Calculate the amount of anthocyanins present in the sample from a standard curve prepared with cyanin hydrochloride.

3.2.1.5.2 Total Phenol Content:

Phenols are aromatic compounds that help to resist pests and diseases in plants. The total phenol content was estimated according to Marinova e*t al.,* 2005.

Principle

Phenols react with an oxidizing agent phosphomolybdate in the Folin-Ciocalteu reagent under alkaline conditions and result in the formation of a blue-colored complex, the molybdenum blue which is measured at 650nm colorimetrically

Reagents

1. 80% Ethanol
2. Folin-Ciocalteu reagent (FCR)
3. 20% Na_2CO_3
4. Standard (100mg catechol in 100ml of water). Dilute 10 times for a working standard.

Method

Step 1 Weigh exactly 1g of the sample and grind it with a pestle and mortar in 5ml of 80% ethanol.

Step 2 Centrifuge the homogenate at 10,000 rpm for 20 min and save the supernatant. Re-extract the residue with 5ml of 80% ethanol, centrifuge and pool the supernatants.

Step 3 Evaporate the supernatant to dryness.

Step 4 Dissolve the residue in a known volume of distilled water (5ml)

Step 5 Pipette out different aliquots (0.2 to 2ml) into test tubes.

Step 6 Make up the volume in each tube to 3ml with water.

Step 7 Add 0.5ml of Folin-Ciocalteu reagent.

Step 8 After 3 min, add 2ml of 20% Na_2CO_3 solution to each tube.

Step 9 Mix thoroughly. Place the tubes in boiling water for exactly one min, cool and measure the absorbance at 650nm against a reagent blank.

Step 10 Prepare a standard curve using different concentrations of catechol.

Calculation

From the standard curve find out the concentration of phenols in the test sample and express it as phenols/100g material.

3.2.1.5.3 Estimation of Anti-Oxidant Activity

The Antioxidant activity was done according to Goupy *et al.* (1999) method

Principle:

DPPH (2,2-diphenyl-1-picryl-hydrazyl) free radical method is an antioxidant assay based on electron transfer that produces a violet solution in methanol. This free radical, stable at room temperature, is reduced in the presence of an antioxidant molecule, giving rise to a colorless methanol solution. The use of the DPPH assay provides an easy and rapid way to evaluate antioxidants by spectrophotometer, so it can be useful to assess various products at a time.

Reagent

DPPH stock standard: 0.05mg DPPH made to 100ml methanol

DPPH working standard: Add 10ml DPPH stock std. and 90ml methanol.

Ascorbic acid stock standard: 100mg Ascorbic acid made up to 100ml Distilled water.

Ascorbic acid working standard: 10 ml stock standard made up to 100ml distilled water.

Procedure:

Step 1 0.5 g defatted rice powder taken into 100ml volumetric flask

Step 2 Add 5 ml Methanol and seal with a parchment sheet.

Step 3 Keep incubator Shaker for 24 hrs at 135 rpm.

Step 4 Filter the solvent using filter paper

Step 5 Add 5ml of methanol to extract.

Step 6 Samples are made with 0.1 of the methanolic extract and 1.9ml DDPH working standard.

Step 7 Blank is made with 2ml methanol, control is made with 0.1ml methanol and 1.9 ml DPPH, standard is made with 0.1ml ascorbic acid and 1.9ml DPPH.

Step 8 Vertex all the test tubes and keep them in dark for 30 minutes and read absorbance at 517nm in a spectrophotometer.

$$\text{Antioxidant activity (\%)} = \frac{(A_O - A_S)}{A_O} \text{X } 100$$

Where,

A_O = Absorbance of control,

A_S = Absorbance of sample

3.2.1.5.4 Estimation of Phytic acid

The Phytic acid was done according to the method of Raghuramulu *et al.* (1983).

Principle

The phytate is extracted with trichloroacetic acid and precipitated as ferric salt. The iron content of the precipitate is determined colorimetrically and the phytate phosphorus content is calculated from this value assuming a constant 4Fe:6P molecular ratio in the precipitate.

Reagents

1. 3% Trichloroacetic acid (TCA)
2. 3% Sodium sulphate in 3% TCA
3. 15N NaOH
4. 3.2N HNO3 1000ml
5. $FeCl_3$ solution: Dissolve 583mg $FeCl_3$ in 100ml of 3% TCA
6. 1.5M Potassium thiocyanate (KCSN): Dissolve 29.15g in 200ml water.
7. Standard $Fe(NO_3)_3$ solution

Method

Step 1 Weigh a finely ground (40 mesh) 5g sample and take it into a 125ml Erlenmeyer flask.

Step 2 Extract in 50ml 3% TCA for 30 min with mechanical shaking or with occasional swirling by hand for 45min.

Step 3 Centrifuge the suspension and transfer a 10ml aliquot of the supernatant to a 40ml conical centrifuge tube.

Step 4 Add 4ml of $FeCl_3$ solution to the aliquot by blowing rapidly from the pipette.

Step 5 Heat the contents in a boiling water bath for 45 min. If the supernatant is not clear after 30 min, add one or two drops of 3% sodium sulphate in 3% TCA and continue heating.

Step 6 Centrifuge (10-15 min) and carefully decant the clear supernatant.

Step 7 Wash the precipitate twice by dispersing well in 20 to 25ml 3% TCA, heat in boiling water for 5 to 10 min and centrifuge.

Step 8 Repeat washing with water.

Step 9 Disperse the precipitate in a few ml of water and add 3ml of 1.5N NaOH with mixing.

Step 10 Bring volume to approximately 30ml with water and heat in boiling water for 30 min.

Step 11 Filter hot (quantitatively) through a moderately retentive paper Whatman No. 2.

Step 12 Wash the precipitate with 60-70ml hot water and discard the filtrate.

Step 13 Dissolve the precipitate from the paper with 40ml hot 3.2 N HNO3 into a 100ml volumetric flask.

Step 14 Wash paper with several portions of water, collecting the washings in the same flask.

Step 15 Cool flask and contents to room temperature and dilute to volume with water.

Step 16 Transfer a 5ml aliquot to another 100ml volumetric flask and dilute to approximately 70ml.

Step 17 Add 20ml of 1.5M KSCN, dilute to volume, and read color immediately (within 1min) at 480nm.

Standard

Weigh accurately 433mg Fe(NO3), and dissolve in 100ml distilled water in a volumetric flask. Dilute 2.5ml of this stock standard and makeup to 250ml in a volumetric flask. Pipette out 2.5, 5, 10, 15 and 20ml of this working standard into a series of 100ml volumetric flasks and proceed from step 16.

Calculation

Find out the µg iron present in the test from the standard curve, and calculate the phytate P as per the equation:

$$\text{Phytate P (mg/100g sample)} = \frac{\mu\text{g Fe} \times 15}{\text{Weight of sample (g)}}$$

3.2.1.5.5 Estimation of oxalates

The oxalates estimation was done according to the method of Raghuramulu *et al.*(1983).

Principle

The acid-treated sample is defatted with ether and extracted with NaOH and water. The water layer is treated with calcium chloride buffer (pH 4.5) and centrifuged. The pellet is treated with acetic acid saturated with calcium oxalate, centrifuged and the residue is dissolved in H_2SO_4 Finally, the extract is titrated against standard 0.02N potassium permanganate solution and the amount of oxalic acid is calculated.

Reagents

1. 4N H_2SO_4
2. 1N NaOH
3. Diethyl ether
4. Calcium chloride-acetate buffer: Dissolve 25g of anhydrous calcium chloride in 500ml of 50% acetic acid. Dissolve 330g of sodium acetate trihydrate in water and make up the volume of 550 ml. Combine the two solutions and adjust the pH to 4.5 if necessary.
5. 5% Acetic acid saturated with calcium oxalate.
6. Standard 0.02N Potassium permanganate solution.

Method

Sample extraction

Step 1 Oven dry the tissue to a constant weight in a hot-air oven at 80°C.

Step 2 Grind the tissue to a fine powder in a mortar and pestle, dry the powder again and weigh 500 mg sample from it.

Step 3 Mix the sample with 1g of asbestos and 1.5ml of 4N H_2SO_4.

Step 4 Fill the extraction thimble (prepared from Whatman filter paper) to a depth of 2cm with clear ground glass (20 mesh). Place two circular pieces of cheesecloth of slightly greater diameter than the thimble over the glass.

Step 5 Transfer the sample mixed with asbestos and H_2SO_4 to the thimble quantitatively.

Step 6 Place the thimble with contents in the soxhlet extraction apparatus and extract with 500ml of pure diethyl ether for 48h.

Step 7 Add 5ml of 1N NaOH and 7ml of water to the extract and shake well.

Step 8 Evaporate the ether layer in a rotary evaporator.

Step 9 Transfer the water phase to a centrifuge tube, add 4ml of calcium chloride-acetate buffer and allow to stand overnight.

Estimation

Step 10 Centrifuge at 3000g for 10 min.

Step 11 Discard the supernatant and wash the pellet with 5ml of 5% acetic acid saturated with calcium oxalate and centrifuge.

Step 12 Dissolve the residue in 5ml of 4N H_2SO_4 and heat at 80-90°C in a water bath.

Step 13 Filter while hot and titrate against standard 0.02N potassium permanganate solution.

Calculate the amount of oxalic acid (mg / 100 g sample) present in the sample using the relationship: 1ml of 0.02N Potassium permanganate = 1.2653mg of oxalic acid

3.2.1.6 Nutritional Traits

3.2.1.6.1 Proximate Composition

The proximate analysis is a quantitative method to determine different macronutrients present in rice. It is the partition of seed compounds into various categories such as moisture (g %), protein (g %), fats (g %), ash (g %), fiber (g %), total carbohydrates (%) and Energy (k.cal) was estimated as per standard AOAC method (2005) for both raw and developed products (Appendix A-E).

3.2.1.6 .2 Micronutrients Estimation (Iron and Zinc)

The estimation of iron and zinc in the Atomic absorption spectrophotometer is done according to Shobhana *et al*. (2013).

Principle:

The sample is treated with a mixture of mineral acid (tri acids) and heated for more rapid decomposition. The volatile constituents disappear and non-volatile mineral elements enter the solution. Heating is continued until digest is reduced to a few ml of clear white residue. The residue is dissolved in HCI (6N), filtered and made to a known volume with distilled water for various elemental analysis.

Reagents required:

Triacid mixture mix: 100 ml of conc. HNO_3, 10 ml of conc. H_2SO_4 and 40ml of 60% $HClO_4$ or 30ml of 72% $HClO_4$ (HNO_3: H_2SO_4 $HClO_4$ in the ratio of 10:1:4 respectively), HCl and conc. HNO_3.

Procedure:

Step 1 Pre digestion of the sample with HNO_3: 1g of sample is transferred into 100 ml conical flask and the sample is wetted with 10 ml of conc. HNO3 and allow to stand overnight. The content is then gently heated on a hot plate till the volume of the content is reduced to 4ml or less and then cooled.

Step 2 Digestion with the tri acid mixture: 5ml of tri acid mixture is added and kept on the hot sand bath until the evaluation of dense white fume subsides leaving about 3 ml of colorless solution. In the conical flask which on cooling gives white residue.

Step 3 Preparation of test solution: 5 ml of 6 N HCl is added to the residue, the contents are swirled and then transferred to 50 ml volumetric flask by filtering through Whatman No. 42 filter paper. The procedure is repeated 3-4 times with an additional quantity of 6N HCl until the entire residue is filtered. The conical flask is rinsed with distilled water and the contents are transferred to the volumetric flask. The volume is made up to 50 ml with distilled water or with 6N HCl, washing of reside on filter paper. The flask is screwed and preserved for elemental analysis. Then the readings are taken using atomic absorption spectrophotometry (AAS) at 248.33 nm for iron and 213.86 nm for zinc and expressed as µg/g of grain.

3.2.1.7 Estimation of Glycemic Index (GI)

GI was performed following Goni *et al*. (1996) method and a detailed protocol is mentioned below. All the polished rice samples were dried in the oven at 50°C till the weight became constant and were subjected to *in-vitro* GI analysis. Two grams of rice sample were taken into a 50 ml tube and 6ml of water was added. The sample was cooked for 20 minutes in a boiling water bath after soaking for 10 minutes. The weight of cooked rice was determined by subtracting the weight of the empty tube from the weight of the tube with cooked rice.

1. An amount (340 mg) of cooked rice equivalent to 100 mg dry weight of rice was taken into a 50 ml tube and cooked grains were crushed to a fine paste with the help of a glass rod. 10 ml of KCl-HCl buffer of pH 1.5 and 0.2 ml of the pepsin solution (1 g pepsin/l0 ml buffer KCl-HCl) were added and the contents were incubated in an orbital shaker at 40°C for 60 min with constant shaking (200 rpm).
2. At the end of the incubation time, 9 ml of 0.1 M Tris- maleate buffer of pH 6.9 and 1 ml of the α-amylase solution (40 mg α- amylase per ml Tris-maleate buffer) were added. All the tubes were again incubated in an orbital shaker at 37°C with constant shaking (200 rpm). At this stage, the total volume of the reaction mixture was 20.2 ml. Simultaneously, 100 mg of glucose was taken into a 50 ml tube and the volume was made up to 20.2 ml with distilled water and this tube was used as a standard solution to calculate the glycemic index.
3. At the end of four hours of incubation, 1ml of this reaction mixture was taken into another tube, 10 µl of amyloglucosidase and 80µl of 0.2M HCl (to bring down the pH to 4.75 Approx.) were added and incubated for 45 minutes in an orbital shaker at 60°C with constant shaking (200 rpm).
4. The released glucose was estimated by taking 0.1 ml of the sample into a fresh tube followed by adding 0.9 ml distilled water to adjust the volume to 1ml and 3ml of GOPOD reagent and the tube was incubated at 40°C for 20 minutes as given in the GOPOD kit (Megazyme) and the developed color measured at 510 nm. Simultaneously, 100 mg of standard glucose was taken into a 50 ml tube, dissolved in water and the volume was made up to 20.2 ml like the test sample. 0.1 ml of this solution was treated with GOPOD reagent to get absorbance of standard glucose.

Calculation

$$\text{Hydrolysis index (HI) of the sample} = \frac{\text{Absorbance of test}}{\text{Absorbance of standard}} \times 100$$

Absorbance of standard = 0.934

The equation was reported by Goni *et al.* (1996). It corrects the variation between in vitro and in vivo GI analysis.

Glycemic index (GI) = 39.71 + (0.549 x HI of the sample).

Table 3.6 Classification of Glycemic Index

Classification	GI range
Low	0-55
Medium	56-69
High	>70

3.3 Standardization of the value-added products from the selected black rice varieties

The suitability of black rice for the development of rice based value-added products was evaluated. Black rice was found to be suitable for rice based products *viz*., payasam (kheer), cake, vadiyalu (fryums) and vermicelli. The standardized procedures are given below.

3.3.1 Payasam (kheer)

Payasam, a traditional food of India is sweetened rice prepared from a combination of rice, sugar and milk, added with cardamom powder for flavor. Payasam is an important food item during all festive occasions and functions, in addition to being part of the weekly diet, particularly in South India. Payasam was standardized from the selected rice (Figure 3.2) varieties as per the procedure given below.

Table 3.7 Ingredients for the preparation of Payasam (Kheer)

S.No	Ingredients	Quantity
1.	Black rice	100g
2.	Milk	100ml
3.	Sugar	100g
4.	Water	50ml
5.	Cardamom powder	0.5g

Selected black rice varieties

↓

Soak with water (1:4) for 4 hours

↓

Boil

↓

Add milk and cook for 5 minutes

↓

Add sugar and cook for 5 minutes

↓

Add cardamom powder

↓

Stir well

↓

Payasam (Kheer)

Figure 3.2 Flow chart for preparation of payasam (kheer)

Method

Black rice varieties were soaked separately in fresh water with a ratio of 1:4 for 4 hours. The soaked rice and water were pressure cooked for 4 whistles. After that milk was added to the cooked rice and boiled for 5 minutes. Then sugar was added and further cooked for 5 minutes. Finally, cardamom powder was added and stirred well. The product was subjected to organoleptic evaluation using the score card furnished in Appendix –F.

3.3.2 Cake

Cakes are baked products that are made with the main ingredient of wheat flour added with sugar, egg, butter, milk, vanilla essence, baking soda and baking powder. The formulations were done with a combination of wheat flour. Among all 60:40 (Black rice flour:Wheat flour) is highly accepted. The procedure is shown in Figure 3.3.

Table 3.8 Ingredients for the preparation of Cake

S.No	Samples	Proportions
1.	Control	100BRF:0WF
2.	T1	90BRF:10WF
3.	T2	80BRF:20WF
4.	T3	70BRF:30WF
5.	T4	60BRF:40WF

Sugar – 100g
Milk – 20ml
Egg – 30g
Melted butter – 20ml
Baking Soda – 2g
Baking powder – 5g
Vanellia essence – 3 drops

BRF-Black rice flour, WF- Wheat flour

Method

1. The dry ingredients including black rice flour, wheat flour, baking powder, baking soda and salt were sieved.
2. The wet ingredients include egg, milk melted butter.

Firstly, the egg was beaten using a mechanical whisker for 5 min. Sugar powder was added and whisked thoroughly for 3 min using a mechanical whisker. Vanilla essence was added and whisked for 30 sec. Dry ingredients were added to the previous wet mixture and mixed with a spatula in a cut-by-cut manner thoroughly. Milk was added and thoroughly mixed. Melted butter was added and mixed gently. Pour into a baking tray and bake in the preheated microwave oven at 160^{o}C for 30 min. The obtained cake has undergone organoleptic studies using the score card given in Appendix –F.

Whisk egg for 5 min using a mechanical whisker

↓

Add sugar powder and whisk for 3 min using a mechanical whisker

↓

Add vanilla essence and whisk for 30 sec using a mechanical whisker

↓

Add sieved black rice flour, wheat flour, baking powder and baking soda

↓

Mix gently with a spatula

↓

Add milk and mix gently

↓

Add melted butter and mix gently

↓

Pour batter into a greased baking tray

↓

Bake in the preheated microwave oven at 160°C for 30 min

↓

Cake

Fig 3.3 Preparation of Cake

3.3.3 Vadiyalu (Fryums)

Fryums were a popular Indian snack item prepared by using rice as a primary ingredient added with spice mix and salt. These were dried in sunlight and deep fried in the oil. The rice flour of the selected black rice varieties was used in the preparation of the fryums. The formulations were done with a combination of sago powder. Among all 80:20 (Black rice: Sago) is highly accepted. The procedure is shown in Figure 3.4.

Table 3.9 Ingredients for the preparation of Vadiyalu (Fryums)

S.No	Samples	Proportions
1.	Control	100BRF:0SP
2.	T1	90BRF:10SP
3.	T2	80BRF:20SP
4.	T3	70BRF:30SP
5.	T4	60BRF:40SP

Water – 1280ml
Jeera, ginger and green chilli paste – 10g
Salt – 5g

BRF-Blackrice flour, SF- Sago powder

Method

Black rice flour and sago powder were mixed in two portions of water (320ml) and make a paste. Black rice paste is added to the boiled six portions of water (960ml) and stirred well to avoid the formation of lumps. Salt and Jeera, Ginger and Green chilli paste were added and cooked for 10 min till pouring consistency is gained. Turn off the stove and take it into the bowl. A plastic wrap is placed under the sun and above the prepared mix is poured spoon by spoon on it. These are completely dried for one day under the sun and removed from the plastic wrap. The completely dried fryums were fried in the oil and the popped black rice fryums were ready to serve. The organoleptic studies were done by using the score card given in Appendix - F.

Boiled six portions of water

⬇

Add selected black rice varieties flour and sago powder mix with 2 portions of water

⬇

Add salt and Jeera-Ginger-Green chilli paste and boil for 10 min

⬇

Cooked Fryums liquid

⬇

Pour on a plastic sheet

⬇

Completely dried under the sun for one day

⬇

Fried in oil

⬇

Vadiyalu (Fryums)

Fig 3.4 Preparation of Vadiyalu (Fryums)

3.3.4 Vermicelli

Extrusion cooking worldwide for the production of extended starch foods, modified starches, ready-to-eat cereals, baby foods, pasta and pet foods is becoming increasingly popular. This technology has many advantages like versatility, low cost and better product quality. Extruded products include macaroni, noodles, spaghetti, vermicelli and other pasta products. Vermicelli /Noodles are one of the preferred items of children and also other age groups on account of their convenience and ready-to-cook nature. Vermicelli was prepared from selected rice flour (Fig. 3.5) as per the procedure detailed below. Among all 60:30:10 (Black rice: Wheat: Corn starch) formulation was highly accepted by panellist.

Table 3.10 Ingredients for the preparation of Vermicelli

S.No	Samples	Proportions	
1.	Control	100BRF:0WF	Water – 50ml Salt – 2g
2.	T1	90BRF:10WF	
3.	T2	80BRF:10WF:10CS	
4.	T3	70BRF:20WF:10CS	
5.	T4	60BRF:30WF:10CS	

BRF-Black rice flour, WF- Wheat flour, CS- Corn starch

Method

Selected black rice flour, wheat flour and corn starch were sieved in a mesh sieve. The sieved flour is mixed with salt and water to make dough. The dough is passed through the vermicelli making machine. The vermicelli is steamed for 10 minutes and dried in a cabinet drier at 105°C for 45min. The dried vermicelli was cooked with seasoning and water for 10 min. The organoleptic studies were done by using the score card given in Appendix –F.

Selected black rice varieties flour: wheat flour: corn starch

↓

Addition of water

↓

Knead uniformly into the dough

↓

Extruded through vermicelli machine

↓

Collected in trays and steamed

↓

Dried in hot air oven (at 105°C)

↓

Cooled to room temperature (uncooked vermicelli)

↓

Added to boiled seasoned water (1:3)

↓

Cook for 10 mins

↓

Vermicelli upma

Fig 3.5 Preparation of Vermicelli

Payasam **Cake**

Vadiyalu (uncooked) **Vadiyalu (fried)**

Vermicelli (uncooked) **Vermicelli (upma)**

Plate 3.3 Highly accepted black rice products

3.4 Sensory Evaluation

The sensory scoring was done by 25 members of Foods and Nutrition laboratory of College of Community Science using a hedonic rating scale. Descriptive terms were given to various quality attributes like appearance, color, flavor, texture, taste and overall acceptability.

Numerical scores were assigned to each attribute. A 9-point scale was adopted to score each attribute, while scoring, the highest score of 9 was assigned to the most preferred characteristic and the least score 1 to the least preferred characteristic. (Peryam and Pilgrim, 1957).

3.5 Storage Studies

3.5.1 Organoleptic Evaluation

Stored vadiaylu and vermicelli were drawn intial day, 15th day and 30th day for evaluation of sensory attributes using hedonic rating scale.

3.5.2 Proximate Composition

Stored vadiaylu and vermicelli were drawn intial day, 15th day and 30th day and subjected to analysis as given in Appendix A-E.

3.5.3 Free fatty acid analysis

Stored samples were drawn fortnightly for 3 months and subjected to free fatty acid analysis. The products were ground and soaked in methanol and chloroform overnight. Soaked samples were filtered in a conical flask and subjected to water bath for evaporation. Sample was titrated against KOH in the presence of 95% ethanol and diethyl ether in the ratio of 1:1 and phenopthalin solution was used as indicator.

