

Composition of plant polyphenolics in local cereals and pseudograins and their bioactivity

*A Dissertation Submitted to University of Dhaka for the Partial Fulfillment of the
Requirements of the Degree of Doctor of Philosophy (PhD) in Nutrition and Food Science*



Submitted By

Anjum Zerine Rupa

Registration no: 76/2018-2019

Re-registration no: 29/ 2023-2024

Session: 2018-2019

**Institute of Nutrition and Food Science
University of Dhaka
Dhaka-1000, Bangladesh
January, 2026**

Declaration

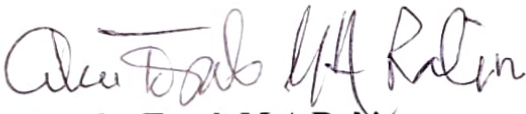
I hereby declare that this thesis, titled "Composition of plant polyphenolics in local cereals and pseudograins and their bioactivity," submitted for the degree of Doctor of Philosophy in the field of Nutrition and Food Science, is the result of my own independent research and has been composed entirely by myself. I certify that the findings presented herein are original and that no part of this work has been submitted for any other degree or diploma at any institution. I further acknowledge that portions of this thesis, specifically concerning the methodology, results, and discussion, have been adapted from my previously published peer-reviewed articles: "Ethnographic survey on cereal and pseudocereal on Bangladesh perspective" published in Food Research, Volume 7 (2), April 2023, "Nutritive, polyphenolic and antioxidative properties of locally produced cereals and pseudograins" published in Journal of Science and Technology Research, Volume 06 (01), 22.06.2024 and "Nutritional, phytochemical and antioxidant properties of Bangladeshi pigmented rice (red and black), grains and pseudograins" published in Food Chemistry Advances, Volume 6 (2025).



Anjum Zerine Rupa
PhD Researcher
Institute of Nutrition and Food Science
University of Dhaka
Dhaka-1000
Email: anjumifst@gmail.com
January, 2026

Certification

This is to certify that Anjum Zerin Rupa has conducted her PhD Thesis titled "Composition of plant polyphenolics in local cereals and pseudograins and their bioactivity" under my supervision for the fulfillment of the degree of Doctor of Philosophy in the field of Nutrition and Food Science from the University of Dhaka. The research reflects the candidate's original contributions to scientific knowledge in Nutrition and Food science. It has been further confirmed that the enquiries concerning the research work, outlined during the seminars, have been accurately and comprehensively incorporated into the thesis. The content of this dissertation has not been submitted, in whole or in part, to any other university or institution for the award of any degree.



Dr. Abu Torab M A Rahim

Professor

PhD Supervisor

Institute of Nutrition and Food Science

University of Dhaka

Dhaka-1000

Email: torabrahim@gmail.com

Abstract

Introduction

Cereals and pseudocereals are increasingly acknowledged for their abundant polyphenolic chemicals, which exhibit advantageous health-promoting qualities, particularly in the prevention and management of non-communicable illnesses such as hyperlipidemia. Due to their higher profiles of antioxidants, flavonoids, dietary fibers, and other bioactive constituents, these grains are frequently utilized as functional foods globally. Cereal crops, including rice, wheat, maize, oats, barley, bajra, and millets (proso and foxtail), are extensively cultivated and consumed in Bangladesh, supported by established agronomic systems and governmental agricultural initiatives. In contrast, pseudocereals—quinoa (*Chenopodium quinoa*), chia (*Salvia hispanica*), buckwheat (*Fagopyrum esculentum*), and amaranth—exhibit limited production, consumption, and research activity. Despite their nutritional and medicinal benefits, pseudo-cereals are significantly undervalued in Bangladeshi cuisine. Current market trends indicate a probable transition towards an expanded national grain inventory as domestically cultivated pseudograins—such as chia, quinoa, cheena, and kaon—become increasingly accessible. A thorough nutritional and phytochemical analysis of both conventional cereals and novel pseudograins growing in Bangladesh is urgently required to facilitate this transformation. The ethnographic study examined the production, utilization, and socio-cultural significance of several cereals and pseudograins in Bangladesh, alongside their functional potential through biochemical analysis. The research examined the macronutrient composition of grains, total flavonoid and phenolic content, and antioxidant capacity. The in vitro assessment of their lipase inhibitory properties facilitated the determination of their potential function in regulating lipid metabolism. The study intends to ascertain the functional importance of cereals and pseudocereals in dietary management, nutrition-sensitive agriculture, and the prevention of

chronic diseases, particularly hyperlipidemia, in Bangladesh by integrating ethnographic knowledge with biochemical investigation.

Methodology

A qualitative, exploratory, longitudinal ethnographic study was undertaken to evaluate the production, consumption, and distribution patterns of cereals and pseudocereals throughout Bangladesh. Focus group discussions were employed to identify the patterns in local agriculture and utilization. Laboratory tests were conducted to determine the proximate composition, total phenolic content (TPC), total flavonoid content (TFC), total antioxidant capacity (TAC), total tannin content (TTC), antioxidant activity (via DPPH, ABTS, and FRAP assays), and polyphenol profiles employing HPLC-DAD screening. The lipase inhibitory activity was evaluated using the ELISA technique, and the IC_{50} values were derived from the absorbance of sample extracts at varying concentrations. Regression analyses were conducted to ascertain the correlation between the dose-dependent sample concentration and lipase enzyme inhibition.

Results

Ethnographic research indicated that 85% of black rice, 80% of red rice, and 99% of buckwheat were sold locally, while 100% of quinoa and chia production was still in the experimental phase. Cheena and kaon had the greatest protein content among cereals, at 13.48% and 13.55%, respectively, although chia and quinoa revealed elevated amounts of protein, fat, and dietary fiber, with chia at 22.40% protein. Black rice and yellow buckwheat exhibited enhanced antioxidant capabilities and phenolic contents. The highest concentration of TPC, TFC, TAC and TTC were observed in two pigmented rice sample extracts (red and black) among cereal samples and two types of buckwheat extracts (yellow and black) among pseudograin samples, respectively. HPLC profiling verified elevated concentrations of epicatechin in quinoa and red

rice. Lipase inhibition experiments indicated that black rice ($IC_{50} = 10.25 \pm 1.06$ mg/mL) and yellow buckwheat ($IC_{50} = 15.69 \pm 1.09$ mg/mL) exhibited significant inhibitory effects relative to the standard epicatechin ($IC_{50} = 0.320 \pm 0.90$ mg/mL). Regression analysis demonstrated substantial correlations ($P < 0.05$) between polyphenolic content and lipase inhibition in red aman rice ($R^2 = 0.9685$), quinoa (F) ($R^2 = 0.9646$) and yellow buckwheat ($R^2 = 0.9442$), signifying robust predictive associations.

Conclusion

This extensive investigation shows that Bangladeshi cereal and pseudograins contain bioactive compounds with nutritional and therapeutic significance. Black rice, red aman rice, chia, quinoa, and yellow buckwheat displayed high total phenolic and flavonoid contents, strong DPPH, ABTS, and FRAP tests, and increased reducing power. HPLC profiling identified the presence of distinct polyphenols, including (-) epicatechin in red aman rice and quinoa. Several grains, including black rice ($IC_{50} = 10.25$ mg/mL), yellow buckwheat (15.69 mg/mL), and quinoa (23.70 mg/mL), showed significant pancreatic lipase inhibition, suggesting a role in lipid metabolism. A regression research found strong correlations ($R^2 > 0.94$, $P < 0.05$) between polyphenol content in methanolic extracts and lipase inhibition activity in red aman rice, quinoa, and yellow buckwheat. Despite their health advantages, pseudocereals are underrepresented in national agriculture and food systems. The results clearly imply including nutrient-dense, bioactive-rich cereals and pseudocereals in public nutrition and agro-food policy frameworks in Bangladesh to boost dietary diversity, chronic illnesses (hyperlipidemia) and sustainable agriculture.

Key words: Ethnographic survey, cereal, pseudograins, nutrient value, polyphenolic composition, antioxidant potential and lipase inhibition activity

Dedicated to
My Parents and beloved family members

Acknowledgement

The Almighty ALLAH is owed all praise and heartfelt gratitude for boundless kindness and blessings to facilitate the successful completion of this thesis.

It is my pleasure and proud privilege to convey my profound heartfelt appreciation to my respected teacher and supervisor, Professor Dr. Abu Torab M A Rahim, Institute of Nutrition and Food Science, University of Dhaka. His approval to carry out this thesis under his constant guidance, as well as his insightful counsel, motivation, helpful critique, and kind support, have been crucial to the laboratory work and thesis writing. I shall always remember his steadfast assistance and indispensable supervision. I am fortunate to have an advisor who provided the freedom to explore independently while offering crucial guidance when required. His insistence on high research standards and strict validation for each result has taught me the true essence of rigorous research. I will forever cherish his patience, generosity and faith in my potential.

I extend my sincere gratitude to my esteemed colleagues, both senior and junior scientists at Bangladesh Council of Scientific and Industrial Research (BCSIR). During the analytical phases of my work, their technical support, instrumental expertise, and professional cooperation were indispensable.

I would like to express special appreciation to Md. Afsar Uddin, Principal Technical Officer of INFS, as well as the dedicated Technical Officers and Lab Attendants at BCSIR, whose consistent assistance and goodwill greatly facilitated my research activities.

I am also profoundly grateful to the authorities of BCSIR and the Science & Technology Fellowship Trust (STFT) under the Ministry of Science & Technology for their technical and financial support and for establishing a facilitating environment that has enabled my research to flourish.

Finally, I express my deepest gratitude to my parents, family and friends whose support helped me to overcome obstacles and stay committed to my studies.

Author

Institute of Nutrition and Food Science

University of Dhaka

January, 2026

Table of Contents

	Title	Page No.
	Declaration	ii
	Certification	iii
	Abstract	iv-vi
	Dedication	vii
	Acknowledgement	viii
	Table of Contents	ix-xii
	List of Tables	xiii-xiv
	List of Figures	xv-xvi
	List of Abbreviations and Symbols	xvii
1.	Chapter 1	1-7
	Introduction	
1.1	Introduction	2-7
2.	Chapter 2	8-35
	Review of Literature	
2.1	Cereals and pseudograins	9
2.2	Nutritional composition	9
2.3	Secondary plant metabolites	10-11
2.4	Classification of secondary plant metabolites	11-12
2.5	Screening of secondary plant metabolites (SPMs)	13-17
2.6	Areas of SPMs research in Bangladesh	17-21
2.7	Study of polyphenolics of cereals, minor cereals and pseudograins of Bangladesh	22-23
2.8	Role of dietary phenolic compound	27-30
2.9	Anti-inflammatory function	30
2.10	Lipase inhibition mechanism (<i>in vitro</i>)	31-32
2.11	Lipase inhibitory polyphenolic compounds and their mechanism	33-35
3.	Chapter 3	36-37
	Objectives	
3.1	General objectives	37
3.2	Specific objectives	37
4.	Chapter 4	38-41
	Study Design	

4.1	Phase 1	39
4.2	Phase 2	40
4.3	Phase 3	40
4.4	Phase 4	41
5	Chapter 5 (Study Phase-1)	42-74
	Ethnographic Survey of Cereals and Pseudograins	
5.1	Introduction	43
5.2	Methodology	44
5.3	Planning and ethics	45
5.4	Interviews	45
5.5	Data collection	46
5.6	Result and discussion	47-57
5.7	Social and political impact on tradition agriculture system	58
5.8	Herbarium sheets	59-72
5.9	Discussions	73
5.10	Summary and recommendation	74-75
6.	Chapter 6 (Study phase -2)	76-104
	Nutrient and Polyphenolic Composition of Cereals and Pseudograins	
	Methodology	77- 85
6.1	Sample collection	77
6.2	Sample description	77
6.3	Sample preparation	77
6.4	Proximate analysis	81
6.4.1	Determination of moisture/water	80
6.4.2	Determination of ash	81
6.4.3	Determination of protein	81
6.4.4	Determination of fat	82
6.4.5	Determination of dietary fiber	83-84
6.4.6	Estimation of available carbohydrate	84
6.4.7	Calculation of energy in kilo-calorie (Kcal)	84
6.5	Compilation of mineral & vitamin values from secondary sources	85
6.6	Phytochemical analysis	85-94

6.6.1	Reagents and standards	85
6.6.2	Determination of total phenolic contents	85
6.6.3	Determination of total flavonoid contents	86
6.6.4	High Performance Liquid Chromatography screening for polyphenols	86
6.7	Statistical analysis	88
6.8	Result and discussion	88-99
6.8.1	Proximate content of food samples	88-89
6.8.2	Minerals and vitamins	93-94
6.8.3	Phytochemicals of cereals and pseudograins	95
6.8.3.1	Total phenolic content (TPC)	95
6.8.3.2	Total flavonoid content (TFC)	97
6.8.3.3	HPLC profiles of polyphenols in studied cereals and pseudocereals	100-102
6.9	Summary and recommendations	102-104
7.	Chapter 7 (Phase-3)	105-135
	Bioactivity of Cereals and Pseudograins	
7.1	Introduction	106
7.2	Methodology	106
7.2.1	Determination of total antioxidant content (TAC)	106
7.2.2	Antioxidant activity of cereals and pseudograins	107
7.2.3	Determination of antioxidant activity by DPPH (2,2-diphenyl-1-picrylhydrazyl)	108
7.2.4	Determination of antioxidant activity by ABTS (2,2-azino-bis-3-ethylbenzothialine-6-sulphonic acid)	109
7.2.5	Determination of antioxidant activity by FRAP	110
7.2.6	Determination of total tanin content (TTC)	111
7.2.7	Lipase inhibition activity of SPMs	112
7.2.8	Determination of antioxidant capacity of SPMs by IC ₅₀	113
7.3	Result and discussion	114
7.3.1	Total antioxidant content (TAC) of cereals and pseudograins	114
7.3.2	Antioxidant activity assay of cereals and pseudograins	116
7.3.2.1	Free radical neutralization assays	116
7.3.2.2	Free radical scavenging activity assay by DPPH	116
7.3.2.3	Free radical scavenging capacity by ABTS	119

7.3.2.4	Metal ion reduction assays	121
7.3.2.5	Ferric reducing antioxidant power (FRAP) assay	121
7.3.2.6	Quantitative measure of antioxidant capacity of the samples	122
7.3.3	Total Tanin Content (TTC)	124
7.3.4	Lipase Inhibition Capacity of Cereals and Pseudograins	126
7.3.4.1	Lipase inhibition by percentage and capacity index (IC ₅₀ value)	126
7.3.4.2	Correlation between lipase inhibition capacity and inhibitor concentration	131
7.4	Summary and recommendation	134
8.	Chapter 8 (Phase-4)	136-148
	Data Integration and Discussions	
8.1	Synthesis of Ethnographic data	137
8.1.1	Socio cultural factors and consumption patterns	137
8.1.2	Production and supply chain limitations	138
8.2	Implication of nutrient and polyphenol composition data	139
8.2.1	Correlation between IC ₅₀ value and polyphenolic components	141
8.2.2	Visualizing Pearson correlation coefficients by Heat Mapping	144
8.3	Lipase inhibition potential of cereals and pseudograins	146
8.4	Summary	148
8.5	Limitation	149
8.6	Recommendation	149
9.	Conclusion and recommendation	150-154
9.1	Conclusion	151
9.2	Recommendation	153
9.2.1	Scope of future research	153
10.	Bibliography	155-173
11.	Annexure	174-182
	Annexure 1, Case study	175-176
	Annexure 2, Minerals & vitamin compilation Excel Sheet	177
	Annexure 3, HPLC chromatograms	178-181
	Annexure 4, Study deliverables	182

List of Tables

Table No.	Title	Page No
2.1	General classification of phenolic compounds	13
2.2	Studies of SPMs conducted in Bangladesh	20-21
2.3	Polyphenol sources in cereal and pseudograins from different database, articles and reports	24-26
5.1	Key questions for Focus Group Discussions (FGD)	46
5.2	Agro-ecological zones (AEZ) of study samples of Bangladesh	47
5.3	Cereal production in Bangladesh (BBS, 2023, 35 th Series)	49
5.4	Per capita daily food grain consumption (in grams) from HIES, BIDS and IFPRI-BIHS.	51
5.5	Farming seasons in Bangladesh Identified by Focus group discussion (FGD)	52-53
5.6	Case Studies with cereal and pseudo cereal	55
5.7	Opinion Survey results of respondents identified by Focus group discussion (FGD)	57
5.8	Herbarium sheet identification table of selected samples	59
6.1	Botanical description of the collected food samples	78-80
6.2	Proximate composition of cereal samples	90
6.3	Proximate composition of pseudograin samples	90
6.4	Minerals content of cereals and pseudograins	91
6.5	Vitamins content of cereals and pseudograins	92
6.6	Total phenolic content (TPC) of cereals by dry extracts	96
6.7	Total flavonoid content (TFC) of cereal sample by dry extracts	97
6.8	Total phenolic content (TPC) and total flavonoid content (TFC) of pseudo grain sample extracts	97
6.9	Polyphenolic compounds screening by HPLC	98
6.10	Polyphenolic compounds screening by HPLC	99
6.11	Polyphenolic compounds screening by HPLC	100
7.1	Total Antioxidant content (TAC) of cereal sample extracts	115
7.2	Total Antioxidant content (TAC) sample extracts	115
7.3	Antioxidant capacity of cereal and pseudograin by IC ₅₀	124
7.4	Total Tanin content of cereal samples	126

7.5	Total Tanin content of pseudograin samples	126
7.6	Lipase inhibition capacity of study samples by IC ₅₀	131
7.7	Coefficient of determination (R^2), adjusted R^2 and P value of regression curve for the standard (Epicatechin) and samples (cereal and pseudograin)	134
8.1	Pearson correlation between polyphenolic compounds and IC ₅₀ values obtained from ABTS and DPPH radical scavenging assays	143

List of Figures

Fig. No.	Title	Page No.
2.1	General classification of secondary plant metabolites	12
2.2	Phenol structures	12
2.3	General mechanism of antioxidant activity	30
2.4	Lipase enzyme converts TG into FA	32
2.5	Polyphenolic compounds that have lipase inhibitory capacity	34
5.1	Agro ecological zones of Bangladesh	48
6.1	Flow chart of the SPMs extraction protocol	80
6.2	Standard curve for total phenolic content	96
6.3	Standard curve for total flavonoid content	96
7.1	Ascorbic Acid standard curve for total antioxidant capacity	115
7.2	Standard curve of Ascorbic Acid as DPPH standard	118
7.3	DPPH scavenging activity (%) of four cereal samples	118
7.4	DPPH scavenging activity (%) of five cereal samples	118
7.5	DPPH scavenging activity (%) of six pseudograins	118
7.6	Standard curve of Ascorbic Acid as ABTS standard	120
7.7	Free Radical Scavenging Capacity of red aman rice, black rice and wheat by ABTS	120
7.8	Free Radical Scavenging Capacity of six cereal samples by ABTS	120
7.9	Free Radical Scavenging Capacity of pseudo grain samples by ABTS	120
7.10	Standard curve of Ascorbic Acid as FRAP standard	123
7.11	Ferric reducing antioxidant power (FRAP) assay of red aman rice, black rice and wheat	123
7.12	Ferric reducing antioxidant power (FRAP) assay of six cereal samples	123
7.13	Ferric reducing antioxidant power (FRAP) assay of pseudograin samples	123
7.14	Tannic acid standard curve for total tannin content	125
7.15	Dose dependent lipase inhibition % of (-) Epicatechin	129
7.16	Dose dependent lipase inhibition % of black and red aman rice	129
7.17	Dose dependent Lipase inhibition % of Minor cereal	129
7.18	Dose dependent Lipase inhibition % of Pseudograins	129

7.19	Linear correlation between inhibition % and concentration	133
8.1	Pearson's correlation analysis of polyphenolic compounds identified in the methanolic extracts of 15 samples	144

List of Abbreviations and Symbols

SPMs	Secondary plant metabolites
AOMs	Anti-obesity medications
PM	Plant metabolites
TPC	Total Phenolic Content
TFC	Total Flavonoid Content
TAC	Total Antioxidant Content
TACa	Total Antioxidant Capacity
TTC	Total Tanin Content
DW	Dry weight
HPLC	High Performance Liquid Chromatography
QE	Quercetin
GA	Gallic acid
TA	Tannic acid
AA	Ascorbic acid
Ec	Epicatechin
NaOH	Sodium hydroxide
HCl	Hydrochloric acid
BBS	Bangladesh Bureau of Statistics
BARI	Bangladesh Agricultural Research Institute
BRRI	Bangladesh Rice Research Institute
DE	Dry Extract
UVS	Ultraviolet-visible Spectrophotometer
AOAC	Association of Analytical Chemist
USDA	US Department of Agriculture
FAO	Food and Agricultural Organization
PL	Pancreatic Lipase
YBW	Yellow buckwheat
BBW	Black buckwheat
mg/mL	milligram/milliliter
µg/mL	microgram/milliliter
µL	microliter
L	Liter
gm	gram
mg	milligram
kg	Kilogram
Et al.,	Association
%	Percentages
IC ₅₀	Half maximal Inhibitory Concentration

Chapter 1

Introduction

1. Introduction

The World Obesity Federation estimated that 800 million people were living with obesity as of 2020. The World Health Organization has affirmed that global mortality is predominantly contributed by the increasing prevalence of overweight and obesity which surpassed existing under nutrition status. The matter of the fact is that, rising prevalence of obesity has been well correlated with an elevated risk of various chronic metabolic diseases viz., cardiovascular diseases, type 2 diabetes, kidney degradation, cancer, and osteoarthritis (Hales et al., 2020). Apart from global perspective, a triple burden of malnutrition persists in Bangladesh that comprises under nutrition, over nutrition, and micronutrient deficiencies. Recently Banik, S., Rahman (2018), in a systematic review, revealed a noticeable upward trend in overweight and obesity across all age and gender groups in Bangladesh.

Obesity is the befall of energy intake, due to storing of triglycerides (TG) in adipose tissues, when exceeds energy expenditure (Bray, 2004). More precisely, overweight and obesity are the obvious consequences of excessive intake of calorie and physical inactivity over time aided by a complex interplay of obesogenic environments, of which the most notable one is the food environment. Modern societies usually offer abundant, inexpensive, and heavily marketed high-calorie, fat-dense foods like fast foods, processed snacks, and sugary drinks. This food culture is notoriously obesogenic and immensely popular around the Globe. Being a country of the increasing Global village, Bangladesh is no exception from this toxic food environment. As a result, overweight and obesity especially abdominal obesity is on the rise among young population (Kabir et al., 2023).

From pathophysiological perspective, obesity is primarily initiated by adipocyte hypertrophy, the enlargement of individual fat cells, which occurs when TG synthesis exceeds its breakdown (lipolysis). As adipose tissue (adipocytes) expands particularly the dysfunctional and hypertrophic, it creates a self-perpetuating cycle that drives further metabolic problems and weight gain. This occurs through a sequence of events involving metabolic dysfunction, chronic inflammation, and altered hormone signaling thereby resulting in a disrupted lipoproteins clearance (Klop et al., 2013; Matar et al., 2025) indicating a consequence of dyslipidemia. A recent report indicated overall too high dyslipidemia prevalence (76.7%) in Bangladesh (Jahan et al., 2023) which is marked by high TG level (35.7%), high LDL-C level (18.5%) while showing a low HDL-C level (63.8%) among the study participants. While obesity itself is a major contributor of hyperlipidemia due to excess circulating fat that affecting lipid metabolism, increased blood levels of triglycerides and LDL-cholesterol very often seen in obesity are found to be correlated with impaired insulin sensitivity, an effector of *de novo* lipid synthesis.

Intestinal fat absorption of human is a very efficient process as approximately 95% of ingested fat is absorbed (Carey, 1983). Digestive lipase in the small intestine is an essential enzyme that hydrolyzes lipids, the ester bonds in TG, to form fatty acids and glycerol. The inhibition of pancreatic lipase (PL) is, therefore, regarded one of the plausible mechanisms to decrease blood TG in normal people (Barbara et al., 2025; Thomson et al., 1997; Tucci et al., 2010). Moreover, inhibition of lipase results incomplete digestion of lipid and hence allows lipid to coat food particles and therefore interferes with the breakdown of other food components such as protein and carbohydrates and thereby exerting an anti-obesity activity (Tucci et al., 2010). Therefore, to cope obesity and overweight, diminishing the activity of enzymes (pancreatic lipase) responsible

for fat digestion by blocking TG hydrolysis remains to be investigated (Barbara et al., 2025; Rahim et al., 2015).

From an immense volume of empirical researches, it is understood that one unifying aspect sprouted in enzyme inhibition scheme, instead of synthetic inhibitor (drug), is using the functional effect of plant secondary metabolites in their ability to inhibit digestive enzymes (Melzig, 2023; Tucci et al., 2010). As a matter of fact, plant polyphenols inhibit nonspecifically the main hydrolytic enzymes in the digestion process, e.g., amylases, proteases, lipases (Rahim et al., 2015; Tucci et al., 2010). So, when absorption is impaired, two key events happen simultaneously that lead to compromised nutritional status: i) Nutrient deficiency in the host - The body's cells do not receive enough monosaccharaides (from carbohydrates), fatty acids (from fats), and amino acids (from proteins); ii) Increased substrate availability for the gut microbiome - The unabsorbed nutrients continue their journey to the ileum and colon, where the gut microbiota ferments and metabolizes. The resulting postprandial blood concentration of monosaccharaides, fatty, and amino acids in blood is decreased to causing different metabolic pathways proceed more slowly (Melzig, 2023).

Obesity pharmacotherapy has amplified significantly over the past 60 years. Up to now, six anti-obesity medications (AOMs) have been approved by the Federal Drug Administration (FDA) of USA for long-term treatment of obesity (Tchang et al., 2021). Most of these drugs are mainly synthesized inhibitors of lipase and HMG-CoA reductase. However, the problem of using these AOMs to treat obesity by preventing the breakdown and absorption of dietary fats is not free of side effects. They are also associated with various health problems, for example, the most well-known lipase inhibitor, orlistat, cause a range of gastrointestinal issues and can lead to nutrient deficiencies and, in rare cases, liver or kidney problems (Bansal et al., 2024; Buchholz &

Melzig, 2015). Alternately, Lipase modulators, which are both activators and inhibitors, are being studied for pharmaceutical use, particularly for weight loss and treating obesity. These modulators are either sourced from nature (plants, animals, and microbes) or are artificially synthesized (Jawed et al., 2019). The development of lipase modulators is an active area of research for therapeutic and diagnostic applications.

Since usage of AOMs is compromised by unpleasant gastrointestinal adverse reactions (oily stools, oily spotting, flatulence), alternate use of plant metabolites as a potential source of obesity treatment venture are generally considered to have less toxic and side effects than totally synthetic drugs. One of the most important sources of potential pancreatic lipase inhibitors represents the class of polyphenols (Buchholz & Melzig, 2015). Earlier, De La Garza et al. (2011) reported that polyphenolic metabolites included in fruits, vegetables, and cereals exhibit *in vitro* lipase inhibitory activity. In pursuit of identifying effective natural lipase inhibitors, researchers have explored plant secondary metabolites for their biological potential since last two decades (Pandey & Rizvi, 2009; Rahim et al., 2015).

Polyphenol content is not fixed; it is influenced by environmental factors such as soil composition, climate, altitude, and sun exposure (Brahmi et al., 2022). Evaluating local crops helps researchers understand how these variables affect the phytochemical profile, which can inform cultivation practices to maximize health-promoting compounds. Given the recognized health-promoting properties of polyphenols, it is vital to evaluate their qualitative and quantitative presence in regionally grown agricultural commodities. Cereals and pseudograins are prominent dietary sources of phenolic acids such as gallic and ferulic acids (Gorinstein et al., 2007; Pasko et al., 2008). Grain crops include rice, wheat, maize, barley, millet, and oats, are gramineous plants cultivated for their starchy, nutrient-rich seeds. They are typically composed

of approximately 75% complex carbohydrates and about 10% protein, along with varying amounts of lipids and dietary fiber.

The scavenging effects of polyphenols derived from grains are amplified *in vivo* through synergistic interactions among different bioactive molecules, which help diminish excessive free radicals (Tian et al., 2019). *In vitro* studies using four common antioxidant assays viz., DPPH, ABTS, FRAP, and ORAC have validated the free radical scavenging capabilities of whole-grain polyphenols. These non-nutritive phytochemicals are essential to the antioxidant properties of whole grains. This antioxidative potential is primarily attributed to their high concentrations of ferulic acid, oxalic acid, p-coumaric acid, caffeic acid, and various flavonoids and anthocyanins (Deng et al., 2012). Additionally, PM have shown the ability to inhibit several enzymes involved in lipid metabolism (Martinez et al., 2017; Rahim et al., 2015). Despite being rich in dietary polyphenols, whole grains have historically received less attention than fruits and vegetables regarding their biological value (Tian et al., 2019). As secondary metabolites, their physiological impact depends largely on dietary intake.

Bangladesh Bureau of Statistics (BBS, 2023) consider rice and wheat as major grain crops, while barley, millets (proso and foxtail), maize and oats categorized as secondary cereals. Pseudograins, or pseudocereals, though botanically distinct, resemble cereals in terms of nutrient content and functional properties. Often referred to as "grains of the 21st century" (Gezici, 2019; Martínez et al., 2020), they have attracted increasing agricultural and nutritional interest. The present study studied the ethnography of locally grown and available minor cereals and pseudograins with a production yield of 1245 kg/acre for wheat and 3245 kg/acre for maize in 2019, reflecting a growing trend in the cultivation of minor cereals in Bangladesh of (Rupa & Rahim, 2023). Agricultural researchers are exploring the commercial potential of colored rice

and pseudograins such as quinoa, chia and buckwheat due to their exceptional nutritional and pharmacological attribute. Notably, colored (red and black) rice variants demonstrate superior nutritional and phytochemical profiles compared to regular rice (Bolea & Vizireanu, 2017; Mazumdar et al., 2022; Pradipta et al., 2020). Pseudograins such as quinoa, buckwheat, and chia are particularly rich in macronutrients (including proteins, fibers, and fats), micronutrients (vitamins and minerals), and phytonutrients such as phenolics, flavonoids, and sterols. Their low gluten content further supports their consumption by individuals with gluten intolerance (Agarwal et al., 2023; Raguindin et al., 2021). Although these pigmented grains and dicotyledonous pseudocereals are known to encompass diverse biologically active compounds, the health advantages of local varieties remain insufficiently explored. High-Performance Liquid Chromatography (HPLC) analyses have detected gallic acid and ferulic acid in cereals, and anthocyanins in black rice. Of the flavonoids tested, gallic acid displayed strong competitive inhibition of pancreatic lipase, with low IC_{50} values indicating potent activity (Rahim et al., 2015). These antioxidant phenolic acids may offer therapeutic level values to lipase inhibition, especially for individuals with hyperlipidemia.

Indigenous Bangladeshi cereals and pseudocereals, however, still needed to be investigated for their potential health benefits, particularly regarding weight regulation and obesity. There is a lack of scientific data on these crops by collecting and analyzing their nutritional, phytochemical, and bioactivity information. This dissertation research explored indigenous and locally available cereals, minor cereals, and pseudograins to depict their potentials as functional foods for weight regulation and obesity management. Through phased studies, the research sought to close knowledge gaps regarding the grains' properties and their ability to inhibit lipase, an enzyme that breaks down fat.

Chapter 2

Review of Literature

2.1 Cereals and pseudograins

Bangladesh Bureau of Statistics (BBS, 2023) reported that, rice (*Oryza sativa*) and wheat (*Triticum aestivum*) are categorized as major cereal crops, whereas barley (*Hordeum vulgare*), maize (*Zea mays*), oat (*Avena sativa*), proso millet (*Panicum miliaceum*), and foxtail millet (*Setaria italica*) are listed as minor cereals in national crop statistics. Bangladeshi agricultural researchers are presently examining the development of colored rice because of their significant nutritional benefits. Black and red are most common colored-varieties of *Oryza sativa*. They have exceptional nutritional and phytochemical attributes that substantially enhance human health, exceeding those of other rice cultivars (Bolea & Vizireanu, 2017; Mazumdar et al., 2022; Pradipta et al., 2020).

The BBS report also quantitated agricultural produce data of wheat yields as 1245 kg per acre and cultivated land for minor cereals in 4813 hectares where foxtail millet accounting for the largest share (63.0%) followed by Proso millet (28.2%), barley (7.5%), pearl millet (0.6%), and oats (0.6%) respectively (BBS 2023). The growing attention toward crops such as millets, oats, and sorghum in Bangladesh is primarily speculated to be attributed to their high nutritional content and emerging functional food potential (Akhi et al., 2023).

2.2 Nutritional composition

Cereals are staples worldwide, providing critical nutrients and energy, but their health benefits and nutritional value depend on whether they are consumed as whole grains or refined grains. Whole grains (primary and secondary cereals) retain all three parts of the grain kernel—the bran, endosperm, and germ are the richest source of vitamins, fiber, minerals, and health-promoting phytochemicals. Refined grains, which have had the bran and germ removed, lose most of these beneficial components (Islam et al., 2022). A dietary focus on gluten-free, non-acidic grains with

a low glycemic index (GI) and gentle digestive profile is beneficial for individuals need to managing diabetes or celiac disease. These grains address the specific challenges of both conditions by preventing blood sugar spikes, reducing gastrointestinal distress, and avoiding the inflammatory trigger of gluten (Geetha et al., 2020). Based on increasing epidemiological evidence, consuming cereal grains, particularly minor cereals like millets, deliver significant health benefits that help reduce the risk of chronic diseases like cardiovascular disease (CVD), diabetes, and cancer. All kind of millets are rich in nutritional components and nutraceuticals that provide antioxidant, anti-inflammatory and antidiabetic effects (Sharma et al., 2020; Tian et al., 2019).

2.3 Secondary plant metabolites

Secondary plant metabolites encompass a diverse array of chemical compounds produced by plant cells via metabolic pathways that diverge from primary metabolic processes (Bottger, 2018). The secondary plant metabolites (SPMs) are organic substances produced via specialized metabolic pathways that branch off from primary metabolism, and they are not directly involved in the plant's normal growth, development, or reproduction. While primary plant metabolites are directly involved in fundamental functions, including metabolism, growth, and reproduction of plants, SPMs involved in mediating ecological interactions and providing a competitive advantage, but are not essential for survival under normal conditions. They are often restricted to specific species, families, or genera, or to certain plant tissues and life stages (Francesca et al., 2020; Teoh, 2016).

SPMs are not essential for a plant's immediate survival or reproduction. Their absence does not lead to immediate death but can impair long-term survivability in a natural environment. However, their absence would leave a plant vulnerable to predators, disease, and environmental

hazards. SPMs are highly influential in mediating the relationship between plants and their environment. There are over 50,000 known SPMs with a wide range of chemical structures and produced in minimal quantities. They are generally categorized into three major groups based on their biosynthetic origins: terpenes, phenolics, and nitrogen-containing compounds (alkaloids). The quantity and type of SPMs can differ greatly depending on the plant species, developmental stage, and environmental conditions. They may be stored in specific plant tissues, such as the vacuole, to prevent self-toxicity (Jan et al., 2021; Kabir et al., 2023).

2.4 Classification of secondary plant metabolites

As outlined by Gezici (2019), plants synthesize a wide range of chemical substances, which are generally divided into two main groups: primary and secondary metabolites. Primary metabolites—such as sugars, proteins, and amino acids—are crucial for the basic growth and development of plants. In contrast, secondary metabolites are not directly involved in the plant's essential life processes. Instead, these compounds are typically stored in specific plant tissues and play a defensive role, protecting the plant against microbial infections. The overall classification of plant secondary metabolites is depicted in Figure 2.1.

Phenolic compounds represent a broad category of bioactive secondary metabolites that hold considerable significance in this investigation. Phenolic compounds are defined as substances that contain a phenol moiety. Phenol consists of a benzene ring with an attached hydroxyl group (Figure 2.2). Consequently, its formal designation is hydroxybenzene. Phenolic chemicals are generally categorized into two primary groups: simple and polyphenolic compounds (Cheynier, 2012; Mamari, 2021).

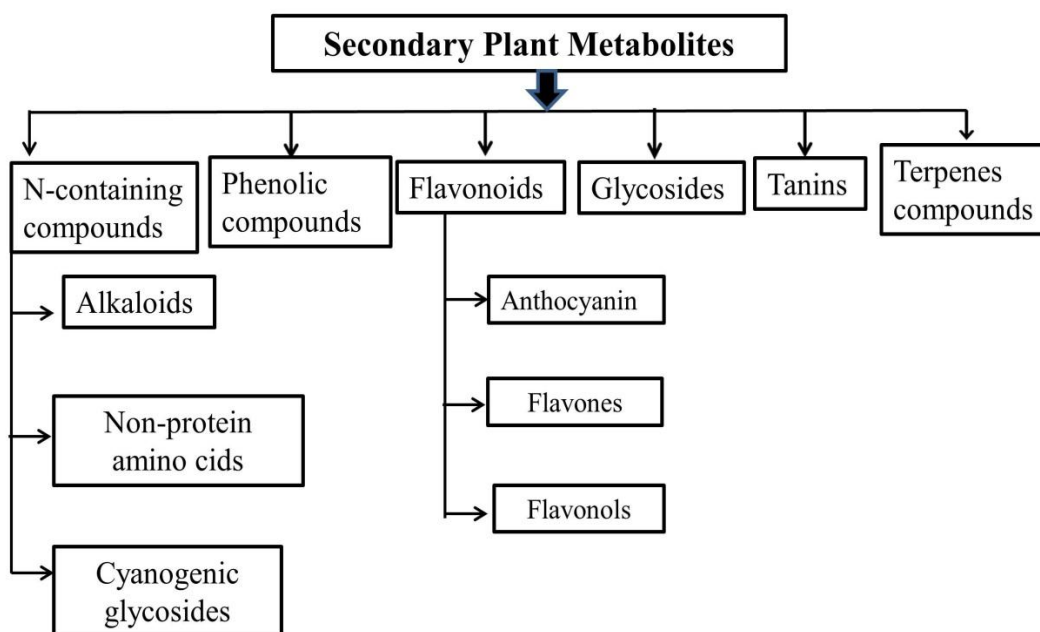


Figure 2.1: General classification of secondary plant metabolites

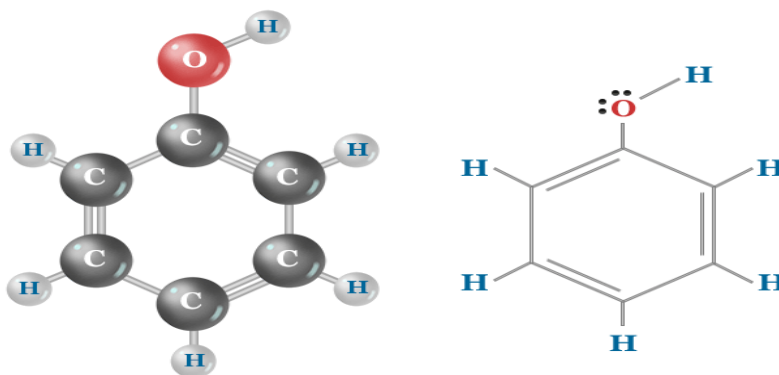


Figure 2.2: Phenol structure

Table 2.1: General classification of phenolic compounds

Phenolic Compounds	Sub groups of phenolic compounds	Examples
1. Simple Phenolic compounds	i. Simple phenolic	Catechol, resorcinol, hydroquinone, Pyrogallol, hydroquinol, phloroglucinol
	ii. Phenolic acid	
	a. Hydroxybenzoic acid	Hydroxybenzoic acid, di-hydroxy benzoic acid, tri-hydroxy benzoic acid (Gallic acid)
	b. Hydroxyl cinnamic acid	
2. Polyphenolic Compounds	c. Coumarin	Cinnamic acid, ferulic acid, sinapic acid, caffeic acid
	i. Flavonoids	
	a. flavone	Leutinine
	b. Flavonols	Kaemperferol
	c. Chalcone	Chalcone
	d. Anthocyanine	delphinidin
	e. Flavonone	naringenin
	f. Iso flavone	diadzein
	ii. Tanins	Tannic acid
	iii. Stillbenes	Cathechin, anthocyanidin
	iv. Lignans, lignins	

(Source, Mamari, 2021)

2.5 Screening of secondary plant metabolites (SPMs)

The methodology for analyzing secondary plant metabolites (SPMs) is a multi-step process that uses a variety of advanced analytical techniques at each stage to move from a raw natural source to a fully characterized compound with a known biological effect (Francesca et al., 2020; Khade et al., 2023). Briefly, the comprehensive methodology for examining SPMs encompasses multiple stages: extracting SPMs from natural sources, performing phytochemical screening of

the extracts to ascertain the predominant chemical classes present, purifying individual constituents and elucidating their chemical structures, and ultimately assessing the biological activity of the SPMs via *in vitro* and *in vivo* assays employing a combination of many analytical techniques (Francesca et al., 2020; Guerriero et al., 2018).

2.5.1 Extraction of SPMs

The initial and crucial step for isolating compounds from the plant matrix is extraction. The choice of extraction method depends on the nature of the plant material and the target SPMs. Techniques include the followings:

2.5.1.1 Maceration: A simple method where powdered plant material is soaked in a solvent at room temperature for an extended period, with occasional shaking. It is suitable for stable compounds but is less efficient than other methods.

2.5.1.2 Soxhlet extraction: A continuous, semi-automated method that uses repeated washing of the sample with a hot solvent under reflux. This is more efficient for extracting compounds with poor solubility but is not suitable for thermo labile (heat-sensitive) compounds.

2.5.1.3 Microwave-assisted extraction (MAE): This technique uses microwave energy to heat solvents and the sample, increasing the efficiency of compound extraction by promoting the partitioning of the target compounds.

2.5.1.4 Ultrasound-assisted extraction (UAE): Uses high-frequency sound waves to create cavitation bubbles, which help rupture cell walls and release SPMs. It requires less solvent and is faster than conventional methods.

2.5.1.5 Supercritical fluid extraction (SFE): A modern method using supercritical fluids, like CO₂, as the solvent. It is a rapid and environmentally friendly technique, especially useful for extracting thermo labile compounds.

2.5.2 Phytochemical screening of extracts

After extraction, a preliminary screening is performed to identify the broad chemical classes of compounds present in the crude extract. This helps guide the subsequent purification process. Techniques are the followings:

2.5.2.1 Colorimetric tests: Simple chemical tests that produce a specific color change or precipitate, confirming the presence of particular compound classes, such as alkaloids, flavonoids, tannins, and saponins.

2.5.2.2 Thin-layer chromatography (TLC): A simple and cost-effective chromatography technique used to separate and visualize components of a mixture. It provides a visual profile of the compounds present, indicating the complexity of the mixture.

2.5.3 Purification and structure elucidation

Purifying individual compounds from a complex mixture is a significant challenge in natural products research and requires a combination of high-performance separation and advanced spectroscopic techniques. Techniques include:

2.5.3.1 High-performance liquid chromatography (HPLC): The gold standard for separating and purifying complex mixtures. Preparative HPLC can be used to isolate individual compounds in pure form.

2.5.3.2 Mass spectrometry (MS): Provides a precise determination of the molecular weight and elemental composition of a compound. Tandem mass spectrometry (MS/MS) helps to determine the structure by fragmenting the molecular ion and analyzing the pieces.

2.5.3.3 Nuclear magnetic resonance (NMR) spectroscopy: A powerful, non-destructive technique that reveals the complete molecular skeleton of a compound. Both 1D (^1H , ^{13}C) and 2D (COSY, HSQC, HMBC) NMR experiments are used to determine connectivity and

stereochemistry. High-field instruments with cryogenic probes enable structure elucidation with sub-milligram sample quantities.

2.5.3.4 X-ray crystallography: Provides the definitive 3D structure of a compound, including its absolute stereochemistry, but requires a high-quality crystal.

2.5.3.5 Infrared (IR) spectroscopy: Used to identify the functional groups present in a molecule by measuring the vibration of its chemical bonds.

2.5.4 Biological activity assessment

The final stage involves testing the biological effects of the isolated compounds. This is typically done through a combination of *in vitro* and *in vivo* assays. Techniques include are the followings:

2.5.4.1 *In vitro* assays: Experiments conducted outside of a living organism, typically in a test tube or culture dish, using isolated cells, enzymes, or receptors.

- i) High-throughput screening: A rapid method for testing a large number of compounds against a specific biological target, such as a cancer cell line or a bacterial strain.
- ii) Cytotoxicity assays: Assess the toxicity of a compound against cultured mammalian cells.
- iii) Enzyme inhibition assays: Measure the ability of a compound to inhibit a specific enzyme, which can reveal its mechanism of action.

2.5.4.2 *In vivo* assays: Experiments conducted on living organisms, such as lab animals or humans, to study the compound's effects within a complex physiological system.

- i) Animal models: Used to assess the efficacy, safety, and pharmacokinetics of a compound, including potential side effects.

- ii) Clinical trials: Involving human subjects, these are the final stage of drug testing and determine the compound's therapeutic value and safety in people.

2.5.4.3 *In silico* (computational) analysis: A computational approach for analyzing biological and chemical data, including molecular docking simulations that predict how a compound will bind to its target protein.

2.6 SPMs research in Bangladesh

Extensive studies in Bangladesh have been conducted on the polyphenolic compounds found in local medicinal plants, common seasonal and exotic fruits, citrus fruits, honey, etc. These natural compounds offer potential applications in medicine and in food industry as natural, health-promoting agents that cope oxidative stress (Table 2.2).

2.6.1 Indigenous medicinal and wild edible plants

Bangladeshi researchers are exploring indigenous plants and wild edibles that have been used in traditional medicine for their potential health benefits.

- i. A 2021 study investigated 15 indigenous plants, including *Moringa oleifera*, and found varying levels of polyphenolic compounds with significant antioxidant capacity (Ahmed et al., 2021)
- ii. Another study assessed the antioxidant, antidiabetic, and polyphenolic properties of five selected wild edible plants (Alam et al., 2020).
- iii. Research has also focused on specific plants like the mangrove species *Viscum monoicum*, identifying polyphenolic compounds such as gallic acid, vanillic acid, and quercetin (Ahmed et al., 2023).

2.6.2 Seasonal and exotic fruits and vegetables

Numerous indigenous seasonal and exotic fruits have been examined for their phenolic and antioxidant compounds.

- i. Research has shown that some indigenous seasonal fruits, such as mango, wood apple, blackberry, Kamranga, Dragon fruit, and jackfruit, contain high levels of polyphenols and act as potential dietary antioxidants (Ahmad, 2024; S. Islam et al., 2015; Mamun et al., 2012; Rhaman et al., 2022).
- ii. A 2024 study analyzed the antioxidant activity and bioactive compounds of 23 fruit species in Bangladesh, finding high total phenolic content (TPC) in mango and katajamini (Ahmad, 2024).
- iii. Studies on vegetables have examined local leafy greens like *Chenopodium album*, which was found to have a high total phenolic content and antioxidant activity (Poonia and Upadhayay, 2015).
- iv. Studies on edible Mangrove fruits like *Carallia decandra* from the Sundarban has shown a strong correlation between total polyphenols and antioxidant (Nazrul et al., 2020).
- v. Citrus fruits are known for their antioxidant properties, and Bangladeshi varieties are no exception. As like satkora peels from this indigenous citrus fruit of the Sylhet region have shown high total phenolic content and strong antibacterial activity against pathogens like *E. coli* (Hasan et al., 2022).

2.6.3 Tea varieties

The phenolic content of different types of Bangladeshi tea has been analyzed for its potential health benefits.

- i. A comparative study of black tea varieties (flowery broken orange pekoe, broken orange pekoe, and red dust) and green tea found that green tea contained higher levels of total polyphenols, flavonoids, and antioxidant activity (Nibir et al., 2017).

2.6.4 Honey

Honey, particularly multi floral varieties, has been studied in Bangladesh and shown to have excellent antioxidant potential.

- i. Multi floral honey: This honey, derived from diverse floral sources, contains high levels of phenolic compounds, flavonoids, and other antioxidants. The variety from the Sundarban mangrove forest is noted for its high antioxidant capacity and rich mineral content (Islam et al., 2015).
- ii. Mono floral honey: Varieties like kalijira (black seed) honey also exhibit superior antioxidant properties, indicating that the botanical source significantly influences the honey's composition (Islam et al., 2012).

2.6.5 Cereals and pseudograins

Bangladeshi researchers have studied the polyphenolic content of locally grown cereals and pseudograins to understand their functional properties.

- i. A 2024 study compared local cereals (bajra, zob, cheena, and kaon) and pseudograins (quinoa and chia). It found that locally grown bajra had a significantly higher concentration of total phenolics and flavonoids (Rupa et al., 2024).
- ii. Research has also explored the nutritional and antioxidant properties of foxtail millet, a common cereal in Bangladesh (Rupa et al., 2025).

Table 2.2: Studies of SPMs conducted in Bangladesh

Foods/Medicinal plants	Title of the articles	References
Seasonal Fruits	Hydrophilic antioxidant capacities and total phenol content of seasonal fruits of Bangladesh. Malaysian journal of nutrition	Mamun et al., 2012
Honey	Identification of phenolic acids and flavonoids in mono floral honey from Bangladesh by high performance liquid chromatography: determination of antioxidant capacity.	(Moniruzzaman et al., 2014)
Medicinal plants	Polyphenols profile and antioxidant capacity of selected medicinal plants of Bangladesh.	(Shaheen et al., 2021)
Fruits	Antioxidant activity and bioactive compounds of fruits available in Bangladesh	Ahmad, 2024
Medicinal plant extractives	Unveiling the apoptotic potential of antioxidant-rich Bangladeshi medicinal plant extractives and computational modeling to identify antitumor compounds	(Haque et al., 2024)
Common seasonal fruits	Antioxidant activity of some common seasonal fruits of Bangladesh	Islam et al., 2015
Stored honey	Physicochemical and antioxidant properties of Bangladeshi honeys stored for more than one year	Islam et al., 2012
Medicinal plants	Pharmacological evaluation of Bangladeshi medicinal plants - a Review.	(Rahman et al., 2001)
Edible fruits from mangrove forest	Comparison of physicochemical and antioxidant properties of edible fruits in the Sundarban mangrove forest, Bangladesh.	(Nazrul et al., 2020)

Citrus fruits (Sylhet)	Antimicrobial activity of peels and physicochemical properties of juice prepared from indigenous citrus fruits of Sylhet region, Bangladesh.	(Hasan et al., 2022)
Medicinal plants	Anti-Inflammatory medicinal plants of Bangladesh- a pharmacological evaluation.	(Most, 2022)
Fruit, Kamranga	Evaluation of total phenolic, flavonoid content and antioxidant capacity of different parts of <i>Averrhoa carambola</i> L.	(Rhaman et al., 2022)
Medicinal plants	<i>Viscum monoicum</i> : A new source of polyphenolic compounds responsible for antioxidant and anti-inflammatory activities.	(Ahmed et al., 2023)
Seaweeds (Bay of Bengal)	Effects of extracting solvents on phytochemical, antioxidant, and antibacterial activity of some seaweeds from the Bay of Bengal offshore Island	(Emu et al., 2023)
Tribal fruits	Comparative assessment of nutritional composition, polyphenol profile, antidiabetic and antioxidative properties of selected edible wild plant species of Bangladesh.	(Alam et al., 2020)
Tea	Comparative assessment of total polyphenols, antioxidant and antimicrobial activity of different tea varieties of Bangladesh.	(Nibir et al., 2017)
Leafy vegetables (Khadamarech shak, Gima shak)	Chromatographic profiling of bioactive polyphenolic compounds and antioxidant evaluation of ethnobotanical leafy vegetables (<i>Amaranthus spinosus</i> and <i>Glinus oppositifolius</i>) from the hilly regions of Bangladesh	(Abdullah et al., 2024)
Minor cereals and Pseudograins	Nutritive, polyphenolic and antioxidative properties of locally produced cereals and pseudograins.	(Rupa et al., 2024)
Pigmented rice, grains and pseudograins.	Nutritional, phytochemical and antioxidant properties of Bangladeshi pigmented rice (red and black), grains and pseudograins.	(Rupa et al., 2025)

2.7 Phytochemicals of cereals and pseudograins

Polyphenols are defensive molecules found in all structural components of cereals in abundances (Tian et al., 2019). The two nutritionally significant polyphenols highlighted are flavonoids and phenolic acids, which are also widespread in many other foods (Abbas et al., 2017). Phenolic acids derived from plants provide approximately one-third of the polyphenolic chemicals in the human diet, encompassing two primary categories: hydroxybenzoic acid derivatives and hydroxycinnamic acid derivatives (Abbas et al., 2017; Tian et al., 2019).

The human body is incapable of synthesizing phenolic chemicals, which are mostly acquired through diet. Whole grains, specifically, are an excellent source of dietary polyphenols. The polyphenol content and biological activity of cereals have historically been neglected relative to those of fruits and vegetables (Tian et al., 2019). In this context of Bangladesh, only two articles from the research works of this dissertation have been published.

Oats, barley, corn and millets are vital components in the food industry for the production of biscuits, cakes, noodles, beverages and soups due to their exceptional nutritional value (Yang et al., 2013). An ethnographic study conducted earlier, which is an integral component of this dissertation revealed that despite government efforts to promote crop diversification and sustainable agriculture, the cultivation, marketing, and consumption of pseudo-grains like quinoa and amaranth are under developed in Bangladesh compared to traditional cereals like rice (Rupa & Rahim, 2023). Rice and wheat dominate Bangladeshi agriculture, occupying most of the cropped land and agricultural research, leaving little space and resources for pseudo-grains.

Pseudo-grains, which are high in protein, fiber, and micronutrients and are naturally gluten-free, offer significant nutritional and health benefits. However, recent trend of healthy food consumption shed light on these pseudograins such as, buckwheat (*Fagopyrum esculentum*), quinoa (*Chenopodium quinoa*), and chia (*Salvia hispanica*). These crops have also started appearing in retail markets, indicating their gradual integration into mainstream food systems.

Table 2.3: Polyphenol sources in cereal and pseudograins from different database, articles and reports

Name of Cereals and pseudograins	Polyphenol compounds/ Phenol class	References / database sources
Red Rice (<i>Oryza sativa L.</i>)	Anthocyanin, proanthocyanin Hydroxybenzoic acid (Protocatechuic acid, <i>p</i> -hydrobenzoic acid; gallic acid vanillic acid), Hydroxycinnamic acid (syringic acid , <i>p</i> -coumaric acid , ferulic acid , sinapic acid)	(Jun et al., 2012; Thitipramote et al., 2016)
Black rice (<i>Oryza sativa L.</i>)	Cyanidin-3-sophorose, Cyanidin-3-O-glucoside, Peonidin-3-glucoside, Procyanidins glucoside, Caffeic acid hexose, Procyanidin B2-3-O-gallate hexose, Epiafzelchin-epicatechin-O-di methylgallate	(Jun et al., 2012; Xie et al., 2017)
Rice (<i>Oryza sativa L.</i>)	Hydroxybenzoic acid (Protocatechuic acid, <i>p</i> -hydrobenzoic acid; gallic acid vanillic acid), Hydroxycinnamic acid (syringic acid , <i>p</i> -coumaric acid , ferulic acid , sinapic acid)	
	Hydroxycinnamic acids, isoflavones, lignans, flavan-3-ols, P-Coumaric acid	Phenol-Explorer ePlantLIBRA/eBASIS § USDA Database 3.1 Gorinstein et al., 2008

Wheat (<i>Triticum aestivum</i> L. <i>ssp. aestivum</i>)	Flavones, hydroxycinnamic acids, lignans anthocyanidins P-Coumaric acid	Phenol-Explorer ePlantLIBRA/eBASIS §/USDA Database 3.1 (Bianca et al., 2024; Boz, 2015)
Barley (<i>Hordeum vulgare</i> L. <i>ssp.</i> <i>vulgare</i>)	Flavanols, lignans, isoflavones, flavan-3-ols, P- Coumaric acid	Phenol-Explorer ePlantLIBRA/eBASIS § USDA Database 3.1 (Bianca et al., 2024; Boz, 2015)
Maize (<i>Zea mays</i> L.)	Anthocyanins, hydroxybenzoic acids, hydroxycinnamic acids, lignans, p-coumaric acid	Phenol-Explorer ePlantLIBRA/eBASIS (Bianca et al., 2024; Boz, 2015)
Sorghum (<i>Sorghum bicolor</i> L.)	Flavanols (proanthocyanidins), flavones, lignans, cinnamic acid derivatives flavanones, p-coumaric acid	Phenol-Explorer ePlantLIBRA/eBASIS §/USDA Database 3.1 (Bianca et al., 2024; Boz, 2015)
Oat (<i>Avena sativa</i> L.)	Hydroxycinnamic acids, lignans isoflavones, p- coumaric acid	Phenol-Explorer ePlantLIBRA/eBASIS (Boz, 2015)
Pearl millet (<i>Pennisetum</i> <i>glacum</i>)	syringic acid, gallic acid, vanillic acid, 4- hydroxyl benzoic acid, and hydroxycinnamic acid derivatives including caffeic acid, ferulic acid, and sinapic acid	(Chandrasekara & Shahidi, 2010)

Proso millet (<i>Panicum miliaceum</i> L)	syringic acid, gallic acid, vanillic acid, 4- hydroxyl benzoic acid, and hydroxycinnamic acid derivatives viz., caffeic acid, ferulic acid, sinapic acid.	(Chandrasekara & Shahidi, 2010)
Foxtail millet (<i>Setaria italica</i>)	syringic acid, gallic acid, vanillic acid, 4- hydroxyl benzoic acid, and hydroxycinnamic acid derivatives including caffeic acid, ferulic acid, and sinapic acid .	(Chandrasekara & Shahidi, 2010; Hithamani & Srinivasan, 2014)
Buck wheat (<i>Fagopyrum esculentum</i>)	Isorientin, kaempferol, vitexin, isovitexin, quercetin, rutin	(Zhong et al., 2022)
Chia (<i>Salvia hispanica</i>)	Hydroxybenzoic acid (Protocatechuic acid, cis-p-coumaric acid , trans-p-Coumaric cis-caffeic acid, trans-caffeic acid, carboxy p-hydroxybenzoic acid, hydroxycoumaric acid, cis-ferulic acid, trans-ferulic acid, cis-hydroxycaffeic acid, cis-Sinapic acid, ellagic acid, rosmarinic acid, flavonoids & procyanidins , myricetin, quercetin) dihydroxyisorhamnetin (daidzein, kaempferol, quercetin, rutin , procyanidin dimer,)	(J. Rahman et al., 2017)
Quinoa (<i>Chenopodium quinoa</i>)	Gallic acid, caffeic acid, p-coumaric acid, vanilin , trans-ferulic acid , hesperedin	(Sekhavatizadeh et al., 2021)

2.8 Role of dietary phenolic compounds

Major classes of secondary plant metabolites (SPMs) with therapeutic effects include polyphenols (flavonoids, phenolic acids, and tannins), terpenoids, and alkaloids. Numerous studies have established that SPMs exhibit potent antioxidant, anti-inflammatory, enzyme inhibitory, antidiabetic, and anticancer properties through a wide range of cellular and molecular mechanisms (Pandurangan et al., 2021). Nevertheless, the main bioactive functions of phenolic compounds in cereals and pseudograins are their potent antioxidant and anti-inflammatory properties, which help prevent chronic oxidative stress and inflammation-related diseases. The ability of dietary phenolic compounds to inhibit oxidative stress and inflammation conditions, the different mechanisms and pathways involved, and the influence on gene expression are currently under comprehensive investigations (Puangpraphant & Oseguera, 2022).