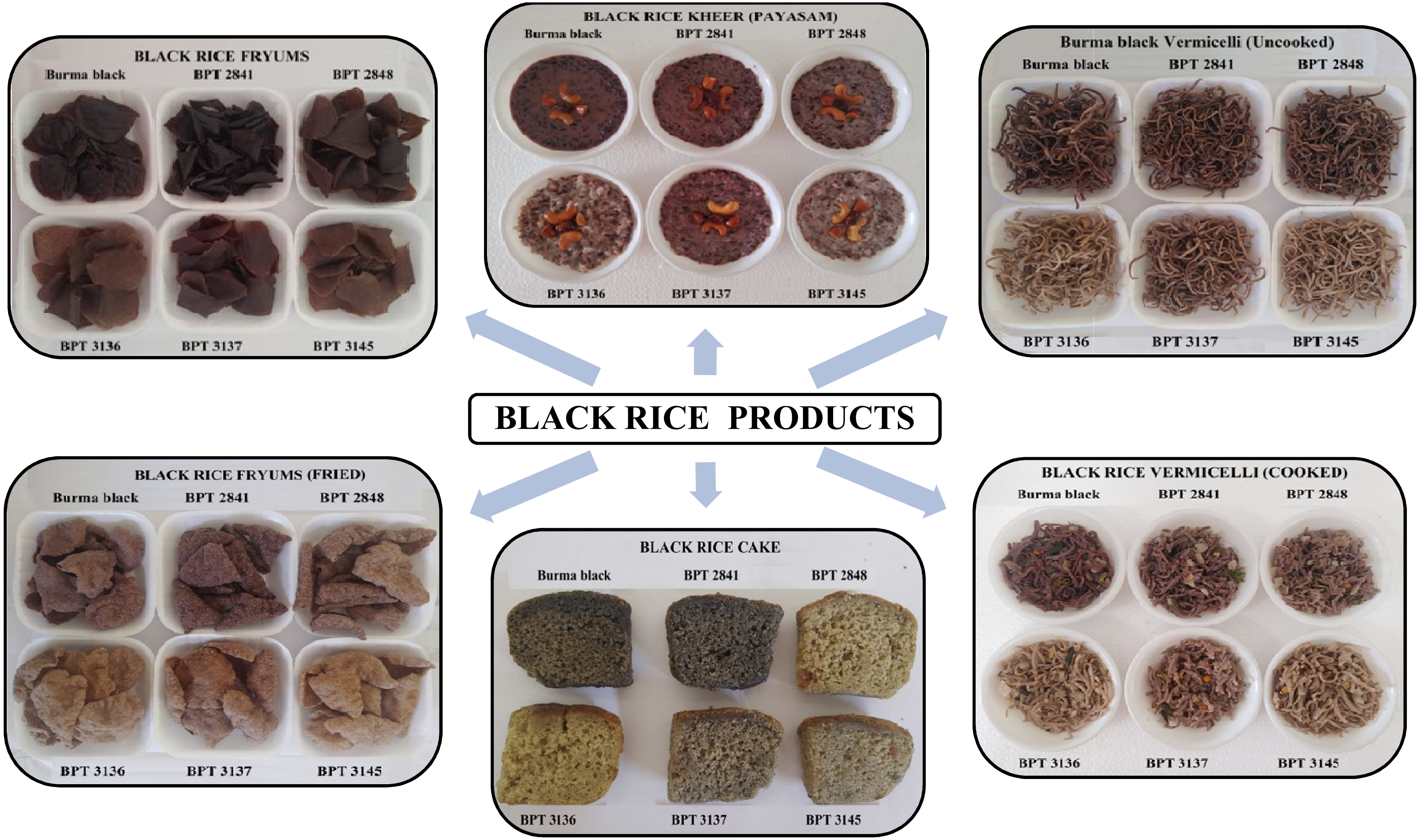


Plate 3.4 Black rice products

Plate 3.5 Senosry evaluation of products by panel members

3.6 Statistical Analysis

3.5.1 Mean (X) The mean values of each character were worked out by dividing the sum by the corresponding number of observations.

$$X = \frac{\Sigma Xij}{N}$$

Where,

Xij = Any observation in i_{th} genotype and j_{th} replication

N = Total number of observations

3.6.1.1 Standard Error (SE)

The standard error of the mean was calculated with the help of the error mean square from the analysis of the variance table as under:

$$SE(m) \pm = \frac{\sqrt{\sigma^2 e}}{r}$$

$$SE(m) \pm = \frac{\sqrt{2\, \sigma^2 e}}{r}$$

Where,

$\sigma^2 e$ = Error mean sum of square

r = Number of replications

3.6.1.2 Critical Difference (C.D)

In case F test was found to be significant, critical differences were calculated to find the superiority of one genotype over the other by the following formula

$$SE\ (m) \pm = \frac{\sqrt{2\, \sigma^2 e}}{r} \times 100$$

t table value at 5% or 1% at error d.f

3.6.1.3 Range

The lowest and highest values for each character were recorded.

3.6.2 Analysis of Variance

Analysis of variance was computed based on the completely randomized design for each of the characters separately.

3.6.3 Correlation Studies

Changes in one characteristic accompanied by a change in another variable are referred to as correlation. The coefficient of correlation is the measure of association between two characteristics. Correlations can be either positive, when an increase in one variable is accompanied by an increase in another one, or negative when an increase in one character is accompanied by a decrease in another (Falconer, 1960).

It is the association between two characteristics that can be directly observed and determined from measurements of the two characteristics in individuals of the population (Falconer, 1960). The correlation between the two characters was determined by using variance and covariance components as suggested by Al-Jibourie *et al.* (1958).

$$rp\,(x,y) = \frac{px\,.py}{\sqrt{Vpx.\ Vpy}}$$

Where,

px py : co-variance of x and y.

Vpx : variance of x

Vpy : variance of y

rp(x,y) : correlation co-efficient of x and y

Chapter IV

RESULT AND DISCUSSION

The present investigation was entitled with "Grain quality evaluation of improved black rice (*Oryza Sativa* L.) genotypes and assessment of their suitability for preparation of south indian foods" has led to some important observations. The experimental findings have been discussed and interpreted below under the following headings.

4.1 Quality traits

- 4.1.1 Physical Quality Traits
  - 4.1.1.1 Hulling (%)
  - 4.1.1.2 Milling (%)
  - 4.1.1.3 Head rice recovery (HRR) (%)
  - 4.1.1.4 Kernel length (mm)
  - 4.1.1.5 Kernel breadth (mm)
  - 4.1.1.6 Length/ Breadth (L/B) ratio
  - 4.1.1.7 Thousand grains weight (g)
- 4.1.2 Chemical quality traits
  - 4.1.2.1 Amylose content (AC) (g%)
  - 4.1.2.2 Gel consistency (GC) (mm)
  - 4.1.2.3 Alkali spreading value (ASV)
- 4.1.3 Cooking quality traits
  - 4.1.3.1 Kernel length after cooking (KLAC) (mm)
  - 4.1.3.2 Kernel breadth after cooking (KBAC) (mm)
  - 4.1.3.3 Kernel elongation ratio (KER)
  - 4.1.3.4 Volume expansion ratio (VER)
  - 4.1.3.5 Water Uptake (WU) (ml)
- 4.1.4 Nutraceutical properties
  - 4.1.4.1 Bulk density (g/ml)

        - 4.1.4.2 Water Absorption Index (WAI) (g/g)
        - 4.1.4.3 Water Solubility Index (WSI) (%)
- 4.2 Biochemical quality profile
    - 4.2.1 Total anthocyanin content
    - 4.2.2 Total phenol content
    - 4.2.3 Total antioxidant activity
    - 4.2.4 Phytic acid
    - 4.2.5 Oxalates
- 4.3 Nutritional traits
    - 4.3.1 Proximate composition
    - 4.3.2 Micronutrients
- 4.4 Glycemic index
- 4.5 Study of the suitability of black rice for product development
    - 4.5.1 Payasam (Kheer)
    - 4.5.2 Cakes
    - 4.5.3 Vadiyalu (Fryums)
    - 4.5.4 Vermicelli
- 4.6 Storage Studies
    - 4.6.1 Shelf-life study of vadiyalu
    - 4.6.2 Shelf-life study of vermicelli

4.1 Quality Traits

The quality of rice is mainly influenced by numerous physical and chemical quality parameters that indicate the cooked rice texture and cooking characteristics. All the traits showed significant difference except bulk denisty. The mean values are presented in Table 4.1.

4.1.1 Physical Quality Traits

The physical quality traits of rice consist of Hulling per cent (%), Milling per cent (%), Head rice recovery (HRR) (%), Kernel length (mm), Kernel breadth (mm), L/B ratio and Thousand kernel weight (g).

4.1.1.1 Hulling Per cent

The hulling per cent among six black rice varieties ranged from 73.63% to 77.57%, which showed on par result with Pal *et al.* (2019) who reported the range as 72.47-76.00%. The observed mean was 75.58% which was in conformity with the mean values 76.67% (Bassuony 2016) and 76.65% (Singh and Devi 2020). The maximum hulling per cent was observed in BPT 3145 (77.57), followed by Burma black (77.53%), BPT 3137 (75.57%), BPT 2841 (74.67%), BPT 3136 (74.53%) and minimum was observed in BPT 2848 (73.63). Generally, hulling percentage was reported to be in the range of 71–83 per cent (Ponnappan *et al.,* 2017). In terms of milling quality, the rice with high hulling percentage is desirable because the hulling percentage is positively correlated with the milling percentage (Ojha *et al.,* 2018).

4.1.1.2 Milling Per cent

Burma Black had the highest milling percentage (71.00%) among the six black rice varieties, followed by BPT 3145 (69.23%) and BPT 3136 (69.23%); BPT 3137 (68.87%), BPT 2848 (68.23%), and BPT 2841 (68.10%). The milling percentage ranged from 68.10% to 71.00% with mean value of 69.22%. The results were compared to the recorded values of 64.6%, 65.77%, 62.64±0.05%, 60.00% to 62.00% and 60.461±1.032%, reported by Bassuony (2016), Ponnappan *et. al.* (2017), Pal *et. al.* (2019) and Singh and Devi (2020). Cultivar differences can have an impact on milling percentages, meteorological conditions during grain maturation, and harvest moisture content (Salassi *et al*., 2013).

4.1.1.3 Head Rice Recovery (HRR)

In the present study, BPT 3145 had the highest head rice recovery (65.30%), followed by Burma Black (65.17%), BPT 3137 (64.97%), BPT 2841 (63.47%), BPT 3136 (62.80%), and BPT 2848 (60.07%). The range lied between 60.07% and 65.30% with mean value of 63.63%. The values resulted were higher than the values 56.5% (Wickert *et al.,* 2014), 58.91% (Bassuony 2016), 573.4±0.04% (Ponnappan *et al.,* 2017), 33.00-52.00% (Pal *et al.,* 2019), 44.12±1.34% (Singh and Devi 2020) and 56.5% (Singh *et al.,* 2020a) from different studies. Village rice mills reported 30% head rice recovery, while commercial rice mills reported 55% head rice recovery. The increase in head rice recovery observed may be due to variations in milling conditions (Dhankhar 2014).

4.1.1.4 Kernel Length

The grains were classified into three categories depending on grain length those were long (>6mm), Medium (5mm-6mm) and Short (<5mm). Kernel length in this study ranged between 5.60mm to 6.18mm and the mean value 5.91mm. The highest kernel length recorded by Burma Black (6.18mm), followed by BPT 3136 (6.09mm), BPT 3145 (6.05mm), BPT 3137 (5.91mm), BPT 2848(5.63mm) and lowest mean was BPT 2841 (5.60mm). The obtained results were comparable to those of Ponnappan *et al.,* (2017) (5.62mm) and Rajenan and chanan (2020) (5.1mm to 6.3mm). Burma black, BPT 3136 and BPT 3145 were classified under long grain length whereas BPT 2841, BPT 2848 and BPT 3137 were classified under medium grain length.

4.1.1.5 Kernel Breadth

In the present study, Kernel breadth ranged between 1.93mm and 2.51mm with a general mean value of 2.10mm. The highest kernel breadth was recorded for Burma black (2.51mm), followed by 3145 (2.14mm), BPT 3136 (2.07mm), BPT 3137 (2.01mm), BPT 2848 (1.96mm), and the lowest mean value was recorded for BPT 2841 (1.93mm). The obtained results were on par with results of Ponnappan *et al.,* (2017) (2.15mm) and Rajenan and chanan (2020) (2.5mm to 3mm).

Table 4.1 Mean performance of Quality traits

Black rice genotypes	Physical traits							Chemical traits			Cooking quality traits					Nutraceutical properties		
	H (%)	M (%)	HRR (%)	KL (mm)	KB (mm)	L/B	TGW (g)	AC (g%)	GC	ASV	KLAC (mm)	KBAC (mm)	KER	VER	WU (ml)	BD (g/ml)	WAI (g/g)	WSI (%)
Burma Black	77.53	71.00	65.17	6.18	2.51	2.46	27.23	5.40	85.00	6.67	8.55	3.84	1.38	3.37	461.67	0.74	1.52	17.17
BPT 2841	74.67	68.10	63.47	5.60	1.93	2.90	13.53	21.21	83.00	4.67	8.06	3.06	1.43	3.42	425.00	0.74	1.61	18.17
BPT 2848	73.63	68.23	60.07	5.63	1.96	2.88	14.31	22.48	78.00	4.33	8.07	3.10	1.43	3.73	416.67	0.74	1.65	19.17
BPT 3136	74.53	69.23	62.80	6.09	2.07	2.94	21.20	24.37	71.00	3.67	8.81	3.88	1.46	4.07	405.00	0.76	1.79	25.17
BPT 3137	75.57	68.87	64.97	5.91	2.01	2.94	18.40	22.94	76.30	4.33	8.56	3.83	1.44	3.77	415.00	0.75	1.69	22.17
BPT 3145	77.57	69.23	65.30	6.05	2.14	2.83	20.52	23.92	74.00	4.00	8.79	3.86	1.45	3.97	408.33	0.75	1.70	24.17
Mean	75.58	69.22	63.63	5.91	2.10	2.82	19.20	20.05	77.88	4.61	8.47	3.60	1.43	3.72	421.94	0.75	1.66	21.00
S.D	1.90	1.41	2.07	0.24	0.21	0.17	4.74	6.82	5.10	1.09	0.33	0.42	0.03	0.28	24.01	0.01	0.10	3.29
CV	2.28	1.08	1.58	0.01	0.01	0.01	0.75	0.05	1.91	6.02	0.15	1.58	0.03	0.40	67.14	0.04	0.36	7.93
CD	2.32	1.53	1.77	0.05	0.03	0.04	0.68	0.19	2.17	0.93	0.20	0.42	0.03	0.22	29.82	0.03	0.14	2.29
S.E	1.07	0.70	0.82	0.02	0.01	0.01	0.31	0.08	0.99	0.43	0.09	0.19	0.01	0.10	13.74	0.01	0.06	1.05
Range lowest	73.63	68.10	60.07	5.60	1.93	2.46	13.53	5.40	71.00	3.67	8.06	3.06	1.38	3.37	405.00	0.74	1.52	17.17
Range highest	77.57	71.00	65.30	6.18	2.51	2.94	27.23	24.37	85.00	6.67	8.81	3.88	1.46	4.07	461.67	0.76	1.79	25.17

H- Hulling per cent, M- Milling percent, HRR- Head Rice Recovery, KL- Kernel Length, KB- Kernel Breadth, L/B- Length/Breadth ratio, TGW- Thousand Grain Weight, AC-Amylose Content, GC- Gel Consistency, ASV- Alkali Spreading Value, KLAC- Kernel Length After Cooking, KBAC- Kernel Breadth After Cooking, KER- Kernel Elongation Ratio, VER- Volume Expansion Ratio, WU- Water Uptake, BD- Bulk Density, WAI- Water Absorption Index and WSI- Water Solubility Index

4.1.1.6 Length/ Breadth (L/B) Ratio

In the current study, L/B ratio varied from 2.46 (Burma black) to 2.94 (BPT 3136 and BPT 3137), with values of 2.90, 2.88 and 2.83 for BPT 2841, BPT 2848 and BPT 3145 respectively. The obtained results were comparable to those of Ponnappan *et al.,* (2017) (2.61±0.04) and Rajenan and chanan (2020) (1.88-2.52). Burma black, BPT 3136 and BPT 3145 were classified as long bold grains based on length and L/B ratio. BPT 2841, BPT 2848 and BPT 3137 were identified as medium slender grains.

4.1.1.7 1000 Grain Weight

In the current study, thousand grains weight ranged between 13.53g to 27.23g with general mean value of 19.20g. The highest mean value was recorded for Burma black (27.23 g), followed by BPT 3136 (21.20 g), BPT 3145 (20.52 g), BPT 3137 (18.40 g), BPT 2848 (14.31g), and BPT 2841 (13.53g). In comparison with other studies, Thomas *et al*. (2013) found that the thousand kernels weight ranged between 16.97 g to 19.43 g. While, Ponnappan *et al.* (2017) and Ray *et al.* (2021) observed it as 17.50±0.04 g and 2.75 g/100 grains weight for black rice respectively, which were comparable to the present obtained result. The higher kernel weight may be related to their larger kernel size as reported by Saikia *et al*. (2012). Consumer preference and pricing of rice is based on the grain dimension and quality (Rajenan and chanan. 2020).

4.1.2 Chemical Quality Traits

The chemical quality traits of rice consist of Amylose content (%), Gel consistency (mm) and Alkali spreading value are shown in Table 4.1.

4.1.2.1 Amylose Content (AC)

Amylose content plays an important role in determining the cooking and pasting properties of a rice variety. The cooking quality of rice depends on the components of the rice variety such as proteins and amylopectin varieties. A positive association was observed between amylose content and hardness rates, whereas stickiness values showed a negative correlation. So, the cooked rice with intermediate amylose appears fluffy and flaky. Thus, amylose content influences the texture of cooked rice. Based on AC, rice varieties were categorized into waxy (0–2%), very low (3–9%), low (10–19), intermediate (20–25%), and high (>25%) amylose (Gani *et al.,* 2017). Amylose content ranged from 5.40 % to 24.37 % in the present study, with a mean value of 20.05 %. The highest amylose content was found in BPT 3136 (24.37 %), followed by BPT 3145 (23.92%), BPT 3137 (22.94%), BPT 2848 (22.48%) and BPT 2841 (21.21%), whereas the lowest was recorded for Burma black (5.40 %). Pakuwal and Manandhar (2021) found the amylose content in black rice to be 5.28 %, while Masniawati *et. al.* (2018) found it to be between 2.51 % and 18.29 %, which contradicted the current result. All the varieties except control possess intermediate amylose which is preferable for consumption of rice varieties as raw rice.

4.1.2.2 Gel Consistency (GC)

Gel consistency determines the cooked rice's potential to become harder upon cooling. Rice eating quality is correlated with the gel consistency (Kanlayakrit and Maweang. 2013). The rice is categorized according to gel consistency based on gel length as hard (26-40 mm), medium (41-60 mm) and soft (61-100 mm). In the present study, the highest gel consistency was recorded for Burma black (85mm), lowest for BPT 3136 (71 mm) and the range lies between 71 to 85 mm with a mean of 77.88 mm for all the investigated black rice varieties. Pal *et al.* (2019) and Krishnan *et al.* (2021) observed it between 66.00 to 77.33 mm and 76 ± 0.72 mm. A high value of gel consistency indicates a soft texture and lower values of gel consistency indicate a harder texture. Rice with soft gel consistency cooks more tenderly and remained soft upon cooling (Chanu *et al.,* 2020). All the black rice genotypes had a soft gel consistency.

4.1.2.3 Alkali Spreading Value (ASV)

The desirable rice genotypes should have an intermediate alkali spreading value (4-5). However, the alkali spreading value of the genotypes ranged from 3.67 (BPT 3136) to 6.67 (Burma black) with an general mean value of 4.61. Singh *et al.* (2020a) found that ASV of black rice pericarp genotypes ranged from 2.50 to 7.00, which was comparable to the current study results. The rice varieties with intermediate alkali spreading value showed medium disintegration and were classified under intermediate gelatinization temperature, which are desirable quality characteristics (Madhubabu *et al.* 2017). The intermediate ASV was obtained for BPT 2841 (4.67), BPT 2848 (4.33), BPT 3137 (4.33) and BPT 3145 (4.00).

4.1.3 Cooking Quality Traits

The cooking quality traits of rice consist of Kernel length after cooking (mm), Kernel breadth after cooking (mm), Kernel elongation ratio, Volume expansion ratio and Water uptake (ml) are shown in Table 4.1.

4.1.3.1 Kernel Length After Cooking (KLAC)

KLAC ranged from 8.06 mm to 8.81 mm, with a mean value of 8.47 mm. The highest mean value was recorded for BPT 3136 (8.81 mm), followed by BPT 3145 (8.79 mm), BPT 3137 (8.56 mm), Burma Black (8.55 mm) and BPT 2848 (8.07 mm). The lowest mean value was recorded for BPT 2841 (8.06 mm). The obtained results are consent with studies of Pal *et al.* (2019) and Nath *et al.* (2022). The kernel length after cooking in the above studies was 8.10 to 10.10 mm and 8.46±0.31 mm respectively. When rice elongates, it appears more palatable and when it enlarges in circumference, it appears coarse. Most often, people choose rice with long cooked grains and a satisfactory appearance (Pathak *et al.* 2016).

4.1.3.2 Kernel Breadth After Cooking (KBAC)

KBAC ranged from 3.06 mm to 3.88 mm, with a mean value 3.60 mm. The highest mean value was recorded for BPT 3136 (3.88 mm), followed by BPT 3145 (3.86 mm), BPT 3137 (3.83 mm), Burma Black (3.84 mm) and BPT 2848 (3.10 mm). The lowest mean value was recorded for BPT 2841 (3.06 mm). According to Nath *et al.* (2022) KBAC was 2.63±0.09 which is lower than the current result.

4.1.3.3 Kernel Elongation Ratio (KER)

The mean value of the kernel elongation ratio is 1.43 and values ranged between 1.38 and 1.46. The highest mean value was recorded for BPT 3136 (1.46), followed by BPT 3145 (1.45), BPT 3137 (1.44), BPT 2848 (1.43) and BPT 2841 (1.43). The lowest mean value was recorded for Burma black (1.38). The values agreed with the findings of Pal *et. al.* (2019) (1.68-1.87), Singh and Devi (2020) (1.35±0.03). Kernel elongation was identified as a physical phenomenon that was influenced by several physicochemical and genetic factors, such as genotype, ageing temperature, ageing time, water uptake, amylose content and gelatinization temperature.

4.1.3.4 Volume Expansion Ratio (VER)

The mean value of volume expansion ratio is 3.72 and values ranged between 3.37 and 4.07. The highest mean value was recorded for BPT 3136 (4.07), followed by BPT 3145 (3.97), BPT 3137 (3.77), BPT 2848 (3.73) and BPT 2841 (3.42). The lowest mean value was recorded for Burma black (3.37). The current study values were in concurrence with the result of Pal *et al.* (2019) (3.75 to 4.00) and Singh and Devi (2020) (4.15±0.02). According to Shahidullah *et al.* (2009), higher elongation ratio (ER) of the cooked rice was preferred over lower ER and consumers generally accept lower VER than higher VER.

4.1.3.5 Water Uptake (WU)

The mean value of water uptake was 421.94 ml and values ranged between 405.00 and 461.67 ml. The highest mean value was recorded for Burma black (461.67 ml), followed by BPT 2841 (425 ml), BPT 2848 (416.67 ml), BPT 3137 (415 ml), BPT 3145 (408.33 ml). The lowest mean value was recorded for BPT 3136 (405 ml). The obtained results differed from those of Pal *et al.* (2019) (156.00-273.33 ml) and Singh and Devi (2020) (297.97±0.718 ml). Water uptake by the rice grains was mostly influenced by their surface area i.e., size and shape. The long and bold varieties took a long time to cook and absorbed less water than the small/medium and slender varieties.

4.1.4 Nutraceutical Properties

The Nutraceutical properties of rice consist of Bulk density (g/ml), Water absorption index (g/g) and Water solubility index (%) are shown in Table 4.1.

4.1.4.1 Bulk Density (g/ml)

The bulk density has a mean value of 0.75 g/ml and a range of 0.74 to 0.76 g/ml. BPT 3136 has the highest mean value (0.76 g/ml), followed by BPT 3137 (0.75 g/ml) and BPT 3145 (0.75 g/ml). The Burma Black (0.74 g/ml), BPT 2841 (0.74 g/ml), and BPT 2848 (0.74 g/ml) had the lowest mean values. Sridevi *et al.* (2015) found a comparable result of 0.77 g/ml, whereas Thomas *et al.* (2013) obtained a higher range value (0.81-0.86 g/ml).

4.1.4.2 Water Absorption Index (WAI) (g/g)

Water Absorption Index plays an important role in food preparation by influencing the other functional and sensory properties. Water absorption index reflects the ability of rice flour to combine with water molecules (Kraithong *et al.,* 2018). Therefore, flours with high water absorption have more hydrophilic constituents, such as polysaccharides (Arora *et al.,* 2021). The variation in WAI might be due to the disparity in the quantity, the ability of OH- groups to form hydrogen and covalent bonds between starch chains and it depends on the loss of starch crystalline structure (Asaduzzaman *et al.,* 2013). It might be due to the greater level of disintegration of starch molecules, which weakened the hydrogen bond between starch chains, the increased active water binding sites, results in increased water absorption capacity of black rice genotypes (Laishram and Das. 2017).

The general mean value of water absorption index was 1.66 g/g and values ranged between 1.52 and 1.79 g/g. The highest mean value was recorded for BPT 3136 (1.79), followed by BPT 3145 (1.70 g/g), BPT 3137 (1.69 g/g), BPT 2848 (1.65 g/g), BPT 2841 (1.61 g/g), and the lowest mean value was recorded for Burma black (1.52 g/g). The obtained results were on par with the results of Arora *et al.* (2021) (1.30 ± 0.12 g/g) and Sushmitha and Reddy (2020) (1.20 g/g) on black rice varieties. The higher WAI values are due to high amount of hydrophilic groups within starch, which results in a soft, smooth, and viscous food product (Lapcikova *et al.,* 2021).

4.1.4.3 Water Solubility Index (WSI) (%)

The water solubility index is determined as the amount of polysaccharide that will be released from the granule in response to the addition of extra water. The general mean value of the water solubility index was 21.00 % and values ranged between 17.17 and 25.17 %. The highest mean value was recorded for BPT 3136 (25.17 %), followed by BPT 3145 (24.17 %), BPT 3137 (22.17 %), BPT 2848 (19.17 %) and BPT 2841 (18.17 %). The lowest mean value was recorded for Burma Black (17.17 %). The obtained result were higher than the result of Pakuwal and Manandhar (2021) (13.5 ± 0.6 %) and lower than the result of Laishram and Das (2017) (30.56 ± 0.01 %). Black rice grains with higher WSI contained more aqueous soluble compounds that increased the stickiness and cohesiveness, which helped in formation of different gluten free products (Lapcikova *et al.,* 2021). The WSI value could be attributed to the semi-crystalline structure and disruption of starch granules (Asaduzzaman *et al.,* 2013).

4.1.5 Analysis of Variance

Analysis of variance was done for eighteen grain quality traits, namely physical quality traits, chemical quality traits, cooking quality traits and nutraceutical properties data depicted in Table 4.2. The F-Cal values of the varieties have statistically displayed significant differences for all the traits. The variability could be due to different sources of materials of the genetically diverse varieties. This shows that there is ample space for choosing desirable lines from the existing gene pool for desirable traits.

Table 4.2 Analysis of variance for Quality traits

Physical quality traits						
Source of Variation	**df**	**SS**	**MSS**	**F-Cal**	**F-Tab**	**P-Value**
Physical traits	6	123071.22	20511.87	38446.83	2.21	<0.05
Rice varieties	5	179.61	35.92	67.33	2.32	<0.05
Physical traits * Rice varieties	30	321.44	10.71	20.08	1.59	<0.05
Error	84	44.82	0.53			
Total	125	123617.09				
Chemical quality traits						
Source of Variation	**df**	**SS**	**MSS**	**F-Cal**	**F-Tab**	**P-Value**
Chemical traits	2	53709.26	26854.63	45150.55	3.25	<0.05
Rice varieties	5	88.98	17.80	29.92	2.47	<0.05
Chemical traits * Rice varieties	10	1144.66	114.47	192.45	2.1	<0.05
Error	36	21.41	0.59			
Total	53	54964.31				
Cooking quality traits						
Source of Variation	**df**	**SS**	**MSS**	**F-Cal**	**F-Tab**	**P-Value**
Cooking traits	4	2512154.76	628038.69	11079.70	2.52	<0.05
Rice varieties	5	1244.16	248.83	4.39	2.36	<0.05
Cooking traits * Rice varieties	20	5168.07	258.40	4.56	1.74	<0.05
Error	60	3401.02	56.68			
Total	89	2521968.02				
Nutraceutical properties						
Source of Variation	**df**	**SS**	**MSS**	**F-Cal**	**F-Tab**	**P-Value**
Nutraceutical properties	2	4710.51	2355.25	4223.52	3.25	<0.05
Rice varieties	5	57.91	11.58	20.77	2.47	<0.05
Nutraceutical properties * Rice varieties	10	106.72	10.67	19.14	2.1	<0.05
Error	36	20.08	0.56			
Total	53	4895.21				

Table 4.3 Correlation coefficients for 18 quality characteristics among black rice

	H	**M**	**HRR**	**KL**	**KB**	**L/B**	**TGW**	**AC**	**GC**	**ASV**	**KLAC**	**KLBC**	**KER**	**VER**	**WU**	**BD**	**WAI**	**WSI**
H	1.000**																	
M	0.751	1.000**																
HRR	0.861*	0.567	1.000**															
KL	0.719	0.868*	0.627	1.000**														
KB	0.766	0.982**	0.525	0.778	1.000**													
L/B	-0.661	-0.858*	-0.368	-0.509	-0.936**	1.000**												
TGW	0.748	0.981**	0.594	0.947**	0.932**	-0.747	1.000**											
AC	-0.524	-0.809	-0.336	-0.413	-0.875*	0.960**	-0.681	1.000**										
GC	0.246	0.271	0.162	-0.211	0.409	-0.670	0.086	-0.761	1.000**									
ASV	0.491	0.712	0.330	0.278	0.796	-0.926**	0.564	-0.984**	0.854*	1.000**								
KLAC	0.578	0.558	0.589	0.895*	0.429	-0.093	0.706	0.029	-0.573	-0.162	1.000**							
KLBC	0.657	0.693	0.682	0.938**	0.566	-0.252	0.809	-0.170	-0.400	0.054	0.956**	1.000**						
KER	-0.391	-0.624	-0.195	-0.155	-0.725	0.898*	-0.460	0.957**	-0.881*	-0.986**	0.289	0.071	1.000**					
VER	-0.129	-0.207	-0.116	0.271	-0.328	0.588	-0.024	0.723	-0.985**	-0.822*	0.622	0.438	0.849*	1.000**				
WU	0.447	0.691	0.295	0.249	0.776	-0.914*	0.540	-0.982**	0.866*	0.997**	-0.194	0.015	-0.985**	-0.840*	1.000**			
BD	-0.019	0.049	0.113	0.511	-0.108	0.432	0.237	0.496	-0.881*	-0.639	0.782	0.620	0.722	0.863*	-0.630	1.000**		
WAI	-0.355	-0.398	-0.188	0.090	-0.536	0.780	-0.214	0.832*	-0.975**	-0.914*	0.480	0.288	0.942**	0.936**	-0.911*	0.880*	1.000**	
WSI	0.021	-0.125	0.135	0.383	-0.265	0.567	0.070	0.682	-0.962**	-0.779	0.744	0.572	0.782	0.957**	-0.798	0.937**	0.927**	1.000**

*Correlation is significant at 0.05% level, **Correlation is significant at 0.01% level.

H- Hulling per cent M- Milling per cent, HRR- Head Rice Recovery, KL- Kernel Length, KB- Kernel Breadth, L/B- Length/Breadth ratio, TGW- Thousand Grain Weight, AC-Amylose Content, GC- Gel Consistency, ASV- Alkali Spreading Value, KLAC- Kernel Length After Cooking, KBAC- Kernel Breadth After Cooking, KER- Kernel Elongation Ratio, VER- Volume Expansion Ratio, WU- Water Uptake, BD- Bulk Density, WAI- Water Absorption Index and WSI- Water Solubility Index

4.1.6 Correlation between Quality Traits of Rice

Eighteen traits were combined into 171 pair wise combinations, of which 23 combinations were found to be significantly correlated at a 0.01% level of significance and 19 combinations were found to be significantly correlated at a 0.05% level of significance. The pair-wise correlations between physical quality, chemical quality, cooking quality and nutraceutical properties of the grains were presented in Table 4.3.

In the current study, hulling per cent showed positive correlation with milling per cent (r = 0.751) and head rice recovery per cent (r = 0.861). Hulling per cent (r = 0.719), milling per cent (r = 0.868) and head rice recovery per cent (r = 0.627) showed positive correlation with kernel length. Thousand grains weight correlated positively with hulling per cent (r = 0.748), milling per cent (r = 0.981), head rice recovery per cent (r = 0.594), kernel length (r = 0.947), kernel breadth (r = 0.932) and negative correlation with L/B ratio (r = -0.747). L/B ratio showed significant positive correlation with amylose content (r = 0.960) and significant negative correlation with Alkali spreading value (r= -0.926).

Hulling per cent and milling per cent showed positive correlation with head rice recovery per centage (r = 0.861, r = 0.567) and Alkali spreading value (r = 0.491, r = 0.712) whereas negative correlation was found with L/B ratio (r = -0.661, r = -0.858) and amylose content (r = -0.524, r = -0.809). Kernel length (r = -0.509) and kernel breadth (r = -0.936) correlated negatively with L/B ratio, which is consistent with the findings of Basri *et. al.* (2015) and Shijagurumayum *et. al.* (2018).

Amylose content correlated negatively with Alkali spreading value (r = -0.984) and Gel consistency (r = -0.761), which was consistent with studies by Pathak *et. al.* (2016) and Shijagurumayum *et. al.* (2018), but positively with volume expansion ratio (r = 0.723). Amylose content is inversely related to rice tenderness and stickiness. Amylose and amylopectin are two types of starches found in rice grains that are responsible for many of the cooking and eating properties of rice. The volume expansion ratio of high amylose grains is higher.

The amylose content and Kernel elongation ratio (r = 0.957) showed a significant and positively correlation which indicates that the elongation was high for those varieties which had high amylose content. It is an important parameter for cooked rice. The length wise kernel elongation gives a fine appearance and girth wise elongation gives coarse look (Matin *et al.,*2017).

Amylose and water uptake were found to have a significant negative correlation (-0.982). Low amylose waxy rice absorb more water than intermediate and amylose rice and becomes moist and sticky. Rice with high amylose content cooks dry, less tender and become harder upon cooling, whereas rice with low amylose content cooks moist and sticky.

A highly positive and significant correlation is observed between gel consistency and alkali spreading value (r = 0.854) showed similarity with studies of Pathak *et. al.* (2016) and Shijagurumayum *et. al.* (2018). Higher gels can frequently result in a higher ASV value. Softer gels were found to be easier to dissolve and cook in water.

Kernel length after cooking is one of the critical quality attributes in the context of cooking quality traits. The grain shape and visual appearance of rice before and after cooking are critical in determining a rice variety's acceptance. Head rice recovery (r = 0.589) was found to be positively correlated with kernel length after cooking. A positive correlation (r = 0.289) was found between kernel length after cooking and kernel elongation ratio, which was similar to the finding reported by Shijagurumayum *et al.* (2018).

A significant positive correlation was observed between alkali spreading value and water uptake (r = 0.997) was in accordance with the findings of Shivani *et al.* (2007). During cooking, grains with higher water uptake can be easily disintegrated in water. The retrogradation behaviour of the starch particles in the rice grains absorbed water and increased in volume during cooking should be considered as reason for positive correlation of increased water uptake.

Water has been shown to act as a plasticiser for starch. In rice flour processing, the increase in the water content contributed to improve the water absorption capacity, which led to higher WAI and lower WSI values (Silva *et al.,* 2009).

Water absorption index showed significant positive correlation with water solubility index (r = 0.927). Increased water absorption causes starch granules to swell and expand, resulting in leaching of aqueous compound into water. Volume expansion ratio showed significant positive correlation water absorption index (r = 0.936) and kernel elongation ratio (r = 0.849) was comparable to the result of Pandey *et. al.* (2016). During cooking, rice grains absorb water and expand in various dimensions (length, breadth, and thickness) resulting in an increase in cooked rice volume. Thus, volume expansion ratio was influenced by water absorption of rice which showed a significant effect with cooking time of rice. This was considered as an economic quality (Danbaba *et al.,* 2011).

4.2 Biochemical Quality Profile

The Biochemical quality profile of black rice genotypes consist of Total Anthocyanin Content (mgC3G/100g), Total Phenol Content (mgGAE/100g), Total Antioxidant Activity (mgAAE/100g), Phytic acid (mg/100g) and Oxalates (mg/100g).

Table 4.4 Mean performance of biochemical quality profile in black rice varieties

Black rice genotypes	Total Anthocyanin Content (mgC3G/100g)	Total Phenol Content (mgGAE/100g)	Total Antioxidant Activity (mgAAE/100g)	Phytic acid (mg/100g)	Oxalates (mg/100g)
Burma Black	30.57	218.89	97.52	410.36	5.38
BPT 2841	26.76	238.17	99.52	352.69	4.03
BPT 2848	24.99	188.23	96.42	389.62	4.00
BPT 3136	20.79	118.69	92.53	367.48	3.11
BPT 3137	22.84	150.23	94.90	351.38	2.24
BPT 3145	19.21	100.32	87.81	359.47	2.67
Mean	24.19	169.09	94.78	371.83	3.57
S.D	4.19	53.11	4.03	26.62	1.40
CV	13.30	109.11	8.75	103.56	32.99
CD	3.21	24.07	25.76	34.68	1.93
S.E	1.48	11.09	5.70	15.98	0.88
Range lowest	19.21	100.32	87.81	351.38	2.24
Range highest	30.57	238.17	99.52	410.36	5.38

4.2.1.1 Total Anthocyanin Content

In the present study, the total anthocyanin content among six black rice varieties ranged from 19.21 to 30.57 mgC3G/100g, with general mean of 24.19 mgC3G/100g. Burma black recorded the highest (30.57 mgC3G/100g) compared to other varieties, but it was not significantly different from BPT 2841 (26.76 mgC3G/100g). The rice exhibited blackish dark purple colour as a result of high anthocyanin content. The lowest value of anthocyanin content was found in BPT 3145(19.21 mgC3G/100g) as shown in the Table 4.4. The obtained values of our study showed similarity with the findings of Sholikhah *et al*., 2021 with a range 5.95-21.12 mg/100g. Our results are lower than those reported by Saikia *et al*., (2012), Ponnappan *et al*., (2017b), Moirangthem *et al*., (2021) and Nath *et al.,* (2022) who obtained 35.87 mgC3G/100g, 244 mgC3G/100g, 172mgC3G/100g and 35.90 mgC3G/100g respectively.

Black rice aleuron and endosperm layers had relatively large quantities of anthocyanins that appears in blackish purple colour. The anthocyanin pigments in black rice have inhibitor compounds that can inhibit oxidation and act as antioxidants. The human health has enormous benefits by these compounds because black rice pigments contain much more active flavonoids compared with white rice (Sholikhah *et al*., 2021).

4.2.1.2 Total Phenol Content

The total phenol content (TPC) values ranged from 100.32 to 238.17 mgGAE/100g with a general mean 169.09 mgGAE/100g. The highest value was obtained for BPT 2841 (238.17 mgGAE/100g), followed by Burma black (218.89 mgGAE/100g), BPT 2848 (188.23 mgGAE/100g), BPT 3137 (150.23 mgGAE/100g) and BPT 3136 (118.69 mgGAE/100g). The lowest value was obtained for BPT 3145 (100.32 mgGAE/100g). These findings are in agreement with studies of Ziegler *et al.,* 2018 (231±0.9 mgGAE/100 g), Rao *et al*. 2020 (204.26-252.99 mgGAE/100g) and Arora *et al*. 2021 (148.65±1.09 mgGAE/100g).

The TPC differed significantly between the identical black rice samples. Therefore TPC seems to be a characteristic of pigmented rice samples specific to each cultivar rather than a general characteristic of rice colour (Sumczynski *et al*., 2016). The bound phenols were found more in rice when compared to free phenols (Acosta-Estrada *et al*., 2014). Phenolic compounds are products of the specialized metabolism of plants and their content may vary according to genotype (Ziegler *et al.,* 2018), as well as climate, storage and growing conditions; therefore, grain pericarp color may vary. In this context, our study highlights the black rice grains, as an excellent source of phenolic compounds for consumption, considering that they are consumed in the integral form.

4.2.1.3 Total Antioxidant Activity

The Table 4.4 displays the total antioxidant activity (DPPH scavenging actvity) of six black rice varieties. The maximum total antioxidant activity (TAA) was found in BPT 2841 (99.52 mgAAE/100g), followed by Burma Black (97.52 mgAAE/100g), BPT

2848 (96.42 mgAAE/100g), BPT 3137 (94.90 mgAAE/100g), BPT 3136 (92.53 mgAAE/100g) and lowest for BPT 3145 (87.81 mgAAE/100g) with general mean value of 94.78 mgAAE/100g. This was in agreement with the previous findings of Ponnappan *et al*., (2017b) (86.12±0.05 mgAAE/100g), Devi *et al*., 2019 (88.43 mgAAE/100g), Rao *et al*., 2020 (96.39 mgAAE/100g), Singh *et al*., 2020a (90.63 mgAAE/100g) and Moirangthem *et al*., 2021 (96.67±6.67 mgAAE/100g) respectively.

When compared to white rice, coloured rice has higher antioxidant activity. The values of TAA of coloured rice were influenced by presence of polyphenols and anthocyanin content. A positive correlation between the content of phenolic compounds (bound and free) and the antioxidant activity of wild rice was observed by Putri *et al*., 2022. Rice varieties, chemical modifications, and extracting solvent played an important role in antioxidant activity testing on varieties rice. Chemical modification treatment significantly decreased the antioxidant activity of rice.

4.2.1.4 Phytic acid

The data pertaining to the phytic acid content in selected rice was given in Table 4.4. The phytic acid (mg/100g) was found highest for Burma Black (410.36 mg/100g), followed by BPT 2848 (389.62 mg/100g), BPT 3136 (367.48 mg/100g), BPT 3145 (359.47 mg/100g) and BPT 2841 (352.69 mg/100g) and lowest for BPT 3137 (351.38 mg/100g). The phytic acid content ranged between 351.38 and 410.36 (mg/100g) with general mean value 371.83 mg/100g. Rao *et al*., 2020 obtained values of phytic acid as 413.45 mg/100g similar to present study result. Whereas Chanu *et al*., 2015 (0.23mg/100g) and Bagchi *et al*., 2021 (0.67-1.39mg/100g) reported values were lower than the present study result.

Phytic acid acts as strong chelating agent for various multivalent metal ions namely iron, zinc and calcium. The greater bran concentration was regarded as greater phytates content in black rice. The treatment soaking, germination significantly reduces the phytic acid in seeds (Kumar *et al.,* 2017a).

4.2.1.5 Oxalates

The oxalate content of different black rice varieties showed in Figure 4.4. The oxalate content ranged between 2.24 and 5.38 mg/100g with general mean value 3.57 mg/100g. Burma Black variety showed highest oxalate content (5.38 mg/100g), followed by BPT 2841 (4.03 mg/100g), BPT 2848 (4.00 mg/100g), BPT 3136 (3.11 mg/100g), BPT 3145 (2.67 mg/100g) and BPT 3137 (2.24 mg/100g). Wanyo *et al.*

(2020) studied on oxalate content of Thai rice varieties and reported 56.03±0.99mg/g which showed higher values of oxalates than present result.

An oxalate restriction is defined as a limit of dietary oxalate to no more than 40–50 mg/day (Massey 2007). Only less than 10% of ingested oxalate is absorbed. This may render dietary oxalate restrictions rather ineffective. Moreover, determining exact oxalate consumption is difficult as there are variations in food levels, the environment wherein the food is grown, and the levels also depend on evaluation and cooking methods (Wanyo *et al*., 2020)

4.2.2 ANOVA

The analysis of variance for biochemical quality profile is displayed in Table 4.5. It was discovered that the biochemical quality profile of all black rice varieties differ significantly.

Table 4.5 Analysis of variance for Biochemical quality profile

Source of Variation	Df	SS	MSS	F-Cl	F-tab	P-Value
Biochemical parameters	4	1576783.87	394195.97	3303.18	2.52	<0.05
Rice varieties	5	17006.55	3401.31	28.50	2.36	<0.05
Biochemical parameters* Rice varieties	20	36714.80	1835.74	15.38	1.74	<0.05
Error	60	7160.31	119.34			
Total	89	1637665.52				

4.2.3 Correlation

The correlation between biochemical qualities among all the varieties is presented in Table 4.6.

A positive significant correlation was observed between total anthocyanin content and total phenol content (r = 0.916); total phenol content and total antioxidant activity (r = 0.947); total antioxidant activity and total anthocyanin content (r = 0.849). The similar result was found by Singh *et al.,* (2020b). Ray *et al.,* (2021) discovered a positive correlation between TPC and TAA. Antioxidant activity is highly influenced by the presence of TPC and TAC.

Table 4.6 Correlation coefficients of biochemical quality profile

	TAC	TPC	TAA	Phytic acid	Oxalates
TAC	1.000**				
TPC	0.916*	1.000**			
TAA	0.849*	0.947**	1.000**		
Phytic acid	0.646	0.369	0.282	1.000**	
Oxalates	0.886*	0.766	0.635	0.816*	1.000**

* significant at 0.05% level, ** significant at 0.01% level.

TAC- Total Anthocyanin Content, TPC- Total Phenol Content, TAA- Total Antioxidant Activity.

4.3 Nutritional Traits

4.3.1 Proximate Composition

The proximate composition such as moisture, protein, fat, crude fiber, ash content, carbohydrate (CHO) and energy analyzed in six black rice varieties. The mean values of proximate composition of all black rice varieties are presented in Table 4.7.

4.3.1.1 Moisture

Moisture content is a critical aspect of cereal grains that can significantly alter the storage period. The moisture levels of all varieties varied between 9.30% and 12.22 % (Table 4.7). The highest level of moisture content has been recorded with Burma black (12.22 %), and the lowest was recorded with BPT 3145 (9.30%). The higher moisture content in Burma black might render it unsuitable for an extended storage period. The difference in moisture content might be due to paddy's inherent moisture content or post-harvest processing practices. The moisture content in this study falls within the range earlier mentioned by Nath *et al.* (2022) (11.00 %), Pakuwal and Manandhar (2021) (12.15±0.01 %) and Colasanto *et al*. (2021) (11.7±0.4 %).

4.3.1.2 Protein

The protein content present in the rice varieties is shown in Table 4.7. The protein content is an essential nutritional component in rice because it is taken as a staple food throughout the world. High protein content in rice helps to fulfill the protein deficiency often observed in economically weaker sections. On quality aspects, the rice protein is equivalent or better than the rest of the cereal grains, although significantly lower than the pulse and oilseed crops (Nath *et al.* 2022). Protein content varied significantly ($p<0.05$) among chosen varieties. The highest protein content among all selected rice varieties was found in Burma black (11.21%), followed by BPT 2841 (11.08%), BPT 2848 (11.07%), BPT 3137 (10.14%) and BPT 3136 (8.65%). The lowest protein content has been recorded with BPT 3145 (8.33%). The findings of the present study together with comparable earlier works strengthen the view that many black rice varieties are nutritionally very rich and some are even superior to improved varieties. In our study, the protein content has been varied from 11.21% to 8.33%, which is comparable to earlier reported values by Yenrina *et al.* (2019) (9.45±0.7%), Devi *et al.* (2019) (11.66%), Colasanto *et al.* (2021) (10.5±0.2%) and Farooq *et al.* (2021) (8.4±0.3%). Protein content is considered as index for nutritional quality of rice and protein content of 10% and above is considered as cultivar with high protein content (Dasgupta and Handique 2018).

Table 4.7 Mean values of proximate composition in black rice varieties

S.No	**Genotypes**	**Proximate composition (g%)**						
		Moisture	**Protein**	**Fat**	**Ash**	**Crude Fiber**	**CHO**	**Energy (Kcal)**
1.	Burma black	12.22	11.21	2.23	0.96	1.36	72.02	353
2.	BPT 2841	11.71	11.08	2.19	0.92	1.16	72.94	356
3.	BPT 2848	11.01	11.07	2.10	0.91	1.21	73.17	358
4.	BPT 3136	9.88	8.65	1.90	0.89	1.30	77.32	361
5.	BPT 3137	10.53	10.14	1.72	0.90	0.93	75.78	359
6.	BPT 3145	9.30	8.33	1.53	0.85	1.00	78.99	363
	Mean	10.78	10.08	1.95	0.91	1.16	75.14	358
	S.D	1.19	1.35	0.81	0.06	0.41	2.87	5.45
	CV	4.76	4.98	43.18	0.48	18.26	3.35	7.14
	CD	1.27	1.26	1.62	0.11	0.81	2.81	8.96
	S.E	0.58	0.57	0.51	0.05	0.37	1.30	4.13
	Lowest range	9.30	8.33	1.53	0.85	0.93	72.02	353
	Highest range	12.22	11.21	2.23	0.96	1.36	78.99	363

The variation in rice protein content in different rice accessions may be due to genetic makeup, agronomic management practices, and environmental factors. The genetic makeup of rice accessions concerning the difference in protein content is primarily due to loci expression related to seed storage protein biosynthesis (Colasanto *et al.,* 2021). The variation in protein content due to agronomic management practices is related to water management, proper balanced nutrient management, and sowing time (Nath *et al.,* 2022). Rice varieties with high concentration of proteins decrease the access of enzyme for starch hydrolysis (Rajenan and chanan 2020). Burma black has a high protein concentration and medium Glycemic index in the same variety

4.3.1.3 Fat

The fat content in rice is relatively low compared to other crops and generally varies from 1.72-3.37% in brown rice and 0.09-1.52% in milled rice (Nath *et al*., 2022). The fat content varied in the range of 1.53% in BPT 3145 to 2.23% in Burma black . The highest fat content has been recorded with Burma black (2.23%), followed by BPT 2841 (2.19%) and BPT 2848 (2.10%), while the lowest fat content has been recorded with BPT 3145 (1.53%). The fat content in this study falls within the range earlier mentioned by Sompong *et al*. (2011) (2.85±0.09%), Saikia *et al*. (2012) (2.1±0.08%), Yenrina *et al*. (2019) (2.19±0.30%) and Murali and Kumar (2020) (2.0±0.06%) for different geographical areas. Despite the lower quantity, fat content significantly influences the eating quality of rice (Verma and Srivastav *et al.,* 2017). The possible reason behind the difference in fat content among rice accessions may be due to milling practice and degree of removal of aleurone layer or may be due to the level of oxidation of unsaturated fatty acid (Verma and Srivastav *et al.,* 2017 and Nath *et al.,* 2022).

4.3.1.4 Ash

The ash content of a food sample gives an idea of the mineral elements present in the food sample. In this study, the ash content ranged between 0.85 to 0.96%. The highest ash content (%) has been observed with Burma black (0.96%) followed by BPT 2841 (0.92%), BPT 2848 (0.91%) and BPT 3137 (0.90%). Conversely, the lowest ash content has been recorded with BPT 3145 (0.85%) and BPT 3136 (0.89%). The obtained results were on par with findings of Pakuwal and Manamdhar (2021) (0.70±0.01%) and Bassuony (2016) (1.13%).The ash content generally indicates the total amounts of minerals present in the sample, and higher values indicate higher mineral contents (Dasgupta and Handique 2018). In general, the ash content in rice varies from 0.3- 0.8%, as reported by Verma and Srivastav *et al*. (2017).

4.3.1.5 Crude Fiber

The Crude fiber content of different black rice varieties also varied about 0.93% in BPT 3137 to 1.36 % in Burma black. The highest Crude fiber content among all selected varieties has been observed in Burma black (1.36%) followed by BPT 3136 (1.30%), BPT 2848 (1.21%) and BPT 2841 (1.16%). On the other hand, the lowest fiber content has been recorded in BPT 3137 (0.93%). The obtained results were on par with findings of Chanu *et al.* (2015) (0.55 – 1.64%), Dasgupta and Handique (2018) (0.42 – 1.43%), Ramelan *et al.* (2018) (0.08 – 1.13%), Singh and Devi 2020 (0.02 – 0.89%) and Nath *et al.* (2022) (0.50 – 0.94%) .The fiber fractions play many significant roles in the human body, including adding bulk to the food, lowering cholesterol levels, maintaining intestinal pH levels and reducing chances of colon cancer (Nath *et al.,* 2022).

4.3.1.6 Carbohydrates

Among all nutritional components, carbohydrate was the major fraction in terms of relative proportion. The range of variation for black rice genotypes was 72.02% (Burma black) to 78.99% (BPT 3145). The ideal carbohydrate content in rice to meet the calorific demand as a staple is 75% (Verma and Srivastav *et al.,* 2017). All our selected black rice varieties have been recorded carbohydrate content values nearer to the ideal range (Table 4.7). The findings of the present study are comparable to reports of earlier workers like Pakuwal and Manandhar., 2021 (73.2±0.01%), Ramelan *et al.,* 2018 (73.80%) and Sompong *et al.,* 2011 (75.71±0.37%).