2.8.1 Antioxidant function

An antioxidant is defined as a substance that inhibits oxidation by significantly slowing or preventing the process when present at low concentrations relative to the oxidizable material (Sehwag & Das, 2014). Oxidative stress—an imbalance between oxidants and antioxidants—is known to worsen many common diseases. One effective approach to mitigate oxidative damage involves lowering free radical levels in biological systems. The primary bioactive function of phenolics is their role as antioxidants, which protect the body's cells from damage by free radicals (Tian et al., 2019). Polyphenols from grains are highly effective antioxidants due to their ability to donate hydrogen atoms to neutralize harmful reactive oxygen species (ROS). After ingestion, their overall antioxidant effect is amplified through complex synergistic interactions with other bioactive compounds in the body. These cooperative processes include metabolic transformations by gut microbes, complementary antioxidant actions, and modulation of cellular defense pathways (Nignpense et al., 2021; Wang et al., 2022; Sugiura et al., 2022) as summarized in the followings:

2.8.1.1 Direct antioxidant action in the upper gastrointestinal tract

Phenolics begin their antioxidant work as soon as they are consumed, acting as reducing agents that stabilize harmful free radicals.

- i. Donation of hydrogen: The phenolic hydroxyl groups (OH) readily donate a hydrogen atom to neutralize and stabilize free radicals.
- ii. Chelation of metals: They can bind to transition metals like iron (Fe^{2+}) and copper (Cu^{2+}), which are involved in the Fenton reaction that produces highly damaging hydroxyl radicals. By chelating these metals, polyphenols prevent the formation of new ROS.
- iii. Protection of biomolecules: This action prevents or repairs oxidative damage to vital biomolecules, such as proteins, lipids, and DNA, and helps manage oxidative stress in the body.

2.8.1.2 Enhanced antioxidant effects through digestion and metabolism

After passing through the acidic stomach, most polyphenols are not absorbed in the small intestine but continue to the colon. Here, the final and most powerful phase of their antioxidant activity is initiated by the gut microbiome.

2.8.1.3 Biotransformation by gut microbiota

The gut microbiome possesses enzymes that metabolize complex, high-molecular-weight polyphenols into smaller, more bioavailable, and often more potent compounds. This process unlocks polyphenols that were bound within the grain's indigestible fiber.

- i. Bound polyphenols: Grains, particularly whole grains, contain a large proportion of polyphenols that are covalently linked to dietary fiber in the outer layers (bran and aleurone).
- ii. Microbial release: Gut bacteria produce enzymes, such as esterase, that hydrolyze these bonds. This action releases phenolic compounds like ferulic acid and vanillic acid.
- iii. Metabolite production: The released phenolics are further metabolized into smaller molecules, such as phenolic acids, which can be readily absorbed by the colon.

2.8.1.3 Synergistic interactions

These newly formed phenolic metabolites, along with other bioactive compounds and dietary fiber, work together to produce an amplified effect that surpasses the activity of the individual components.

- i. Polyphenol-fiber-microbiota axis: The synergistic relationship between polyphenols, dietary fiber, and the gut microbiota improves intestinal health and can reduce the risk of diseases like colon cancer.
- ii. Interactions with other nutrients: Phenolic compounds can also interact with other dietary components, like polysaccharides, which can affect their bioavailability and overall antioxidant effect.
- iii. Enhanced systemic delivery: These smaller, more readily absorbed metabolites can be transported through the circulatory system to protect various tissues and organs. The liver may further modify these compounds before they are delivered to peripheral tissues, including the brain.

2.8.1.4 Systemic benefits

The enhanced antioxidant effect of grain polyphenols extends beyond the digestive tract, contributing to various systemic health benefits.

- i. Regulating gene expression: Polyphenols and their metabolites influence signaling pathways, such as the Nrf2 pathway, which regulates the expression of antioxidant and anti-inflammatory genes.
- ii. Protecting against chronic diseases: This enhanced, long-term antioxidant activity is linked to a lower risk of chronic conditions, including cardiovascular disease, neurodegenerative disorders, and cancer.

The mitochondria are the principal source of reactive oxygen species (ROS), generated as byproducts during aerobic respiration's electron transport chain. Oxidative stress damages cellular macromolecules irreversibly, contributing to various diseases. Antioxidants counteract this damage

by preventing ROS formation and neutralizing free radicals (Adwas et al., 2019). Common *in vitro* assays used to evaluate antioxidant activity in spices, herbs, cereals, and other plants include DPPH (2,2-diphenyl-1-picrylhydrazyl), FRAP (Ferric reducing antioxidant power), hydrogen peroxide scavenging, and ABTS (3-ethylbenzothiazoline-6-sulfonic acid), all of which are cost-effective and straightforward methods (Dikkumburage et al., 2023; Ilyasov et al., 2020).

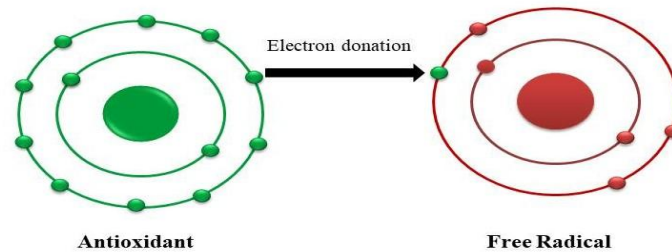


Figure 2.3: General mechanism of antioxidant activity

2.9 Anti-inflammatory function

Chronic inflammation is a significant risk factor for many diseases, and phenolic compounds play a crucial role in mitigating this process.

- i. Mechanism: Phenolics can down regulate inflammatory responses by suppressing key signaling pathways, such as NF- κ B and MAPK, and inhibiting pro-inflammatory enzymes like cyclooxygenase-2 (COX-2).
- ii. Examples of action:
 - a. Oats: The avenanthramides in oats have been shown to reduce plasma levels of inflammatory cytokines, such as IL-6.
 - b. Buckwheat: The flavonoid rutin and other polyphenols in buckwheat contribute to its significant anti-inflammatory capacity.
- iii. Quinoa and amaranth: Studies show that phenolic extracts from these pseudograins can down regulate inflammatory mediators.

- iv. Suppressing NF- κ B pathway: Many SPMs inhibit the nuclear factor-kappa B (NF- κ B) signaling pathway. Since NF- κ B regulates the expression of many pro-inflammatory genes; its suppression reduces the production of inflammatory cytokines and mediators.
- v. Inhibiting pro-inflammatory enzymes: SPMs can inhibit enzymes involved in the inflammatory cascade, such as cyclooxygenase (COX) and lipoxygenase (LOX), which are responsible for producing prostaglandins and leukotrienes, respectively.
- vi. Examples: Curcumin (from turmeric), gingerols (from ginger), and flavonoids found in fruits and vegetables are prominent anti-inflammatory SPMs.

2.10 Lipase inhibition mechanism

The prevalence of obesity in contemporary society is frequently attributed to the consumption of an excessive amount of dietary fat and a sedentary lifestyle. Obesity is the result of a buildup of excess fat due to inadequate fat burning and storage. Main organs for lipid storage include white adipose tissue and the liver (Li et al., 2010; Schwartz, 2006). Hyperlipidemia and obesity are medical conditions that raise the risk of insulin resistance, liver fibrosis and damage, decreased glucose tolerance, hypertension, and overall mortality (Belfort et al., 2005). Among the lipases found in the digestive tract are pancreatic lipase, gastric lipase, and tongue lipase. Often regarded as a crucial component controlling pancreatic lipase secretion and supporting function in lipolysis is gastric lipase. Among these, pancreatic lipase is particularly crucial since it directly influences intestinal absorption of fatty acids. Pancreatic lipase (PL), the principal lipase (50%-70%) secreted by the pancreas, degrades dietary lipids in the digestive system, yielding mono glycerides and free fatty acids from triacylglycerol substrates derived from ingested oils. The small intestine absorbs lipid emulsions, including bile acids, which are subsequently utilized to synthesize triacylglycerol, thereby storing energy as adipose tissue. Excessive lipid absorption by the duodenal mucosa results in overweight and obesity.

A significant goal in addressing obesity is the creation of inhibitors that affect nutrient digestion and absorption (Foster-schubert & Cummings, 2006). Currently, the most common pharmacological

methods for reducing weight involve the use of peripheral lipase inhibitors and central appetite suppressants. These therapies can be broadly categorized into two main groups. First one is pharmacological substances that hinder the absorption of fats in the intestines, such as orlistat and secondly, a centrally acting appetite suppressant principally composed of fenfluramine and sibutramine that affects the central nervous system. Nevertheless, multiple clinical research have demonstrated that the utilization of these medications can heighten the probability of experiencing adverse effects, such as insomnia, dizziness, headache, bitterness, dry mouth, constipation, and various negative mental or cardiovascular reactions, which greatly limit their use in medical practice and sometimes lead to their removal from the market.

Al-Suwailem et al., 2006 found that orlistat, the sole FDA-approved hyperlipidemic drug, inhibits stomach and pancreatic lipase. Orlistat, an anti-hyperlipidemic drug reduces dietary fat absorption. Orlistat blocks dietary fat breakdown by interacting with lipases at the active site. This medicine may cause gas, stomach pain, bowel issues, and feces fat. It can also cause fat-soluble vitamin deficits.

Natural materials that may aid in obesity treatment are generally regarded as possessing lower toxicity and fewer side effects than entirely synthetic medications. Numerous phytochemicals and plant extracts have undergone testing for their lipase inhibitory activity in the pursuit of a naturally occurring, biologically active pancreatic lipase inhibitor. Research is increasingly indicating that polyphenols found in fruits, vegetables, and cereals may inhibit certain digestive enzymes in vitro (Garza et al., 2011; Gondoin et al., 2010; Mcdougall and Stewart, 2018). Polyphenols serve as a notable source of potential inhibitors for pancreatic lipase. Buchholz & Melzig, (2015) offers a clear summary of the primary subclasses of polyphenols that have been thoroughly researched. The subclasses encompass flavonoids, hydroxycinnamic acids, hydroxybenzoic acids, and lignans, each of which has shown inhibitory effects on pancreatic lipase.

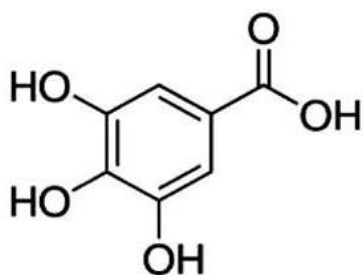


Figure 2.4: Lipase enzyme converts TG into FFA

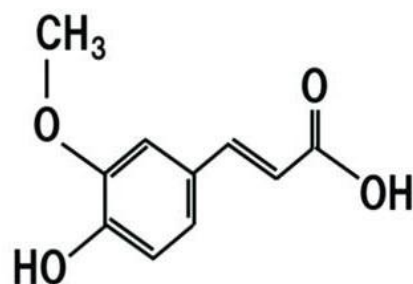
2.11 Lipase inhibitory polyphenolic compounds and their mechanism

Phenolic chemicals are aromatic secondary metabolites found in plants that have a hydroxyl group or groups of hydrogen bonds. The powerful antioxidant activities of naturally occurring polyphenols are the basis for their beneficial health-related characteristics (Yang et al., 2014). Numerous studies have shown that many extracts rich in polyphenols can suppress pancreatic lipase *in vitro*. Flavonols, tannins, and other phenolic found in plant extracts decreased obesity *in vivo* in conjunction with lipase inhibition. These findings provide more evidence that phenolic compounds have potential as a means to reduce the absorption and storage of dietary fat (Birari & Bhutani, 2007; Gondoin et al., 2010; Yang et al., 2014). Martinez et al., (2017), reported quercetin ($IC_{50} = 6.1 \pm 2.4 \mu\text{m}$) as a strong pancreatic lipase inhibitor *in vitro* followed by p-coumaric acid and caffeic acid on the other hand, Grove et al., 2012, found (-) Epigallocatechin-3-gallate as lipase inhibitor from tea (*Camellia sinensis*). Rahim et al., (2015) reported gallic acid and ferulic acid as great porcine pancreatic lipase inhibitor after analyzing nine types of beans whether alkaloids, flavonoids, glycosides and carotenoids besides of plant polyphenolic compounds found to be prime inhibitors (Lunagariya et al., 2014). (-) Epicatechin (EC) is a naturally occurring flavanols monomer seen in chocolate, green tea, and various other plant-based foods. Cheng et al., (2017) examined the effects of EC on hepatic steatosis and blood TG, along with the underlying processes. A substantial body of experimental data from studies on rodents and, to a lesser extent, from studies on humans, suggests that (-) epicatechin (EC) and EC rich diets can help to reduce a number of the comorbidities associated with obesity (Cremonini et al., 2020). Polyphenols, non-nutritive secondary metabolites of plants, are evaluated for antioxidant activity in whole grain varieties by *in vitro* methods such as DPPH, ABTS, FRAP, and ORAC. The cortical layer of grains comprises the

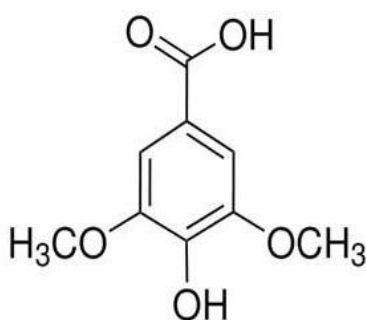
majority of phenolic compounds, such as ferulic acid, oxalic acid, p-coumaric acid, and caffeic acid, which function as antioxidants that prevent the oxidation of cortical tissue (Deng et al., 2012).



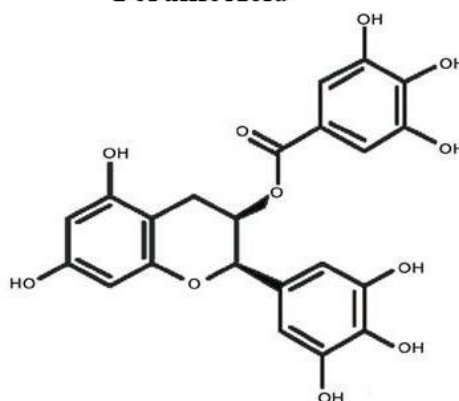
Gallic Acid



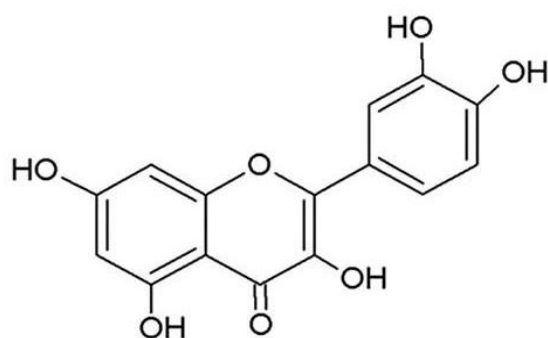
Ferulic Acid



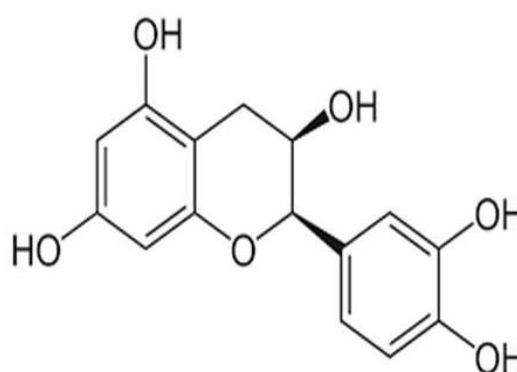
P-Coumaric Acid



**Epigallocatechin gallate
(ECGC)**



Quercetin



(-) Epicatechin

Figure 2.5: Polyphenolic compounds that have lipase inhibitory capacity

Regarding the significant potential and health advantages, there is an absence of thorough physico-chemical analytical data on certain cereals and pseudograins in Bangladesh. The proposed study aims to produce compositional and bioactive data on polyphenols derived from locally cultivated cereals and pseudograins. An assessment of their antioxidant capacity and enzyme inhibitory efficacy would be beneficial for the dietary treatment of obesity through nutritional therapy. The objective is to highlight their importance as conceivable future food supplies.

Chapter 3

Objectives

3. Objectives

3.1 General objective:

To evaluate bioactive polyphenolic compounds in locally grown and available cereals and pseudograins for their explicable anti-oxidant capacity and lipase inhibition activity.

3.2 Specific objectives:

- i. To conduct an ethnographic survey of indigenous cereals and pseudograins.
- ii. To analyze nutrient and polyphenolic contents of selected cereals and pseudograins.
- iii. To extract and determine polyphenolic composition of the food samples using High Performance Liquid Chromatography.
- iv. To assess antioxidant and lipase enzyme inhibitory activities of high-potency cereals and pseudograins by using *in vitro* bioassay methods.
- v. To conduct a comparative data analysis to elucidate the farming, nutritional, and bioactive features of the grains for the users and policy planners.

Chapter 4

Study Design

In Bangladesh, minor cereals have been cultivated on a small-scale for a long time, but limited information is available on their growth, yield, and the possibility of expanding the cultivated area (Islam et al., 2023). Therefore, the research work was designed to be conducted in distinct, sequential phases to systematically investigate the cereals and pseudograins farming, the compositional profile of the seeds, and their antioxidant and enzyme inhibition potencies. These stages were designed to provide a full picture of the grains agricultural context, chemical composition, and bioactivity. A brief account is presented in the followings paragraphs.

Phase 1: Ethnographic survey: agro-cultural and sourcing study

This initial phase established the foundation for the study by focusing on the agricultural practices and sourcing of the grains obtained by ethnographic method. Ethnographic methods provide a powerful tool for examining the complex and interrelated issues affecting agricultural practices. It moves beyond quantitative data by exploring the social, cultural, and environmental factors influencing food production, distribution, and consumption. The key components are:

- i. **Identification of target crops:** Phytochemical-rich cereals (e.g., pigmented rice, wheat, sorghum), minor cereals (e.g., millet, cheena, kaon), and pseudo-grains (e.g., quinoa, amaranth, buckwheat) were identified from literature review and selected for ethnographic survey.
- ii. **Agronomic and Farming analysis:** Investigations on multiple factors affecting food systems of these grains, including agricultural production, public opinion, market forces, and wider socio-political issues were covered. It provided crucial insights into the dynamics these aspects by allowing for an in-depth, on-the-ground understanding of local context of the selected grains.
- iii. **Sample collection:** Samples were carefully collected on the basis of documented herbarium sheets to ensuring consistency in variety and origin for later analysis.

Phase 2: Compositional profiling of the grains

In the second phase, the collected seed samples were subjected to detailed laboratory analysis to establish their nutritional and phytochemical composition.

- i. **Proximate nutrient analysis:** The basic nutritional profile of the seeds, including water, protein, carbohydrates, dietary fiber, ash, and fat, were determined using validated Standard Operating Procedure (SOP).
- ii. **Bioactive compound extraction and identification:** Methods were customized to extract the bioactive compounds from the seeds for further testing. Specific bioactive compounds, mainly SPMs, were screened and quantified, such as:
 - a. Phenolic compounds: A wide class of antioxidants and lipase inhibitors were found in these grains.
 - b. Flavonoids: These compounds contribute significantly to the grains' antioxidant potential.
- iii. **Advanced analytical techniques:** An advanced analytical techniques- methods like, high-performance liquid chromatography was employed to precisely separate and quantify the polyphenolic composition in these grains.

Phase 3: Evaluation of bioactive potency

Moving beyond identification, this phase tests the functional properties having reported health effects of the extracted compounds. Lab-based experiments evaluated the functional properties of the extracts. Common assays measured:

- i. **Antioxidant activity assays:** Conduct *in vitro* assays, such as the DPPH (2,2-diphenyl-1-picrylhydrazyl), ABTS (2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid)) and FRAP (ferric reducing antioxidant power assay) tests, to measure the free radical scavenging capacity of the extracts.

- ii. Lipase inhibition activity assay:** A lipase inhibition activity assay is a biochemical method used to assess the effectiveness at blocking lipase enzymes by drugs or SPMs. By targeting pancreatic lipase, which breaks down dietary fats, these assays measure a grain extracts' potential to reduce fat absorption and for developing a coping strategy against overweight and obesity.

Phase 4: Data integration and reporting

The final phase involves combining the data from all previous stages to build a comprehensive picture of each collected food sample.

- i. Data integration:** Correlation the farming conditions, production dynamics, and sociocultural features (Phase 1) with the compositional profile (Phase 2) and the bioactive potencies (Phase 3). This can help determine the optimal agronomic practices for maximizing the health-promoting properties of the grains.
- ii. Comparative analysis:** Comparing the results across different cereals, minor cereals, and pseudo-grains to identify the most potent and promising crops for health benefits.
- iii. Reporting and publication:** Summarization of the findings in a comprehensive report and research papers for publication in a scientific journal, contributing to the broader knowledge of phytochemical-rich foods.

Chapter 5

Study Phase-1:

Ethnographic Survey of Cereals and Pseudograins

5.1 Introduction

Ethnography is an adaptable qualitative research method that allows researchers and policymakers to gain a deep, contextual understanding of agricultural production systems, societal perspectives, market dynamics, and the broader socio-political issues influencing food systems, and lived experiences that are often missed by quantitative approaches (Archer et al., 2008; Onzere, 2019). Recently, the intersection of agriculture and public health has received more attention, especially regarding functional foods and their impact on reducing non-communicable illnesses. Plant-based enzyme inhibitors have emerged as a promising strategy for managing lifestyle-related NCDs like obesity. Plants also contain numerous other bioactive components, including polyphenols, carotenoids, and antioxidants, which contribute to their health-promoting properties (Nignpense et al., 2021; Dixit et al., 2023). There are foods with beneficial health effects beyond basic nutrition, often rich in "bioactive" compounds.

In Bangladesh, ethnographic research on cereals and pseudograins reveals an *in toto* contrast between the traditional dominance of cereals, particularly rice, and the limited but growing adoption of nutritionally rich pseudograins like buckwheat, chia, and quinoa. Most studies in this area are still nascent and qualitative, identifying significant gaps in the production, consumption, and distribution of pseudograins. In fact, minor cereals have been cultivated on a small-scale for a long time, but limited information is available on their growth, yield, and the possibility of expanding the cultivated area. The current yield of minor cereals is low; around 2.0 tons/hectare and the crops are mostly grown on marginal lands formed by river siltation, locally called **char lands** (Islam et al., 2023).

The increasing emphasis on diversified and nutritious diets in the global market has brought minor cereals and pseudograins as healthy foods (Rodríguez et al., 2020). As an alternative grain, sorghum and millet are often ingested in many developing areas and are linked to a lower incidence of chronic illnesses relative to wheat (Rathore et al., 2016; Stefoska-needham et al., 2015). Pseudocereals such as buckwheat, quinoa, and amaranth are becoming recognized for their

exceptional nutritional characteristics. Moreover, the polyphenolic prospect of minor cereals and pseudograins are significant but remained underutilized in developing countries like Bangladesh. Increasing global interest highlights these grains as potential functional foods, though their wider adoption faces challenges related to production, processing, and consumer awareness.

Compared to major cereals like rice and wheat, minor cereals and pseudograins have received limited research attention in Bangladesh regarding their nutritional and health-promoting properties. Therefore, an ethnographic investigation of indigenous cereals and pseudo-cereals, emphasizing their traditional use, attributes to local food system, and health advantages, would assemble a considerable promise for mitigating lifestyle-related disorders. This investigation looked for a connection ethnographic insight with bioactive applications, enhancing sustainable agriculture, nutritional security, and the formulation of evidence-based health policies.

5.2 Methodology

Ethnography is acknowledged as a rigorous research approach owing to its fundamental foundation in empirical observation and descriptive analysis (Hammersley & Atkinson, 2009). The present study gave primary importance to immersive fieldwork, a core component of ethnography which involved researcher's direct, sustained participation and observation within a community. The combinations of immersive fieldwork and ethno-historical analysis have created a robust mixed-methods framework for deeply understanding cultural practices and social realities. The methodological framework included immersive fieldwork, such as interviews and the investigation of individual and community perceptions, as well as ethno-historical approaches that involved analyzing archival sources, including reports, personal and institutional documents, journals, and diaries. This approach triangulated the data by contrasting, live experience with historical context, allowing experts to uncover how a community's present-day actions and perceptions are shaped by its past.

5.3 Planning of access and ethics

Ethnographic research requires meticulous planning in order to ensure ethical integrity and valid access to study environments (Hammersley & Atkinson, 2009). It asserts that obtaining approval from appropriate legal and institutional entities is an essential condition for accessing field sites and interacting with participants. In accordance with these norms, official written requests were filed to the appropriate authorities of the Bangladesh Agricultural Research Institute (BARI), Bangladesh Rice Research Institute (BRRI), and the Bangladesh National Herbarium. These applications requested authorization to access study locations conduct discussions with participants, and gather qualitative data and physical specimens. This method maintained ethical research practices while promoting openness, mutual respect, and trust among the participating communities and institutions.

5.4 Interviews

In-depth and wide-ranging interviews were conducted as part of the survey process, offering valuable insights and addressing several gaps left by existing literature. An unstructured questionnaire served as the main instrument for gathering information from selected resource personnel (Table 5.1). The key aim was to engage participants in open dialogue, allowing them to share their views and interpretations on research-specific topics that had not been covered in previous studies. Additionally, focus group members provided detailed descriptions of prevailing agricultural methods and their related socioeconomic impacts. Annexure 1 includes two case studies derived among all interviews to illustrate the focus group discussion process. They also proposed strategies for revitalization and identified key significances aimed at enhancing household food security through the integration of pseudocereals into diversified cropping systems.