4.3.1.7 Energy

The variation in nutritive values is reflected in the calorific values The highest net energy output has been recorded in BPT 3145 (363 kcal/100g), while the lowest food energy was recorded in Burma black (353 kcal/100g). Our results were on par with the results of Nath *et al*., 2022 (355 kcal/100g) and Sompong *et al*., 2011 (362.25±0.96 kcal/100g). Food energy indicates the amount of energy extracted from food due to cellular respiration (Nath *et al.,* 2022).

Among all the black rice genotypes, Burma black recorded the highest percent of moisture, protein, fat, ash, fiber and lowest percent of carbohydrates and energy, whereas BPT 3145 recorded lowest percent of moisture, protein, fat, ash, fiber and highest percent of carbohydrates and energy.

Table 4.8 Analysis of variance for proximate composition

Proximate composition						
Source of Variation	Df	S.S.	MSS	F-Cl	F-tab	P-value
Proximate composition	6	1876970.98	312828.50	8523.20	2.21	<0.05
Rice varieties	5	575.27	115.05	3.13	2.32	<0.05
Proximate composition * Rice varieties	30	1500.40	50.01	1.36	1.59	>0.05
Error	84	3083.07	36.70			
Total	125	1882129.71				

4.3.1.8 Analysis of Variance

The analysis of variance for proximate composition is displayed in Table 4.8. Significant difference was observed for proximate composition between the rice varieties.

4.3.2 Micronutrients

The iron and zinc content of black rice varieties were classified into three distinct groups as mentioned in the Table 4.9.

Table 4.9 Classification of micronutrient content

Micronutrients	**Grades**	**Content (mg/100g)**
Iron	Low	<1.0
	Moderate	1.0-2.0
	High	>2.0
Zinc	Low	<1.5
	Moderate	1.5-3.0
	High	>3.0

The results of mean values of iron (mg/100g) and zinc (mg/100g) content determined in the seeds of different rice genotypes were presented in Table 4.10. The mineral composition mostly affected by soil, growing environment and genetic variations (Meng *et al.,* 2005).

Table 4.10 Mean values of iron and zinc of black rice varieties

S.No	Minerals (mg%)		
	Genotypes	Iron	Zinc
1.	Burma Black	1.55	2.05
2.	BPT 2841	1.13	1.35
3.	BPT 2848	1.06	1.30
4.	BPT 3136	0.93	1.23
5.	BPT 3137	1.03	1.26
6.	BPT 3145	0.91	0.73
	Mean	1.10	1.32
	S.D	1.19	1.35
	CV	4.76	4.98
	CD	1.27	1.26
	S.E	0.58	0.57
	Lowest range	0.91	0.73
	Highest range	1.55	2.05

4.3.2.1 Iron mg/100g

In the present investigation it was observed that the mean iron content ranged between 0.91 to 1.55mg/100g with a general mean value of 1.10 mg/100g. The highest iron content recorded for Burma black (1.55 mg/100g) followed by BPT 2841 (1.13mg/100g), BPT 2848 (1.06mg/100g), BPT 3137 (1.03mg/100g) and BPT 3136 (0.93mg/100g) and the lowest mean value was recorded for 3145 (0.91mg/100g). The present study was in accordance to Devi *et al.* (2019) (1.07 mg/100g), Singh *et al.* (2020b) (1.45 mg/100g), Rao *et al.* (2020) (1.55 mg/100g) and Sridevi *et al.*, 2021 (0.84-1.23 mg/100g). Among all the varieties BPT 3145 and BPT 3136 were classified as low iron and remaining varieties under medium iron category.

4.3.2.1 Zinc mg/100g

The zinc content ranged between 0.73 to 2.05 mg/100g and the mean value was 1.32 mg/100g. The highest zinc content recorded for Burma black (2.05 mg/100g) followed by BPT 2841 (1.35 mg/100g), BPT 2848 (1.30 mg/100g), BPT 3137 (1.26 mg/100g) and BPT 3136 (1.23 mg/100g) and the lowest mean value was recorded for 3145 (0.73 mg/100g). Sridevi *et al.* (2021) (0.84-1.23 mg/100g), Singh *et al.* (2020) (2.78 mg/100g), Rao *et al.* (2020) (2.04 mg/100g) and Devi *et al.* (2019) (2.53

mg/100g) findings showed similarity with results of present study. Among all the varieties, Burma black was classified as medium zinc and remaining varieties under low zinc category.

4.3.3 ANOVA

The analysis of variance for micro nutrients is displayed in Table 4.11. It was found that $P<0.05$ for all the means which shows that there was a significant difference between the iron and zinc content of black rice genotypes.

Table 4.11 Analysis of variance for iron and zinc

Micro nutrients (Iron and Zinc)						
Source of Variation	Df	S.S.	MSS	F-Cl	F-tab	P-Value
Micronutrients	1	30098.20	30098.20	108214.61	3.25	<0.05
Rice varieties	5	166.32	33.26	119.59	2.47	<0.05
Micro nutrients * Rice varieties	5	1050.38	210.08	755.31	2.1	<0.05
Error	65	18.08	0.28			
Total	118	31332.98				

4.3.4 Correlation studies of Nutritional Traits

The relationship between nutritional traits such as proximate composition and micronutrients was analyzed by correlation coefficient and displayed in Table 4.12. A positive correlation was found between protein and fat ($r = 0.829$) similar with findings of Thongbam *et al.* (2012). Moisture and energy ($r = -0.991$) showed significant negative correlation similar to findings of Lahkar *et al.* (2020) and Verma and Srivastav *et al.* (2017).

A positive significant correlation was observed between iron and zinc ($r = 0.932$). The comparable results were noted for studies of Madhubabu *et al.* (2020), Shivakumar *et al.* (2018) and Verma and Srivastav *et al.* (2017). Iron ($r = 0.904$) and zinc ($r = 0.975$) with ash showed significant positive correlation. Selection for ash per cent will ultimately select for high iron and zinc.

Table: 4.12 Correlation coefficients of quality traits and nutritional traits

	H	M	HRR	KL	KB	L/B	TGW	AC	GC	ASV	KLAC	KBAC	KER	VER	WU	M	P	Fat	Ash	CF	CHO	E	Fe	Zn
H	1.000**																							
M	0.751	1.000**																						
HRR	0.861*	0.567	1.000**																					
KL	0.719	0.868*	0.627	1.000**																				
KB	0.766	0.982**	0.525	0.778	1.000**																			
L/B	-0.661	-0.858*	-0.368	-0.509	-0.936**	1.000**																		
TGW	0.748	0.981**	0.594	0.947**	0.932**	-0.747	1.000**																	
AC	-0.524	-0.809	-0.336	-0.413	-0.875*	0.960**	-0.681	1.000**																
GC	0.246	0.271	0.162	-0.211	0.409	-0.670	0.086	-0.761	1.000**															
ASV	0.491	0.712	0.330	0.278	0.796	-0.926**	0.564	-0.984**	0.854*	1.000**														
KLAC	0.578	0.558	0.589	0.895*	0.429	-0.093	0.706	0.029	-0.573	-0.162	1.000**													
KBAC	0.657	0.693	0.682	0.938**	0.566	-0.252	0.809	-0.170	-0.400	0.054	0.956**	1.000**												
KER	-0.391	-0.624	-0.195	-0.155	-0.725	0.898*	-0.460	0.957**	-0.881*	-0.986**	0.289	0.071	1.000**											
VER	-0.129	-0.207	-0.116	0.271	-0.328	0.588	-0.024	0.723	-0.985**	-0.822*	0.622	0.438	0.849*	1.000**										
WU	0.447	0.691	0.295	0.249	0.776	-0.914*	0.540	-0.982**	0.866*	0.997**	-0.194	0.015	-0.985**	-0.840*	1.000**									
M	-0.053	0.235	-0.074	-0.247	0.333	-0.575	0.058	-0.746	0.906*	0.816*	-0.630	-0.439	-0.789	-0.950**	0.844*	1.000**								
P	-0.246	-0.022	-0.277	-0.496	0.089	-0.381	-0.204	-0.549	0.835*	0.655	-0.811	-0.621	-0.682	-0.886*	0.676	0.934**	1.000**							
FAT	-0.324	0.105	-0.394	-0.318	0.197	-0.429	-0.045	-0.588	0.712	0.617	-0.659	-0.563	-0.605	-0.766	0.666	0.901*	0.829*	1.000**						
ASH	-0.032	0.408	-0.060	-0.036	0.467	-0.636	0.256	-0.813*	0.786	0.841*	-0.444	-0.236	-0.827*	-0.839*	0.867*	0.956**	0.852*	0.885*	1.000**					
CF	-0.157	0.422	-0.338	0.245	0.435	-0.450	0.384	-0.496	0.187	0.390	-0.027	-0.045	-0.386	-0.202	0.436	0.420	0.221	0.695	0.561	1.000**				
CHO	0.225	-0.094	0.288	0.390	-0.202	0.477	0.085	0.642	-0.844*	-0.718	0.749	0.574	0.733	0.891*	-0.748	-0.972**	-0.976**	-0.924**	-0.922**	-0.421	1.000**			
E	-0.040	-0.360	-0.004	0.117	-0.447	0.658	-0.190	0.821*	-0.896*	-0.875*	0.524	0.318	0.848*	0.933**	-0.899*	-0.991**	-0.896*	-0.875*	-0.978**	-0.455	0.946**	1.000**		
Fe	0.380	0.676	0.237	0.231	0.755	-0.893*	0.526	-0.978**	0.850*	0.990**	-0.217	-0.003	-0.968**	-0.837*	0.996**	0.867*	0.706	0.707	0.904*	0.478	-0.781	-0.921**	1.000**	
Zn	0.104	0.588	0.046	0.183	0.625	-0.731	0.458	-0.883*	0.707	0.877*	-0.241	-0.028	-0.865*	-0.747	0.896*	0.878*	0.729	0.804	0.975**	0.621	-0.821*	-0.929**	0.932**	1.000**

*Correlation is significant at 0.05% level, **Correlation is significant at 0.01% level.

H- Hulling per cent, M- Milling percent, HRR- Head Rice Recovery, KL- Kernel Length, KB- Kernel Breadth, L/B- Length/Breadth ratio, TGW- Thousand Grain Weight, AC-Amylose Content, GC- Gel Consistency, ASV- Alkali Spreading Value, KLAC- Kernel length after cooking, KLAB- Kernel breadth after cooking, KER- Kernel elongation ratio, VER- Volume expansion ratio, WU- Water uptake, M- Moisture, P- Protein, CF- Crude Fiber, CHO- Carbohydrates, E- Energy, Fe- Iron, Zn- Zinc.

Carbohydrate has positive significant relation with energy (r = 0.946). However, carbohydrates have a negative correlation with moisture (r = -0.972) and protein (r = -0.976) which showed similarity with the investigations of Thongbam *et al.* (2012) and Oko *et al.* (2012).

4.3.4.1 Correlation among Quality Traits and Nutritional Traits

The correlation coefficients between quality and nutritional traits are shown in Table 4.12. Positive correlations was found between thousand grain weight and kernel length (r = 0.947), kernel breadth (r = 0.932) and iron (r = 0.526). L/B ratio showed significant negative correlation with milling percent (r = -0.858), kernel breadth (r = -0.936) and iron (r = -0.893). The amylose was negative and significant with iron (r = -0.978) and zinc (r = - 0.883). Gel consistency showed significant positive correlation with iron (r = 0.850). Significant positive association was obtained between ASV with iron (r = 0.990) and zinc (r = 0.877), water uptake with iron (r = 0.996) and zinc (r = 0.896) and negative association between kernel elongation ratio with iron (r = -0.968) and zinc (r = -0.865), iron with volume expansion ratio (r = -0.849).

Gel consistency was significantly and positively correlated with iron (r = 0.850) contents in our experiments, which were relatively dissimilar from the results are shown by Zhang *et al*. (2011). The results with positive correlations between ASV with iron (r = 0.990) and zinc (r = 0.877) align with the results reported by Jiang *et al.* (2007), Thongbam *et al.* (2012) and Singh *et al.* (2020a).

The correlation of gel consistency was positively significant with moisture (r = 0.906), protein (r = 0.835), iron (r = 0.850) and negatively significant relation was noticed with carbohydrates (r = -0.844) and energy (r = -0.896). Kernel elongation ration showed negative association with ash (r = -0.827) and positive association with energy (r = 0.848). Alkali spreading value was positively significantly associated with moisture (r = 0.816), ash (r = 0.841) and negatively significantly associated with energy (r = -0.848). The significant positive association was between volume expansion ratio with carbohydrates (r = 0.891) and energy (r = 0.933), water uptake with moisture (r = 0.844), ash (r = 0.867) and energy (r = 0.899) and significant negative association was observed between volume expansion ratio with moisture (r= -0.950), protein (r= -0.844) and ash (r = -0.839). Carbohydrate had no significant association with amylose. Similar results were reported by Girma *et al.* (2016) and Singh *et al.* (2020a).

Table 4.13 Correlation coefficients of biochemical quality profile and nutritional traits

	TAC	TPC	TAA	PH	O	Moisture	Protein	Fat	Ash	CF	CHO	Energy	Iron	Zinc
TAC	1.000**													
TPC	0.916*	1.000**												
TAA	0.849*	0.947**	1.000**											
PH	0.646	0.369	0.282	1.000**										
O	0.886*	0.766	0.635	0.816*	1.000**									
Moisture	0.987**	0.962**	0.920**	0.535	0.833*	1.000**								
Protein	0.896*	0.940**	0.926**	0.452	0.691	0.934**	1.000**							
Fat	0.879*	0.896*	0.890*	0.579	0.874*	0.901*	0.829*	1.000**						
Ash	0.965**	0.851*	0.860*	0.651	0.834*	0.956**	0.852*	0.885*	1.000**					
CF	0.469	0.327	0.341	0.685	0.728	0.420	0.221	0.695	0.561	1.000**				
CHO	-0.949**	-0.957**	-0.936**	-0.564	-0.814*	-0.972**	-0.976**	-0.924**	-0.922**	-0.421	1.000**			
Energy	-0.995**	-0.917*	-0.875*	-0.597	-0.849*	-0.991**	-0.896*	-0.875*	-0.978**	-0.455	0.946**	1.000**		
Iron	0.932**	0.721	0.617	0.747	0.865*	0.867*	0.706	0.707	0.904*	0.478	-0.781	-0.921**	1.000**	
Zinc	0.917*	0.722	0.730	0.727	0.823*	0.878*	0.729	0.804	0.975**	0.621	-0.821*	-0.929**	0.932**	1.000**

*Correlation is significant at 0.05% level, **Correlation is significant at 0.01% level.

TAC- Total anthocyanin content, TPC- Total phenol content, TAA- Total antioxidant activity, PH-Phytic acid, O- Oxalates, CF- Crude fiber and CHO- Carbohydrates

4.3.4.2 Correlation among Biochemical Quality Profile and Nutritional Traits

The relationship between biochemical quality profile and nutritional traits was analyzed by correlation coefficient and displayed in Table 4.13. There is no significant correlation between phytic acid and protein showed similarities with the results of Liu., 2005. Phytic acid content depends on cultivators, genetic and environmental conditions. Iron (r=0.747) and Zinc (r=0.727) showed a positive correlation with phytic acid which showed similarity with the result of Liang *et al*., 2007.

A significant correlation was observed between total antioxidant activity and minerals (iron and zinc) (r = 0.932, r = 0.917) which were also stated in studies of Ngamdee *et al*., 2016 on glutinous black rice.

4.4 Glycemic Index

The glycemic index (GI) of black rice varieties was estimated using in vitro starch digestibility method given by Goni *et al.* (1996).

Table 4.14 Mean values of glycemic index

S.No	Name of the variety	GI value
1.	Burma Black	65.81
2.	BPT 2841	55.46
3.	BPT 2848	53.33
4.	BPT 3136	57.48
5.	BPT 3137	60.11
6.	BPT 3145	56.88
	Mean	58.17
	SD	5.01
	CV	4.62
	CD	2.89
	SE	1.33
	Highest mean	65.81
	Lowest mean	53.33

The range of glycemix index was 53.33 to 65.81 with a general mean of 57.68 for all the 6 black rice varieties as shown in Table 4.14. The highest mean value was observed in Burma Black (65.81), followed by BPT 3137 (60.11), BPT 3136 (57.48), BPT 3145 (56.88), BPT 2841 (55.46) and the least was recorded in BPT 2848 (53.33). Except BPT 2848, all varieties were categorized as medium GI (55.46-65.81) varieties and BPT 2848 was classified as low GI (53.33) variety. The low GI indexed food is ideal for Type II diabetic patients (Veni. 2019). Saragih *et. al.* (2019) observed the lowest GI in black adan rice among different pigmented and non pigmented rice varieties. Meera *et. al.* (2019) found GI in Black kavuni rice value as 56.27 (medium GI) whereas Karuppasamy and Latha. (2020) found it as 53.10 (low GI) and 55.50 (medium GI) in black kavuni and karungkuruvai traditional black rice varieties. The aforementioned findings were in agreement with present study result.

4.4.1 ANOVA

The analysis of variance for the glycemic index of all the varieties was given in Table 4.15. A significant ($p<0.05$) difference was observed for glycemic index among all the black rice varieties.

Table 4.15 ANOVA for glycemic index

Source of Variation	Df	S.S.	MSS	F-Cl	F-tab	P-value
Rice varieties	5	394.90	78.98	29.62	3.105	<0.05
Error	12	32.00	2.67			
Total	17	426.90				

Table: 4.16 Correlation coefficients of quality, nutritional traits and glycemic index

	H	M	HRR	KL	KB	L/B	TGW	AC	GC	ASV	M	P	Fat	Ash	CF	C	E	Iron	Zinc	GI
H	1.000**																			
M	0.751	1.000**																		
HRR	0.861*	0.567	1.000**																	
KL	0.719	0.868*	0.627	1.000**																
KB	0.766	0.982**	0.525	0.778	1.000**															
L/B	-0.661	-0.858*	-0.368	-0.509	-0.936**	1.000**														
TGW	0.748	0.981**	0.594	0.947**	0.932**	-0.747	1.000**													
AC	-0.524	-0.809	-0.336	-0.413	-0.875*	0.960**	-0.681	1.000**												
GC	0.246	0.271	0.162	-0.211	0.409	-0.670	0.086	-0.761	1.000**											
ASV	0.491	0.712	0.330	0.278	0.796	-0.926**	0.564	-0.984**	0.854*	1.000**										
M	-0.053	0.235	-0.074	-0.247	0.333	-0.575	0.058	-0.746	0.906*	0.816*	1.000**									
P	-0.246	-0.022	-0.277	-0.496	0.089	-0.381	-0.204	-0.549	0.835*	0.655	0.934**	1.000**								
Fat	-0.324	0.105	-0.394	-0.318	0.197	-0.429	-0.045	-0.588	0.712	0.617	0.901*	0.829*	1.000**							
Ash	-0.032	0.408	-0.060	-0.036	0.467	-0.636	0.256	-0.813*	0.786	0.841*	0.956**	0.852*	0.885*	1.000**						
CF	-0.157	0.422	-0.338	0.245	0.435	-0.450	0.384	-0.496	0.187	0.390	0.420	0.221	0.695	0.561	1.000**					
C	0.225	-0.094	0.288	0.390	-0.202	0.477	0.085	0.642	-0.844*	-0.718	-0.972**	-0.976**	-0.924**	-0.922**	-0.421	1.000**				
E	-0.040	-0.360	-0.004	0.117	-0.447	0.658	-0.190	0.821*	-0.896*	-0.875*	-0.991**	-0.896*	-0.875*	-0.978**	-0.455	0.946**	1.000**			
Iron	0.380	0.676	0.237	0.231	0.755	-0.893*	0.526	-0.978**	0.850*	0.990**	0.867*	0.706	0.707	0.904*	0.478	-0.781	-0.921**	1.000**		
Zinc	0.104	0.588	0.046	0.183	0.625	-0.731	0.458	-0.883*	0.707	0.877*	0.878*	0.729	0.804	0.975**	0.621	-0.821*	-0.929**	0.932**	1.000**	
GI	0.731	0.871*	0.795	0.764	0.822*	-0.686	0.854*	-0.732	0.341	0.684	0.308	0.046	0.060	0.444	0.171	-0.112	-0.420	0.649	0.586	1.000**

*Correlation is significant at 0.05% level, **Correlation is significant at 0.01% level.

H- Hulling per cent, M- Milling percent, HRR- Head Rice Recovery, KL- Kernel Length, KB- Kernel Breadth, L/B- Length/Breadth ratio, TGW- Thousand Grain Weight, AC-Amylose Content, GC- Gel Consistency, ASV- Alkali Spreading Value, M- Moisture, P- Protein, CF-Crude fiber, C- Carbohydrates, E- Energy and GI- Glycemic index

4.4.2 Correlation among Quality, Nutritional Traits and Glycemic Index

The correlation coefficients for the quality, nutritional traits and glycemic index are presented in Table 4.16. The GI showed significant positive correlation with milling (r = 0.871), kernel breadth (r = 0.822) and thousand grain weight (r = 0.854). From aforementioned data, thousand grain weight showed negative correlation with amylose and positive correlation with milling, kernel length and kernel breadth. The negative association thousand grain weight and amylose explains that low grain weight rice has high amylose content whereas high amylose content rice has low GI. Therefore, GI showed positive association with thousand grain weight and kernel breadth.

The findings of Prasad *et al.* (2017), Meera *et al.* (2019) and Sivakamasundari *et al.* (2020) studied on different factors that influenced the rate of rice starch hydrolysis and described the significant correlation between the quality, nutritional traits and glycemic index. The rice amylose content affects the glycemic index. A low GI value was observed in rice varieties with high amylose content (Mehta *et al.,* 2020). The glycemic index showed non-significant negative correlation with amylose which explains that high amylose content rice has low GI and vice versa. This is in agreement with Meera *et al.* (2019) who studies who studied glycemic index and glycemic load of indigenous pigmented rice cultivars.

A positive correlation was observed between glycemic index and iron content (r = 0.649) among the rice varieties. From the findings of Wahenbam *et al.* (2019), the iron and folic acid bio fortified rice engendered the right amount of bio-accessibility, bioavailability and a lower starch rate hydrolysis which reported low to intermediate range of GI values for the fortified rice. There is no significant association between the GI and other individual principal constituents such as protein, fat and carbohydrates, similar to Prasad *et al.* (2017).

Table 4.17 Glycemic index and amylose categorization of black rice varieties

Black rice varieties	**Glycemic index**	**Amylose content (g%)**
Burma black	Medium	Low
BPT 2841, BPT 3136, BPT 3137 and BPT 3145	Medium	Intermediate
BPT 2848	Low	Intermediate

From the data given in Table 4.17, Burma black, a low amylose content rice variety was categorized as medium GI variety. The intermediate amylose content rice varieties, BPT 2841, BPT 3136, BPT 3137 and BPT 3145 were categorized under medium GI varieties. BPT 2848, an intermediate amylose content rice variety was categorized as low GI variety. The low to medium GI and intermediate amylose content rice varieties provides well balanced healthy diet for consumers

4.5 Study of the Suitability of Black Rice for Product Development

The suitability of black rice for product development was evaluated for like payasam and vadiyalu (traditional foods), cake (baked product) and vermicelli (extruded product). The sensory attributes of rice-based developed products were evaluated by 25 semi-trained judges using a nine-point hedonic scale rating and proximate composition. The literature on suitability of black rice value added products were extremely limited/scarce.

4.5.1 Payasam (Kheer)

Payasam or kheer is a popular cereal based milk product which is made from cooked rice, milk and sugar much like a rice pudding. It is typically flavoured with cardamom, raisins, cashews, and almonds. The use of milk and cereals make it a wholesome, palatable and highly nutritious weaning food, breakfast, side dish or dessert.

4.5.1.1 Sensory Evaluation of Black Rice Payasam

The mean sensory score of payasam prepared by six black rice varieties were statistically analyzed and results are shown in Appendix-G and graphically illustrated in Figure 4.1.

The colour of the product kheer/payasam prepared from the black rice varieties retained the original pigmented colour which was an inherent quality of the grain characteristics blakish purple coloured as can be judged from Plate. The statistical difference ($p<0.05$) among the six rice varieties was significant for colour attribute (Appendix-H). The average scores for the colour and appearance of kheer were ranged from 8.04 to 8.28 (“like very much”) and 8.12 to 8.64 (“like very much”) respectively. The highest score for colour and appearance was found in BPT 2841 and BPT 2848 black rice payasam respectively The visual appearance and eatable quality are mostly judged by colour of the food. The colour of payasam prepared from different black rice varieties was blackish purple varied from dark to dull depending on the original natural pigmented colour (anthocyanin content) of rice which was an inherent quality of the grain. The colour of the black rice based product was opined to add novelty to the product which was distinct in having a black purple tinge which was preferred by the consumers.