Table 5.1: Key questions for Focus Group Discussions (FGD)

Unstructured questionnaires		Expected Outcome
1.	What is the pattern of cereal and pseudocereal farming in Bangladesh?	Pattern of comparative farming system.
2.	Do farmers have interest in farming pseudograins?	Current scopes of pseudograins farming.
3.	What kinds of cereals/pseudograins are cultivated more?	Pattern of significantly produced crops.
4.	Why is pseudocereal cultivation undeveloped?	Problems of pseudocereal cultivation.
5.	Do farmers know the health benefits of pseudograins?	Knowledge on the role of a healthy food.
6.	Is there any socioeconomic and political impact of farming cereals/pseudocereals?	Socioeconomic and political policy revitalization on agro-ecological farming
7.	Are there any initiatives for encouraging farmers/ researchers for pseudocereal cultivation?	Status of agricultural extension initiatives of pseudocereal research
8.	How many registered varieties of crops are there in Bangladesh?	Record of crop varieties released for field cultivation

5.5 Data collection

Primary data were collected through focus group discussions that included scientists, academics, agricultural technicians, and other stakeholders involved in the agricultural sector. Secondary information was obtained from a variety of sources, including online databases, published books, reports from the Bangladesh Bureau of Statistics (BBS), Department of Agricultural Extension (DAE), FAO statistics, scholarly journals, research articles, and annual publications from institutions such as BARI and BRRI.

5.6 Results and discussion

5.6.1 Agro ecological zone of selected samples in Bangladesh

Bangladesh comprises 30 unique Agro-Ecological Zones (AEZs) as depicted in Figure 5.1 (Nasim et al., 2017). From these AEZs, selective zones were chosen purposively to conduct the focus group discussions and direct interviews with specialists, farmers, and researchers on the issues of the production, market availability, and applications of cereals and pseudograins. Table 5.2 delineates the agricultural region comprising particular cereals and pseudograins, based on primary data sources.

Table 5.2: Agro-ecological zones (AEZ) of study samples of Bangladesh

Crop name	AEZ No.	Places
Rice & wheat	All	30 agro-ecological zones of Bangladesh are included
Maize	25, 26, 27	Dinajpur, Gaibandha, Joypurhat, Bogra, Naogaon, Sirajganj, Natore, Rajshahi, Nawabganj, Rangpur.
Barley		Selected places in Chowhali and Tarash , Sirajgang
Cheena	7	Eastern Part of Kurigram, Gaibandha, Bogra, Sirajganj and Pabna district. Minor areas also occur in Dhaka, Munsiganj, Narayanganj and Chandpur district.
Kaon	2, 7, 8, 12	Nilphamari, Rangpur, Lalmonirhat, kurigram, Gaibandha, Manikganj, munsiganj, Gazipur, Dhaka, Mymensing, Kishorganj, Faridpur, Madaripur, Khulna
Till	1, 14, 27	Panchagarh, Thakugaon, Dinajpur, Narail, Jessore, Bagerhat, Khulna, Rangpur, joypurhat, Gaibandha, Bogra

Source : (Nasim et al., 2017)

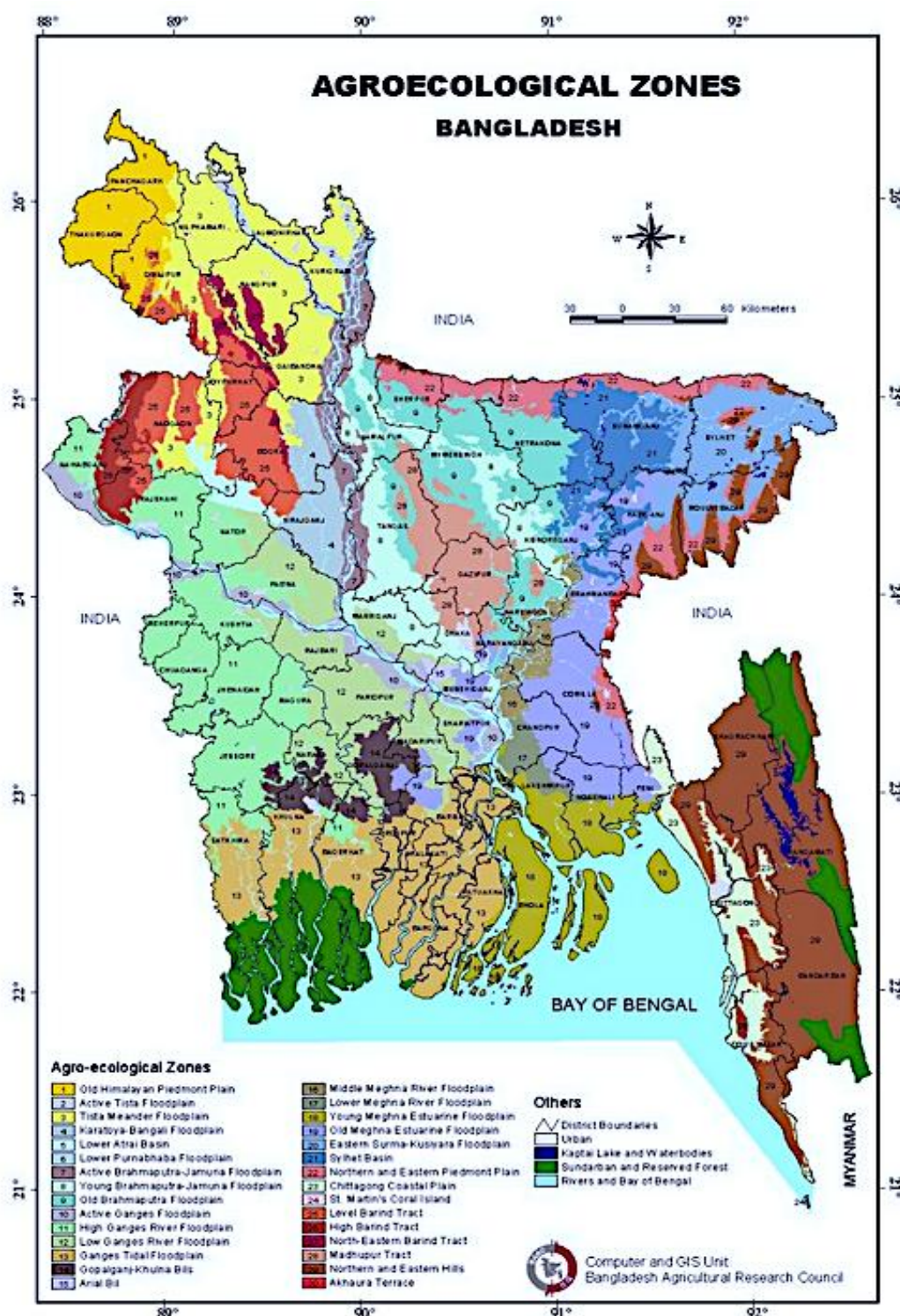


Figure 5.1: Agro ecological zones of Bangladesh [Source: Bangladesh Agro Meteorological Information (BAMIS)]

5.6.2 Cereals

In Bangladesh, crops are primarily divided into two categories based on the seasons of growth: Rabi crops and Kharif crops. Kharif crops are harvested in late summer or early winter after being planted in the spring or summer. Rabi crops, on the other hand, are harvested in the early summer or spring after being sown in the winter. According to Table 5.3, farmers in Bangladesh mainly grow wheat and rice (aus, aman, and boro), with barley, jowar, bajra, maize, cheena, and kaon classified as secondary cereals (Bangladesh Bureau of Statistics (BBS), Statistics and Information Division (SID), 2024).

Table 5.3: Cereal production in Bangladesh (BBS, 2023, 35th Series)

Crops		Per acre yield/kg
Rice (Aus)	Local	557
	HYV	1103
Aman	T. Local	588
	HYV	1136
Boro	local	756
	HYV	1598
	Hybrid	1950
Wheat		1245
Barley		333
Jower		443
Bazra		535
Maize		3245
Cheena & Kaon		400
Other cereals		018

(HYV - High Yielding Variety, T. local - Total local)

5.6.2.1 Rice (*Oryza sativa*)

The Bangladesh Rice Research Institute (BRRI) has developed 102 high-yield rice varieties suitable for both optimal and challenging growing conditions. A study was conducted to evaluate the total polyphenolic content, DPPH free radical scavenging activity, and ferric reducing antioxidant power

of ten selected varieties. The current investigation have focused on the varieties BR 5, BR 7, BR 16, BR 22, BRRI 28, BRRI 29, BRRI 34, BRRI 37, BRRI 38, and BRRI 50.

Field interviews of 20 farmers across the selected AEZs revealed that they had planted a total of 10 acres land for black rice (table 5.6) and 15% of the yields were reserved to research whereas the rest 85% were sold of the yield. Separately, a local agronomist harvested red rice at 13 mon per bigha, allocating 20% for research and selling 80% (Table 5.6). A cultivar from Cumilla, Bangladesh collected black rice seeds from six Asian countries and reported to produce 5.5 tons per hectare (Shykh Seraj, 2019).

5.6.1.2 Wheat (*Triticum aestivum*)

The Bangladesh Institute of Development Studies (BIDS) and the Bangladesh Integrated Household Survey (BIHS) reported that the national average per capita consumption of rice and wheat is 459 g and 33.5 g, respectively (Hossain & Yunus, 2017) (Table 5.4). Regarding the consumption point of view, wheat (*Triticum aestivum*) is the second major calorie-providing cereal in Bangladesh along with the rest of Asia (Table 5.3). The Bangladesh Agricultural Research Institute (BARI) has released 33 high-yielding wheat varieties and 9 of these hybrid wheat varieties. Among them the variety Shatabdi, exhibited the highest total phenolic content (1.316 mg/g), while another variety Akbar demonstrated the lowest at 1.269 mg/g. The differences in PPO and antioxidant activity were not statistically significant across the nine wheat varieties studied (Akond et al., 2010).

5.6.1.3 Barley (*Hordeum vulgare*)

Nine varieties of high-yielding diversified barley, of which BARI has developed seven high-yielding barley cultivars, were found cultivated across 471 acres in Bangladesh as a minor crop (Table 5.3). A comprehensive search of literature between 2004 and 2020 on PubMed, CNKI, and ISI Web of Science, revealed that the barley seed extract is rich in functional ingredients that combat chronic diseases. A meta-analysis of the studies conducted during this time period confirmed that barley health benefits of seed extracts are attributed to its specific components:

phytosterols, polyphenols, arabinoxylan, tocopherols, β -glucans, and resistant starch. More than 20 chronic diseases may be affected by these constituents of barley (Zeng et al., 2020).

Table 5.4: Per capita daily food grain consumption (in grams) from HIES, BIDS and IFPRI-BIHS.

Institute	Type	Rural	Urban	National
BBS (From HIES),	Rice	386.1	316.7	367.2
	Wheat	17.4	26.2	19.8
BIDS	Rice	540.5	249.5	459.4
	Wheat	23.8	89.0	41.5
IFPRI	Rice	447.8	367.3	425.9
BIHS	Wheat	29.4	44.3	33.5

BBS-Bangladesh Bureau of Statistics; HIES-Household Income and Expenditure survey
BIDS-Bangladesh Institute of Development Studies, IFPRI-International Food Policy Research Institute,
BIHS-Bangladesh integrated Household Survey.

5.6.1.4. Maize (*Zea mays*)

The Bangladesh Agricultural Research Institute (BARI) has developed 19 high-yielding maize varieties, including specialized types like waxy corn, popcorn, and sweet corn. One of these varieties is quality protein maize (QPM), which has been formulated for making roti or chapatti and is among BARI's three white kernel varieties. A summarized description obtained from ethnographic search about maize cultivation in Bangladesh was the followings:

- i. Optimal season: Maize has higher productivity during the Rabi season than the Kharif season.
- ii. Cultivation area: Approximately 963 acres nationwide are devoted to maize cultivation.
- iii. Dominant cropping pattern: The most common farming approach is the "Maize–T. aman (monsoon rice)" cropping sequence.
- iv. Crop diversification: The T. aman rice in the traditional cropping sequence can be replaced with other crops such as potato, mung bean, or mustard to improve diversification. Zhang et al. (2017) reported the presence of both free phenolics and flavonoids, in addition to identifying bound ferulic acid in nine sweet corn varieties.

5.6.1.5 Cheena (*Setaria italica*) and Kaon (*Panicum miliaceum*)

Table 5.3 demonstrates that Bangladesh produced millets (kaon and cheena) in about 1063 hectares as petty crops, yielding a total production of 1058 metric tons annually. BARI has developed a high yielding cheena variation named Tushar and two kaon varieties designated as Titas and Kaon-2. Cultivating millets like proso and foxtail millet on unmanured lands in the Char areas of Bangladesh addresses major challenges in food security, public health, and environmental sustainability. Char lands are unstable riverine islands and riverbanks defined by poor, sandy soil, frequent floods, and drought. Millets thrive in these harsh conditions, providing a resilient food source for the vulnerable communities living there (Masao Goto, 2012; Shaheen et al., 2013).

Table 5.4 reveals that the International Food Policy Research Institute (IFPRI) documented quantitative information regarding the validation survey report on per capita consumption of primary grains from a national perspective in Bangladesh (Yunus et al., 2019). Answers of three prestigious agricultural establishments to the survey questionnaire revealed that rice is the predominant grain consumed in Bangladesh. The "Country Fact Sheet on Food and Agriculture Policy Trends" of FAO (2016) for Bangladesh revealed that the predominant commodities consumed in 2014 were rice, wheat, and potatoes, with a dietary energy supply of 2450 kcal per capita per day.

Table 5.5: Farming seasons in Bangladesh identified by focus group discussion (FGD)

Crop Name	Time of sowing	Time of harvesting
Aus (Local, HYV)	Mid-March- Mid April	July to August
Aman (Local)	End June – Early September	December to early January
Aman (HYV)	Late June- Mid August	December to early January
Boro (Local)	Mid November- Mid January	April - May
Boro (HYV/Hybrid)	December – Mid February	Mid April-June
Wheat	November- December	March- Mid April
Maize	Mid October- Late December	Early April-End May
Jowar	Mid April- June	Mid-August- Mid October
Kaon	November- December (Low land)	Mid-March- Mid June
	Mid-March- Mid May (Hilly Land)	Mid June- Mid August
Cheena	November-Mid December	Mid February- Mid April

Barley	Mid October-Mid December	Mid February- Mid April
Chia	Beginnig September - October	Late October - December
Quinoa	Beginnig September - October	Late October - December
Amaranth	Beginnig September - October	Late October - December

5.6.2 Pseudo-cereal

Pseudocereal flours serve as a healthful component in a variety of bread goods globally (De Aguiar et al., 2021). Pseudograin cultivation in Bangladesh is a small but growing sector, driven by interest in the high nutritional value and adaptability of crops like quinoa and chia. Although production data are still limited, research initiatives and local farmers are beginning to explore these crops as viable alternatives to traditional cereals like rice. A recent research disclosed that in most cases, six minor cereals are cultivated in Bangladesh; proso millet (*Panicum miliaceum*) and foxtail millet (*Setaria italic*) cover larger areas and are mainly grown in north, north-west, central parts and hilly regions of the country and provide 400-1500 kg ha⁻¹ grain yield (Biswas & Tanni, 2020).

5.6.2.1 Buckwheat (*Fagopyrum esculentum*)

The study revealed that buckwheat is not commonly cultivated in Bangladesh because of its unknown use in daily dietary. Common buckwheat is familiar as a rabi season (winter) crop and is rarely cultivated in some areas of northern part in Bangladesh (Nasim et al., 2017). To address this, the Bangladesh Agricultural Research Institute (BARI) began a buckwheat research program in 2018, which has involved collecting five genotypes, characterizing them, and conducting yield trials to identify promising lines for future development. Characterizations, different yield trial in different regions of Bangladesh have been conducted for selection of promising genotype (A.H. Akhi et al., 2023). From the cultivation experiences of buckwheat in Panchagarh district, Bangladesh, the Department of Agricultural Extension (DAE) have noted a significant increase in demand for buckwheat production due to its profitable price, nutritional benefits, and disease-preventive qualities. A recent news feature reported the experience of a buckwheat farmer from Rajshahi district by quoting "no need of fertilizer in buckwheat production" but "need training and agricultural understanding" for better output (Tribune, 2021). Since 2013, buckwheat has been

grown as an organic crop by an organic farm operator (Table 5.5). As part of his scheme, buckwheat is grown as a companion crop in Sayedpur and Panchagarh throughout the winter. Table 5.5, shows that about 15-20 Mon/Bigha (ton/hectare) of buckwheat are produced each year, of which 99% is sold as grain and the remaining portion is consumed as a vegetable by the local population. Buckwheat yields were assessed by Mondal et al. (1992) throughout a range of planting dates with notable seed rates; 20 kg of seed per hectare was distributed to get the best crop output during the November to March arid seasons of 1988–89 and 1989–90.

5.6.2.2 Quinoa (*Chenopodium quinoa*)

Quinoa production is a relatively new initiative in Bangladesh, starting with pilot projects in 2020 following five years of research at Sher-e-Bangla Agricultural University, Dhaka, Bangladesh. Quinoa production in Bangladesh shows promise as a new cash crop due to its climate resilience and high export demand, despite a small domestic market. After initial research at Sher-e-Bangla Agricultural University, pilot projects began in 2020 in climate-vulnerable districts, with the first successful harvests reported in 2021 (Biswas & Tanni, 2020). The crop is being cultivated in areas like Lalmonirhat, Kurigram, Patuakhali, and Chattogram, with initial results showing promise for crop viability, although a large domestic market has not yet been fully established (W. Rahman, 2021).

In 2017, a Bangladeshi grain scientist started growing quinoa after importing seeds from Denmark. Quinoa seeds from Bangladesh have been registered by the Ministry of Seed Board under the designation SAU-1. SAU-1 is a winter crop (Table 5.5). It was highlighted for its low tolerance to salinity and moisture, necessitates no chemical fertilizers or insect repellent (Biswas & Tanni, 2020). Table 5.7 demonstrates that the Sher-E-Bangla agricultural research field yielded 700/800-1.5 tons/ hectare. In Kurigram district it was reported to produce 2 tons/ hectare, in Lalmonirhat district it was a production of 1.5 tons/ hectare, and in Kuakata research field it was 1 ton per hectare. All quinoa production was designated for research purposes (Table 5.6).

5.6.2.3 Chia seed (*Salvia hispanica*)

The study observed from the FGD and questionnaire survey that successful cultivation of chia seeds in Bangladesh occurred during the early winter season, specifically from October to December, which yielded better production compared to other times of the year. The Table 5.5 summarized that Bangladeshi chia is a Rabi crop (October–December) that requires organic fertilizer, one or two irrigations, and minimal pesticide use. Chia seeds were found to grow as an experimental crop in areas of Dinajpur, Mymensingh, Gaibandha, and Jashore districts and the whole production was found to keep for only research purposes (table 5.6).

Nutritional and health benefits of the harvested chia seeds were also noted from secondary sources (Gabal, 2024). The seeds were highly unsaturated, rich in alpha-linolenic acid and linoleic acid. When chia seeds were placed in water, the seeds exuded a mucilaginous, a soluble fiber. Protein content was 19% (favorable in the Bangladesh context), and the seeds were an excellent source of minerals. Consumption of chia seeds for a week significantly lowered post-prandial blood sugar.

Table 5.6: Case Studies with cereal and pseudo cereal

	Case Study	Occupation	Area	Production
1.	Black Rice	Farmer and Entrepreneur	10 acres in Cumilla	17 mon/bigha
2.	Red Rice	Farmer and Entrepreneur	Cumilla	13 mon/bihga
3.	Chia	Cereal Researcher	Dinajpur, Jashore Mymensingh, & Gaibandha	Not available
4.	Quinoa	Cereal Researcher	Sher-E-Bangle AURF, Kurigram, Lalmonirhat, Kuakata	~1.5 ton/hector Sher-E-Bangla AURF 2.0 ton/hector -Kurigram RF, 1.5 ton/hector -Lalmonirhat RF, 1 ton/hector -Kuakata RF
5.	Buckwheat	Entrepreneur	Sayedpur, Jessore, & Potuakhali.	15-20 mon/bigha

5.6.3 Genotype research of pseudograins in Bangladesh

BARI conducted research on buckwheat, oat, and sorghum genotypes to develop high-yielding seed variants and improve production growth (Table 5.3). Four genotypes of foxtail millet were released by the Plant Genetic Resource Centre (PGRC) at Gazipur, whereas four genotypes of buckwheat

were developed by RCBD at Bogura and one oat genotype (BD-4271) was evaluated by them for high production potential. During the Rabi season of 2018–2019, the BD-4271 oat line yielded 11.0 kg of seed, whereas the germplasm gE3 had a significantly greater seed production of 268.8 g among the four genotypes. Following an evaluation of salt tolerance, three sorghum genotypes (IS-29468, IS-21891, and IS-9745) were selected for further investigation (BARI, 2020).

5.6.4 Findings of the Opinion Survey

The data collected from participants demonstrate substantial support for the production and study of both traditional cereals and innovated pseudograins (Table 5.7). Participants strongly endorsed the need of increased cultivation of red and black rice, knowing the information of their higher antioxidant content and positive impact on immune health. These categories have consistently been acknowledged as traditional staples and functional foods thereby their progressive importance in public health nutrition. Stakeholders recognized that BARI's role in developing improved varieties of wheat, barley, and maize, indicating institutional support for grain diversity. Rice variants rich in antioxidants are recognized as functional foods in addition to their role as staple food, highlighted their potential in public health nutrition. It was noted that BARI enhanced wheat, barley, and maize varieties, demonstrating institutional support for grain diversity. The survey noted that the respondents' acknowledged Chia, quinoa, and buckwheat pseudograins are gaining popularity in the healthy food basket.

It was also found that in several AEZ locations, farming occurs despite insufficient information on agricultural inputs. The respondents understood that psyllium husk, tokma dana, haleem dana, black cumin, and methi are polyphenol-rich seeds having medicinal potential. They also opined that chemical study of aromatic rice, wheat, teel and tisi need to assess the quality and research value. Traditional grains like cheena, kaon, and sorghum were found to be culturally integrated and widely used, offering opportunity for community-focused research and diet implementation.

Table 5.7: Opinion survey results of respondents identified by Focus Group Discussion (FGD)

	Cereals and Pseudograins	Opinion of respondents
1.	Red rice, Black rice	Red and black rice farming should be spread more.
2.	Wheat, Barley, Corn	BARI would provide all available released grains varieties.
3.	Antioxidant-rich rice, Red, & Black rice	Helpful for people to keep them in good health and boost immune system.
4.	Pseudograins	a) Very scanty information about pseudograins, however, they are cultivating scattered in several AEZ areas. b) If lipase inhibitor identified in them, they could be used as functional foods
5.	Psyllium husk, Tokma dana & Haleem dana	Local sources of these foodstuffs could be great sources of polyphenolic compound
6.	Buckwheat	Buckwheat should be cultivated by government inputs
7.	Aromatic Rice	Need chemical analysis to determine the quality of aroma
8.	Quinoa	Quinoa should cultivate more and more
9.	Chia	Chia is an easily grown grain, but it needs government's support
10.	Teel and Tisi	Chemical analysis of Teel and Tisi will help research and development
11.	Cheena, Kaon, Sorghum	Sorghum, Cheena and Kaon are popular seeds for consumption and have culturally accepted tradition
12.	Black Cumin, Methi	Black cumin could be an excellent source of polyphenolic compounds

5.7 Social and political impact on tradition agricultural system

The reintroduction and expansion of minor cereals, like millets, and pseudograins, like quinoa and amaranth, into the traditional agricultural system of Bangladesh creates significant social and political impacts (Sumi et al., 2023) by enhancing climate resilience and food security, challenging existing power structures, and creating complex new economic dynamics. The influential effectors could be, i) Reintegrating them into existing agricultural traditions would diversifies farming systems, reducing the vulnerability of monocultures to climate-related shocks like pests and diseases; ii) Minor cereals and pseudograins boast high nutritional values, including protein, fiber, essential amino acids, vitamins, and minerals, directly addressing malnutrition and "hidden hunger". Their ability to provide consistent yields under variable conditions ensures more stable food availability, especially for smallholder farmers who rely on locally produced food and very often lack access to national food system; iii) The shift toward minor cereals and pseudograins can challenge established power structures mainly by empowerment of marginalized farmers, changing consumption patterns, policy shifts and government support, influence on land use policy, etc. In fact, these crops are often linked to indigenous and traditional farming practices, and their resurrection can help preserve cultural heritage and traditional diets that were previously declining due to the so-called 'Green Revolution's focus on major cereals.

The qualitative research conducted in this study indicated a positive and progressive political and social impact on agriculture in Bangladesh. These were understood by the volume of releasing high-yielding crop varieties (545) and development of 505 innovative technologies for crop production by The Bangladesh Agricultural Research Institute (BARI, 2020).

considerable studies in other nations (Kaur et al., 2023; Talha et al., 2023). For bridging this gap a systematic laboratory analysis should de conduct for establishing nutritional and health benefit profiles.

5.8 Herbarium Sheet Preparation

Herbarium Sheets of all selected samples were created in accordance with the guidelines of the BNH and the samples were also recognized by the Bangladesh National Herbarium. The identified samples are as follows:

Table 5.8: Herbarium sheet identification of selected food samples

Sl.No	Sample Name	Figure Number
1.	Red aman rice (<i>Oryza sativa</i>)	I
2.	Black rice (<i>Oryza sativa</i>)	II
3.	Wheat (<i>Triticum aestivum</i>)	III
4.	Maize (<i>Zea mays</i>)	IV
5.	Barley (<i>Hordeum vulgare</i>)	V
6.	Kaon (<i>Setaria italic</i>)	VI
7.	Cheena (<i>Panicum miliaceum</i>)	VII
8.	Oat (<i>Panicum miliaceum</i>)	VIII
9.	Bajra (<i>Pennisetum glaucu</i>)	IX
10.	Yellow buckwheat (<i>Fagopyrum esculentum</i>)	X
11.	Black buckwheat (<i>Fagopyrum esculentum</i>)	XI
12.	Quinoa (local) (SAU-1) (<i>Chenopodium quinoa</i>)	XII
13.	Chia (Local) (<i>Salvia hispanica</i>)	XIII



Lal Aman Rice (Red Aman Rice)



Oryza sativa L.