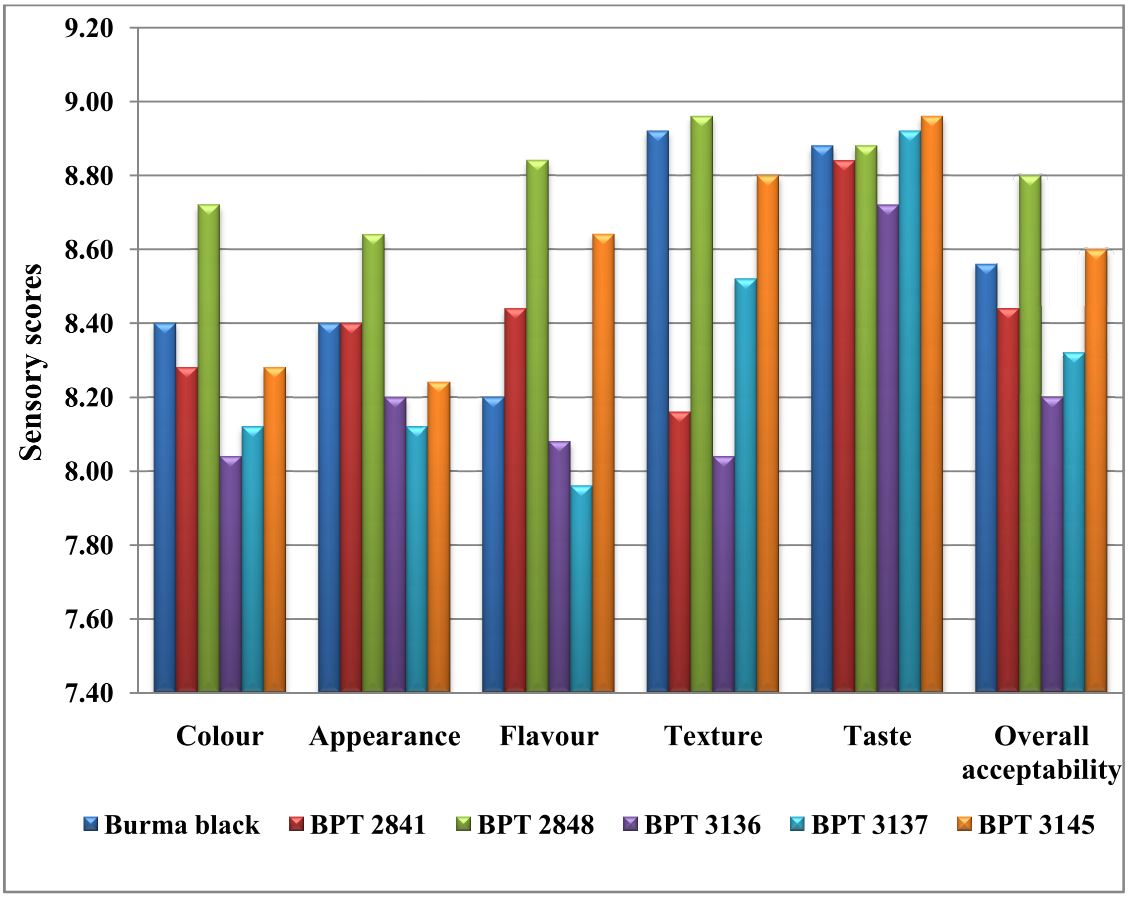


Figure 4.1 Sensory scores of black rice payasam

Scores:

Like extremely: 9
Like very much: 8
Like moderately: 7
Like slightly: 6
Neither like nor dislike: 5
Dislike slightly: 4
Dislike moderately: 3
Dislike very much: 2
Dislike extremely: 1

The results of flavour showed significant difference ($p<0.05$) among the rice varieties. The average flavour value of the kheer/payasam made from all rice varieties ranged from 7.96 to 8.84. The BPT 2848 (8.84) was scored highest for flavour, followed by BPT 3145 (8.64), BPT 2841 (8.44), Burma black (8.20) and BPT 3136(8.08) varieties. The lowest score was recorded for BPT 3137 (7.96).The flavour of the payasam prepared from the black rice varieties was found to be acceptable ("like moderately to like very much").

The black rice based payasam exhibited the characteristic nutty taste which is preferred by majority of panelists. On account of the sensory evaluation for the taste and texture parameter, black rice varieties based payasam were liked very much (sensory score of above 8). A significant difference was observed in texture attribute. The taste and texture scores of payasam ranged from 8.72-8.96 ("like very much") and 8.04-8.96 ("like very much"). The highest score for taste and texture was found in BPT 3145 and BPT 2848 black rice payasam respectively. The lowest score for taste and texture was found in BPT 3136.

The results of overall acceptability showed no significant difference among the rice varieties. Sensorial analysis showed that all samples were appreciated. The mean value of overall acceptability of payasam made from six black rice varieties ranged from 8.20 to 8.80. The mean values scored highest for BPT 2848 (8.80), followed by BPT 3145(8.60), Burma black (8.56), BPT 2841 (8.44), BPT 3137 (8.32) and BPT 3136 (8.20). A significant statistical difference was observed between the control and other black rice genotypes. The overall acceptability score for all the black rice varieties were above 8 ("like very much"). The obtained result was comparable with the range value 8.70 to 9.00 reported by Saravanan (2014) who studied on black, red and white rice payasam.

Among the payasam prepared from different black rice varieties, BPT 2848 scored highest in colour, flavour, texture and overall acceptability. All the kheers were accepted by the panellists, even control (Burma black) also exhibited similar trend.

4.5.1.2 Proximate Composition of Black Rice Payasam/Kheer

The mean scores of proximate composition of payasam prepared from six varieties of black rice were computed and are given in Table 4.18.

The moisture content of payasam revealed no significant difference among the rice varieties. The average moisture content in payasam was found to be 43.72%. Burma black had the highest mean value (44.63%), while BPT 3145 had the lowest mean value (42.46%). The observations reported for moisture content of kheer by Bhusnar *et al.* (2016) was in agreement with the value 50.56 to 53.16%, who prepared kheer with cow milk, sweet potato and white rice. Bhavika (2020) found the moisture content in instant black rice kheer as 6.5±0.04%. The disparity in values was caused primarily by two factors. The first is the type and quantity of wet and dry ingredients used in the product's preparation. Another advantage of black rice is its high water absorption capacity.

Table 4.18 Mean scores for proximate composition of payasam

S.No	Rice varieties	Proximate composition (g%)						
		Moisture	Protein	Fat	Ash	Crude fiber	CHO	Energy (kcal)
1.	Burma black	44.63	5.78	1.25	0.80	0.50	47.05	223
2.	BPT 2841	44.58	5.72	1.19	0.74	0.44	47.32	223
3.	BPT 2848	43.80	5.72	1.05	0.74	0.43	48.26	225
4.	BPT 3136	43.17	4.71	0.92	0.72	0.41	50.08	227
5.	BPT 3137	43.67	5.33	0.98	0.73	0.43	48.87	226
6.	BPT 3145	42.46	4.58	0.90	0.70	0.40	50.97	230
	Mean	43.72	5.30	1.05	0.74	0.43	48.76	226
	SD	1.20	0.52	0.14	0.12	0.12	1.75	4.67
	SE	0.88	0.14	0.04	0.11	0.11	0.96	3.7
	C.D.	1.92	0.31	0.10	0.25	0.25	2.09	8.02
	C.V.	2.69	0.59	0.35	2.71	4.58	2.87	9.09
	Lowest range	42.46	4.58	0.90	0.70	0.40	47.05	223
	Highest range	44.63	5.78	1.25	0.80	0.50	50.97	230

The protein content results revealed a significant difference ($p<0.05$) among the rice varieties. The protein content in 100g of cooked kheer was found to be 5.30%. Burma black had the highest mean value (5.78%), while BPT 3145 had the lowest mean value (4.58%). The obtained result values were lower than the value 8.54±0.11 to 13.49±0.24% and 13.54±0.36% reported by Chanu (2015) and Bhavika (2020). The protein content in black rice kheer depends on inherent protein content in black rice and quantity of milk used in preparation of kheer.

The fat content results revealed a significant difference ($p<0.05$) between the rice varieties. The average fat content in 100g of cooked kheer was found to be 1.05%. The highest value was recorded for Burma black (1.25%) and the lowest mean value was recorded for BPT 3145 (0.90%). The obtained result was lower than the mean value

5.11±0.26% reported by Bhavika (2020). The variation in fat values was observed due to type of milk (whole or skimmed milk) used in preparation of kheer.

The amount of ash in the food product is critical in determining the levels of essential minerals. The ash content result showed no significant difference between rice varieties. The ash content in 100g of cooked kheer was found to be 0.74%. Burma black had the highest mean value (0.80%), while BPT 3145 had the lowest mean value (0.70%). The obtained result showed close proximity with the values 1.51±0.17 to 1.58±0.01% and 1.84±0.05% reported by Chanu (2015) and Bhavika (2020) respectively.

The crude fibre content results revealed no significant differences between rice varieties. The fiber content in 100g of cooked kheer was found to be 0.43%. Burma black had the highest mean value (0.50%), while BPT 3145 had the lowest mean value (0.40%). The obtained result was lower than the value 1.51±0.18% reported by Bhavika (2020).

The result for carbohydrates content revealed a significant difference ($p<0.05$) among the rice varieties.The average carbohydrates content in 100g of cooked kheer was found to be 48.76%. The highest value was recorded for BPT 3145 (50.97%) and the lowest mean value was recorded for Burma black (47.05%). The obtained result was lower than the values 72.92±0.51 to 78.78±0.66% and 72.57±0.51% reported by Chanu (2015) and Bhavika (2020) respectively.

The energy results revealed no significant difference between the rice varieties. The average energy content of cooked kheer was found to be 226 kcal/100g. BPT 3145 had the highest mean value (230 kcal/100g), while Burma black had the lowest mean value (223 kcal/100g). The obtained result showed lower values than Bhavika (2020) who reported the value as 390 kcal/100g. The energy value of kheer was determined by the amount of carbohydrates and fat added to the product.

4.5.1.3 Analysis of variance

For six different black rice varieties payasam, an analysis of variance was performed for 13 parameters (sensory parameters and proximate composition), namely colour, appearance, flavour, taste, and texture; moisture, protein, fat, ash, fibre, carbohydrates, and energy. Table 4.19 shows the mean sum of squares. A significant difference was observed among sensory parameters. No significant difference was observed among the rice genotypes in proximate composition of payasam.

Table 4.19 Analysis of variance for sensory parameters and proximate composition of payasam

Sensory parameters						
Source of Variation	Df	S.S.	MSS	F-Cal	F-Tab	P-value
Sensory traits	5	6.734	1.347	24.244	3.123	<0.05
Rice genotypes	5	6.676	1.335	24.033	2.341	<0.05
Sensory traits * Rice genotypes	25	3.712	0.148	2.673	1.964	<0.05
Error	144	8.000	0.056			
Total	179	25.122				
Proximate composition						
Source of Variation	Df	S.S.	MSS	F-Cal	F-Tab	P-value
Proximate composition	6	721460.58	120243.43	35755.18	2.21	<0.05
Rice Genotypes	5	18.95	3.79	1.13	2.32	>0.05
Proximate composition * Rice genotypes	30	165.82	5.53	1.64	1.59	<0.05
Error	84	282.49	3.36			
Total	125	721927.83				

4.5.2 Cake

Cake is a type of soft bakery products produced mainly from flour, sugar, butter, egg, baking powder and other ingredients. Cake made from wheat flour has become popular in most tropical developing countries, particularly among children and adolescents. Bakery products are sometimes used as a vehicle for the incorporation of various nutritionally rich ingredients.

The flour mixture of black rice and wheat flour was prepared in ratios of 100:0(control), 90:10(T1), 80:20(T2), 70:30(T3) and 60:40(T4). Panelists accepted cake made with 60% black rice and 40% wheat flour (T4) as the control, while T1, T2, and T3 were rejected. As a result, the T4 formulation was used for further cake preparation using selected black rice genotypes. The hedonic test was used to determine the degree of overall preference for baked black rice cakes.

4.5.2.1 Sensory evaluation of black rice cakes

The sensory score obtained for cake prepared by six black rice varieties was statistically analyzed and results are shown in Appendix-I and graphically illustrated in Figure 4.2.

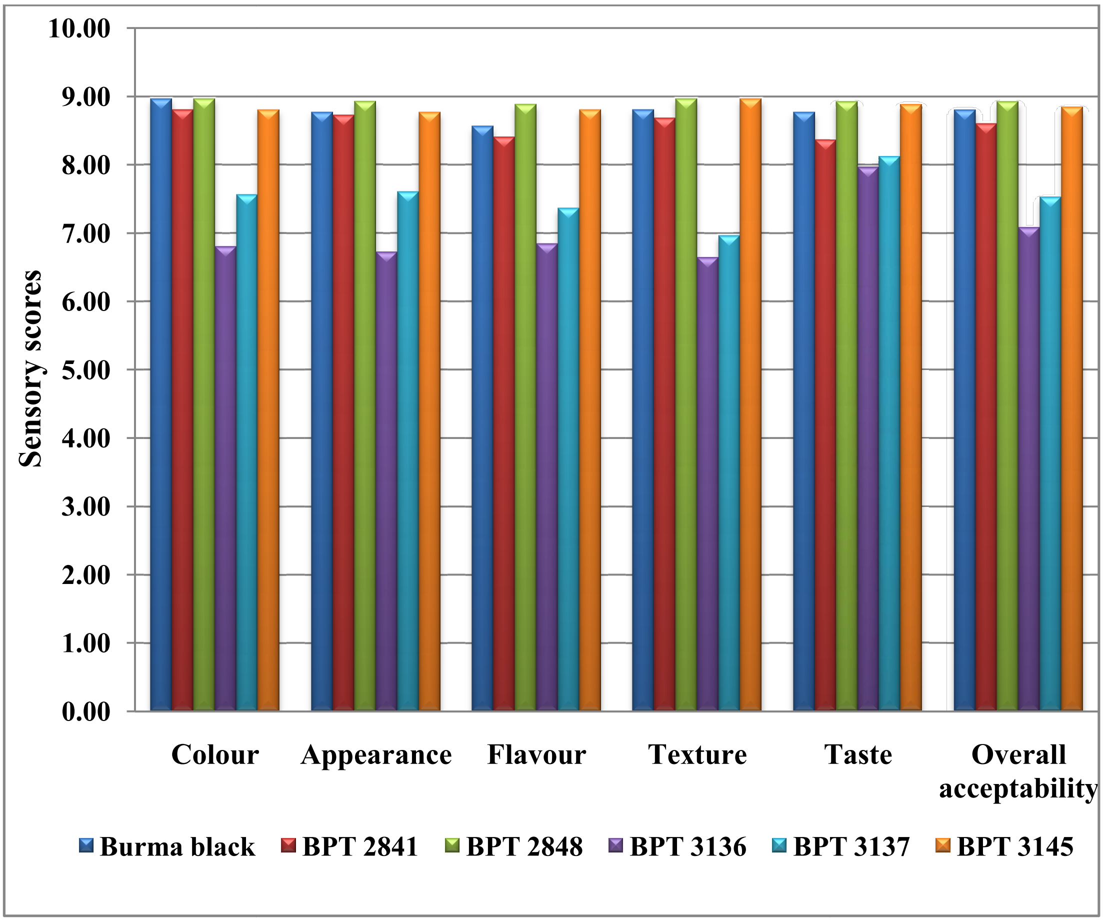


Figure 4.2 Sensory scores of black rice cakes

The result obtained for appearance, colour, flavour, texture, taste and overall acceptability indicated significant difference ($p<0.05$) among the rice varieties (Appendix-J). The mean value for colour was scored highest for Burma black (8.96) and BPT 2848 (8.96) followed by BPT 2841 and BPT 3145 cake varieties. The lowest score was recorded by BPT 3136 (6.80). It was observed that baked cakes fortified with black rice powder were darker than wheat flour cakes. The colour change of baked cakes could be due to the oxidation of black rice pigments and polyphenol compounds (Lee *et al.,* 2008 and Mau *et al.,* 2017).

In sensory evaluation, the highest score for appearance attribute was obtained for BPT 2848 (8.92), followed by Burma black (8.76) and BPT 3145 (8.76) in sensory evaluation. The lowest score was recorded for BPT 3136 (6.72). The cake volume of baked cakes decreased significantly as the black rice powder level increased. The baked cakes with more black rice powder had a lower ability to retain air, resulting in an undesirable aerated structure with a lower volume. The baked cake's final cake volume was determined not only by the initial air incorporated into the cake batter, but also by its ability to retain air during baking (Mau *et al.,* 2017). Cake expansion was greatly dependent on starch gelatinization temperature, obtaining better dough expansion at high gelatinization temperatures (Lee *et al.,* 2008).

In terms of flavour, BPT 2848 (8.88) received the highest score and BPT 3136 (6.84) received the lowest score. For texture, BPT 2848 (8.96) and BPT 3145 (8.96) scored highest compared to control (Burma black) (8.80) and lowest was recorded in BPT 3136 (6.64). Some panelists even perceived that cakes with black rice flour contain pleasant crispy particles. Mau *et al.* (2017) found that increased cake cohesiveness makes baked cakes harder with the increased levels of black rice powder. Cake cohesiveness was used to express the internal resistance of cake structure.

The highest score for taste was observed in BPT 2848 followed by BPT 3145 (8.88) and Burma black (8.76). The lowest score was recorded for BPT 3136 (7.96). The overall acceptability was scored highest for BPT 2848 (8.92), followed by BPT 3145 (8.84) and the lowest for BPT 3136 (7.08). A significant statistical difference was observed between the control and other black rice genotypes. The overall acceptability scores for Burma black (control), BPT 2841, BPT 2848 and BPT 3145 black rice cakes were above 8 (“like very much”) whereas BPT 3136 and BPT 3137 scored between 7 to 8 (“like moderately”). The obtained result was higher than the range value 5.1 to 5.8 reported by Mau *et al.* (2017).

Among the cakes prepared from different black rice varieties, BPT 2848 scored highest in colour, appearance, flavour, texture, taste and overall acceptability. All the cakes were accepted by the panelists, even control (Burma black) also exhibited similar trend.

4.5.2.2 Proximate Composition of Black Rice Cakes

The mean scores of proximate composition of cake from six varieties of black rice were computed and are given in Table 4.20.

The moisture content revealed no significant differences between the rice varieties. The average moisture content in cake was found to be 20.29%. The highest moisture content was observed in Burma black (20.63%), followed by BPT 2841

(20.61), BPT 2848 (20.32), BPT 3137 (20.27), BPT 3136 (20.09) and BPT 3145 (19.83) respectively. The obtained result showed similarity with the range value from 16.00% to 20.00%, reported by Lee *et al.* (2008).

Table 4.20 Mean scores for proximate composition of cakes

S.No	Rice varieties	Proximate composition (g%)						
		Moisture	Protein	Fat	Ash	Crude fiber	CHO	Energy (kcal)
1.	Burma black	20.63	7.32	8.86	0.50	0.36	62.32	358
2.	BPT 2841	20.61	6.30	8.83	0.45	0.22	63.60	359
3.	BPT 2848	20.32	7.30	8.77	0.44	0.27	62.90	360
4.	BPT 3136	20.09	6.93	8.73	0.44	0.33	63.49	360
5.	BPT 3137	20.27	6.16	8.75	0.44	0.23	64.15	360
6.	BPT 3145	19.83	6.88	8.72	0.43	0.28	63.86	361
	Mean	20.29	6.81	8.78	0.45	0.28	63.39	360
	SD	1.35	0.47	0.14	0.11	0.05	1.54	5.30
	SE	1.29	0.11	0.12	0.10	0.01	1.36	5.06
	C.D.	2.80	0.24	0.28	0.23	0.03	2.95	10.99
	C.V.	12.32	0.27	0.28	3.77	0.12	4.39	10.70
	Lowest range	19.83	6.16	8.72	0.43	0.23	62.32	358
	Highest range	20.63	7.32	8.86	0.50	0.36	64.15	361

The protein content results revealed a significant difference ($p<0.05$) among the rice varieties. The protein content in cake was found to be 6.81% on average. Burma black had the highest mean value (7.32%), while BPT 3137 had the lowest mean value (6.16%). The obtained results showed close proximity to the value 7.13% reported by Fiqri and Anggraeni (2019).

The average fat content in cake was found to be 8.78%. Burma black had the highest mean value (8.86%), while BPT 3145 had the lowest (8.72%). The obtained result was lower than the value 28.68% reported by Fiqri and Anggraeni (2019). The fat content depends on the quantity of emulsifying agents (oil or butter or milk or eggs) added to the cake.

The ash content result revealed no significant difference among the rice varieties. The average ash content in cake was found to be 0.45%. Burma black had the highest mean value (0.50%), while BPT 3145 had the lowest mean value (0.43%). The obtained results were very close to the value 0.98% reported by Fiqri and Anggraeni (2019).

The fiber content revealed a significant difference between rice varieties. The avaerage fiber in cake was found to be 0.28%. The highest value was recorded for Burma black (0.36%) and the lowest mean value was recorded for BPT 3137 (0.23%). Fibers increased the hardness and cohesiveness, and also lowered the resilience in cakes (Lee *et al.,* 2008).

The average carbohydrate content of cake was found to be 63.39%. BPT 3137 had the highest mean value (64.15%), while Burma black had the lowest mean value (62.32%). The obtained result exceeded the value 50.09% reported by Fiqri and Anggraeni (2019). The carbohydrate content results revealed no significant differences between rice varieties.

The energy results revealed no significant differences among the rice varieties. The average energy of cake was found to be 360kcal/100g with a range 358 to 361kcal/100g. The highest value was recorded for BPT 3145 (361 kcal/100g), followed by BPT 2848, BPT 3136 and BPT 3137 with common value 360 kcal/100g. The obtained result was lower than the value 487 kcal/100g reported by Fiqri and Anggraeni (2019). The quantity of ingredients used in cake preparation had a direct impact on the total calorie value.

4.4.2.3 Analysis of variance

For six different black rice varieties cakes, an analysis of variance was performed for 13 parameters (sensory parameters and proximate composition), namely colour, appearance, flavour, taste, and texture; moisture, protein, fat, ash, fibre, carbohydrates, and energy. The mean sum of squares is given in Table 4.21. A significant difference was observed among sensory parameters. A non significant difference was observed among the rice varieties in proximate composition of black rice cakes.

Table 4.21 Analysis of variance for sensory parameters and proximate composition of cakes

Sensory parameters						
Source of Variation	**Df**	**S.S.**	**MSS**	**F-Cal**	**F-Tab**	**P-value**
Sensory attributes	5	2.428	0.486	6.830	3.123	<0.05
Rice genotypes	5	97.922	19.584	275.405	2.341	<0.05
Sensory attributes * Rice genotypes	25	8.542	0.342	4.805	1.964	<0.05
Error	144	10.240	0.071			
Total	179	119.132				
Proximate composition						
Source of Variation	**Df**	**S.S.**	**MSS**	**F-Cal**	**F-Tab**	**P-value**
Proximate composition	6	1867760.72	311293.45	50070.35	2.21	<0.05
Rice genotypes	5	3.01	0.60	0.10	2.32	>0.05
Proximate composition * Rice genotypes	30	29.46	0.98	0.16	1.59	>0.05
Error	84	522.24	6.22			
Total	125	1868315.42				

4.5.3 Vadiyalu (Fryums)

"Fryums" are cereal-based ready-to-fry snacks that are popular in many Indian households. They puff up instantly when deep fried. They can be eaten as a snack or as a meal accompaniment. White rice flour is a key ingredient in one of the most popular fryums recipes in South Indian households. This was chosen as the base recipe, and it was replaced in varying proportions by different black rice genotypes.

The flour mixture of black rice flour and sago powder was prepared in ratios of 100:0(control), 90:10(T1), 80:20(T2), 70:30(T3) and 60:40(T4). Fryums prepared with 80% black rice and 20% sago powder (T2) was accepted by panelist as control, while T1, T3 and T4 were rejected. As a result, the T2 formulation was used to prepare vadiyalu using selected black rice genotypes.

4.5.3.1 Sensory evaluation of black rice vadiyalu

The mean scores of sensory qualities of Vadiyalu (Fryums) from six varieties of black rice were computed and are given in Appendix-K and illustrated in Figure 4.3.

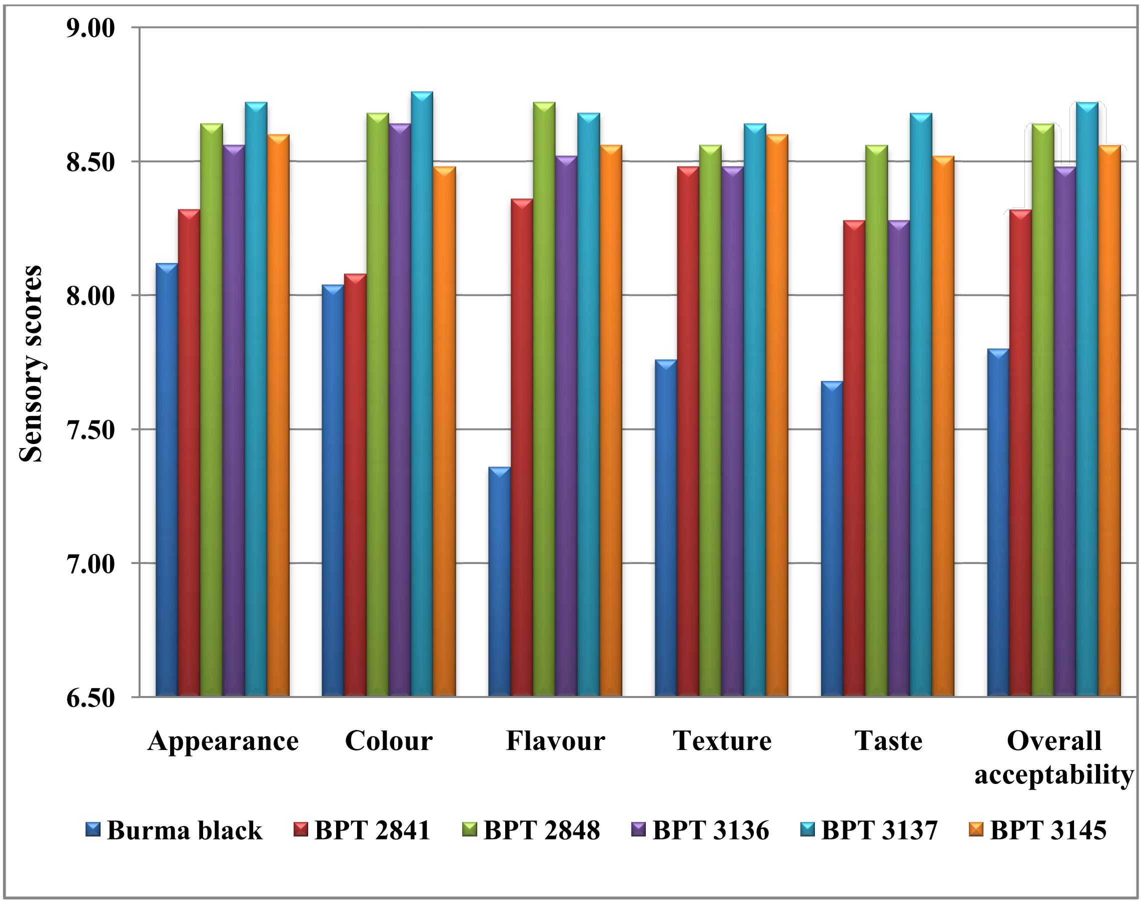


Figure 4.3 Sensory scores of black rice vadiyalu

The result obtained for appearance, colour, flavour, texture, taste and overall acceptability indicated significant difference ($p<0.05$) among the rice varieties (Appendix-L). The mean value for colour was scored highest for BPT 3137 (8.72) followed by BPT 2848 (8.64) and BPT 3145 (8.60) black rice fryums. The lowest score was recorded by Burma black (8.12). After frying, the colour of control (Burma black) was in dark purple and BPT 2841 was in blackish purple and the remaining were in hue of blackish brown. The highest score for appearance attribute was obtained for BPT 3137 (8.76), followed by BPT 2848 (8.68) and BPT 3136 (8.64) in sensory evaluation. The lowest score was recorded for Burma black (8.04). This result showed similarity with the range value 7.65-8.39 reported by Mangalemia *et. al.* (2019).