Poaceae

বাংলাদেশ জাতীয় উদ্ভিদ
উদ্যান, ঢাকা-১২০৮
১২/০৬/২০২১

FLORA OF BANGLADESH
BANGLADESH NATIONAL HERBARIUM

Date: 12/06/2021

Bot. Name : *Oryza sativa*

Family : Poaceae

Loc. Name : Lal Aman Chal (Red Rice)

Locality : Monagram, Cumilla, Bangladesh

Notes : Herb

Collector/s: Anjum Zerin Rupa No

(V)

Figure: I

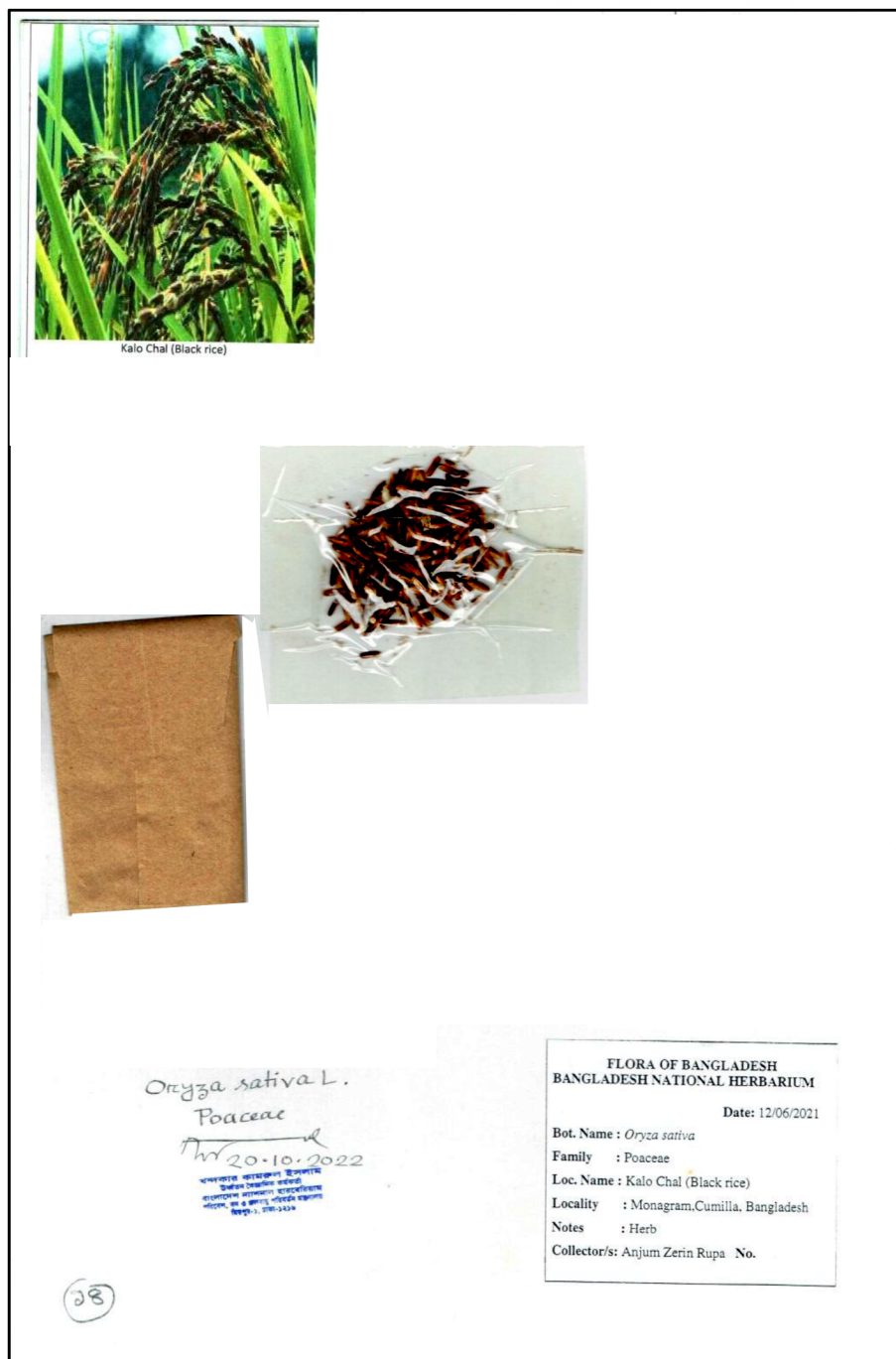


Figure: II



Figure: III

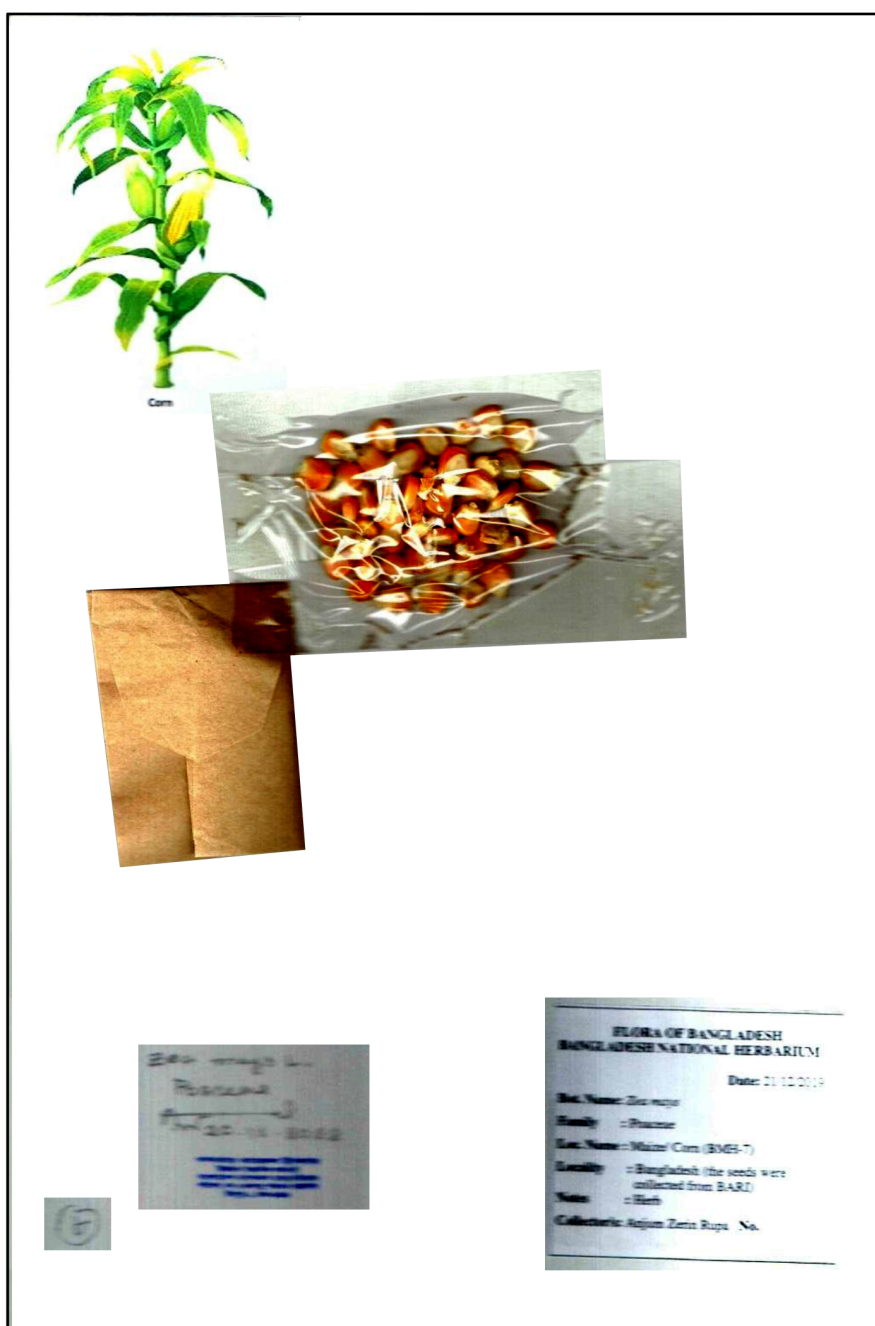


Figure: IV

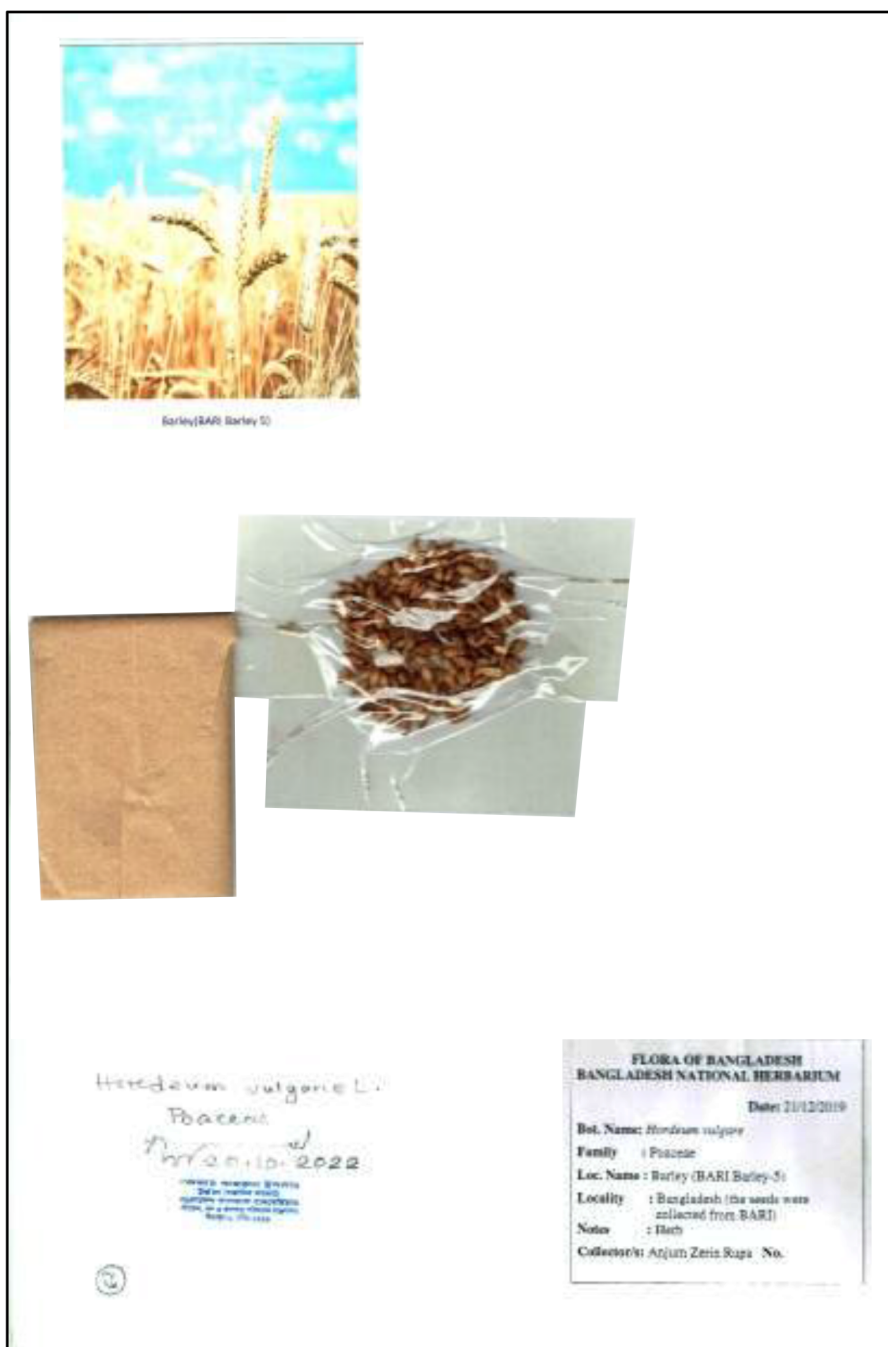


Figure: V



Figure: VI

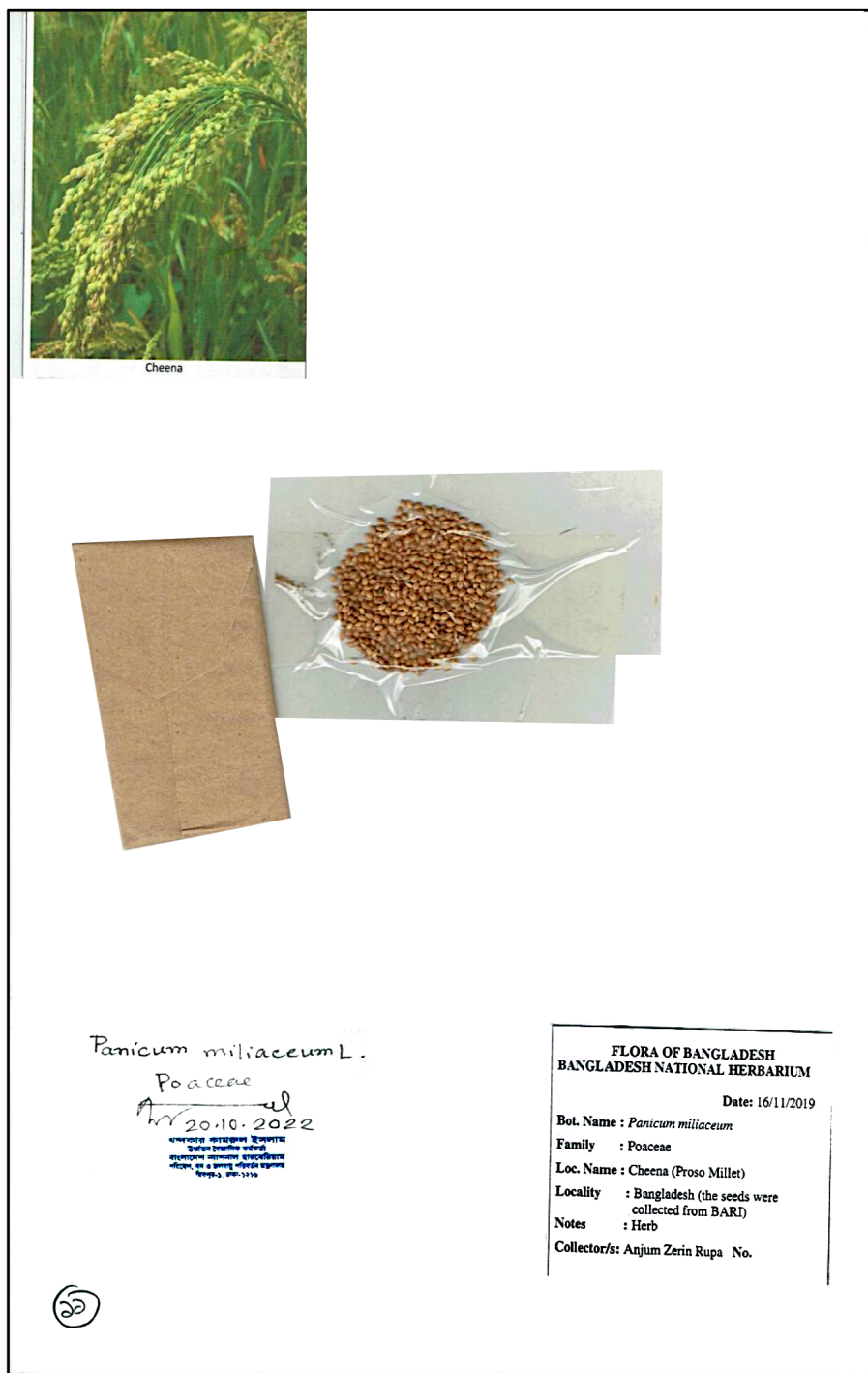


Figure: VII



Figure: VIII



Pennisetum glaucum (L.) R.Br.
Poaceae
Anj
20.10.2022

খাদ্যকাজে ব্যবহৃত হয়।
উচ্চমানের খাদ্য।
বাংলাদেশের খাদ্যশস্যের অন্যতম প্রধান।
খাদ্য, মাংস ও পশুপালনের জন্য।
বিস্তৃতি: ১০০-১৫০০



FLORA OF BANGLADESH
BANGLADESH NATIONAL HERBARIUM

Date: 21/12/2019

Bot. Name: *Pennisetum glaucum*

Family : Poaceae

Loc. Name : Bajra

Locality : Bangladesh (collected from local market)

Notes : Herb

Collector/s: Anjum Zerin Rupa No.

Figure: IX



Yellow Buck Wheat



Fagopyrum esculentum Moench
Polygonaceae

20.10.2022

সংগ্রহকারী: ড. আনজুম জেরিন রূপা
সংগ্রহস্থল: বাংলাদেশ জাতীয় হারবারিয়াম
তারিখ: ২০.১০.২০২২

২০

FLORA OF BANGLADESH
BANGLADESH NATIONAL HERBARIUM

Date: 30/12/2021

Bot. Name: *Fagopyrum esculentum*

Family : Polygonaceae

Loc. Name : Dhemshi (Yellow buckwheat)

Locality : Imported from China
(collected from local Bangladeshi market)

Notes : Herb (Pseudograin)

Collector/s: Anjum Zerir Rupa No.

Figure: X

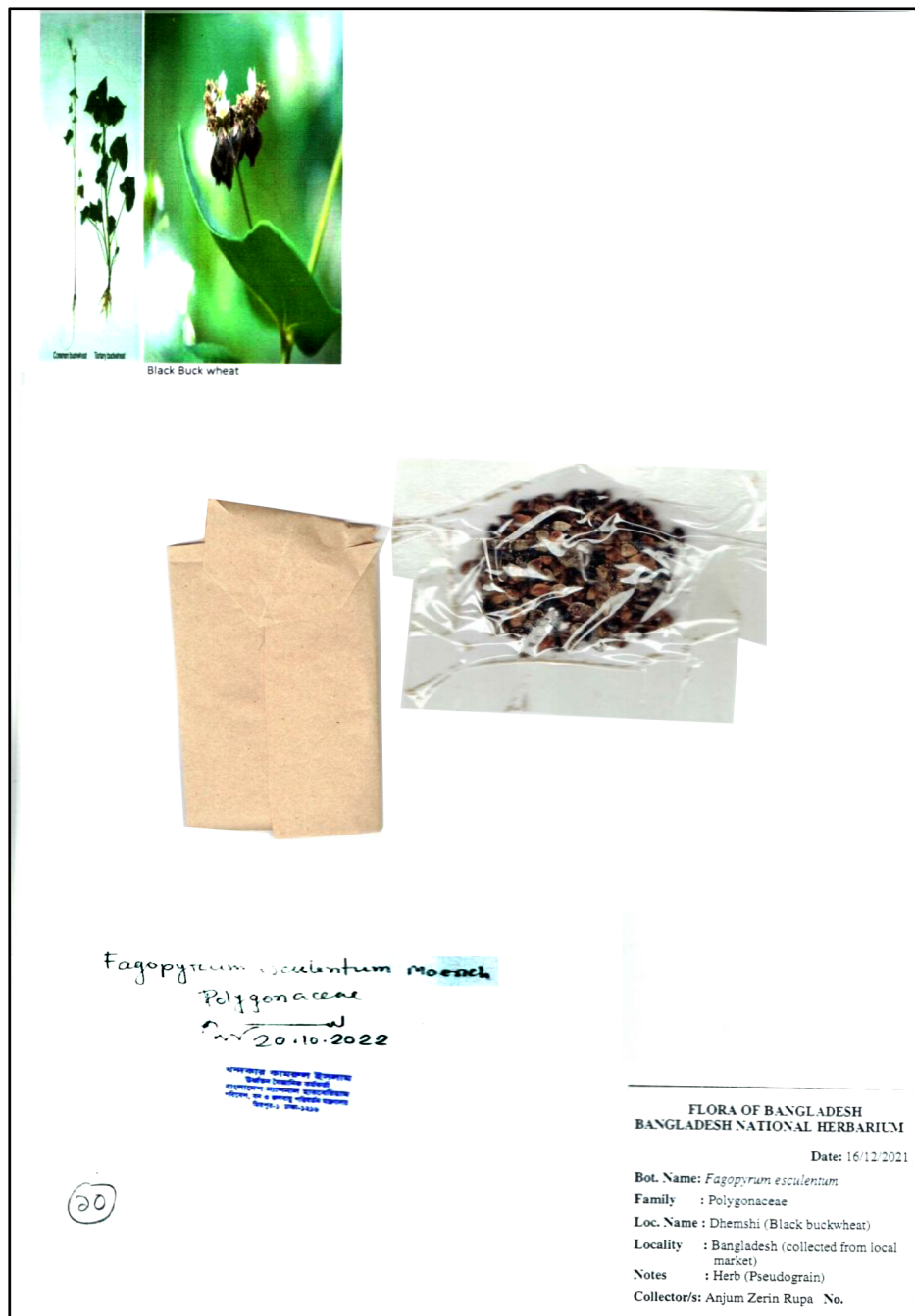


Figure: XI

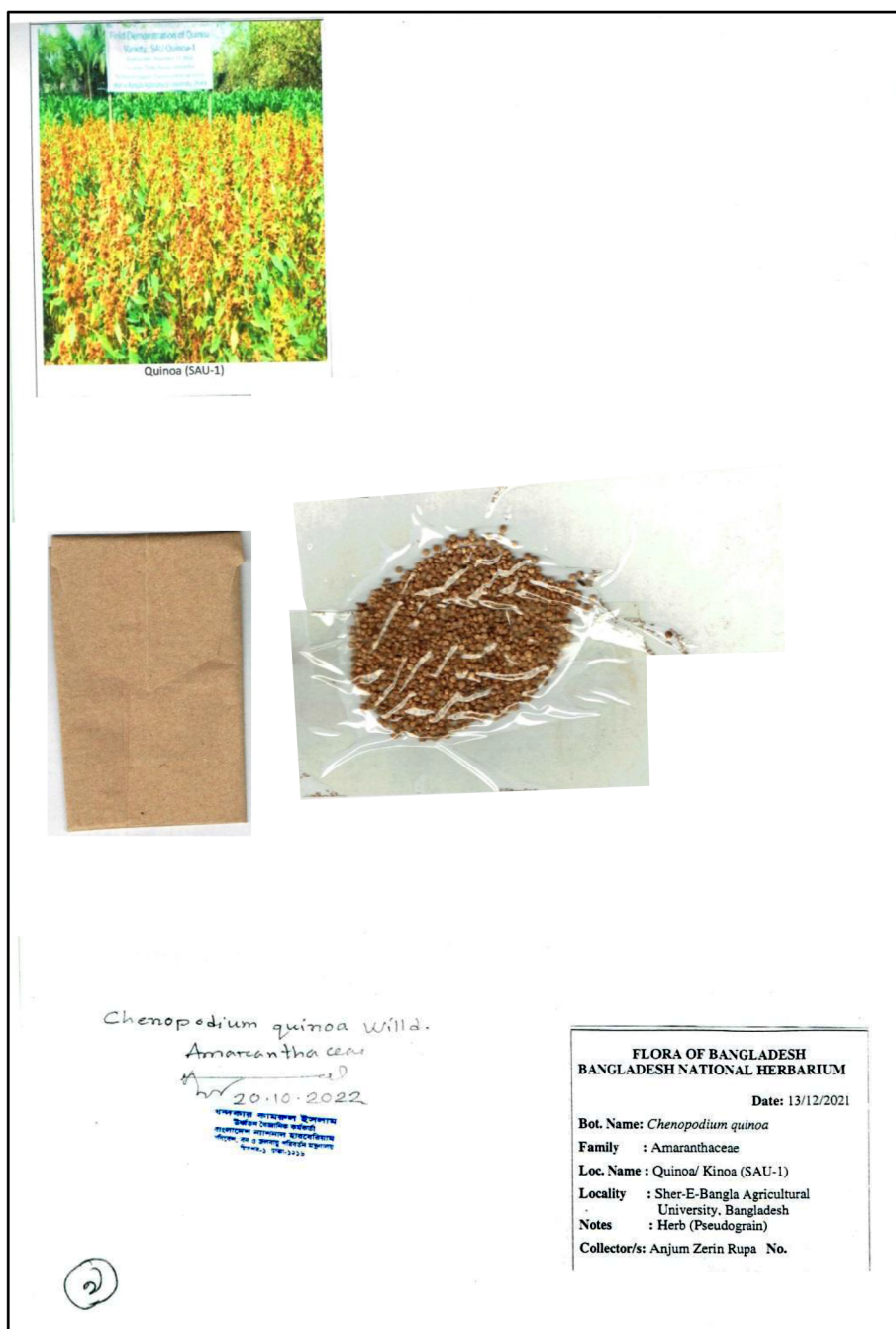


Figure: XII

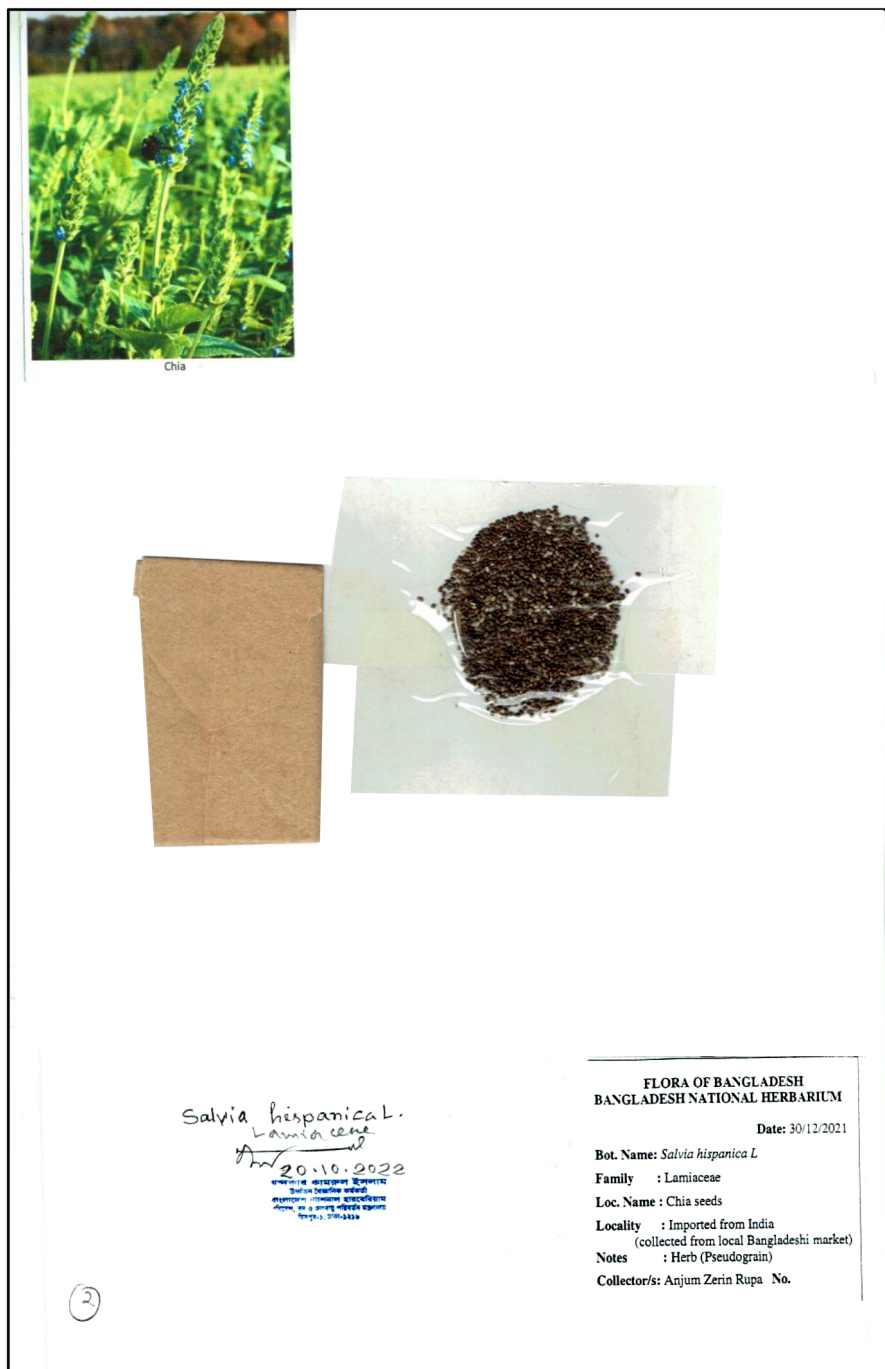


Figure: XIII

5.9 Discussions

The reintroduction of minor cereals and pseudograins into Bangladesh's agriculture has a positive and progressive political and social impact by improving climate resilience and food security, empowering marginalized farmers, and preserving cultural heritage. These impacts are supported by research findings from institutions like Bangladesh Agricultural Research Institute (BARI), Bangladesh Agricultural University (BAU) and several other organizations. Our study, in this regard, details several "influential effectors" through which minor cereals and pseudograins create positive sociopolitical and cultural impacts outlined in the followings:

- 1) Diversification of farming systems: Reintegrating these crops diversifies agricultural practices, moving away from vulnerable monocultures. This enhanced biodiversity reduces susceptibility to climate-related shocks such as pests and diseases, which is crucial for climate resilience.
- 2) Improved nutrition and food security: The high nutritional value of millets, quinoa, and amaranth (rich in protein, fiber, essential amino acids, vitamins, and minerals) directly addresses malnutrition and "hidden hunger". Their ability to provide consistent yields under variable climate conditions ensures more stable food availability, particularly for smallholder farmers who may lack access to national food systems.
- 3) Challenging power structures and empowering marginalized farmers: The shift toward these crops can challenge established power dynamics. These crops are often suitable for marginal lands and require less intensive inputs, providing opportunities for smallholder farmers to improve their livelihoods and economic standing.
- 4) Preservation of cultural heritage: Linking these crops to indigenous and traditional farming practices helps preserve cultural heritage and diets that were declining due to the 'Green Revolution's focus on major cereals like rice and wheat.

- 5) Policy shifts: The growing interest and research like BARI's release of 545 high-yielding crop varieties and 505 innovative technologies demonstrate government and institutional support, leading to potential shifts in land use and agricultural policy that favor these resilient crops. This volume of scientific output signifies a substantial political and institutional commitment to diversifying agriculture and improving food security, thus supporting the reintroduction and expansion of a wider range of crops, including minor cereals and pseudograins, as a strategic approach to national agricultural resilience.

These developments indicate that the government and research institutions in Bangladesh are actively supporting the diversification of the agricultural system, which validates the positive social and political impacts observed in the study regarding minor cereals and pseudograins

5.10 Summary and recommendation

While Bangladesh has established a strong governmental support and good agricultural practices for primary crops, this ethnographic survey disclosed that pseudocereal e.g., buckwheat, amaranth, quinoa, chia production and consumption remain disproportionately low. This gap persists despite their massive potential to address the country's malnutrition and chronic health issues. These unpleasant gaps are the followings:

- a. Dominance of traditional cereals: Rice occupies over 96% of land under cereal agriculture in Bangladesh. In contrast, pseudocereal data is described as "very scanty".
- b. Low market penetration: Approximately 99% of buckwheat is sold by local producers rather than integrated into mainstream commercial channels.
- c. Research vs. reality: While 100% of experimental quinoa and chia production is currently used for research, these crops have yet to reach a widespread commercial scale.
- d. Stagnating diversity: Despite 316 recorded cropping patterns, the vast majority of farmers remain focused on the boro-fallow-rice cycle, which limits the expansion of minor grains.