Regarding flavour, BPT 2848 (8.72) scored highest value and Burma black (7.36) scored lowest value. The highest score for taste was observed in BPT 3137 (8.68) followed by BPT 2848 (8.56) and BPT 3145 (8.52). The lowest score was recorded for Burma black (7.68). Similar observations were reported by Mangalemia *et. al.* (2019).

For texture, BPT 3137 (8.64) scored highest compared to control (Burma black) (7.76) which scored lowest value. It was perceived that fryums with black rice flour were crispy and crunchy.

The overall acceptability was scored highest for BPT 3137 (8.72), followed by BPT 2848 (8.64) and the lowest for Burma black (7.80). The overall acceptability scores for BPT 2841, BPT 2848, BPT 3136, BPT 3137 and BPT 3145 black rice cakes were above 8 ("like very much") whereas Burma black (control) scored 7.80 value between 7 to 8 ("like moderately"). The obtained result showed similarity with the range value 7.41 to 8.73 reported by Mangalemia *et. al.* (2019).

Among the vadiyalu (fryums) prepared from different black rice varieties, BPT 2848 and BPT 3137 scored highest in appearance, colour, flavour, texture, taste and overall acceptability.

4.5.3.2 Proximate composition of black rice vadiyalu

The mean scores of proximate composition of vadiyalu from six varieties of black rice were computed and are given in Table 4.22.

Table 4.22 Mean scores for proximate composition of vadiyalu

S.No	Rice varieties	Proximate composition (g%)						
		Moisture	Protein	Fat	Ash	Crude fiber	CHO	Energy (kcal)
1.	Burma black	5.74	9.21	2.70	3.40	2.90	76.05	365
2.	BPT 2841	5.67	9.12	2.63	3.30	2.84	76.45	366
3.	BPT 2848	5.41	9.11	2.39	3.32	2.05	77.71	369
4.	BPT 3136	4.19	7.35	2.16	3.28	2.36	80.66	371
5.	BPT 3137	5.07	8.43	2.27	3.02	1.99	79.21	371
6.	BPT 3145	4.09	7.12	2.13	3.12	2.12	81.43	373
	Mean	5.03	8.39	2.38	3.24	2.38	78.58	369
	SD	0.69	0.88	0.24	0.20	0.38	2.12	3.18
	SE	0.08	0.13	0.10	0.14	0.07	0.39	1.02
	C.D.	0.19	0.29	0.21	0.30	0.16	0.86	2.22
	C.V.	0.23	0.32	0.62	1.00	0.35	0.30	0.42
	Lowest range	4.09	7.35	2.13	3.02	1.99	76.05	365
	Highest range	5.74	9.21	2.70	3.40	2.90	81.43	373

The result obtained for moisture, protein, fat, fiber, carbohydrate and energy indicated significant difference ($p<0.05$) among the rice varieties. The average moisture content of fryums was found to be 5.03%. Burma black had the highest mean value (5.74%), while BPT 3145 had the lowest mean value (4.09%). The obtained result agreed with the value 4.02-5.02% in papad, reported by Mangaleima *et. al* (2019). The moisture content of the food is extremely important in extending the shelf life of the fryums.

The protein content in fryums was found to be 8.39% on average. Burma black had the highest mean value (9.21%) and BPT 3145 had the lowest mean value (7.12%). The result was observed to be on par with the value 8.71% reported by Kanabur and Kamath. (2020).

The average fat content in fryums was found to be 2.38%. Burma black had the highest mean value (2.70%), while BPT 3145 had the lowest mean value (2.13%). The obtained result showed similarity with the value 1.53-2.53% reported by Mangaleima *et. al.* (2019).

The ash content in fryums was found to be 3.24% on average. Burma black had the highest mean value (3.40%), while BPT 3137 had the lowest mean value (3.02%).

The fiber content in fryums was found to be 2.38% on average. The highest value was recorded for Burma black (2.90%) and the lowest mean value was recorded for BPT 3137 (1.99%). The obtained result was found to be higher than the value 0.3% reported by Kanabur and Kamath. (2020).

The average carbohydrates content in fryums was found to be 78.58%. BPT 3145 had the highest mean value (81.43%), while Burma black had the lowest mean value (76.05%). The obtained result showed comparision with the values 83.38 to 83.91% and 72.25% reported by Mangaleima *et. al.* (2019) and Kanabur and Kamath (2020) respectively.

The average energy content in fryums was found to be 369kcal/100g. The highest value was recorded for BPT 3145 (373 kcal/100g) and the lowest value was recorded for Burma black (365 kcal/100g). The obtained result was found proximate with range value 379 to 392 kcal/100g reported by Mangaleima *et. al.* (2019) and greater than the value 291kcal/100g reported by Kanabur and Kamath (2020).

4.4.3.3 Analysis of variance

For six different black rice varieties fryums, an analysis of variance was performed for 13 parameters (sensory parameters and proximate composition), namely colour, appearance, flavour, taste, and texture; moisture, protein, fat, ash, fibre, carbohydrates, and energy. The mean sum of squares are given in Table 4.23. A significant variance was observed in sensory parameters and proximate composition of six black rice vadiaylu.

Table 4.23 Analysis of variance for sensory parameters and proximate composition of vadiyalu

Sensory parameters						
Source of Variation	**Df**	**S.S**	**MSS**	**F-Cal**	**F-tab**	**P-value**
Sensory traits	5	2.858	0.572	9.268	3.123	<0.05
Rice varieties	5	16.767	3.353	54.380	2.341	<0.05
Sensory traits * Rice varieties	25	10.588	0.424	6.868	1.964	<0.05
Error	144	8.880	0.062			
Total	179	39.092				
Proximate composition						
Source of Variation	**Df**	**S.S**	**MSS**	**F-Cal**	**F-tab**	**P-value**
Proximate composition	6	2022974.59	337162.43	2177069.65	2.21	<0.05
Rice varieties	5	27.66	5.53	35.72	2.32	<0.05
Proximate composition * Rice varieties	30	261.82	8.73	56.35	1.59	<0.05
Error	84	13.01	0.15			
Total	125	2023277.08				

4.5.4 Vermicelli

Rice vermicelli is a thin type of noodle that is one of the most important dehydrated extruded products made from rice flour. It is also known as 'rice noodles' or 'rice sticks.' Vermicelli/Noodles are one of the most popular foods consumed worldwide and are made from simple ingredients such as wheat flour, water, and salt. Consumers prefer vermicelli/noodles for their ease of cooking, handling, transportation, and low cost. Noodles, on the other hand, frequently lack other essential nutritional components such as protein, dietary fibre, and vitamins, which are lost during the wheat refinement process. Secondary features such as functional and nutritional aspects of products are now being considered by consumers.

The flour mixture was prepared in the following ratios: 100:0:0 (control), 90:10:0 (T1), 80:10:10 (T2), 70:20:10 (T3), and 60:30:10 (T3) (T4). Panelists accepted vermicelli prepared with 60% black rice flour, 30% wheat flour (T4), and 10% corn starch as the control, while T1, T2, and T3 were rejected. As a result, the T4 formulation was used to prepare vermicelli using selected black rice genotypes.

4.5.4.1 Sensory Evaluation of Black Rice Vermicelli

Sensory evaluation plays critical role in improvement, development and acceptance of new food products. Appendix-M and Figure 4.4 shows the organoleptic properties of vermicelli from six varieties of black rice.

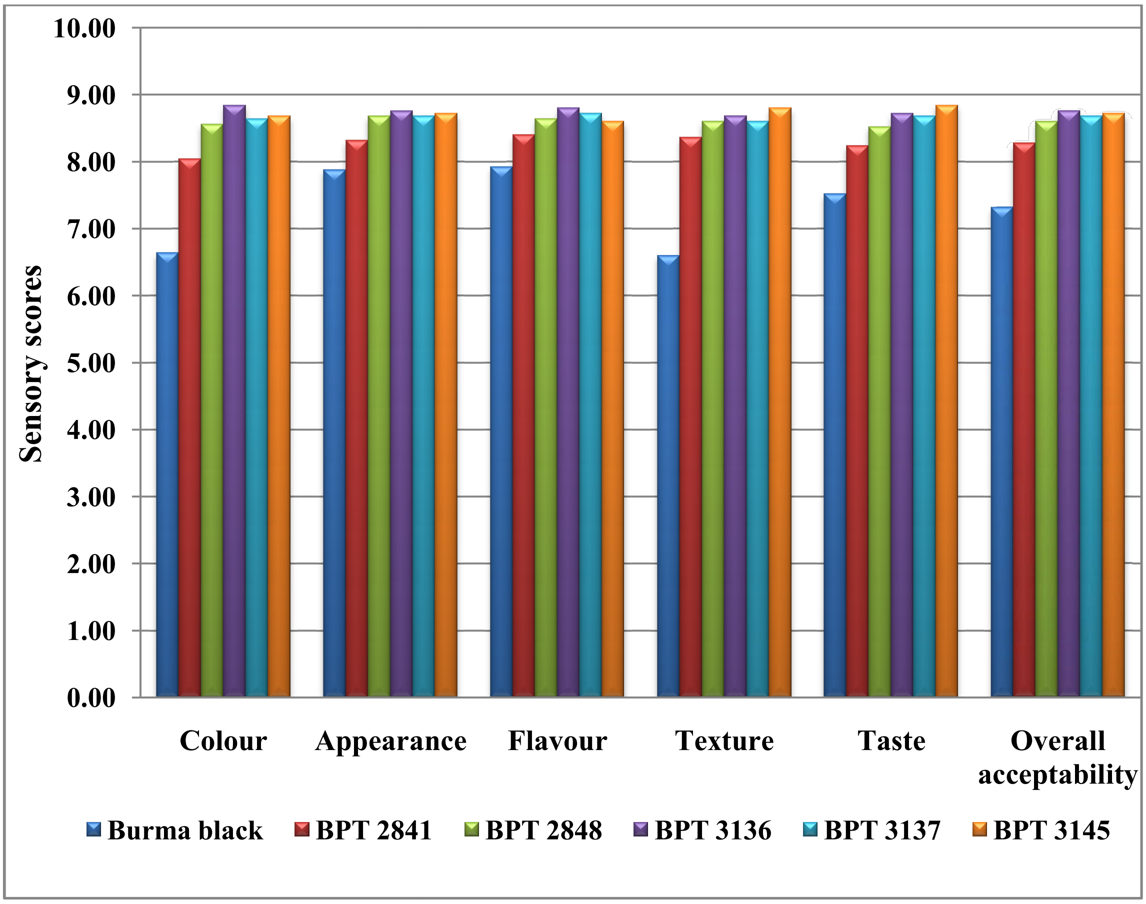


Figure 4.4 Sensory scores of black rice vermicelli

The statistical difference ($p<0.05$) among the six rice varieties was significant for colour, appearance, flavour, texture, taste and overall acceptability attributes (Appendix-N). The colour of vermicelli prepared from different black rice varieties was found in hues of purple and brown depending on the anthocyanin content present in rice grain. The average scores for the colour and appearance of vermicelli were ranged from 7.88 to 8.76 ("like moderately to like very much") and 6.64 to 8.84 ("like slightly to like very much") respectively. The highest scores in colour and appearance were observed in BPT 3136 and the lowest values were recorded in Burma black. The elasticity and visco-elastic structure of the dough were improved by increasing the concentration of smaller granule starches, and it was also hypothesised that these variations resulted from the interaction between protein and starch. The characteristics of rice flour are impacted by the significant amounts of protein and fats present. It prevents retrogradation and restricts starch granule expansion during gelatinization (Ahmed *et al.,* 2016).

The mean value for flavour of the vermicelli prepared from all rice varieties ranged from 7.92 to 8.80. The BPT 3136 (8.80) was scored highest for flavour, followed by BPT 3137 (8.72), BPT 2848 (8.64), BPT 3145 (8.60) and BPT 2841 (8.40) varieties. The lowest score was recorded for Burma black (7.92). The flavour of the payasam prepared from the black rice varieties was found to be acceptable ("like very much").

On account of the sensory evaluation for the taste and texture parameter, black rice varieties based vermicelli were acceptable (sensory score of above 6). The taste and texture scores of payasam ranged from 7.52 to 8.84 ("like moderately to like very much") and 6.60 to 8.80 ("like slightly to like very much"). The highest scores for taste and texture were found in BPT 3145 black rice vermicelli. The lowest scores for taste and texture were found in Burma black. Rice flour provides smooth and creamy texture to vermicelli, which gives a clean taste .The texture of black rice vermicelli was less cohesive and extensive due to low amount of gluten. The textural, cooking and sensory properties depend upon the pasting and physicochemical attributes of rice flour obtained from different rice genotypes (Ahmed *et al.,* 2016).

The mean value of overall acceptability of payasam made from six black rice varieties ranged from 7.32 to 8.76. The mean values scored highest for BPT 3136 (8.76), followed by BPT 3145 (8.72), BPT 3137 (8.68), BPT 2848 (8.60), BPT 2841 (8.28) and Burma black (7.32). Starch is the main component of rice flour and has significant impact on the overall quality of vermicelli. A significant statistical difference was observed between the control and other black rice genotypes. The overall acceptability scores of all the black rice varieties were above 8 (“like very much”) except the control (7.32). The obtained result showed close proximity with the value 8.9 reported by Saravanan (2014).

Among the vermicelli prepared from different black rice varieties, BPT 3136 scored highest in colour, appearance, flavour and overall acceptability whereas BPT 3145 scored highest in taste and texture attributes. The vermicelli made from control showed least acceptable scores because it has low amylose content which gives sticky nature to the cooked product.

4.5.4.2 Proximate Composition of Black Rice Vermicelli

A food sample is analysed proximally to determine its nutritional profile as well as its amount by weight in the sample. The analysis is critical in understanding the nutritional benefit of that particular product in the diet. The mean scores of proximate composition of vermicelli from six black rice varieties are given in Table 4.24.

Table 4.24 Mean scores for proximate composition of vermicelli

S.No	Rice varieties	Proximate composition (g%)						
		Moisture	**Protein**	**Fat**	**Ash**	**Crude fiber**	**CHO**	**Energy (kcal)**
1.	Burma black	9.06	7.16	1.41	0.58	0.97	80.81	365
2.	BPT 2841	9.02	7.11	1.37	0.54	0.55	81.42	366
3.	BPT 2848	8.22	7.10	1.23	0.53	0.68	82.24	368
4.	BPT 3136	7.56	6.06	1.09	0.51	0.86	83.92	370
5.	BPT 3137	8.08	6.70	1.15	0.52	0.58	82.96	369
6.	BPT 3145	6.84	5.93	1.07	0.49	0.72	84.96	373
	Mean	8.13	6.68	1.22	0.53	0.73	82.72	369
	SD	1.16	0.63	0.17	0.08	0.18	1.67	4.33
	SE	0.81	0.34	0.10	0.07	0.09	0.80	3.23
	C.D.	1.77	0.74	0.22	0.16	0.20	1.73	7.01
	C.V.	12.29	2.67	1.37	1.58	1.84	1.16	4.24
	Lowest range	6.84	5.93	1.07	0.49	0.55	80.81	365
	Highest range	9.06	7.16	1.41	0.58	0.97	84.96	373

The moisture content results showed no significant difference among the rice varieties. The average moisture in vermicelli was found to be 8.13%. Burma black had the highest mean value (9.06%) and BPT 3145 had the lowest mean value (6.84%). The obtained result was comparable to the value of 6.90 to 7.21% reported by Ronge *et. al.* (2017).

The protein content results revealed a significant difference among the rice varieties. The average protein in vermicelli was found to be 6.68%. The highest value was recorded for Burma black (7.16%) and the lowest mean value was recorded for BPT 3145 (5.93%). According to the findings of and Kong *et. al.* (2012) and Bedier *et. al*. (2020) who studied extruded products, the obtained result values were higher than the values 10.94 to 11.88% and 9.67 to 12.66%.

The fat content results revealed a significant difference among the rice varieties. The fat content in vermicelli was observed as 1.22% on average. Burma black had the highest mean value (1.41%), while BPT 3145 had the lowest mean value (1.07%). Our results are in agreement with those reported by Kong *et. al.* (2012) who stated the values ranged from 0.36 to 2.46%.

The ash content results showed no significant difference among the rice varieties. The average ash content in vermicelli was found to be 0.53%. Burma black had the highest mean value (0.58%), while BPT 3145 had the lowest mean value (0.49%). The obtained result was higher than the range value 1.02 to 2.03% reported by Kong *et. al.* (2012).

The crude fiber content results revealed significant difference among the rice varieties. The average crude fiber in vermicelli was found to be 0.73%. The highest value was recorded for Burma black (0.97%) and the lowest mean value was recorded for BPT 2841 (0.55%). The result showed similarity with the findings of Bedier *et. al.* (2020) who stated the range value 0.48 to 1.23%.

The carbohydrates content results revealed significant difference between the rice varieties. The average carbohydrates content in vermicelli was found to be 82.72%. The highest value was found in BPT 3145 (84.96%) and the lowest mean value was found in Burma black (80.81%). The obtained result showed similarity with the range value 83.38-83.91% reported by Kong *et. al.* (2012).

The energy results showed no significant difference among the rice varieties. The average vermicelli content was found to be 369 kcal/100g. The highest value was found in BPT 3145 (373 kcal/100g) and the lowest mean value was found in Burma black (365 kcal/100g). The obtained value was comparable to the range value of 398 to 426 kcal/100g reported by Bedier *et. al.* (2020).

4.4.4.3 ANOVA

For six different black rice varieties vermicelli, an analysis of variance was performed for 13 parameters (sensory parameters and proximate composition), namely colour, appearance, flavour, taste, and texture; moisture, protein, fat, ash, fibre, carbohydrates, and energy. The mean sum of squares are given in Table 4.25. A significant difference was observed among sensory parameters. No significant difference was observed between rice varieties in proximate composition of vermicelli.

Table 4.25 Analysis of variance for sensory parameters and proximate composition of vermicelli

<table>
<tr><th colspan="7">Sensory parameters</th></tr>
<tr><th>Source of Variation</th><th>Df</th><th>S.S.</th><th>MSS</th><th>F-Cal</th><th>F-Tab</th><th>P- value</th></tr>
<tr><td>Sensory traits</td><td>5</td><td>2.050</td><td>0.410</td><td>5.703</td><td>3.123</td><td><0.05</td></tr>
<tr><td>Rice varieties</td><td>5</td><td>46.396</td><td>9.279</td><td>129.078</td><td>2.341</td><td><0.05</td></tr>
<tr><td>Sensory traits * Rice varieties</td><td>25</td><td>7.188</td><td>0.288</td><td>3.999</td><td>1.964</td><td><0.05</td></tr>
<tr><td>Error</td><td>144</td><td>10.352</td><td>0.072</td><td></td><td></td><td></td></tr>
<tr><td>Total</td><td>179</td><td>65.986</td><td></td><td></td><td></td><td></td></tr>
<tr><th colspan="7">Proximate composition</th></tr>
<tr><th>Source of Variation</th><th>Df</th><th>S.S.</th><th>MSS</th><th>F-Cal</th><th>F-Tab</th><th>P- value</th></tr>
<tr><td>Proximate composition</td><td>6</td><td>2004392.79</td><td>334065.46</td><td>123938.34</td><td>2.21</td><td><0.05</td></tr>
<tr><td>Rice varieties</td><td>5</td><td>21.76</td><td>4.35</td><td>1.61</td><td>2.32</td><td>>0.05</td></tr>
<tr><td>Proximate composition * Rice varieties</td><td>30</td><td>187.69</td><td>6.26</td><td>2.32</td><td>1.59</td><td><0.05</td></tr>
<tr><td>Error</td><td>84</td><td>226.42</td><td>2.70</td><td></td><td></td><td></td></tr>
<tr><td>Total</td><td>125</td><td>2004828.65</td><td></td><td></td><td></td><td></td></tr>
</table>

The black rice value added products namely, payasam (kheer), cake, vadiyalu (fryums) and vermicelli were analysed for sensory evaluation and proximate composition. For products, Kheer and cake, BPT 2848 scored highest and BPT 3136 scored lowest but both were accepted by panelists. For products, fryums and vermicelli, BPT 3137 and BPT 3136 respectively scored highest and Burma black scored lowest. The vermicelli made with control became sticky due to low amylose which wasn't an acceptable trait. Among all the forementioned products, the highest moisture, protein, fat, fiber and ash content was recorded for Burma black and the lowest was recorded for BPT 3145 except for ash (BPT 3137) and fiber (BPT 2848) in fryums. The highest carbohydrates and energy content were found in BPT 3145 and lowest was found in Burma black.

4.6 Shelf-life studies of value added products

The value added products namely, vadiyalu and vermicelli (except payasam and cake because their storage periods were few days and few weeks respectively) were investigated for sensory evaluation, proximate composition and free fatty acids during the period of 30 days storage.

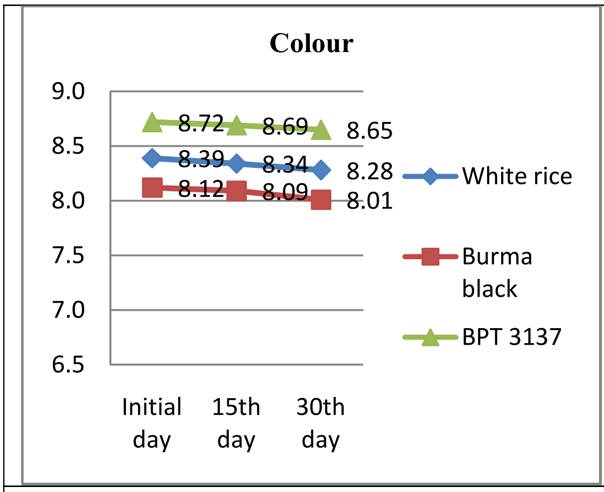
4.6.1 Shelf-Life study of Vadiyalu

The shelf-life parameters of highly accepted variety BPT 3137, BPT 5204(white rice) and Burma black (control) vadiyalu were assessed for a period of one month, which were packed in High Density Polyethylene (HDPE) covers and stored in clean, dry and well-ventilated room. Samples were drawn for every 15 days and evaluated for sensory attributes and proximate composition.

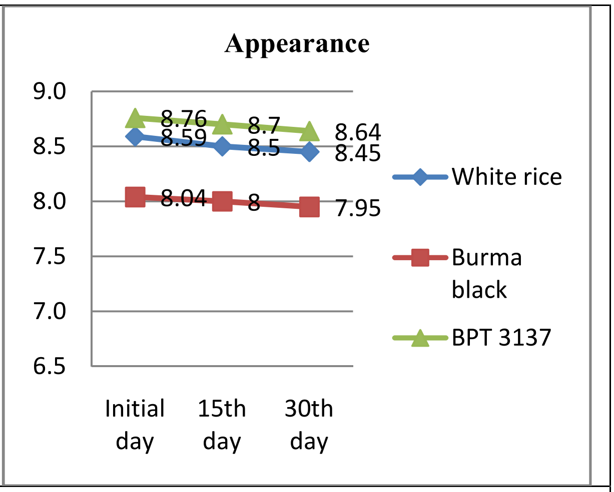
4.6.1.1 Organoleptic Evaluation of Stored Rice Vadiyalu

The colour, appearance, flavour, taste, texture and overall acceptability were found decreased continuously during storage with the advancement of storage period as shown in Figure 4.5. From initial day to 30th day, the mean scores of overall acceptability of vadiyalu made with BPT 3137 ranged from 8.72 to 8.68, white rice from 8.34 to 8.24 and Burma black from 7.80 to 7.68. The sensory scores of overall acceptability vadiyalu with BPT 3137 was higher when compared to white rice and Burma black vadiyalu. The overall acceptability scores of vadiyalu with BPT 3137 and white rice were greater than 8, which were liked moderately. Burma black vadiyalu scored least in all the sensory attributes. The shelf-life study of vadiyalu conducted for

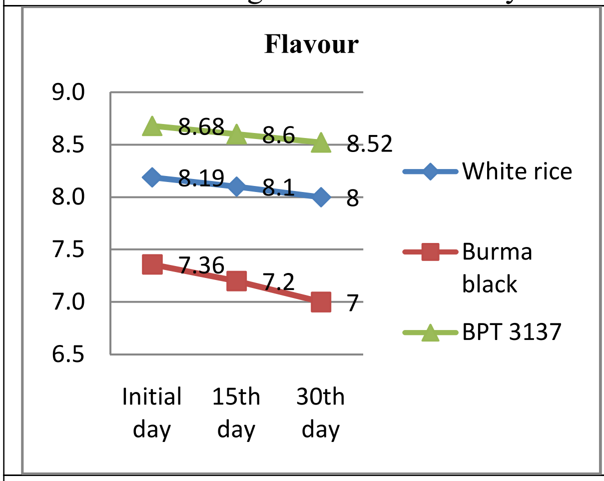
30 days revealed no significant difference among the sensory attributes because the general shelf-life of vadiyalu was nearly one year as they were hundred percent sun dried.