Therefore, to move beyond current "scanty" production levels, this survey and recent agricultural reports suggest the future research and policy initiatives should be:

- i. Bridging the knowledge gap: There is a lack of awareness among both farmers and consumers regarding the health benefits of pseudocereals. Mass awareness campaigns and chemical analysis are needed to promote their use as nutritional enriched food.
- ii. Technological acknowledgment: Expansion requires specific technology for processing and storage, as high protein and lipid contents make pseudocereals more susceptible to spoilage.
- iii. Market development: Current government support focuses heavily on rice and wheat procurement, e.g., a 1.46 MMT rice procurement target for 2025 (FPMU, 2025). Similar incentives, such as guaranteed fair prices and specialized cold storage, are necessary to protect small pseudocereal farmers from price volatility.
- iv. Agripreneurship: Developing modern value chains and "smart" agricultural models, similar to the technology-driven production in the Netherlands could help Bangladesh double its output on limited land.

Chapter 6

Study Phase-2:

Nutrient and Polyphenolic Composition of Cereals and Pseudograins

6. Methodology

Samples for nutrient and polyphenolic composition analysis were identified and selected in ‘Study Phase-1’ (chapter 4). The following sections briefly elaborated the analytical procedures as precise and objectives as possible.

6.1 Sample collection

Pseudograin samples were acquired from both nearby marketplaces and diverse local research fields. Cereal samples were obtained from various sources including farmers, supermarkets, agricultural organizations associated with BARC (Bangladesh Agricultural Research Council), BARI (Bangladesh Agricultural Research Institute), BRRI (Bangladesh Rice Research Institute), and BAU (Bangladesh Agricultural University) seed archives, as well as other personal sources.

6.2 Sample description

Study samples were selected and identified from ethnographic survey and sample descriptions (collected samples, their local and scientific names, sources and pictures) are presented in Table 6.1.

6.3 Sample preparation

6.3.1 Sample preparation for proximate composition

Samples were allowed to air dry, and seeds that were deformed and distorted were removed. In order to prepare food samples for analysis, they were initially ground into a fine powder and subsequently stored in small zip lock sachets. A portion of the samples were immediately taken for moisture analysis and rest of the samples were kept in desiccators at room temperature until use.

6.3.2 Sample preparation for dietary fiber

Samples were defatted with hexane (1:20w/v) for 30 min. The defatted samples were kept in zip lock sachets and placed in desiccators at room temperature until analysis.

6.3.3 Sample extraction and preparation for phytochemical analyses

The phytochemical analyses and antioxidant activities of the sample extracts were evaluated by dissolving them in methanol at a concentration of 1 mg/mL. Absorbance was quantified via a UV spectrophotometer (Specord 205, Analytic Jena, Germany).

Table 6.1: Botanical description of the collected food samples

Sl. No.	Sample Description	Sample picture
1.	Local Name: Lal Aman Chal English Name: Red Aman Rice Scientific Name: <i>Oryza sativa</i> Source: Monagram field, Cumilla	
2.	Local Name: Kalo Chal English Name: Black Rice Scientific Name: <i>Oryza sativa</i> Source: Monagram field, Cumilla	
3.	Local Name: Gom English Name: Wheat Scientific Name: <i>Triticum aestivum</i> Source: Bangladesh Agricultural Research Institute (BARI)	
4.	Local Name: Bhutta English Name: Maize/ Corn Scientific Name: <i>Zea mays</i> Source: Bangladesh Agricultural Research Institute (BARI)	
5.	Local Name: Barley English Name: Barley Scientific Name: <i>Hordeum vulgare</i> Source: Bangladesh Agricultural Research Institute (BARI)	

6. Local Name: Kaon
English Name: Foxtail Millet
Scientific Name: *Setaria italic*
Source: Bangladesh Agricultural Research Institute (BARI)



7. Local Name: Cheena
English Name: Proso Millet
Scientific Name: *Panicum miliaceum*
Source: Bangladesh Agricultural Research Institute (BARI)



8. Local Name: Oat
English Name: Oat
Scientific Name: *Panicum miliaceum*
Source: Bangladesh Agricultural Research Institute (BARI)



9. Local Name: Bajra
English Name: Pearl millet
Scientific Name: *Pennisetum glaucu*
Source: Local Market



10. Local Name: Dhemshi (holud)
English Name: Yellow Buckwheat
Scientific Name: *Fagopyrum esculentum*
Source: Local Market



11. Local Name: Dhemshi (kalo)
English Name: Black Buckwheat
Scientific Name: *Fagopyrum esculentum*
Source: Local Market



12. Local Name: kinoa/ quinoa
English Name: Quinoa
Scientific Name: *Chenopodium quinoa*
Source: Local Market & Sher-E-Bangla
Agricultural University research field



13. Local Name: Chia
English Name: chia
Scientific Name: *Salvia hispanica*
Source: Local Market, Bogra,
Mymensingh and Dinajpur field

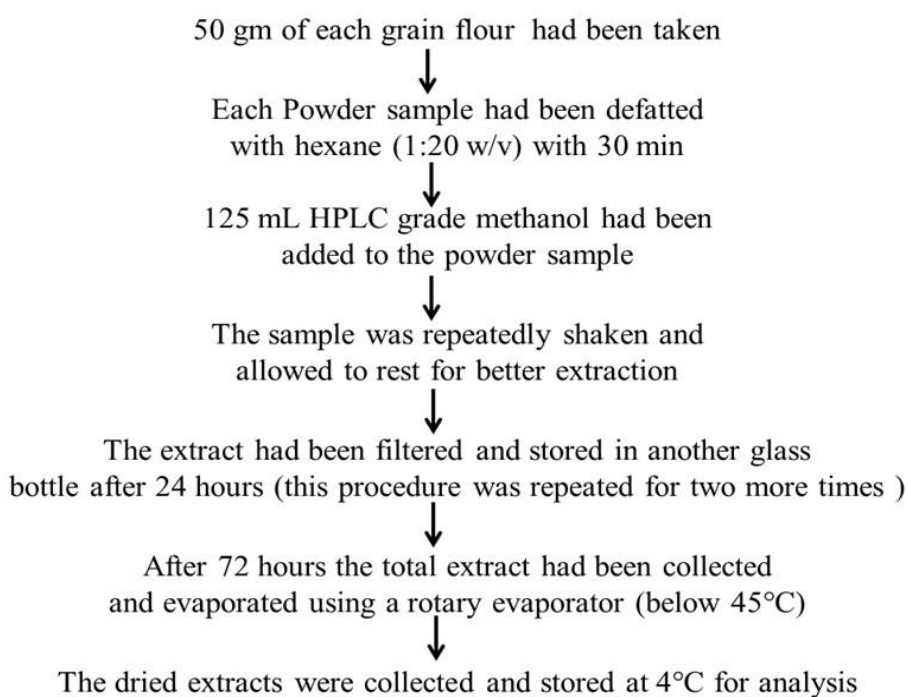


Figure 6.1: Flow chart of the sample extraction protocol

6.4 Proximate analysis

All methods used for proximate analysis were ‘Association of Official Analytical Chemists, AOAC’ recommended methods (AOAC, 2000). The proximate components, which include moisture/water, protein, fat, ash, and total dietary fiber, were estimated according to the procedures reported earlier (Afrin et al., 2024; Mili & Rahim, 2024).

6.4.1 Determination of moisture/ water

The moisture content (method no. 925.09) was identified by measuring the weight loss of the sample after drying in an oven at 100° C for 5 hours.

6.4.2 Determination of ash

Ash content was determined by charring the moisture free sample at 200° C for 1 hours and heating it at 600° C for 5 hours in a muffle furnace (method 923.03). The empty crucibles were carefully dried in a 105° C oven for one hour, removed, and stored in a desiccator until a steady weight was attained. Pre-weighed empty crucible received 0.5 gram sample. Nitric acid (0.5–1mL) was added to the crucible and gradually burned over a moderate flame. The crucible was carefully heated to 650° C in a muffle furnace for 4-5 hours. The material was preserved after extraction, cooling, and desiccating. The weight of the crucible was then measured. The ash content was measured to quantify the inorganic residue.

$$\text{Ash (g/100g)} = \frac{\text{weight of sample}}{\text{weight of residue}} \times 100 \dots \dots \dots (1)$$

6.4.3 Determination of protein

Nitrogen content was determined by the micro-Kjeldahl method according to AOAC (2000; Method 984.13), and crude protein was calculated by multiplying the nitrogen value by the Jones factor (6.25) for cereals (Jones, 1931). Briefly, a 0.5 g food sample was digested with 10 mL concentrated sulfuric acid and 0.5 g digestion mixture in a Kjeldahl flask for 4–5 h until a clear solution was obtained. After cooling, the digest was diluted, quantitatively transferred, and made up to 100 mL with distilled water. A 10 mL aliquot was rendered alkaline with 20 mL of 33% NaOH

and steam-distilled, and the liberated ammonia was absorbed in 10 mL of 2% boric acid. The distillate was titrated against 0.02 N HCl using a mixed indicator until the color changed from green to light purple.

Calculation:

$$\text{Protein content (g/100g)} = \frac{(S-B) \times N \times 14 \times f}{W \times 1000} \times 100 \dots \dots \dots (2)$$

Where,

S = Titration reading for sample

B = Titration reading for blank

N = Strength of HCl solution (0.02 N)

W = Weight of sample

14 = Nitrogen Factor

f = Conversion factor of nitrogen to protein (6.25)

6.4.4 Determination of fat

Crude fat content was determined by continuous solvent extraction using a Soxhlet apparatus following AOAC (2000; Method 991.06). All glassware was rinsed with petroleum ether, drained, oven-dried at 105° C for 30 min, and cooled in a desiccator prior to use. An accurately weighed 5 g food sample was placed into thimble and fitted into the Soxhlet extractor. A clean, dry 250 mL round-bottom flask was weighed and filled with a solvent mixture consisting of 60 mL petroleum ether and 90 mL n-hexane. The extraction assembly was mounted on an electric heating mantle, and heating was initiated to allow the solvent to boil and continuously extract fat from the sample.

$$\text{Crude Fat content (g/100g)} = \frac{W_2 - W_1}{W} \times 100 \dots \dots \dots (3)$$

Where, W1 = weight of empty flask (g)

W2 = weight of flask and extracted fat (g)

W = Sample weight (g)

6.4.5 Determination of total dietary fiber (TDF)

The Prosky method for TDF (method no. 985.29; AOAC 2000) typically involves an enzymatic digestion of food samples to mimic human digestion, followed by precipitation of the insoluble fiber, and the collection of soluble fiber from the filtrate. The method is based on the principle that dietary fiber is the portion of food that is not hydrolyzed by the endogenous enzymes of the human digestive tract. In this *in vitro* method, non-fiber components like starch and protein are broken down by thermo stable α -amylase (at 98° - 100° C) and amyloglucosidase (at 60° C) into small, soluble fragments that are washed away during processing, while the insoluble and high-molecular-weight soluble fiber components remain as extracts and are measured gravimetrically. The final TDF value is obtained through a series of enzymatic digestions, precipitation with ethanol, filtration, and subsequent corrections for residual protein and ash.

Briefly, 0.5 g sample was dispersed in 50 mL phosphate buffer (pH 6.0) in a tall-form beaker, followed by the addition of 0.1 mL α -amylase. The mixture was covered with aluminum foil and incubated in a boiling water bath, after reaching 95° C. It was gently agitated and incubated for 15 min. The digest was cooled to room temperature and the pH was adjusted to 7.5 ± 0.2 using 10 mL of 0.275 N NaOH, with minor adjustments using NaOH or HCl as required. Freshly prepared protease solution (50 mg/mL) was added (0.5 mg in 0.1 mL), and the mixture was incubated at 60° C for 30 min with continuous agitation. After cooling, the pH was adjusted to 4.0–4.6 with 10 mL of 0.325 M HCl. Amyloglucosidase (1 mL) was then added, and the mixture was further incubated at 60° C for 30 min.

The reaction mixture was treated with four volumes of 95% ethanol and allowed to stand overnight at room temperature for complete precipitation. The precipitate was filtered through a celite-packed crucible pre-moistened with 78% ethanol and washed sequentially with 75% ethanol (2×10 mL), acetone, and 78% ethanol (3×20 mL). The crucible was dried at 105° C (or 70° C under vacuum), cooled in a desiccator, and weighed (W_2). The residue was analyzed for protein by Kjeldahl

nitrogen determination (conversion factor 6.25) and subsequently ashed at 500–600° C for 5 h. After cooling in a desiccator, the crucible was reweighed to obtain ash weight (W_3).

$$\text{Weight of residue} = W_2 - W_1$$

$$\text{Weight of ash} = W_3 - W_1$$

$$B = R_{\text{BLANK}} - P_{\text{BLANK}} - A_{\text{BLANK}}$$

$$\% \text{ TDF} = \frac{(R_{\text{sample}} - A_{\text{sample}} - P_{\text{sample}} - B) \times 100}{SW} \dots\dots\dots (4)$$

Here,

TDF = Total dietary fiber

R = Average weight of residue (g)

P = Average weight of protein (g)

A = Average weight of ash (g)

SW = Average weight of sample (g)

6.4.6 Estimation of available carbohydrate

The available carbohydrates were calculated by subtracting the sum of the percentages of moisture, protein, fat, ash and total dietary fibre (TDF) from 100 (AOAC 2006). This calculated value represents the total available carbohydrate content. The formula used for this calculation is as follows:

$$\text{Available CHO (g/100g)} = [100 - (\text{protein} + \text{lipid} + \text{moisture} + \text{ash} + \text{TDF})] \dots\dots\dots (5)$$

6.4.7 Calculation of energy in kilo-calorie (Kcal)

Utilizing conversion factors for protein, fat, carbohydrate, and TDF, the energy content of the sample was determined using Atwater & Bryant (1900) conversion factors shown as follows:

$$\text{Energy (Kcal/100gm)} = (\text{Carbohydrate} * 4 + \text{Protein} * 4 + \text{Fat} * 9 + \text{Dietary fiber} * 2) \dots\dots\dots (6)$$

6.5 Compilation of minerals and vitamins values from secondary sources

Minerals and vitamins contents were compiled from various local (FCT, 2013), regional (IFCT, 2017), and global datasets (USDA FoodData Central and FAO/INFOODS Analytical Food Composition Database, AnFoodD). This was performed by creating an archival, reference, and user data file respectively using the FAO/INFOODS Data Compilation Tool version 1.2.1 (INFOODS, 2017). The final calculated nutrient values were adjusted for water and fat corrections (Mili and Rahim, 2024). The compiled Excel data sheet has been enclosed as Annexure 2.

6.6 Phytochemical analysis

6.6.1 Reagents and standards

Ferulic acid, gallic acid, vanillic acid, catechin hydrate, caffeic acid, gallic acid, epicatechin, rutin hydrate, p-coumaric acid, ellagic acid, quercetin, 2,2-azino-bis-3-ethylbenzthiazoline-6-sulphonic acid, ascorbic acid, folin-ciocalteu-phenol reagent were obtained from Merck and Sigma. Methanol (HPLC), acetonitrile (HPLC), ethanol, acetic acid (HPLC), phosphate buffer (pH 6.6), potassium ferricyanide [$K_3Fe(CN)_6$], trichloroacetic acid (TCA), ferric chloride ($FeCl_3$), EDTA, sodium phosphate, ammonium molybdate and sodium carbonate were purchased from Sigma and BDH.

6.6.2 Determination of total phenolic content (TPC)

The total concentration of phenolic compounds was quantified in the methanol extract using the standard Folin-Ciocalteu reagent (Ahmed et al., 2023). The reaction mixture was comprised 0.5 mL (1000 μ g/mL) of extract, 5.0 mL of Folin-Ciocalteu reagent (diluted 1:10 v/v with distilled water) (Merck), and 4.0 mL of sodium carbonate (75 g/L). The sample was combined using a vortex mixer and diluted with distilled water to achieve a final volume of 10 mL. The color was manifested after 30 minutes at 40° C of reaction. The absorbance at 765 nm was measured and utilized to ascertain the phenolic content by the calibration curve of gallic acid (Sigma-Aldrich).

6.6.3 Determination of total flavonoid content (TFC)

Total flavonoid content (TFC) was determined using the aluminum chloride colorimetric method as described earlier (Ahmed et al., 2023), with minor modifications. Briefly, 2.5 mL of aluminum chloride and sodium acetate reagent was mixed with 2.5 mL of sample solution (1000 µg/mL) in test tubes. The reaction mixtures were incubated at room temperature for 30 min. Absorbance was measured at 430 nm using a UV–visible spectrophotometer against a reagent blank. Quercetin was used as the standard for calibration, and results were quantified from the standard curve.

6.6.4 High Performance Liquid Chromatography (HPLC) screening for polyphenols

Reverse-phase High-Performance Liquid Chromatography (RP-HPLC) works by using a non-polar stationary phase and a polar mobile phase to separate compounds based on hydrophobicity. Compounds that are more polar interact more with the polar mobile phase and elute first, while less polar (more hydrophobic) compounds are retained longer by the non-polar stationary phase and elute later. This is a widely used technique, with common stationary phases being C18 or C8 bonded silica and the mobile phase typically being a mixture of water and an organic solvent like methanol or acetonitrile polar (Dickei A, 2025; Ahmed et al., 2021, 2023).

6.6.4.1 Preparation of working standard solutions

In a volumetric flask with a capacity of 25 milliliters, sixteen (16) phenolic standards were dissolved with methanol in order to make stock standard solutions. There was a variation of concentrations for the stock solutions, which were between 4.0 and 5.0 µg/mL. For the purpose of preparing the working standard solutions, the appropriate volumes of each stock solution were combined, and then the mixture was diluted in a sequential manner. Each and every solution was kept in aluminum foiled container in a refrigerated environment.

6.6.4.2 HPLC analysis protocol

HPLC analysis was performed utilizing a Shimadzu apparatus (LC-20A, Japan). The apparatus comprised a binary solvent delivery pump (SIL-20A HT), an auto sampler, a column oven (CTO-20A), and a photodiode array detector (SPD-M20A). The complete system was governed by the LC solution program (Lab solution). A separation was performed utilizing a Luna C18 (5 μ m) Phenomenex column (4.6 x 250 mm) at a temperature of 33°C. This investigation included a mobile phase composed of two solutions. The gradient elution technique was utilized, incorporating variable ratios of solution A and solution B at distinct time intervals. The mobile phase composition was altered as follows: From 0.01 to 20 minutes, solution A varied from 5% to 25%, while solution B fluctuated from 95% to 75%. From 20 to 30 minutes, solution A increased from 25% to 40%, and solution B decreased from 75% to 60%. From 30 to 35 minutes, solution A rose from 40% to 60%, whereas solution B declined from 60% to 40%. From 35 to 40 minutes, solution A decreased from 60% to 30%, while solution B increased from 40% to 70%. From 40 to 45 minutes, solution A diminished from 30% to 5%, and solution B ascended from 70% to 95%. Finally, from 45 to 50 minutes, solution A remained at 5%, while solution B was at 95%. The injection volume was 20 μ L, and the flow rate was set to 0.5 mL/min. The UV detector was calibrated to 270 nm to authenticate the procedure and conduct the analysis. The mobile phase was filtered through a 0.45 μ m Nylon 6, 6 membrane filter (India) and subsequently degassed under vacuum. A standard stock solution was formulated in methanol, comprising several components at designated quantities. The components comprise gallic acid, 3,4- dihydroxybenzoic acid, catechin hydrate, catechol, (-) epicatechin, rosmarinic acid, caffeic acid, vanillic acid, syringic acid, rutin hydrate, p-coumaric acid, trans-ferulic acid, quercetin, myricetin, kaempferol, and trans-cinnamic acid.

6.7 Statistical analysis

Statistical data were reported as means $\pm$ standard deviation. Results were subjected to correlation analysis, descriptive statistics and analysis of differences among mean values. Graphical representations were illustrated and calculated by Origin 2018 software. Pearson's correlation analysis was used to ascertain the connections among the different measured parameters. Because it evaluates the direction and strength of the linear relationship between two continuous variables, this approach was selected.

6.8 Result and discussion

6.8.1 Proximate content of food samples

Protein content varied considerably among cereals (Table 6.2), with oat and proso millet showing the highest amounts (13.65 g/100 g), while black rice exhibited the lowest (8.24 g/100 g) value. In contrast, pseudograins demonstrated substantially higher protein levels, particularly chia seeds (22 g/100 g), followed by quinoa SAU-1 and buckwheat (Table 6.3). These findings indicate that pseudograins can serve as superior protein sources compared to conventional cereals, supporting earlier reports on their nutritional potential (Cremonini et al., 2020; Mounika et al., 2022). Whole-grain proteins are also known to provide bioactive peptides that contribute to enzyme regulation, lipid metabolism, and oxidative stress reduction (Jenny et al., 2022).

Fat content among cereals was found generally low, ranging from 1.50 g/100 g in foxtail millet to 5.08 g/100 g in maize (Table 6.2). In contrast, chia seeds exhibited markedly high fat content (22.99 – 29.67 g/100 g) (Table 6.3), aligning with previous research and highlighting their substantial energy density (Bartosz et al., 2019). The lipid contents of black rice were reported as 5.70% and 6.86% by Nashrurrokhman et al. (2019), while maize varieties demonstrate a higher fat concentration compared to sorghum and wheat varieties (Sulaiman et al., 2020). Numerous scientific studies demonstrate that whole cereals, especially grain fiber, reduce mortality, type 2 diabetes, and cardiovascular disease (Smith & Tucker, 2011).

Total dietary fiber (TDF) was found highest among cereals in barley (15.11 g/100 g), followed by bajra and maize (Table 6.2), supporting their benefits for gastrointestinal health and glycemic regulation (Romania et al., 2025). Among pseudograins, black buckwheat contained high TDF (18.36 g/100 g), while chia seeds exhibited exceptionally high fiber content (36.85 g/100 g) (Table 6.3), exceeding all cereals and establishing chia as an outstanding fiber source. These trends are consistent with earlier reports on cereals and pseudograins (Alam, 2015; Filho et al., 2017).

Available carbohydrate (AvCHO) content was highest in black rice (67.89 g/100 g), followed by oat and red rice, reinforcing their role as primary energy sources. Barley showed the lowest AvCHO among cereals (57.77 g/100 g), likely due to its higher dietary fiber content. Among pseudograins, yellow buckwheat exhibited AvCHO values comparable to cereals, whereas quinoa SAU-1 contained lower levels. Chia seeds showed extremely low AvCHO (3.83 g/100 g), attributable to their high lipid and fiber contents. Numerous prior studies have established the nutritional profiles of black and yellow buckwheat, chia and quinoa from various nations (Agarwal et al., 2023; Martínez-Villaluenga et al., 2020). Paiva et al. (2019) identified carbohydrates as the predominant macronutrient in black, red, and white *Chenopodium quinoa* Willd.

The energy content of cereals ranged from 322.74 to 358.57 kcal/100 g, with maize (Table 6.2) providing the highest caloric value. Among pseudograins, chia seeds exhibited the greatest energy density (up to 452.17 kcal/100 g) (Table 6.3), largely due to their high fat content, while black buckwheat showed comparatively lower energy values. The variations in macronutrient composition among yellow and black buckwheat, chia and quinoa, identified in the prior study may be assigned to the distinct drying methods employed, varying storage conditions, and geographical differences in cultivation (Neacsu et al., 2022; Tahiri, 2020).

Table 6.2: Proximate composition of cereal and minor cereal samples (gm/100g of edible portion)

Sl. No	Sample Name	Energy (Kcal)	Moisture	Protein	Fat	A-CHO	TDF	Ash
1.	Red Aman Rice	338.43 ± 3.90	12.67 ± 0.34	10.33 ± 0.05	2.23 ± 0.39	65.23 ± 0.37	8.04 ± 0.65	1.50 ± 1.5
2.	Black Rice	351.71 ± 5.01	12.00 ± 0.28	8.24 ± 0.45	3.66 ± 0.47	67.89 ± 1.16	7.09 ± 1.03	1.10 ± 0.13
3.	Wheat	344.61 ± 3.45	10.87 ± 0.95	12.07 ± 0.92	2.33 ± 0.51	64.52 ± 3.63	8.65 ± 1.61	1.57 ± 0.31
4.	Barley	322.74 ± 4.16	11.61 ± 1.03	11.65 ± 0.67	1.65 ± 0.21	57.77 ± 1.02	15.11 ± 0.18	2.21 ± 0.28
5.	Maize	358.57 ± 4.93	10.50 ± 0.62	10.80 ± 0.96	5.08 ± 0.25	62.32 ± 1.85	10.15 ± 0.36	1.13 ± 0.15
6.	Bajra	334.60 ± 11.29	12.93 ± 2.37	9.47 ± 0.50	2.73 ± 0.25	62.61 ± 3.07	10.84 ± 0.89	1.41 ± 0.18
7.	Oat	343.69 ± 8.11	12.43 ± 1.52	13.65 ± 0.62	1.67 ± 0.31	66.07 ± 1.04	4.9 ± 0.36	1.28 ± 0.25
8.	Proso millet	339.48 ± 0.81	10.77 ± 0.07	13.47 ± 0.11	1.65 ± 0.11	62.72 ± 0.27	9.88 ± 0.215	1.48 ± 0.09
9.	Foxtail Millet	344.87 ± 3.57	9.48 ± 0.49	13.65 ± 0.56	1.50 ± 0.51	64.37 ± 1.13	9.27 ± 0.48	1.54 ± 0.13

A-CHO, Available carbohydrate; TDF, Total dietary fiber

Table 6.3: Proximate composition of pseudograin samples (gm/100g of edible portion)

Sl. No	Sample Name	Energy (Kcal)	Moisture	Protein	Fat	A-CHO	TDF	Ash
1.	Yellow buck wheat	343.15 ± 3.98	11.31 ± 0.34	14.70 ± 0.71	1.86 ± 0.41	63.42 ± 0.58	6.96 ± 1.11	1.50 ± 1.5
2.	Black buck wheat	321.28 ± 2.21	12.11 ± 0.88	11.34 ± 0.71	2.34 ± 0.27	54.54 ± 1.32	18.36 ± 0.89	1.10 ± 0.13
3.	Quinoa (Commercial)	356.22 ± 1.64	10.65 ± 0.85	12.43 ± 0.78	5.17 ± 0.65	59.76 ± 0.69	10.40 ± 0.50	1.57 ± 0.31
4.	Quinoa SAU-1 (Local)	328.07 ± 3.07	12.36 ± 0.32	16.04 ± 0.31	4.38 ± 0.17	49.43 ± 0.83	13.37 ± 0.27	2.21 ± 0.28
5.	Chia (Foreign)	386.29 ± 6.86	9.81 ± 0.36	22.57 ± 0.75	22.99 ± 0.21	3.83 ± 2.26	36.85 ± 0.97	1.13 ± 0.15
6.	Chia (Dinajpur)	383.83 ± 10.24	10.00 ± 0.02	20.44 ± 0.95	20.88 ± 1.80	12.83 ± 2.08	32.01 ± 3.14	1.41 ± 0.18
7.	Chia (Bogra)	452.17 ± 2.44	7.14 ± 0.93	19.22 ± 1.13	28.72 ± 1.69	13.48 ± 4.99	31.43 ± 1.23	1.28 ± 0.25
8.	Chia (Mymensingh)	437.49 ± 7.45	6.99 ± 0.75	22.36 ± 1.42	29.67 ± 0.09	4.53 ± 5.07	31.43 ± 1.00	1.48 ± 0.09
9.	Yellow buck wheat	343.15 ± 3.98	11.31 ± 0.34	14.70 ± 0.71	1.86 ± 0.41	63.42 ± 0.58	6.96 ± 1.11	1.54 ± 0.13

A-CHO, Available carbohydrate; TDF, Total dietary fiber

Table 6.4: Minerals content of cereals and pseudograins (mg/100g EP)

Sl. No	Sample Name	Ca	Fe	Mg	P	K	Na	Zn	Cu
1.	Red Aman Rice	1.0	348	12.6	7.6	2.3	72.4	3.8	1.3
2.	Black Rice	16.0	2.4	0.08-0.15	186	-	1.20	-	-
3.	Wheat	41.0	4.9	142	316	293	0.18	2.79	0.70
4.	Barley	26.0	5.5	1.33	264	452	4.0	2.77	0.50
5.	Maize	8.0	2.9	143	329	248	14	3.27	0.43
6.	Bajra	42.0	[8.0]	137	296	307	11	3.1	1.06
7.	Oat	80.0	5.8	0	340	350	10	4.50	0.47
8.	Proso millet	14.0	5.0	114	285	195	5	2.3	0.75
9.	Foxtail Millet	32.0	2.8	81	290	250	7	1.50	1.40
10.	Buck wheat	18.0	2.20	231	347	460	1.00	2.40	1.10
11.	Quinoa	198.0	7.51	119	212	474	4.50	3.31	-
12.	Chia	631.0	7.7	335.0	860	407	16.0	4.6	-

(-), not detected/data not available

Table 6.5: Vitamin content of cereals and pseudograins (mcg/100 g and mg/100 g of edible portion, EP)

Sl. No	Sample Name	Vit A (mcg)	β Carotene (mcg)	Vit D (mcg)	Vit E (mg)	Thiamin (mg)	Riboflavin (mg)	Niacin (mg)	B6 (mcg)	Folic acid (mg)	Vit C (mg)
1.	Red Aman Rice	-	-	-	1.40	0.17	0.03	2.70	0.29	9.90	-
2.	Black Rice	-	-	-	0.04	0.72	0.21	2.00	4.01	10.01	-
3.	Wheat	-	-	-	1.89	0.49	0.12	5.55	0.30	38.38	-
4.	Barley	-	-	-	-	0.46	0.19	7.72	0.97	33.66	-
5.	Maize	10.80	11.00	-	0.48	0.39	0.11	2.00	0.62	20.00	-
6.	Bajra	-	-	-	0.24	0.25	0.19	0.85	0.26	35.74	-
7.	Oat	-	-	-	0.95	0.18	0.09	0.84	-	-	-
8.	Proso millet	-	-	-	0.51	0.42	0.20	6.76	0.38	85.85	-
9.	Foxtail Millet	5.14	5.00	-	0.51	0.60	0.11	3.26	0.39	87.72	-
10.	Buck wheat	-	-	-		0.09	0.42	6.87	0.20	29.40	-
11.	Quinoa	-	-	-		0.81	0.21	1.66	1.69	20.58	-
12.	Chia	16.44	16.20	-	0.50	0.31	0.16	8.74	-	48.51	-

(-), not detected, mcg = microgram, mg = miligram

6.8.2 Minerals and vitamins

Minerals and vitamins were obtained from non-analyzed value compiled from secondary sources. The mineral composition of the analyzed cereals and pseudocereals (Table 6.4) revealed marked nutritional variability, underscoring their potential role in improving micronutrient adequacy. Chia seeds exhibited exceptionally high calcium (631 mg/100 g), magnesium (335 mg/100 g), phosphorus (860 mg/100 g), potassium (407 mg/100 g), iron (7.7 mg/100 g), and zinc (4.6 mg/100 g), confirming their superior mineral density, consistent with USDA data and previous reports (US Department of Agriculture, 2018; Vani & Soni, 2024). Quinoa also demonstrated substantial contributions of calcium, iron, magnesium, phosphorus, and potassium, supporting earlier findings on its mineral richness and bioavailability (González et al., 2014; Gordillo et al., 2017; Vega-g et al., 2010). Among cereals, oats and barley were notable sources of calcium, iron, potassium, and zinc, while wheat and millets contributed moderate but nutritionally relevant levels. Sodium levels were low across all samples, an advantage for cardiovascular health. Variations in mineral composition are attributable to differences in genotype, soil conditions, and processing practices, particularly milling and refining, which reduce mineral-rich bran fractions (Bouis & Welch, 2010; Khan et al., 2022; Nashrurrokhman et al., 2019; Welch & Graham, 2004).