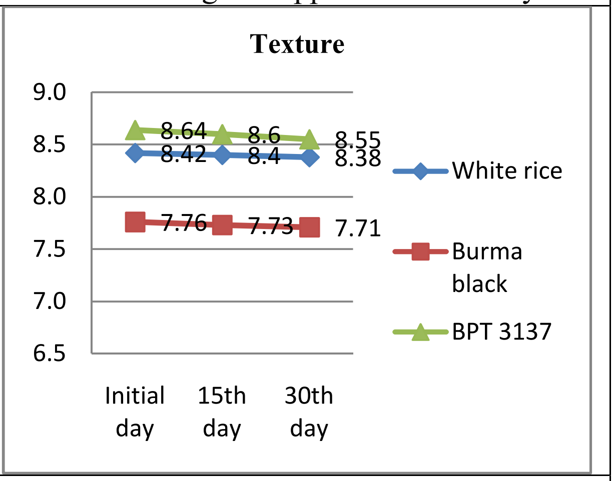
Effect of storage on colour of vadiyalu



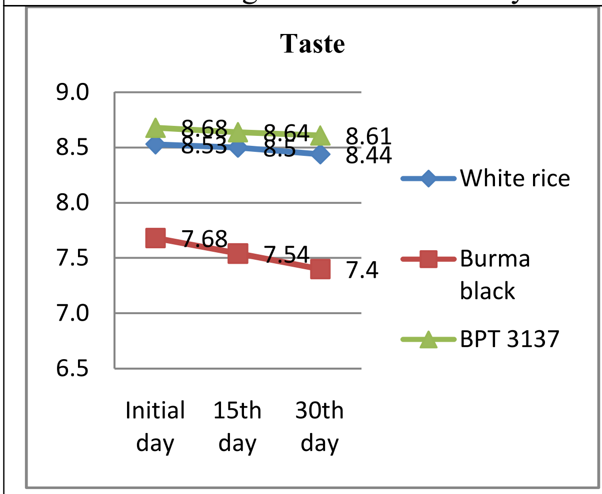
Effect of storage on appearance of vadiyalu



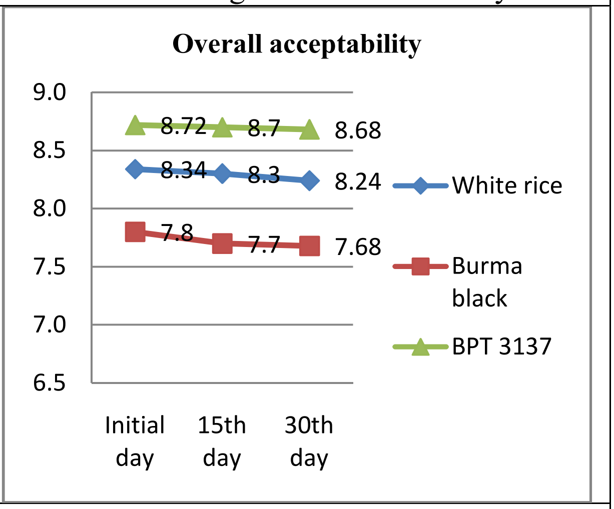
Effect of storage on flavour of vadiyalu



Effect of storage on texture of vadiyalu



Effect of storage on taste of vadiyalu



Effect of storage on overall acceptability of vadiyalu

Figure 4.5 Effect of storage period on sensory attributes of vadiyalu

4.6.1.2 Effect of Storage on Proximate Composition and Free fatty acids of Rice Vadiyalu

It is evident from the Table 4.26 that with increase in days of storage, there was gradual increase in moisture in developed vadiyalu. The highest increase in moisture was observed in Burma black rice vadiyalu from 5.74 to 5.97 g%, which probably had higher starch content and higher water absorption index compared to white rice and BPT 3137 vadiyalu.

A gradual decrease in protein content was noticed during storage in all the vadiyalu samples. A slight decrease in the fat content was observed in Burma black vadiyalu from 2.70 to 2.61, whereas the other two samples were unaffected during storage for 30 days. Two processes are augmented to account for the changes observed in the lipid during storage. One involves hydrolysis of lipids to produce free fatty acids and the other is the oxidation of lipids to produce hydroperoxides. No significant difference in terms of ash content was noticed during storage among the different rice vadiyalu.

A slight decrease carbohydrates was observed in similar results of Tiwari *et al.* (2020) due to decrease in starch content during storage of rice flour were noticed in the present investigation also. The total energy was unaccepted during the storage of 30 days.

FFA is an important determinant of hydrolytic rancidity and off-flavour in fatty foods. An increase in the FFA of Burma black vadiyalu from 1.31 to 1.51 was observed during 30 days of storage as shown in Table 4.26. The increase in FFA during storage was observed due to the presence of lipids and lipolytic enzymes in the unpolished rice kernels. There was no increase in free fatty acid of the developed white rice and BPT 3137 vadiyalu during storage of 30 days. The storage studies showed that the vadiyalu can be stored safely for 30 days of storage at ambient temperature.

Table 4.26 Effect of storage on proximate composition of vadiyalu

Days of storage	Proximate composition (g%)											
	Moisture			Protein			Fat			Ash		
	White rice	Burma black	BPT 3137	White rice	Burma black	BPT 3137	White rice	Burma black	BPT 3137	White rice	Burma black	BPT 3137
Initial day	5.01	5.74	5.07	5.51	9.21	8.43	0.42	2.70	2.27	1.13	3.40	3.02
15th day	5.15	5.86	5.19	5.46	9.17	8.40	0.42	2.67	2.27	1.08	3.21	3.00
30th day	5.26	5.97	5.29	5.40	9.06	8.33	0.41	2.61	2.26	1.01	3.16	2.92

Days of storage	Proximate composition (g%)									Free fatty acids (mg KOH/g)		
	Crude fiber			Carbohydrates			Energy (k.cal)					
	White rice	Burma black	BPT 3137	White rice	Burma black	BPT 3137	White rice	Burma black	BPT 3137	White rice	Burma black	BPT 3137
Initial day	1.89	2.90	1.99	86.04	76.05	79.21	370	365	371	1.12	1.31	1.24
15th day	1.85	2.85	1.86	86.04	76.24	79.28	370	365	371	1.12	1.45	1.24
30th day	1.83	2.76	1.78	86.09	76.44	79.42	370	365	371	1.13	1.51	1.24

4.6.2 Vermicelli

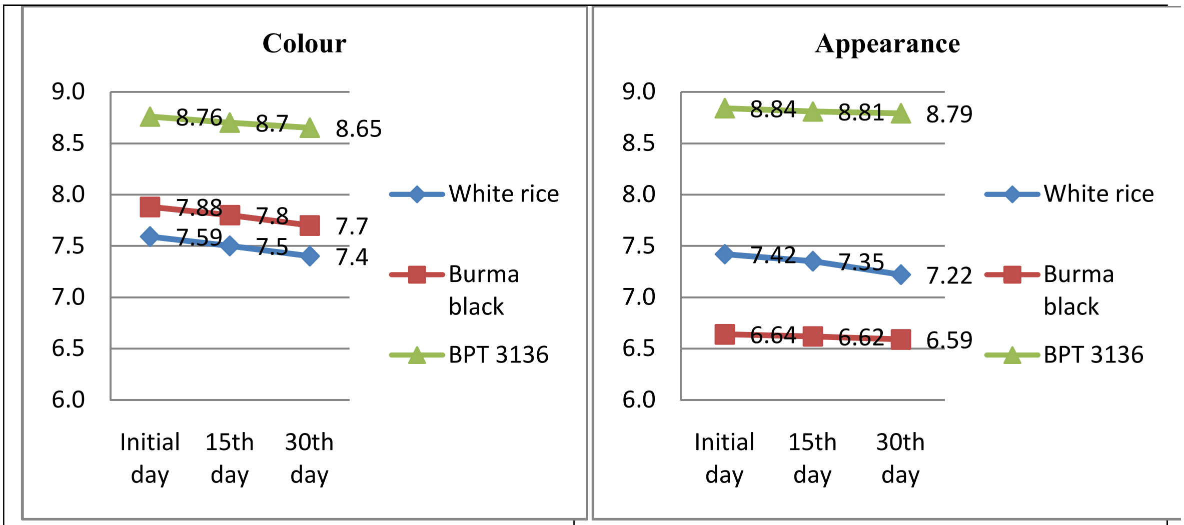
The shelf-life parameters of the highly accepted variety BPT 3136, white rice (BPT 5204), and Burma black (control) vermicelli were evaluated during a one-month period after being packaged in High Density Polyethylene (HDPE) covers and stored in a clean, dry, and well-ventilated room. For every 15 days, samples were collected and analysed for sensory characteristics and proximate composition.

4.6.2.1 Organoleptic Evaluation of Stored Rice Vermicelli

Figure 4.5 shows the mean scores of sensory attributes namely colour, appearance, flavour, taste, texture, and overall acceptability during the storage of 30 days.

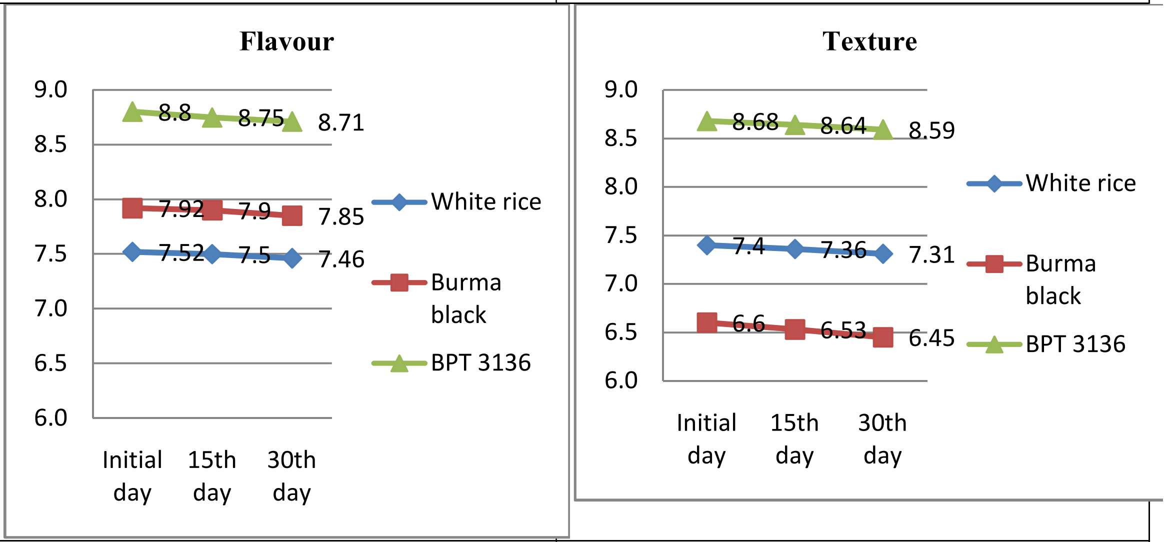
Colour is one of the prominent quality aspects for almost all the foods, which indicates the chemical changes in food during storage. The mean scores for colour of all variations stored in both packaging material showed a decrease in the colour from initial to 30 days. The mean scores for appearance of all variations showed a gradual decrease in the appearance from initial to 30 days in the packaging material. The decreasing trend in appearance of biscuits may be due to increase in moisture during storage.

The mean scores for texture, taste and flavour were also decreased gradually with increase in storage days. The observed changes were mainly due to moisture and the chemical composition of the rice. From the initial day to the 30th day, the mean overall acceptance scores of vermicelli produced with BPT 3136 varied from 8.76 to 8.65, white rice from 8.13 to 7.98, and Burma black from 7.32 to 7.24. When compared to white rice and Burma black vermicelli, the sensory scores of overall acceptability vermicelli with BPT 3136 were higher. The acceptability scores of vermicelli with BPT 3136 and white rice were greater than 8, indicating that it was ‘liked moderately’. The sensory parameters such as appearance, texture, taste and overall acceptability were scored lowest for Burma black vermicelli, whereas colour and flavour were scored lowest in white rice vermicelli.



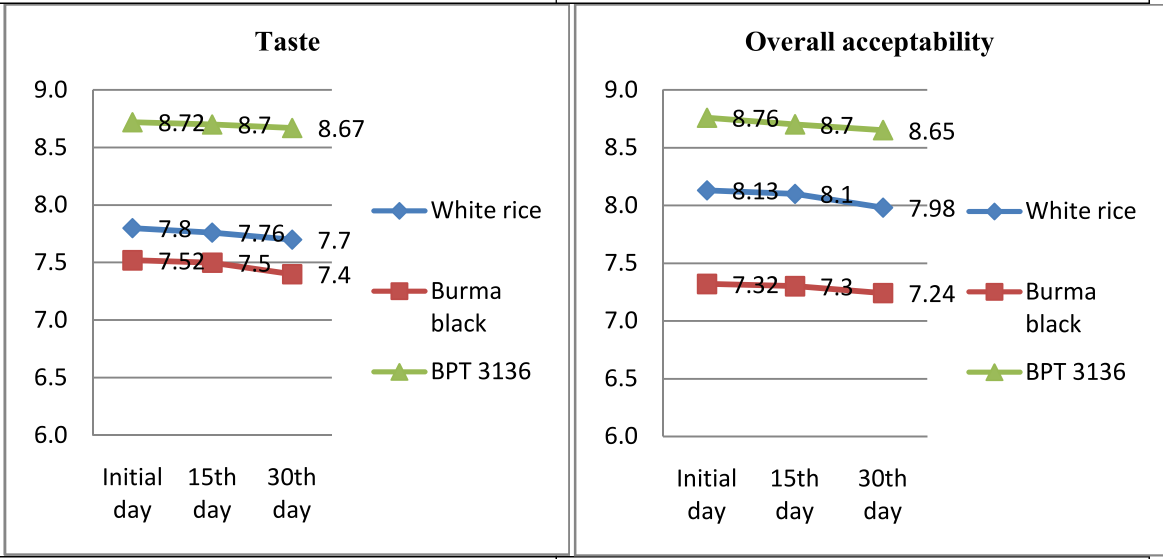
Effect of storage on colour of vermicelli

Effect of storage on appearance of vermicelli



Effect of storage on flavour of vermicelli

Effect of storage on texture of vermicelli



Effect of storage on taste of vermicelli

Effect of storage on overall acceptability of vermicelli

Figure 4.6 Effect of storage period on sensory attributes of vermicelli

Table 4.27 Effect of storage on proximate composition of vermicelli

Days of storage	**Proximate composition (g%)**											
	Moisture			**Protein**			**Fat**			**Ash**		
	White rice	**Burma black**	**BPT 3136**	**White rice**	**Burma black**	**BPT 3136**	**White rice**	**Burma black**	**BPT 3136**	**White rice**	**Burma black**	**BPT 3136**
Initial day	8.22	9.06	7.56	5.93	7.16	6.06	0.35	1.41	1.09	0.25	0.58	0.51
15th day	8.67	9.24	7.78	5.84	7.09	6.00	0.34	1.39	1.08	0.25	0.58	0.51
30th day	8.94	9.86	7.92	5.72	7.02	5.91	0.32	1.34	1.07	0.25	0.58	0.51

Days of storage	**Proximate composition (g%)**									**Free fatty acids (mg KOH/g)**		
	Crude fiber			**Carbohydrates**			**Energy (k.cal)**					
	White rice	**Burma black**	**BPT 3136**	**White rice**	**Burma black**	**BPT 3136**	**White rice**	**Burma black**	**BPT 3136**	**White rice**	**Burma black**	**BPT 3136**
Initial day	0.56	0.97	0.86	84.69	80.81	83.92	366	365	370	1.10	1.25	1.19
15th day	0.55	0.96	0.86	84.35	80.74	83.77	364	364	369	1.10	1.28	1.19
30th day	0.55	0.95	0.86	84.22	80.25	83.73	363	361	368	1.12	1.31	1.19

4.6.2.2 Effect of Storage on Proximate Composition and Free fatty acids of Rice Vermicelli

The data on changes in proximate composition during storage of 30 days is shown Table 4.27. The moisture content increased slightly with increase in storage period, hydroscopic nature of the flour played a crucial role in it. The protein content was degraded from initial day to 30th day. Fat content in Burma black vermicelli was decreased slightly from initial day to 30th day whereas in white rice and BPT 3136, it was unaffected. The ash and crude fiber content remained constant during 30 days storage. The carbohydrates and energy content were decreased slightly from initial day to 30th day in all rice vermicelli. Among all the vermicelli, BPT 3136 and white rice varieties had highest energy (370 kcal/100g) and carbohydrates (84.69 g) respectively.

The hydrolysis of lipids was measured by free fatty acids. The data from Table 4.27 revealed that there was no noticeable change in FFA content of white rice and BPT 3136 vermicelli during the storage period whereas in Burma black vermicelli the increased values of FFA was observed from 1.25 to 1.31 mg KOH/g as it has high amount of fat compared to other samples. The antioxidant activity played an important role in reduction of lipid hydrolysis. The obtained result was comparable to findings of Ponnapan (2014).

The samples examined for shelf-life study revealed that all of them were suitable for consumption for 30 days since the sensory and nutritional parameters were remain unchanged.

All the six varieties were characterized for physical, chemical, cooking quality, nutraceutical, proximate composition, micronutrients and the best genotypes were subsequently mentioned as below in Table 4.28.

Table 4.28 Best varieties with desirable overall quality parameters and suitable for product development

Physical traits	
Hulling	Burma black, BPT 2841, BPT 2848, BPT 3136, BPT 3137 and BPT 3145
Milling	
HRR	
Kernel length	
L/B ratio	
Chemical traits	
Amylose content	BPT 2841, BPT 2848, BPT 3136, BPT 3137 and BPT 3145
Gel consistency	Burma black, BPT 2841, BPT 2848, BPT 3136, BPT 3137 and BPT 3145
Alkali spreading value	BPT 2841, BPT 2848, BPT 3136, BPT 3137 and BPT 3145
Cooking quality traits	
KLAC	Burma black, BPT 2841, BPT 2848, BPT 3136, BPT 3137 and BPT 3145
Kernel elongation ratio	
Nutraceutical properties	
Bulk density	Burma black, BPT 2841, BPT 2848, BPT 3136, BPT 3137 and BPT 3145
Water absorption index	
Water solubility index	
Biochemical profile	
Total anthocyanin content	Burma black, BPT 2841, BPT 2848, BPT 3136, BPT 3137 and BPT 3145
Total phenol content	
Total antioxidant content	
Proximate composition	
Protein	Burma black, BPT 2841, BPT 2848, BPT 3136, BPT 3137 and BPT 3145
Fat	
Fiber	Burma black, BPT 3136 and BPT 3145
Micro nutrients	
Iron	Burma black, BPT 2841, BPT 2848 and BPT 3137

Zinc	Burma black, BPT 2841 and BPT 2848
Iron and zinc	Burma black
Glycemic index	BPT 2848
Genotypes with all desired characteristics	BPT 2841, BPT 2848, BPT 3136, BPT 3137 and BPT 3145
Value added products	
Payasam	Burma black, BPT 2841, BPT 2848, BPT 3136, BPT 3137 and BPT 3145
Cake	Burma black, BPT 2841, BPT 2848 and BPT 3145
Fryums	BPT 2841, BPT 2848, BPT 3136, BPT 3137 and BPT 3145
Vermicelli	
Genotypes with all desired characteristics and suitable for development of value added products	BPT 2841, BPT 2848, BPT 3136, BPT 3137 and BPT 3145

Chapter V

SUMMARY AND CONCLUSIONS

Black rice is one of the speciality rice with purple or black colour kernel pericarp. This colour is due to the presence of anthocyanins which are flavonoids that perform antioxidant and anti-inflammatory properties. So the present investigation was carried on "Grain quality evaluation of improved black rice (*Oryza sativa* L.) genotypes and assessment of their suitability for preparation of south indian foods" was undertaken mainly to study the rice varieties for grain quality, biochemical profile, nutritional parameters, glycemic index of the grains; sensory and nutritional parameters of developed value added products along with the correlation between grain quality, biochemical profile, nutritional parameters, glycemic index between black rice genotypes. The raw material was procured from Agricultural Research Station (ARS), Bapatla during *Kharif* – 2021. Quality traits evaluation and biochemical analysis were performed on 6 black rice genotypes (Burma black –control, BPT 2841, BPT 2848, BPT 3136, BPT 3137 and BPT 3145) at Quality Lab, Agricultural Research Station, Bapatla and Food Science and Nutrition lab, College of Community Science, Guntur.

The data was recorded for seven physical quality parameters viz., hulling, milling, head rice recovery, kernel length, kernel breadth, length/breadth ratio, thousand grains weight; three chemical quality parameters viz., amylose content, gel consistency, alkali spreading value; five cooking parameters viz., kernel length after cooking, kernel breadth after cooking, kernel elongation ratio, volume expansion ratio, water uptake; three nutraceutical properties viz., bulk density, water absorption index, water solubility index; five biochemical quality profile viz., total anthocyanin content, total phenol content, total antioxidant activity, phyates, oxalates; seven proximate composition analysis viz., moisture, protein, fat, ash, fiber, carbohydrates, energy; two micronutrient viz., iron and zinc; glycemic index was evaluated using *in vitro* starch hydrolysis method. Analysis of variance has revealed a significant difference for all the attributes studied and among the varieties except for proximate composition of rice genotypes.

The results of the present study are summarized below:

The mean values for hulling percentages ranged from 73.63% (BPT 2848) to 77.53% (Burma black), with a general mean of 75.58%. The general mean value for milling percent was 69.22% which varied in the range of 68.10% (BPT 2841) to 71.00% (Burma black). Head rice recovery per cent was ranged from 60.07% (BPT 2848) to

65.30% (BPT 3145) with a general mean of 63.63%. The kernel dimensions such kernel length, kernel breadth and L/B ratio ranged from 5.60 mm (BPT 2841) to 6.18 mm (Burma black), 1.93 mm (BPT 2841) to 2.51 mm (Burma black) and 2.46 (Burma black) to 2.94 (BPT 3136 and BPT 3137) with general mean value of 5.91, 2.10 and 2.83 respectively. The thousand grains weight was ranged from 13.53g (BPT 2841) to 27.23g (Burma black) with a general mean of 19.20.

The general mean of amylose content was 19.20% which varied in the range of 5.40% (Burma black) to 24.37% (BPT 3136). The mean values of gel consistency and alkali spreading value ranged from 71.00mm (BPT 3136) to 85.00mm (Burma black) and 3.67 (BPT 3136) to 6.67 (Burma black) with a general mean of 77.88mm and 4.61 respectively.

The mean values of kernel length after cooking and kernel breadth after cooking was ranged from 8.06 mm (BPT 2841) to 8.81 mm (BPT 3136) and 3.06 (BPT 2841) to 3.88 (BPT 3136) with a general means of 8.47 mm and 3.60 mm respectively. With regarding to kernel elongation ratio, it ranged from 1.38 in Burma black to 1.46 in BPT 3136 respectively and the general mean was noted as 1.43. The volume expansion ratio was ranged from 3.37 (Burma black) to 4.07 (BPT 3136) with a general mean value of 4.07. Higher water uptake was observed in BPT 3136 (405.00 ml) and lower uptake was observed in Burma black (461.67 ml) with a mean of 421.94 ml.

The bulk density ranged from 0.74g/ml (Burma black, BPT 2841 and BPT 2848) to 0.76 g/ml (BPT 3136) with a general mean of 0.75 g/ml. Water absorption index and water solubility index of black rice genotypes varied from 1.52ml (Burma black) to 1.79ml (BPT 3136) and 17.17 (Burma black) to 25.17 (BPT 3136) with a general mean of 1.66 and 21.00 respectively.

The general mean of total anthocynanin content was 24.19 mgC3G/100g which varied in the range 19.21 mgC3G/100g (BPT 3145) to 30.57 mgC3G/100g (Burma black). The total phenol content ranged from 100.32 mgGAE/100g to 238.17 mgGAE/100g with a general mean of 169.09 mgGAE/100g and the maximum and minimum values were observed in BPT 2841 and BPT 3145. The mean values for total antioxidant activity ranged from 87.81 mgAAE/100g (BPT 3145) to 99.52 mgAAE/100g (BPT 2841), with a general mean of 94.78 mgAAE/100g. The phytate content was ranged from 351.38 mg/100g (BPT 3137) to 410.36 mg/100g (Burma black) with a general mean of 371.83 mg/100g. The oxalates content was ranged from

2.24 mg/100g (BPT 3137) to 5.38 mg/100g (Burma black) with a general mean value of 3.57mg/100g.