The vitamin profiles of the analyzed cereals and pseudocereals (Table 6.5) exhibited clear interspecies variation, underscoring their complementary roles in micronutrient supply and metabolic health. Provitamin A activity was limited in most cereals, with detectable vitamin A and β -carotene only in maize and foxtail millet. In contrast, chia seeds showed the highest carotenoid concentrations, indicating superior antioxidant potential. Vitamin E (tocopherol) occurred at nutritionally relevant levels in wheat and red aman rice, with moderate contributions

from oats and chia. This aligns with literature highlighting cereals and oil-rich seeds as important dietary sources of lipid-soluble antioxidants. Folate levels varied substantially, with foxtail and proso millets exhibiting the highest content, followed by chia and wheat.

Pseudocereals, particularly chia, quinoa, and buckwheat, demonstrated higher vitamin density than conventional cereals, especially for pro-vitamin A, B-complex vitamins, and tocopherols. Such variation is attributable to grain type, pigmentation, and retention of germ and bran fractions, which are often reduced during refining. These findings agree with reports showing cereals as major sources of thiamine, niacin, pyridoxine, riboflavin, and minerals when consumed in whole form (Bouis & Welch, 2010; Welch & Graham, 2004). The nutritional fraction is predominantly located in the germ and bran, and losses during milling can exceed 80% for thiamine and pyridoxine, 67% for niacin, and 50% for phosphorus and manganese (Babu et al., 2009; Slavin, 2004). Similar patterns were noted for brown rice, which contains almost twice the B-vitamin and tocopherol content compared to polished rice.

Pseudocereals have been increasingly recognized as nutrient-dense grain substitutes (Repocarrasco-valencia & Serna, 2011). USDA data and recent analyses confirm chia as a rich source of riboflavin, niacin, pantothenic acid, and folate, consistent with concentrations reported by Nieman et al. (2012) and Vani & Soni (2024). Buckwheat likewise provides high riboflavin levels and is cultivated widely across Asia, Europe, and the Americas (USDA, 2018). Quinoa exhibited diverse vitamin B content, including thiamine (0.4 mg/100g), pyridoxine (0.20 mg/100g), pantothenic acid (0.61 mg/100g), folic acid (78.1 mg/100g), and vitamin C (1.4 mg/100g), along with tocopherols ranging from 37.49–59.82 µg/g, dominated by α - and γ -isoforms.

6.8.3 Phytochemicals of Cereals and Pseudograins

6.8.3.1 Total phenolic content (TPC)

The total phenolic content (TPC) of cereals and pseudograins showed pronounced variability (Tables 6.6 and 6.8), reflecting differences in grain type and pigmentation. Among cereals, black rice exhibited exceptionally high TPC (276.72 ± 0.08 mg GAE/g), markedly exceeding all other samples, followed by red aman rice (156.19 ± 0.01 mg GAE/g) and bajra (135.75 ± 0.33 mg GAE/g). These findings confirm the strong association between grain pigmentation and phenolic accumulation, as previously reported for colored rice varieties (Deng et al., 2012). Among pseudograins, black buckwheat showed the highest TPC (90.56 ± 0.35 mg GAE/g), followed by local chia, while quinoa samples exhibited comparatively lower values. Similar trends of high phenolic content in buckwheat have been documented in studies from Italy and Latvia, although absolute values were higher than those observed in the present study (Beitane et al., 2018; Rocchetti et al., 2019). Lower TPC in chia and quinoa may be related to phenolics occurring in bound forms and to differences in geographical origin, cultivation practices, and extraction methods (Khursheed et al., 2023; Uddin et al., 2013).

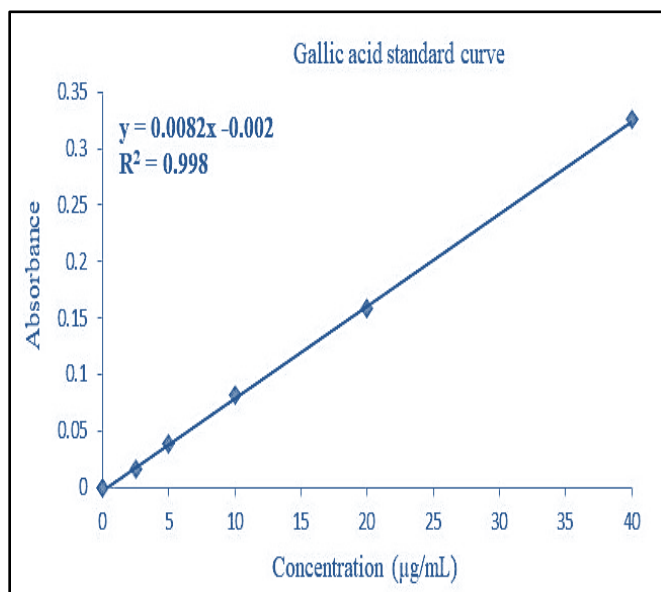


Figure 6.2 Standard curve of total phenolic content with Gallic acid as standard

Table 6.6: Total phenolic content (TPC) of cereals by dry extracts (DE)*

Sl. No.	Sample Name	TPC (GAE mg/gm of DE)
1.	Red Aman Rice	156.19 ± 0.01
2.	Black Rice	276.72 ± 0.08
3.	Wheat	42.08 ± 0.07
4.	Maize	86.25 ± 0.87
5.	Barley	102.25 ± 0.26
6.	Foxtail Millet	61.24 ± 0.03
7.	Proso millet	22.96 ± 0.04
8.	Oat	57.75 ± 0.37
9.	Bajra	135.75 ± 0.33

*Each value represents average of triplicate estimations and expressed as Mean ± SD.

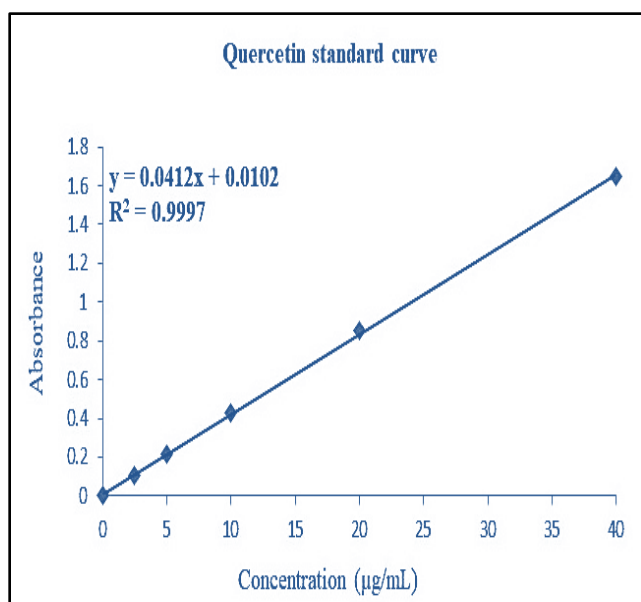


Figure 6.3 Standard curve of total flavonoid content with Quercetin as standard

Table 6.7: Total flavonoid content (TFC) of cereal sample by dry extracts (DE)*

Sl. No.	Sample Name	TFC (mg of QE/gm DE)*
1.	Red Aman Rice	13.93 ± 0.05
2.	Black Rice	20.19 ± 0.18
3.	Wheat	10.30 ± 0.05
4.	Maize	6.02 ± 0.01
5.	Barley	7.11 ± 0.02
6.	Foxtail Millet	7.12 ± 0.01
7.	Proso millet	7.71 ± 0.02
8.	Oat	4.45 ± 0.01
9.	Bajra	17.44 ± 0.05

*Each value represents average of triplicate estimations and expressed as Mean ± SD.

Table 6.8: Total phenolic content (TPC) and total flavonoid content (TFC) of pseudo grain sample extracts

Sl. No	Sample Name	TPC (mg of GAE/gm of DE)	TFC (mg of QE/gm DE)
1.	Yellow buck wheat	54.09 ± 0.28	39.44 ± 0.10
2.	Black buck wheat	90.56 ± 0.35	58.52 ± 0.15
3.	Quinoa (foreign)	29.38 ± 0.10	5.86 ± 0.09
4.	Quinoa SAU-1 (Local)	54.09 ± 0.28	6.66 ± 0.01
5.	Chia (Foreign)	42.34 ± 0.20	25.83 ± 0.14
6.	Chia (Local)	79.75 ± 0.19	3.65 ± 0.07

*Each value represents the average of triplicate estimations and expressed as Mean ± SD.

6.8.3.2 Total flavonoid content (TFC)

Total flavonoid content (TFC) varied significantly across cereals and pseudograins (Tables 6.7 and 6.8). Among cereals, black rice recorded the highest TFC (20.19 ± 0.18 mg QE/g), followed by bajra (17.44 ± 0.05 mg QE/g) and red aman rice (13.93 ± 0.05 mg QE/g). Pseudograins especially black buckwheat demonstrated the highest flavonoid content (58.52 ± 0.15 mg QE/g), followed by yellow buckwheat and chia, while both foreign and local quinoa showed comparatively low TFC. These results are consistent with previous reports highlighting buckwheat as a rich source of flavonoids and confirming higher TFC in pigmented cereals and pseudocereals (Beitane et al., 2018; Deng et al., 2012; Grande et al., 2023). Differences between the present findings and earlier studies, which reported higher flavonoid levels in quinoa and chia, are likely attributable to varietal diversity, geographic location, and methodological variations in extraction and analysis (Sharma et al., 2022; Uddin et al., 2013).

Table 6.9: HPLC analysis of polyphenolic composition of cereals (mg/100 g DE)

Phenolic acids	Red aman Rice	Black rice	Wheat	Barley	Maize
Gallic acid	-	-	-	-	-
3,4-Dihydroxybenzoic acid	-	-	249.97 $\pm$ 0.54	-	-
Catechin hydrate	-	-	-	-	-
Catechol	-	-	-	19.57 $\pm$ 0.18	-
(-) Epicatechin	13.05 $\pm$ 0.47	-	-	-	-
Caffeic acid	-	-	-	2.82 $\pm$ 0.04	59.94 $\pm$ 0.38
Vanillic acid	-	3.95 $\pm$ 0.12	-	-	-
Syringic acid	-	0.45 $\pm$ 0.02	3.14 $\pm$ 0.03	-	0.79 $\pm$ 0.02
Rutin hydrate	-	-	1.42 $\pm$ 0.06	1.92 $\pm$ 0.17	8.07 $\pm$ 0.07
p-Coumaric acid	-	6.89 $\pm$ 0.08	-	0.57 $\pm$ 0.01	-
trans-Ferulic acid	-	0.63 $\pm$ 0.05	-	0.61 $\pm$ 0.04	-
Rosmarinic acid	-	0.62 $\pm$ 0.01	-	-	-
Myricetin	-	0.54 $\pm$ 0.04	-	-	-
Quercetin	0.41 $\pm$ 0.02	-	-	-	-
trans-Cinnamic acid	0.45 $\pm$ 0.02	-	-	-	-
Kaempferol	0.36 $\pm$ 0.01	0.76 $\pm$ 0.06	11.37 $\pm$ 0.27	-	-

*Each value represents the average of three determinations $\pm$ SD (n=3). (-) = Not Detected

Table 6.10: HPLC analysis of polyphenolic composition of cereals (mg/100 g DE)

Polyphenolic acid	Bajra	Oat	Proso millet	Foxtail millet
Gallic acid	-	-	-	-
3,4-Dihydroxybenzoic acid	3.34 ± 0.05	7.98 ± 0.39	17.83 ± 0.02	5.29 ± 0.08
Catechin hydrate	-	3.85 ± 0.05	-	8.40 ± 0.06
Catechol	30.87 ± 0.03	ND	70.02 ± 0.22	1.93 ± 0.06
(-) Epicatechin	78.18 ± 0.01	44.10 ± 0.05	-	25.83 ± 0.08
Caffeic acid	-	-	-	-
Vanillic acid	-	-	-	-
Syringic acid	1.64 ± 0.01	-	3.93 ± 0.09	-
Rutin hydrate	-	42.44 ± 0.05	10.57 ± 0.12	25.35 ± 0.20
p-Coumaric acid	-	-	0.44 ± 0.01	-
trans-Ferulic acid	-	-	-	-
Rosmarinic acid	-	9.27 ± 0.07	-	-
Myricetin	-	0.65 ± 0.02	-	-
Quercetin	-	-	-	-
trans-Cinnamic acid	-	-	-	-
Kaempferol	-	-	-	7.59 ± 0.27

*Each value represents the average of three determinations ±SD (n=3). (-) = Not Detected

Table 6.11: HPLC analysis of polyphenolic composition of pseudograins (mg/100 g DE)

Polyphenolic acid	Black BW	Yellow BW	Chia	Chia (Local)	Quinoa (Imported)	Quinoa (Local)
Gallic acid	-	-	-	-	-	-
3,4-Dihydroxybenzoic acid	-	-	81.91 ± 0.33	41.16 ± 0.11	-	-
Catechin hydrate		-	-	-	-	-
Catechol	12.26 ± 0.02	-	-	-	-	9.01 ± 0.07
(-) Epicatechin	47.08 ± 0.87	66.22 ± 0.26	60.12 ± 0.30		104.26 ± 0.98	
Caffeic acid	-	-	0.87 ± 0.04		10.79 ± 0.13	
Vanillic acid	-	-	-	0.93 ± 0.02	-	0.84 ± 0.02
Syringic acid	-	-	-		-	
Rutin hydrate	274.86 ± 1.45	112.64 ± 0.57	-	3.18 ± 0.07	-	12.30 ± 0.04
p-Coumaric acid	22.38 ± 0.24	0.89 ± 0.05	217.47 ± 0.40	120.56 ± 0.19	2.23 ± 0.03	
trans-Ferulic acid	-	-	-		-	
Rosmarinic acid	8.32 ± 0.16	-	-		-	
Myricetin	2.41 ± 0.07	2.84 ± 0.01	-		-	
Quercetin	10.86 ± 0.05	-	-	-	15.33 ± 0.17	4.21 ± 0.01
trans-Cinnamic acid	-	-	-	-	-	-
Kaempferol	-	-	-	-	8.41 ± 0.28	-

*Each value represents the average of three determinations ±SD (n=3). (-) = Not Detected

6.8.3.3 HPLC profile of polyphenols in studied cereals and pseudograins

The HPLC–DAD chromatographic profiling of polyphenolic compounds in 99.9% methanolic extracts is presented in Tables 6.9, 6.10 and 6.11, expressed as mg/100 g dry extract (DE). Sixteen standard phenolic and flavonoid compounds were identified across cereals, millets, and pseudograins, with notable variations in both composition and concentration.

Among cereals (Table 6.9), (–) epicatechin was the dominant polyphenol in red aman rice and bajra, whereas p-coumaric acid was predominant in black rice. Wheat exhibited the highest concentration of 3,4-dihydroxybenzoic acid (249.97 mg/100 g), while maize contained the greatest amount of caffeic acid (59.94 mg/100 g). Between the pigmented rice varieties, red aman rice was characterized by a higher level of (–) epicatechin (13.05 mg/100 g), while black

rice contained trans-ferulic acid (0.63 mg/100 g), both of which are associated with anti-hyperlipidemic activity. Barley showed comparatively lower phenolic diversity, with trans-ferulic acid as its principal compound.

The HPLC screening of bajra, oats, and millets (Table 6.10) revealed (–) epicatechin as the major polyphenol in bajra, oat, and foxtail millet (78.18, 44.10, and 25.83 mg/100 g, respectively). In contrast, proso millet exhibited a higher concentration of catechol (70.02 mg/100 g). Additionally, 3,4-dihydroxybenzoic acid was consistently detected in all millets, with the highest level observed in proso millet (17.83 mg/100 g), indicating its widespread occurrence in these grains. The phenolic acid composition observed in this study aligns well with previous reports. Ferulic acid, p-coumaric acid, gallic acid, and vanillin were identified as major phenolics in whole black rice bran and BF1 (Lázaro et al., 2024), while ferulic, vanillic, and p-coumaric acids were predominant in red rice bran (Jun et al., 2012). Similarly, wheat has been reported to contain resorcinol, tyrosol, caffeic acid, syringic acid, and ferulic acid in significant concentrations (Grande et al., 2023), and elevated levels of caffeic and ferulic acids have been documented in oat cultivars using HPLC-DAD analysis (Sinay et al., 2022).

Pseudograins demonstrated a comparatively richer and more diverse polyphenolic profile (Table 6.11). Black buckwheat (BW) showed the highest overall polyphenolic content, dominated by rutin hydrate (274.86 mg/100 g), followed by (–) epicatechin, p-coumaric acid, rosmarinic acid, and catechol. Yellow BW contained lower overall levels but comparatively higher amounts of epicatechin (66.22 mg/100 g) and rutin (112.64 mg/100 g), with myricetin detected exclusively in this sample. Native chia was characterized by the presence of vanillic acid and moderate levels of p-coumaric acid and 3,4-dihydroxybenzoic acid, whereas imported chia showed higher concentrations of these compounds. Kaempferol was detected only in imported quinoa, which

also exhibited the highest (–) epicatechin content (104.26 mg/100 g), while native quinoa contained moderate levels of quercetin, rutin, and catechol. The high rutin concentrations detected in buckwheat support previous research connecting rutin concentration with total phenolic content and antioxidant capacity (Beitane et al., 2018), as well as its role in cellular defense mechanisms against oxidative stress and inflammation (EROL et al., 2021; Raguindin et al., 2021). The comparatively higher levels of caffeic and p-coumaric acids and lower quercetin and kaempferol contents in quinoa, relative to earlier reports from Egypt (Abdelaleem & Elbassiony, 2021), may reflect differences in geographic origin, environmental conditions, and extraction protocols. Phenolic acids such as p-coumaric and hydroxycinnamic acids, commonly present in graminaceous plant cell walls, are known to reduce LDL oxidation and exhibit antioxidant and antibacterial activities (Boz, 2015). Furthermore, (–) epicatechin has been widely reported to improve metabolic health, cardiovascular function, and neurological protection. Overall, variations in the qualitative and quantitative distribution of polyphenolic compounds across samples may be attributed to genetic diversity, growing conditions, harvest time, plant parts, and extraction methodologies, as supported by earlier studies (Georgescu et al., 2022; Liu et al., 2018).

6.9 Summary and recommendation

The study found locally available cereals (like black/red rice, oats, wheat) and pseudograins (chia, quinoa) are exuberant with fiber, protein, carbs, and antioxidants, potentially impeding chronic health problems like overweight and obesity. Other key aspects of the study are:

1. Black rice dominance: Black rice demonstrated the highest total phenolic content (TPC) and total flavonoid content (TFC) making it a standout for its antioxidant properties.

2. Strong correlation with health benefits: The higher levels of TPC and TFC found in red aman rice and black buckwheat directly correlated with better free radical scavenging activity, indicating effective protection against cellular damage.
3. Dietary management potential: The study advocates for the consumption of these accessible, nutrient-dense foods as a natural way to boost antioxidant intake and support a healthy lifestyle, potentially mitigating the risks associated with chronic health problems.
4. Future research implications: The future research implications of the studied cereals and pseudograins could focus on clinical validation, product development, and practical dietary applications. Moreover, the polyphenolic content and activity could be further studied to evaluate the followings:
 - i. By creation of novel functional food products using these nutrient-dense ingredients.
This could involve developing gluten-free products, fortified bread, pasta, snacks, or porridge mixes using black rice, red aman rice, black buckwheat, chia, and quinoa flour.
 - ii. By the Development of informed dietary guidelines that promote the inclusion of these specific, locally available whole grains and pseudograins into habitual diets for the general population to manage disease risk effectively.
 - iii. Agronomic research to optimize cultivation practices and genetic selection to maximize the yield and concentration of beneficial bioactive compounds (TPC, TFC, TAC) in locally grown varieties, considering environmental factors like soil type and sun exposure.
 - iv. By bioavailability and bio accessibility studies to determine how processing, cooking methods (e.g., full water absorption cooking is better for antioxidant preservation), and digestion affect the absorption and effectiveness of these compounds in the human body.

- v. By investigating the molecular pathways to understand precisely how the bioactive compounds, especially the high levels of anthocyanin in black rice and epicatechin in red rice/quinoa interact with the human body on a cellular level.

These research avenues will help translate the promising *in vitro* findings into tangible public health recommendations and innovative food products, leveraging the potent bioactive properties of these underutilized local crops.

Chapter 7

Study Phase-3:

Bioactivity of Cereals and Pseudograins

7.1 Introduction

Secondary plant metabolites (SPMs) are directly involved in plant defense, systemic resistance and other ecological functions and are subdivided into three major classes: terpenoids, phenolic compounds and nitrogen-containing compounds (Elshafie & Camele, 2023; Lin et al., 2016). Their specific amounts in plants are highly variable, influenced by a complex interplay of species-specific traits, developmental stages, and diverse environmental factors (Elshafie & Camele, 2023). Diverse analytical methods are available for quantitating extracted metabolites. A general process of SPMs estimation involves extraction using organic solvents followed by quantification using analytical techniques such as spectrophotometry, High-Performance Liquid Chromatography (HPLC), or Gas Chromatography-Mass Spectrometry (GC-MS). The choice of method depends on the specific SPMs of interest (e.g., phenolics, flavonoids, tannin, saponins, etc.) and their bioactive capacity measurement (Roopashree & Naik, 2019).

Whereas the bioactivity of SPMs refers to the wide range of beneficial effects these compounds have, including their use in medicine to treat diseases. Their bioactivities include antioxidant, anti-inflammatory, anti-enzyme activity, antiviral, antimicrobial, and anticancer effects, etc., among other organisms. Since, the matter is elaborately discussed in Chapter 1, here the antioxidant and Lipase inhibitory activity of SPMs in cereals and pseudograins will be narrated in the following sections.

7.2 Methodology

7.2.1 Determination of total antioxidant content (TAC)

Antioxidant capacity (AOC) is a thermodynamic measure that quantifies the efficiency of a substance in neutralizing reactive species. It is distinct from antioxidant activity (AOA), which is

a kinetic measure referring to the rate or speed at which these reactions occur. A substance might have high AOC but low AOA if its neutralization process is slow. On the other hand, total antioxidant content (TAC) refers to the specific, measurable amount (e.g., in milligrams or moles) of individual antioxidant compounds like Vitamin C, Vitamin E, or specific phenolic compounds present in a sample. Measurement of TAC involves analytical chemistry methods, such as colorimetric methods or high-performance liquid chromatography (HPLC), to quantify each specific substance.

The quantification of total antioxidant neutralizing substances in cereals and pseudograins were determined by using a modified colorimetric method used in our laboratory which uses the UV–Visible spectrophotometric wavelengths (Ahmed et al., 2023). Plant extract (0.1 mL) was mixed with the 1 mL of reagent solution (0.6M H₂SO₄, 28mM sodium phosphate and 4mM ammonium molybdate mixture). Test tubes were incubated for 90 minutes at a 95° C constant temperature. The absorbance was measured at 695 nm in a spectrophotometer against the blank.

7.2.2 Antioxidant activity of cereals and pseudograins

Determining the bioactivity of secondary plant metabolites in cereals and pseudograins involves a two-pronged approach: analytical techniques for identification and quantification, followed by biological assays (*in vitro*, *in vivo*, or *in silico*) to assess their functional effects. The initial step involves identifying and quantifying the specific secondary metabolites present in the grain extracts and it was narrated in Chapter 6 elaborately. Once extracted and characterized, the compounds or extracts are tested for specific biological effects. *In vitro* assays are basically laboratory bench tests conducted with great care, precision, and quality assurances. These are common for initial screening of various health-promoting properties, such as antioxidant

capacity, anti-inflammatory activity, enzyme inhibitory capacity, etc. Antioxidant activity using standard chemicals measures the ability of SPMs extracts or their purified and identified compounds to neutralize free radicals, such as: DPPH (2,2-diphenyl-1-picrylhydrazyl) which measures free radical scavenging activity, ABTS (2,2'-azino-bis-(3-ethylbenzothiazoline-6-sulfonic acid)) which measures the capacity to scavenge the ABTS radical, FRAP (ferric reducing antioxidant power) which measures the electron-donating ability, etc.

7.2.3 Determination of antioxidant activity by DPPH (2,2-diphenyl-1-picrylhydrazyl)

The DPPH (2,2-diphenyl-1-picrylhydrazyl) assay is one of the various analytical methods that have been developed to measure the antioxidant capacity mainly in plant and food extracts. DPPH is a stable, deep violet-colored free radical, usually dissolved in methanol or ethanol. When it encounters an antioxidant, the DPPH radical is reduced, causing its color to fade from violet to yellow. The reduction in color intensity is quantified using a spectrophotometer at a wavelength of 517 nm. A greater loss of violet color indicates stronger antioxidant (scavenging) activity in the sample. The results are typically expressed as a percentage of DPPH radical scavenging activity or as an IC_{50} value (the concentration required to reduce the initial DPPH concentration by 50%).

The free radical scavenging activity of cereals and pseudograins extracts, in this study, were determined by the DPPH method harmonized by Ahmed et al., (2023). 2ml of each sample (2.5µg/mL to 500µg/mL concentration) were combined with 2 mL DPPH solution (0.1 mM). Mix thoroughly and let it sit in a cool, dark location for 30 minutes. The absorbance of the mixture was measured against a blank at 517 nm using a double beam UV/Visible

spectrophotometer (Model 205, Jena, Germany). The radical scavenging activity was expressed as the inhibition percentage (I %) and calculated as per the equation:

$$I (\%) = \frac{(A_{blank} - A_{sample})}{A_{blank}} \times 100 \dots \dots \dots (7)$$

Here,

A_{blank} is the absorbance of the control (containing all the reagents except the testing compound)

A_{sample} is the absorbance of the experimental sample with all reagents.