Burma black had highest moisture (12.22%), protein (11.21%), fat (2.23%), ash (0.96%) and crude fiber (1.36%), whereas BPT 3145 had lowest moisture (9.30%), protein (8.33%), fat (1.53%), ash (0.85%) and crude fiber (0.93%). BPT 3145 had highest carbohydrates (78.99%) and energy (363kcal), whereas Burma black had lowest carbohydrates (72.02%) and energy (353kcal). All the samples recorded more than 78 per cent of carbohydrates. Iron and zinc showed significant positive correlation. The highest mean values of iron and zinc were found in Burma black (1.55mg/100g and 2.05mg/100g respectively) and the lowest mean values were found in BPT 3145 (0.91mg/100g and 0.73mg/100g respectively). Burma black was classified under medium iron and zinc variety, where as BPT 2841, BPT 2848 and BPT 3137 genotypes were classified under medium iron and remaining varieties under low iron and zinc category. The glycemic index was varied from 53.33 to 65.81 with a general mean of 58.17. All the varieties were classified as medium GI varieties (56-69) except BPT 2848 (<55) which falls under low GI variety.

According to the correlation studies, grain hulling a physical character had shown a positive association with milling. A significant positive correlation was noted between the characters thousand grain weight and kernel length, kernel breadth. A significant negative relation of kernel breadth was noticed with L/B ratio and amylose content. Kernel length after cooking had a significant positive association with the kernel breadth after cooking. Alkali spreading value showed a significant positive association with gel consistency and water uptake. There is a significant positive relation of iron with chemical traits such as gel consistency, alkali spreading value; cooking traits such as water uptake; biochemical parameters such as total anthocyanin content and oxalates and proximate composition such as moisture and ash. Total antioxidant activity showed significant positive correlation with total anthocyanin content and total phenol content. Moisture had a significant positive correlation with protein, fat, ash and significant negative correlation with carbohydrates and energy. A significant positive correlation was detected among the zinc and iron content of the grain. Ash was significantly and positively associated with iron and zinc. Carbohydrate had a significant positive relation with volume expansion ratio, bulk density, water solubility index and energy. However, carbohydrate had a significant negative association with moisture, protein, fat and ash.

Glycemic Index significantly associated with milling, kernel breadth, thousand grains weight and it had a non-significant negative relation with amylose and energy. Higher the L/B ratio, more is the kernel elongation ratio. Selection for these significantly and positively correlated traits will improve the overall quality trait. The chances of selecting desirable intermediate values of gel consistency lead to the automatic selection of an intermediate and desirable amylose content level. Selection of rice made for high protein would ultimately select rice with high fat and high zinc per cent, which had a positive correlation with iron. The black rice varieties such as Burma black, BPT 2841, BPT 3136, BPT 3137 and BPT 3145 showed intermediate glycemic index and BPT 2848 showed low glycemic index. The low and intermediate glycemic index rice varieties were good for diabetic patients. On comparison of all the quality, biochemical and nutritional parameters between control and other black rice genotypes, most of them exhibited nearly values except amylose and alkali spreading value. These were the two main parameters for determination of characteristic quality of the grain. All the black rice varieties except control recorded intermediate amylose and intermediate alkali spreading value which gave flaky and non sticky quality to cooked rice. These features were desirable for rice consumers while counting for better rice with the best quality.

The value added products such as payasam, cake, vadiyalu and vermicelli were standardized with different formulations. In this study, payasam was prepared with 100g rice (no formulations). Cakes were prepared from different proportions of black rice flour and wheat flour as 100:0(control), 90:10(T1), 80:20(T2), 70:30(T3) and 60:40(T4). Vadiyalu were prepared from different proportions of black rice flour and sago powder as 100:0(control), 90:10(T1), 80:20(T2), 70:30(T3) and 60:40(T4). Vermicelli were prepared from different proportions of black rice flour, wheat flour and corn starch as 100:0:0 (control), 90:10:0(T1), 80:10:10(T2), 70:20:10(T3), and 60:30:10(T4). The further proportions were not considered because the suitable product with maximum incorporation of black rice flour was identified. Among all the trials conducted, the proportion T4 for cakes, T2 for vadiyalu and T4 for vermicelli were most accepted. Hence these formulations were used for development of value added products with different black rice varieties. The developed value added products were subjected to sensory evaluation and proximate composition estimation.

When the ranks were given based on overall acceptability, BPT 2848 black rice payasam (8.80) and cake (8.92); BPT 3137 black rice vadiyalu (8.72) and BPT 3136 black rice vermicelli (8.76) scored first among all the black rice varieties value added products. The control exhibited the similar score with the other black rice genotypes in paysam and cake. The remarkable difference was observed in vadiyalu and vermicelli made with control and other black rice genotypes. The Burma black (control) scored least in vadiyalu and vermicelli as it was unacceptable by the panellist due to the sticky nature caused by low amylose and high alkali spreading value. Hence Burma black is not suitable for preparation of vadiyalu and vermicelli whereas payasam and cake can be prepared with it. On comparision with control the other black rice genotypes value added products were liked and accepted by panellist.

For all the value added products, the highest content of moisture, protein, fat, ash, fiber and lowest carbohydrates and energy were observed in Burma black, whereas vice versa was observed in BPT 3145.

Among all the value added products, the highest moisture, protein, fat, ash, fiber, carbohydrates and energy per 100g were observed in Burma black payasam (44.63%), Burma black vadiyalu (9.21%), Burma black cake (8.86%), Burma black vadiyalu (3.40%), Burma black vadiyalu (2.90%), BPT 3145 vermicelli (84.96%) and BPT 3145 vermicelli (373kcal).

Results revealed that the value added products made with Burma black had highest moisture, protein, fat, ash, fiber and lowest carbohydrates and energy. When compared to other black rice genotypes, the major drawbacks of Burma black products were high moisture that decreases shelf life and low energy.

The highly accepted samples of vermicelli and vadiyalu were assessed with control and white rice products for shelf-life study (30 days), which revealed that all samples were suitable for consumption, since the sensory and nutritional parameters remain unchanged.

Hence, the study concluded that all the black rice genotypes exhibited similar biochemical and nutritional parameters but in context of quality parameters the black rice genotypes other than control has all the desired grain characteristics such as intermediate amylose and intermediate alkali spreading value. Regarding the value added products obtained with black rice and black rice flour especially cake and vermicelli could be an alternative for people suffering from gluten intolerance, whereas proving a significant amount of polyphenolic content and antioxidant activity, with potentially beneficial effects on human health.

Future line of work:

- Awareness and introduction of the black rice among the people to promote health.
- More research can be done in black rice should be strengthen to develop more improved varieties with desired traits.
- Effect of different processing methods such as parboiling, flaking, puffing etc., on nutrient content of black rice can be studied.
- Shelf life and microbial studies of the value added products can be studied.
- In vivo glycemic index of black rice varieties can be studied.

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APPENDICES

Appendix - A

Estimation of Moisture

1. Empty dish and lid were dried in the oven at 105°C for 3 hours and transferred to the desiccator to cool. The empty dish and lid were weighed.

2. 3 g of sample was weighed and taken in a dish. The sample was spread to uniformity.

3. Dish with the sample was placed in the oven. It was dried for 3 hours at 105°C.

4. After drying, the dish with a partially covered lid was transferred to the desiccator to cool. The dish and its dried sample were reweighed.

Calculation

$$\text{Moisture (\%)} = \frac{(W1-W2)}{W1} \times 100$$

- W1 = weight (g) of the sample before drying
- W2 = weight (g) of the sample after drying

Appendix - B

Estimation of Protein

Principle: Organic nitrogen digested with sulphuric acid in the presence of a catalyst is converted to ammonium sulphate. Ammonium liberated by making the solution alkaline is distilled into a known volume of standard acid which is then back titrated. Protein percent was calculated by multiplying the nitrogen present in the sample. The nitrogen conversion factor is 6.25.

Reagents:

- Kjeldhal catalyst: Mix 9 part of potassium sulphate (K2SO4) with 1 part of copper sulphate (CuSO4)
- Sulphuric acid (H2SO4)
- 40 % NaOH solution
- 0.2N HCL solution
- 4% H3BO3
- Indicator solution: Mix 100 ml of 0.1% methyl red (in 95% ethanol) with 200 ml of 0.2% bromocresol green (in 95% ethanol)

Procedure:

One gram of defatted powdered sample of each product was weighed on butter paper, in triplicate and placed in each separate 300ml Kjeldahl flask. An amount of 5.0g of catalyst mixture, 20ml of concentrated sulphuric acid and 2-3 glass bids were added to each flask. Similarly, the blank was also prepared using other reagents except for the sample. The contents in the flask were digested by heating for about 8 hours until the digested material was clear. The contents were allowed to cool and diluted by rinsing down the neck of the flask with distilled water. The contents were then transferred to a 100ml volumetric flask and the volume was made up to the mark with distilled water. 10ml of the boric acid solution was delivered into a 100ml conical flask and two drops of methyl red indicator were added and mixed well. The flask was then placed under the condenser with the tip of the condenser extending below the surface of the boric acid solution; 5ml of the digested sample was delivered into the distillation apparatus. Then 10ml of 40 percent NaOH was added and the funnel was washed with 2 to 3ml of distilled water. Steam distillation was carried out and it was continued for 10 to 15 min, until about 40ml of distillate was collected in boric acid solution. The tip of the condenser was washed with distilled water and the flask was removed. The ammonia collected in boric acid was titrated against the standard 0.1 N sulphuric acid solution. The endpoint of the titration was noted when 0.1 N sulphuric acid produced a light pink color. Then the volume of 0.1 sulphuric acids required to neutralize the sample was noted.

Calculation:

$$\text{Protein (\%)} = \frac{(\text{Titre volume of sample} - \text{Titre volume of blank}) \times N \times 14 \times 100 \times 6.25}{\text{Weight of the sample (mg)}}$$

Where

N= Normality of H_2SO_4

6.25= Protein- nitrogen conversion factor

Appendix - C

Estimation of Fat

Principle:

The extraction of fat from substances is often tedious and requires thorough contact and heating with the solvent. This is done in the soxhlet apparatus in which fresh solvent continuously comes into contact with the material to be extracted over a relatively long period.

Reagent: Petroleum ether

Procedure:

1. Place the bottle and lid in the incubator at 105˚C overnight to ensure that the weight of the bottle is stable.

2. Weigh about 3 - 5 g of sample to paper filter and wrap.

3. Take Sample into extraction thimble and transferred into soxhlet.

4. Fill Petroleum ether about 250 ml into the bottle and take it on the heating mantle.

5. Heat the Sample for about 14 hours.

6. Evaporate the solvent by using the vacuum condenser.

7. Incubate the Bottle at 80-90°C until the solvent completely got evaporates and the bottle is completely dry.

8. After drying, transfer the bottle with was partially covered lid to the desiccator to cool. Reweigh the Bottle and its dried content.

Calculation:

$$\text{Fat (\%)} = \frac{\text{Weight of ether extract}}{\text{Weight of sample}} \quad \text{X } 100$$

Appendix - D

Estimation of Ash

Procedure:

1. Place the Crucible and lid in the muffle furnace at 550˚C overnight to ensure that impurities on the surface of the crucible are burnt off.

2. Cool the crucible in the desiccator (30 min).

3. Crucible and lid were weighed to 3 decimal places.

4. 5 g sample was weighed and taken into the crucible. Heated over low Bunsen flame with the lid half covered. When fumes are no longer produced, the crucible and lid were placed in a furnace.

5. Heated at 550˚C overnight. During heating, the lid was not covered. The lid was placed after complete heating to prevent the loss of fluffy ash. Cool down in the desiccator.

6. Ash was weighed with crucible and lid when the sample turned grey.

Calculation:

$$\text{Ash (\%)} = \frac{\text{Weight of Ash}}{\text{Weight of sample}}$$

Appendix - E

Estimation of Crude Fibre

Principle: During the acid and subsequent alkali treatment, oxidative hydrolytic degradation of the native cellulose and considerable degradation of lignin occurs. The residue obtained after final filtration is weighed, incinerated, cooled and weighed again. The loss in weight is the crude fiber content.

Reagents:

- 0.255 ± 0.005 N standard H_2SO_4
- 0.313 ± 0.005 N standard NaOH

Procedure:

A weighed amount of (2.5-5g) of moisture and the fat free sample was transferred to a fiber bag which was pre-heated and weighed. These bags were inserted into tubes and placed in a beaker provided in the instrument. The sample was boiled with 300ml 0.255 ± 0.005N H2SO4 for 30 minutes. Then the residue was washed with boiling water until acid-free. Then the residue was boiled with 300ml of 0.313 ± 0.005 N NaOH for 30 minutes. Again, the residue was washed with boiling water followed by an alcohol wash. The residue was transferred to pre-weighed crucibles (W1) and it was dried for 2 hours at 130± 2°C, cooled in desiccators the weighed (W2). The dried desiccators containing samples were then ignited for 30 minutes at 60˚ ± 15°C. Finally, the sample was cooled and weighed again.

$$\text{Crude Fibre (g/100g of sample)} = \frac{[100 - (\text{Moisture} + \text{fat})] \times (W1 - W2)}{\text{Weight of sample taken (moisture and fat free)}}$$

- W1 = Pre-weighed ashing dish
- W2 = Weight of the dish after ashing

Appendix - F

SCORE CARD FOR SENSORY EVALUATION

Score card for sensory evaluation of specialty rice Payasam (kheer), Cake, Vermicelli and Fryums (Vadiyalu)

Name of evaluator :

Name of product :

Date of evaluation :

Note: You are given samples of specialty rice product. Score each sample of specialty rice product for the given attributes. Please use the nine-point scale given below.

9- Like extremely	8- Like very much	7- Like moderately
6- Like slightly	5- Neither like nor dislike	4- Dislike slightly
3- Dislike moderately	2- Dislike very much	1- Dislike extremely

Please evaluate the following samples for the attributes using the nine point hedonic rating scale

S.No	Sample code	Colour	Appearance	Flavour	Texture	Taste	Overall acceptability
1.							
2.							
3.							
4							
5.							
6.							

SUGGESTIONS:

SIGNATURE OF THE EVALUATOR

Appendix - G

Mean scores for sensory evaluation of payasam

S.no	Black rice varieties	Colour	Appearance	Flavour	Texture	Taste	Overall acceptability
1.	Burma black	8.40±0.58	8.40±0.71	8.20±0.58	8.92±0.28	8.88±0.33	8.56±0.51
2.	BPT 2841	8.28±0.54	8.40±0.72	8.44±0.65	8.16±0.62	8.84±0.37	8.44±0.51
3.	BPT 2848	8.72±0.46	8.64±0.49	8.84±0.37	8.96±0.20	8.88±0.33	8.80±0.41
4.	BPT 3136	8.04±0.98	8.20±0.87	8.08±0.57	8.04±0.45	8.72±0.46	8.20±0.50
5.	BPT 3137	8.12±0.67	8.12±0.83	7.96±0.68	8.52±0.59	8.92±0.28	8.32±0.48
6.	BPT 3145	8.28±0.79	8.24±0.72	8.64±0.49	8.8±0.41	8.96±0.20	8.60±0.50
	Mean	8.31	8.33	8.35	8.57	8.87	8.49
	SED	0.14	0.9	0.15	0.09	0.11	0.15
	C.D.	0.30	0.40	0.31	0.20	0.24	0.32
	C.V.	0.37	1.17	0.71	0.28	0.38	0.72
	Lowest range	8.04	8.12	7.96	8.04	8.72	8.20
	Highest range	8.28	8.64	8.84	8.96	8.96	8.80

Appendix - H

Mean scores for sensory evaluation of cakes

S.no	Black rice varieties	Colour	Appearance	Flavour	Texture	Taste	Overall acceptability
1.	Burma black	8.96±0.20	8.76±0.44	8.56±0.58	8.80±0.41	8.76±0.44	8.80±0.41
2.	BPT 2841	8.80±0.50	8.72±0.54	8.40±0.50	8.68±0.56	8.36±0.49	8.60±0.50
3.	BPT 2848	8.96±0.20	8.92±0.28	8.88±0.33	8.96±0.20	8.92±0.28	8.92±0.28
4.	BPT 3136	6.80±0.87	6.72±0.74	6.84±1.03	6.64±1.41	7.96±0.45	7.08±0.40
5.	BPT 3137	7.56±0.77	7.6±0.82	7.36±0.99	6.96±1.21	8.12±0.44	7.52±0.59
6.	BPT 3145	8.80±0.41	8.76±0.44	8.80±0.41	8.96±0.20	8.88±0.33	8.84±0.37
	Mean	8.31	8.25	8.14	8.17	8.50	8.29
	SED	0.15	0.13	0.22	0.19	0.08	0.17
	C.D.	0.32	0.28	0.46	0.40	0.18	0.35
	C.V.	0.72	0.59	1.54	1.20	0.23	0.89
	Lowest range	7.56	6.72	6.84	6.64	7.96	7.08
	Highest range	8.96	8.92	8.88	8.96	8.92	8.92

Appendix - I

Mean scores for sensory evaluation of vadiyalu

S.No	Black rice genotypes	Colour	Appearance	Flavour	Texture	Taste	Overall acceptability
1.	Burma black	8.12±0.60	8.04±0.6	7.36±0.64	7.76±0.44	7.68±0.56	7.80±0.82
2.	BPT 2841	8.32±0.56	8.08±0.64	8.36±0.57	8.48±0.51	8.28±0.46	8.32±0.56
3.	BPT 2848	8.64±0.49	8.68±0.48	8.72±0.46	8.56±0.51	8.56±0.51	8.64±0.49
4.	BPT 3136	8.56±0.51	8.64±0.49	8.52±0.51	8.48±0.51	8.28±0.56	8.48±0.51
5.	BPT 3137	8.72±0.46	8.76±0.44	8.68±0.48	8.64±0.49	8.68±0.48	8.72±0.46
6.	BPT 3145	8.60±0.50	8.48±0.51	8.56±0.51	8.60±0.50	8.52±0.51	8.56±0.51
	Mean	8.49	8.45	8.37	8.42	8.33	8.42
	SED	0.15	0.13	0.12	0.12	0.16	0.15
	C.D.	0.32	0.27	0.26	0.26	0.33	0.31
	C.V.	0.73	0.51	0.47	0.49	0.77	0.69
	Lowest range	8.12	8.04	7.36	7.76	7.68	7.8
	Highest range	8.72	8.76	8.56	8.60	8.56	8.72

Appendix - J

Mean scores for sensory evaluation of vermicelli

S.No	Black rice varieties	Colour	Appearance	Flavour	Texture	Taste	Overall acceptability
1.	Burma black	7.88±0.73	6.64±0.70	7.92±0.49	6.60±0.65	7.52±0.65	7.32±0.56
2.	BPT 2841	8.32±0.56	8.04±0.68	8.40±0.50	8.36±0.57	8.24±0.44	8.28±0.68
3.	BPT 2848	8.68±0.48	8.56±0.51	8.64±0.49	8.60±0.50	8.52±0.51	8.60±0.50
4.	BPT 3136	8.76±0.44	8.84±0.37	8.80±0.41	8.68±0.48	8.72±0.46	8.76±0.44
5.	BPT 3137	8.68±0.48	8.64±0.49	8.72±0.46	8.60±0.50	8.68±0.48	8.68±0.48
6.	BPT 3145	8.72±0.46	8.68±0.48	8.6±0.50	8.80±0.41	8.84±0.37	8.72±0.46
	Mean	8.51	8.23	8.51	8.27	8.43	8.39
	SED	0.17	0.14	0.15	0.18	0.17	0.18
	C.D.	0.35	0.29	0.31	0.38	0.35	0.38
	C.V.	0.87	0.63	0.68	1.04	0.87	1.02
	Lowest range	7.88	6.64	7.92	6.60	7.52	7.32
	Highest range	8.76	8.84	8.80	8.80	8.84	8.76

Appendix – K

ANOVA of Sensory Parameters of Payasam

(One way Analysis)

Colour						
Source	SS	df	MSS	F-Cal	P-value	F-Tab
Rice varieties	7.173333	5	1.434667	3.006286	0.013018	2.277044
Error	68.72	144	0.477222			
Total	75.89333	149				
Appearance						
Source	SS	df	MSS	F-Cal	P-value	F-Tab
Rice varieties	4.373333	5	0.874667	1.63659	0.153986	2.277044
Error	76.96	144	0.534444			
Total	81.33333	149				
Flavour						
Source	SS	df	MSS	F-Cal	P-value	F-Tab
Rice varieties	14.35333	5	2.870667	9.002091	1.83E-07	2.277044
Error	45.92	144	0.318889			
Total	60.27333	149				
Texture						
Source	SS	df	MSS	F-Cal	P-value	F-Tab
Rice varieties	19.47333	5	3.894667	19.10191	1.51E-14	2.277044
Error	29.36	144	0.203889			
Total	48.83333	149				
Taste						
Source	SS	df	MS	F-Cal	P-value	F-Tab
Rice varieties	0.853333	5	0.170667	1.491262	0.196235	2.277044
Error	16.48	144	0.114444			
Total	17.33333	149				
Overall Acceptability						
Source	SS	df	MSS	F-Cal	P-value	F-Tab
Rice varieties	5.713333	5	1.142667	4.873934	0.000378	2.277044
Error	33.76	144	0.234444			
Total	39.47333	149				

Appendix – L

ANOVA of Sensory Parameters of Cake

(One way Analysis)

Colour						
Source	SS	df	MSS	F-Cal	P-value	F-Tab
Rice varieties	98.83333	5	19.76667	60.5102	1.09E-33	2.277044
Error	47.04	144	0.326667			
Total	145.8733	149				
Appearance						
Source	SS	df	MSS	F-Cal	P-value	F-Tab
Rice varieties	104.1933	5	20.83867	68.0755	3.28E-36	2.277044
Error	44.08	144	0.306111			
Total	148.2733	149				
Flavour						
Source	SS	df	MSS	F-Cal	P-value	F-Tab
Rice varieties	88.14	5	17.628	36.30481	6.26E-24	2.277044
Error	69.92	144	0.485556			
Total	158.06	149				
Texture						
Source	SS	df	MSS	F-Cal	P-value	F-Tab
Rice varieties	142.7533	5	28.55067	42.79034	7.43E-27	2.277044
Error	96.08	144	0.667222			
Total	238.8333	149				
Taste						
Source	SS	df	MSS	F-Cal	P-value	F-Tab
Rice varieties	21.1	5	4.22	24.90492	4.99E-18	2.277044
Error	24.4	144	0.169444			
Total	45.5	149				
Overall Acceptability						
Source	SS	df	MSS	F-Cal	P-value	F-Tab
Rice varieties	77.81333	5	15.56267	82.14897	2.03E-40	2.277044
Error	27.28	144	0.189444			
Total	105.0933	149				

Appendix – M

ANOVA of Sensory Parameters of Vadiyalu

(One way Analysis)

Colour						
Source	SS	df	MSS	F-Cal	P-value	F-Tab
Rice varieties	12.27333	5	2.454667	8.663529	3.353E-07	2.277044
Error	40.8	144	0.283333			
Total	53.07333	149				
Appearance						
Source	SS	df	MSS	F-Cal	P-value	F-Tab
Rice varieties	6.453333	5	1.290667	4.760656	0.0004683	2.277044
Error	39.04	144	0.271111			
Total	45.49333	149				
Flavour						
Source	SS	df	MSS	F-Cal	P-value	F-Tab
Rice varieties	32.43333	5	6.486667	23.12079	5.362E-17	2.277044
Error	40.4	144	0.280556			
Total	72.83333	149				
Texture						
Source	SS	df	MSS	F-Cal	P-value	F-Tab
Rice varieties	13.58	5	2.716	11.18719	4.022E-09	2.277044
Error	34.96	144	0.242778			
Total	48.54	149				
Taste						
Source	SS	df	MSS	F-Cal	P-value	F-Tab
Rice varieties	58.13333	5	11.62667	22.57605	1.124E-16	2.277044
Error	74.16	144	0.515			
Total	132.2933	149				
Overall Acceptability						
Source	SS	df	MSS	F-Cal	P-value	F-Tab
Rice varieties	13.9	5	2.78	8.58319	3.874E-07	2.277044
Error	46.64	144	0.323889			
Total	60.54	149				

Appendix – N

ANOVA of Sensory Parameters of Vermicelli

(One way Analysis)

Colour						
Source	SS	df	MSS	F-Cal	P-value	F-Tab
Rice varieties	85.39333	5	17.07867	56.61436	2.61E-32	2.277044
Error	43.44	144	0.301667			
Total	128.8333	149				
Appearance						
Source	SS	df	MSS	F-Cal	P-value	F-Tab
Rice varieties	14.93333	5	2.986667	10.60355	1.1E-08	2.277044
Error	40.56	144	0.281667			
Total	55.49333	149				
Flavour						
Source	SS	df	MSS	F-Cal	P-value	F-Tab
Rice varieties	12.83333	5	2.566667	11.32353	3.18E-09	2.277044
Error	32.64	144	0.226667			
Total	45.47333	149				
Texture						
Source	SS	df	MSS	F-Cal	P-value	F-Tab
Rice varieties	86.59333	5	17.31867	63.61959	9.45E-35	2.277044
Error	39.2	144	0.272222			
Total	125.7933	149				
Taste						
Source	SS	df	MSS	F-Cal	P-value	F-Tab
Rice varieties	29.89333	5	5.978667	24.73931	6.20E-18	2.277044
Error	34.8	144	0.241667			
Total	64.69333	149				
Overall Acceptability						
Source	SS	df	MSS	F-Cal	P-value	F-Tab
Rice varieties	38.27333	5	7.654667	27.8915	1.10E-19	2.277044
Error	39.52	144	0.274444			
Total	77.79333	149				