The IC₅₀ value was calculated from the plot of inhibition (%) against the concentration of the extract. All determinations were carried out in triplicate and their average was noted. Ascorbic acid was used as the standard antioxidant.

7.2.4 Determination of antioxidant activity by ABTS (2,2-azino-bis-3-ethylbenzothialine-6-sulphonic acid)

The ABTS assay determines antioxidant activity by measuring the ability of an antioxidant to neutralize the blue-green ABTS (2,2-azino-bis-3-ethylbenzothialine-6-sulphonic acid) radical cation (ABTS⁺). The antioxidant donates an electron, which causes the radical to lose its color and absorb less light, a reaction that is quantified using a spectrophotometer (ROBERTA et al., 1999). The results are quantified and compared to a standard curve made with ascorbic acid, a water-soluble vitamin C analog, to give the antioxidant capacity in terms of ascorbic acid equivalents.

One mL of each sample extract was combined with 1 mL of ABTS solution. The test tubes were vigorously mixed using a vortex and then left undisturbed in a dark location for duration of 06 minutes. The mixture's absorbance was measured at 734 nm using a double beam UV/Visible

spectrophotometer (Model 205, Jena, Germany), immediately after comparing it to a blank sample. The radical scavenging activity was expressed as the inhibition percentage (I %) and calculated as per the equation:

$$I (\%) = \frac{(A_{blank} - A_{sample})}{A_{blank}} \times 100 \dots\dots\dots (8)$$

Where,

A_{blank} = Absorbance of the control (containing all the reagents except the testing compound)

A_{sample} = Absorbance of the experimental sample with all reagents.

The IC₅₀ value of DPPH and ABTS radical was calculated from the plot of inhibition (%) against the concentration of the extract. All determinations were carried out in triplicate and their average was noted. Ascorbic acid was used as the standard antioxidant.

7.2.5 Determination of antioxidant activity by FRAP

The FRAP assay determines antioxidant capacity by measuring the ability of a sample to reduce ferric ions (Fe³⁺) to ferrous ions (Fe²⁺). The ferrous ions (Fe²⁺) then form an intensely blue-colored complex with TPTZ (2,4,6-tris(2-pyridyl)-s-triazine) in an acidic media. This color change is quantified using a spectrophotometer, where the intensity of the blue color is directly proportional to the sample's antioxidant power. The results are often expressed as micromolar Fe²⁺ equivalents or in terms of micromolar ascorbic acid equivalents per gram (Antolovich et al., 2002).

Each sample extract was combined with 2.5 mL of a 1% potassium ferricyanide solution. The test tubes were thoroughly mixed and carefully placed in a water bath set at a temperature of

50°C for a period of 20 minutes. Following the cooling of the mixture, 2.5mL of 10% trichloro acetic acid was introduced and then subjected to centrifugation at 3000 rpm for 10 minutes. 2.5mL of the supernatant was combined with 2.5mL of distilled water. After the reaction was allowed to complete for 10 minutes, 0.5 mL of 0.1% ferric chloride was added to the test tubes. The absorbance of the mixture was then measured at 700 nm using a double beam UV/Visible spectrophotometer (Model 205, Jena, Germany), immediately after reading against a blank. The rise in absorbance of the reaction mixture suggests a corresponding increase in its reducing power. The radical scavenging activity was calculated as per the equation:

$$\text{Result} = \text{Absorbance of Sample} - \text{Absorbance of Blank} \dots\dots\dots (9)$$

7.2.6 Determination of total tannin content (TTC)

The effectiveness of antioxidant materials in preventing free radical formation is well known. Tannins as phenolic materials are also known to have antioxidant properties. However, the antioxidant effectiveness shows variations regarding to the type and structure of tannins (Cosme et al., 2025). Total tannin content (TTC) was determined by the UV-visible spectrophotometric technique using folin-ciocalteu phenol reagent as harmonize by Hossain (2013). Standard curve was calibrated using tannic acid as standard. 1.0 mL of plant extract was mixed with the 7.5 mL of DI water and 0.5 mL of folin-ciocalteu reagent. 1 mL of 35% sodium carbonate was added into the test tubes. Shake well and leaved for 30 minutes in room temperature. Absorbances of the mixtures were measured at 725 nm in a spectrophotometer against the blank

7.2.7 Lipase inhibition activity of SPMs

Since triglycerides (TG) from food are not absorbed as such, lipases of stomach and small intestine break down TG into absorbable fatty acids and monoglycerides. Lipase inhibitors prevent this breakdown. By blocking the enzyme, fats from food are not broken down and are instead excreted from the body. This reduces the body's caloric intake from fat. This approach is used to manage obesity and associated conditions like cardiovascular disease. The typical measure of the potency of an enzyme inhibitor is its IC₅₀. The IC₅₀ is generally defined as the concentration of the inhibitor, at which the velocity of product formation is half the velocity without inhibitor (Cheng, & Prusoff, 1973). The selected cereals and pseudograins extracts were screened to determine IC₅₀ values by using a single concentration of enzyme and substrate using commercial Lipase assay Kit 482 (Sigma Aldrich) with BALB as substrate. The reaction protocol was according to the descriptions of the booklet supplied in each Lipase assay Kit 482 was conducted in 96-well (8 by 12 matrix) micro plate as harmonized by Rahim et al., (2015). The inhibition percentage of lipase was calculated by the following equation:

$$\% \text{ Inhibition} = \left[1 - \left(\frac{\text{sample absorbance}}{\text{Control absorbance}} \right) \right] \times 100 \dots\dots\dots (10)$$

Assay protocol was conducted as follows

1. Preparation of working reagents: The lipase assay is based on an enzyme-catalyzed kinetic reaction. To ensure uniform incubation times, the addition of the Working Reagent was performed rapidly, and mixing was brief but thorough.
2. Sufficient reagents were mixed according to the number of assays to be performed. For each Sample well, the Working Reagent was prepared following the proportions in

according to the instruction of assay Kit. The reagent mixture was prepared freshly and used within one hour of its preparation.

3. A volume of 130 μ L of the freshly prepared Working Reagent and 10 μ L lipase enzymes (1mg/mL) were added to each sample well. No Working Reagent was added to the blank or calibrator wells.
4. Samples were prepared at 10 mg/mL, 5 mg/mL, 2.5 mg/mL and 1.25 mg/mL. 10 μ L of concentration and added to each well.
5. The plate was tapped briefly to ensure proper mixing of the reaction mixture. Absorbances were measured at 412nm wavelength with the micro titer plate reader (ELISA).

7.2.8 Determination of lipase inhibition capacity of SPMs by IC₅₀ values

The IC₅₀ value of the extracts was assessed at concentrations of 10, 5, 2.5 and 1.25 mg/mL for both sample and standard. Epicatechin served as a positive control. The IC₅₀ value was determined by the formula as follows:

$$IC_{50} = \frac{50\% - low\ inh\ \%}{high\ inh\ \% - low\ inh\ \%} \times (high\ conc - low\ conc) + low\ conc \dots\dots\dots (11)$$

Here, Low inh%/high inh% denote the percentage of inhibition immediately below or over 50%, whereas low conc/high conc represent the equivalent extract concentrations.

7.3 Result and discussion

7.3.1 Total antioxidant content (TAC)

The total antioxidant content (TAC), expressed as mg of ascorbic acid equivalent per gram of dry extract (mg AA/g), is presented in Tables 7.1 and 7.2 and standard curve has been illustrated in Figure 7.1. Among all samples, black rice exhibited the highest TAC (229.61 ± 0.06 mg AA/g), followed by red aman rice (187.55 ± 0.58 mg AA/g) and bajra (165.02 ± 0.01 mg AA/g). Among pseudograins, local chia showed the highest antioxidant capacity (179.50 ± 0.05 mg AA/g), closely followed by yellow buckwheat (176.39 ± 0.08 mg AA/g). In contrast, foxtail millet exhibited the lowest TAC (73.28 ± 0.05 mg AA/g), while foreign quinoa (85.67 ± 0.17 mg AA/g) and local quinoa (SAU-1) (108.61 ± 0.16 mg AA/g) also demonstrated comparatively lower antioxidant activity.

The exceptionally high TAC observed in black rice is consistent with previous studies, reporting that colored rice varieties are rich in anthocyanins, flavonoids, and phenolic compounds, which play a crucial role in scavenging reactive oxygen species and reducing oxidative stress (Chen et al., 2012; Zhang et al., 2006). Similarly, the elevated TAC of red aman rice supports earlier findings that red rice cultivars possess enhanced antioxidant potential due to their high polyphenolic content (Walter & Marchesan, 2014). Bajra also demonstrated considerable antioxidant capacity, supporting previous reports identifying pearl millet as a valuable source of natural antioxidants with promising functional food applications (Alka & Kapoor, 1996).

Previous investigations have highlighted millets as important contributors of polyphenols and antioxidant activity, suggesting that varietal differences and growing conditions may influence antioxidant expression (Chandrasekara & Shahidi, 2010). The reduced TAC observed in imported chia and quinoa compared to local varieties may be attributed to genetic variability,

environmental conditions, and post-harvest handling, all of which are known to affect secondary metabolite composition (Ganachari et al., 2022).

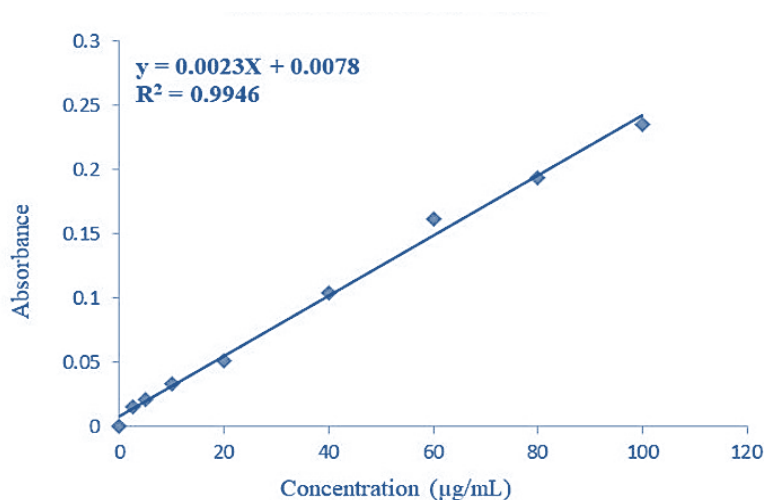


Figure 7.1 Ascorbic Acid standard curve for total antioxidant content (TAC)

Sample Name		TAC value
1.	Red Aman Rice	187.55 ± 0.58
2.	Black Rice	229.61 ± 0.06
3.	Wheat	96.14 ± 0.0
4.	Maize	98.14 ± 0.08
5.	Barley	102.78 ± 0.06
6.	Foxtail Millet	73.28 ± 0.05
7.	Proso millet	86.56 ± 0.24
8.	Oat	94.33 ± 0.14
9.	Bajra	165.02 ± 0.01

Sample Name		TAC value
1.	Yellow buck wheat	187.55 ± 0.58
2.	Black buck wheat	229.61 ± 0.06
3.	Quinoa (foreign)	96.14 ± 0.0
4.	Quinoa SAU-1(Local)	98.14 ± 0.08
5.	Chia (Foreign)	102.78 ± 0.06
6.	Chia (Local)	73.28 ± 0.05

7.3.2 Antioxidant activity assay of cereals and pseudograins

Antioxidant activity is not a single property, but rather a measure of how a sample performs in various chemical tests designed to simulate different oxidative processes. Typically, the antioxidant activity of a food sample is measured by its ability to neutralize or reduce oxidizing agents such as, free radicals and metal ions, and the reported findings indicate that the antioxidant properties of the sample are primarily due to its polyphenols and phenolic acids (Shela et al., 2008; Tsao, 2010). Common assays measure the ability to neutralize free radicals by Free Radical Neutralization Assays (DPPH, ABTS, etc.) and to reduce metal ions by Metal Ion Reduction Assays (FRAP, CUPRAC, etc).

7.3.2.1 Free radical neutralization assays

Free radical neutralization assays are laboratory techniques used to measure the ability of antioxidants to interact with deactivate unstable free radicals. This process, also known as free radical scavenging, helps prevent the oxidative damage that free radicals can cause to cells, lipids, proteins, and DNA. The two free radical neutralization assays, DPPH and ABTS, were conducted and the findings are described below

7.3.2.2 Free radical scavenging activity assay by DPPH

The findings on the DPPH free radical scavenging activity of various cereals and pseudocereals were illustrated in figures 7.3, 7.4, 7.5 and standard curve was presented in figure 7.2. Among cereals, red aman rice, black rice, barley, and bajra exhibited significant DPPH inhibition, whereas the remaining cereals showed comparatively lower and non-significant activity. At the highest tested concentration (0.5 mg/mL), the antioxidant activity followed the order: red aman rice > black rice > bajra > barley > local chia > black buckwheat > foreign chia > yellow

buckwheat > foreign quinoa > local quinoa. Ascorbic acid, used as the standard antioxidant, exhibited 95.2% inhibitions at the same concentration. The strong DPPH scavenging activity of red aman and black rice aligns with earlier reports attributing their antioxidant potential to high levels of phenolic compounds and anthocyanins (Khatun & Mollah, 2024; Thitipramote et al., 2016). The notable performance of bajra corroborates previous findings reporting substantial antioxidant activity in pearl millet extracts (Krishnan et al., 2022). Variations observed among pseudograins, particularly quinoa and buckwheat, may be influenced by geographical origin, extraction solvent, and sample matrix, as reported by Klepacka & Najda, (2021). Lower DPPH scavenging activity recorded for quinoa compared to Indian quinoa varieties (Namrata, S ; Haripriya, 2022) highlights the influence of varietal and environmental factors on antioxidant expression.

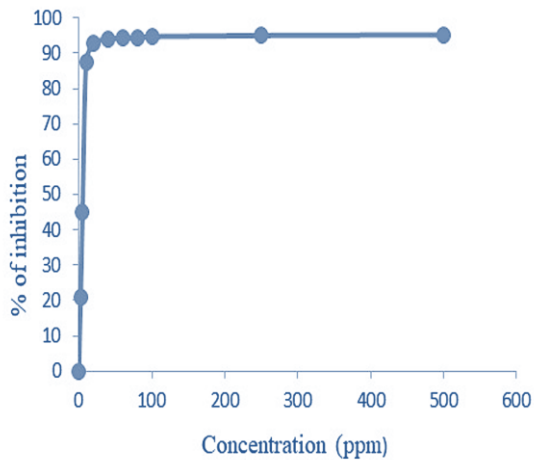
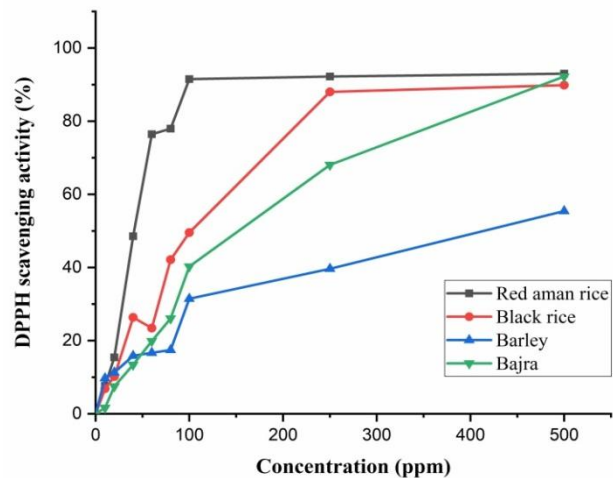


Figure 7.2 Standard curve of Ascorbic Acid for DPPH assay



7.3 DPPH scavenging activity (%) of four cereal samples

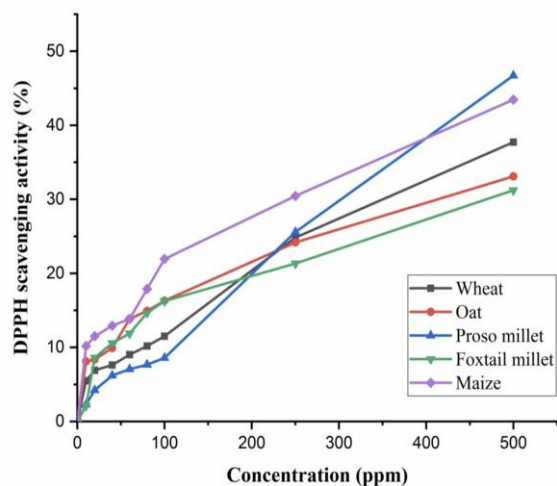


Figure 7.4 DPPH scavenging activity (%) of five cereal samples

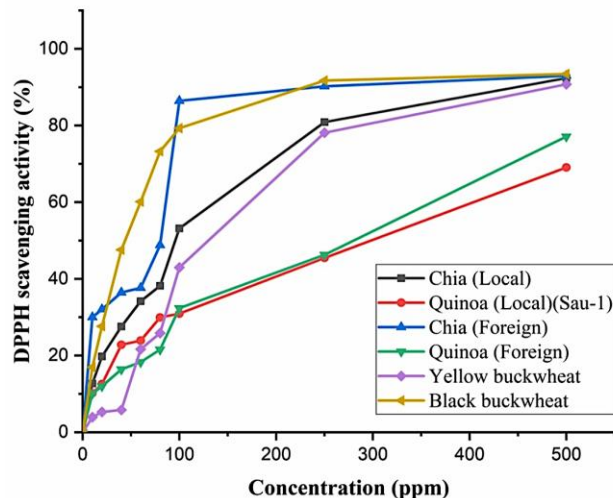


Figure 7.5 DPPH scavenging activity (%) of six pseudograins

Key observations include: I) Significant activity in cereals: rice (black and red), barley, and bajra demonstrated significant antioxidant inhibition activity. Other tested cereals were found to be non-significant; II) Dose-dependent effect: the antioxidant activity for all tested cereals and pseudograins increased notably as the extract concentration rose from 0.005 mg/mL to 0.5

mg/mL; III) Overall ranking at 0.5 mg/mL: at the highest tested concentration (0.5 mg/mL), the antioxidant activity followed this specific order from highest to lowest: red aman rice, black rice, bajra, barley, chia (local), black buckwheat, chia (foreign), yellow buckwheat, quinoa (foreign), quinoa (local) respectively; IV) Comparison to standard: ascorbic acid, used as a standard, exhibited 95.2% free radical inhibition at the same 0.5 mg/mL concentration.

7.3.2.3 Free radical scavenging capacity by ABTS

The scavenging powers of the cereal and pseudograins were relatively increasing with the concentrations (Fig. 7.7, 7.8 and 7.9). The ascorbic acid standard curve was illustrated in Figure 7.6 for ABTS assay. Based on IC_{50} values derived from the ABTS assay (Table 7.3), bajra demonstrated the lowest IC_{50} , indicating the strongest antioxidant capacity among the tested samples, followed by oat and maize. Additionally, black buckwheat, red aman rice, quinoa, and black rice exhibited significantly higher maximal reduction capacities, suggesting strong electron-donating potential.

At lower concentrations, red aman rice and black buckwheat extracts showed greater inhibition than ascorbic acid, highlighting their potent antioxidant efficacy. These findings are consistent with earlier reports demonstrating superior ABTS scavenging activity in pigmented rice varieties, particularly in red rice bran compared to white rice (Khatun & Mollah, 2024; Thitipramote et al., 2016). Previous studies have also reported stronger ABTS scavenging ability in wheat grain and bran compared to oats (Martín-Diana et al., 2021), which partially aligns with the present findings. The superior radical scavenging capacity of total phenolic compounds measured by ABTS compared to DPPH and FRAP has also been reported in quinoa varieties (Kato et al., 2021), supporting the sensitivity of the ABTS assay to phenolic antioxidants.

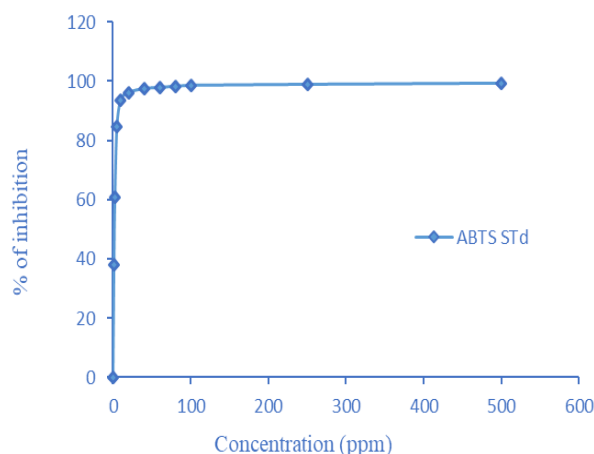


Figure 7.6 Standard curve of Ascorbic Acid for ABTS assay

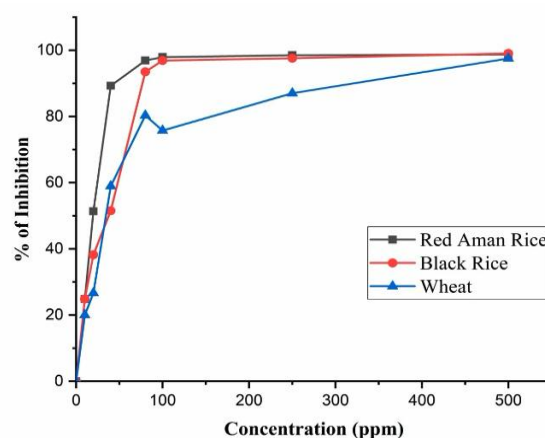


Figure 7.7 ABTS scavenging activity (%) of four cereal samples

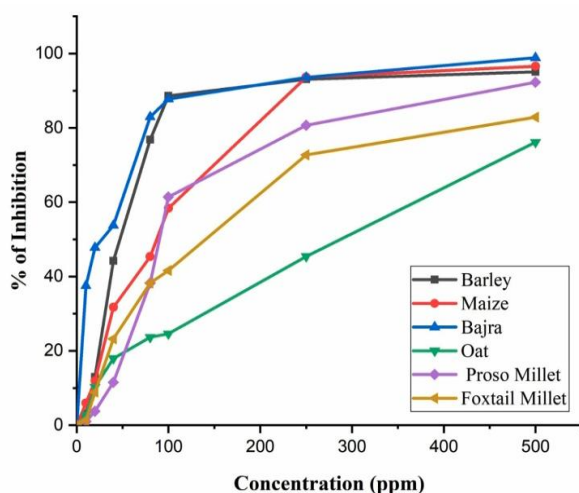


Figure 7.8 ABTS scavenging activity (%) of six minor cereal samples

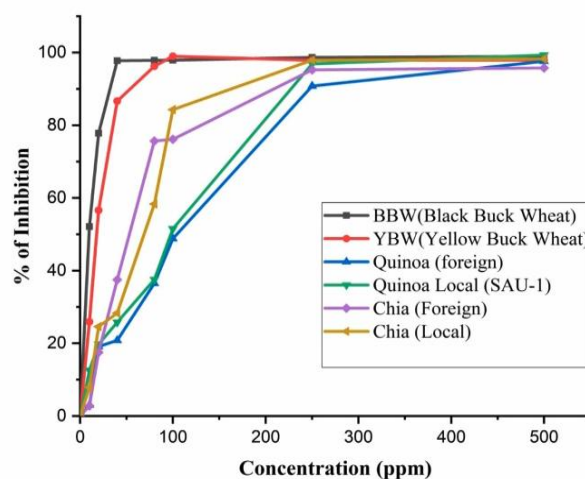


Figure 7.9 ABTS scavenging activity (%) of six pseudograin samples

The key findings are summarized as: i) Concentration-dependent activity: Scavenging powers for all tested cereal and pseudograin extracts increased with concentration; ii) Superior performers: Bajra demonstrated the lowest IC_{50} value among the six crops examined, indicating the highest antioxidant capacity in the ABTS analysis. It was followed by oat and maize; iv) Maximal reduction capacity: Black buckwheat, red aman rice, quinoa, and black rice exhibited significantly higher maximal reduction capacities compared to the other samples; v) Comparison

to standard: At minimum concentrations, extracts of red aman rice and black buckwheat showed greater inhibition than the standard ascorbic acid.

7.3.2.4 Metal ion reduction assays

Metal ion reduction assays are analytical techniques that primarily assess the reducing capacity of a substance, usually an antioxidant, by measuring its ability to donate an electron to a metal ion, or for the qualitative/quantitative analysis of metal ions in a sample. One metal ion reduction assay was conducted and the results are described below.

7.3.2.5 Ferric reducing antioxidant power (FRAP) assay

In the Ferric Reducing Antioxidant Power (FRAP) assay, an increase in the absorbance level with a higher concentration of the sample extract indicates a stronger reducing power and, consequently, greater antioxidant capacity (Figure 7.11, 7.12 and 7.13). Figure 7.10 was illustrated the standard curve of ascorbic acid for FRAP assay.

The results align with earlier findings that methanolic extracts rich in antioxidants effectively reduce ferric–ferricyanide complexes (Amarowicz et al., 2004). Consistent with previous reports, red and black rice exhibited greater FRAP activity than white rice (Thitipramote et al., 2016). The strong reducing power of bajra observed in this study also corresponds with earlier reports on pearl millet extracts (Krishnan et al., 2022). The FRAP assay confirms that the methanolic extracts of the studied cereals and pseudograins possess substantial reducing power, and their antioxidant efficacy increases with concentration, reinforcing their potential role in mitigating oxidative damage in biological systems (Fang et al., 2002).

The summary of the findings of the study are: I) Concentration-dependent activity: The observation that absorbance increased with the concentration of the sample extracts as shown in Fig. 7.11, 7.12, and 7.13 respectively confirms that the extracts contain compounds (likely

phenolic compounds) capable of donating electrons or hydrogen atoms to neutralize free radicals, and this activity is dose-dependent; II) "Favorable inhibitory outcome": The term "favorable inhibitory outcome" is used because the antioxidant compounds are effectively "inhibiting" the oxidation process by reducing the Fe^{3+} ions. In biological systems, this mechanism is crucial for protecting the body's cells and tissues from damage caused by harmful free radicals (oxidative stress).

7.3.2.6 Quantitative measure of antioxidant capacity of the samples

The IC_{50} (half-maximal inhibitory concentration) value is the specific concentration of an antioxidant sample e.g., SPMs that is required to inhibit or scavenge 50% of the free radicals (DPPH or ABTS radicals) present in the reaction mixture under specific experimental conditions. The IC_{50} value is a crucial index in DPPH and ABTS assays because it provides a quantitative and comparable measure of an antioxidant's potency: a lower IC_{50} value indicates a higher (stronger) antioxidant capacity (Tomczyk, 2021). The IC_{50} value obtained from DPPH and ABTS assays is a widely used index of antioxidant capacity. Table 7.3 disclosed the finding of antioxidant activity assays.

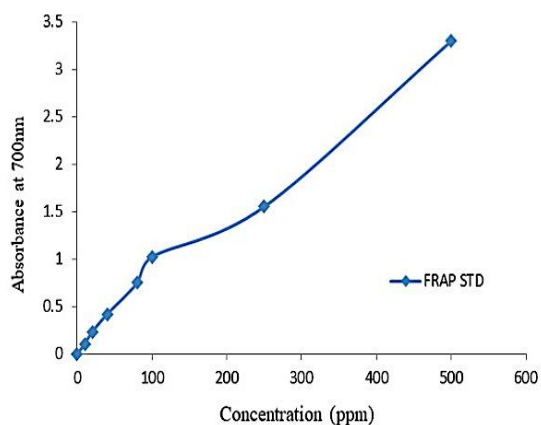


Figure 7.10 Standard curve of Ascorbic Acid for FRAP assay

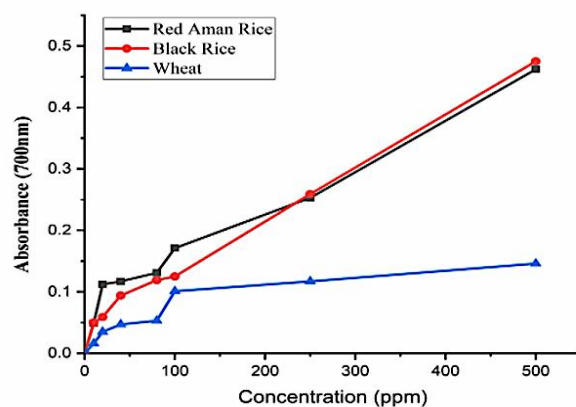


Figure 7.11 FRAP scavenging activity (%) of three cereal samples

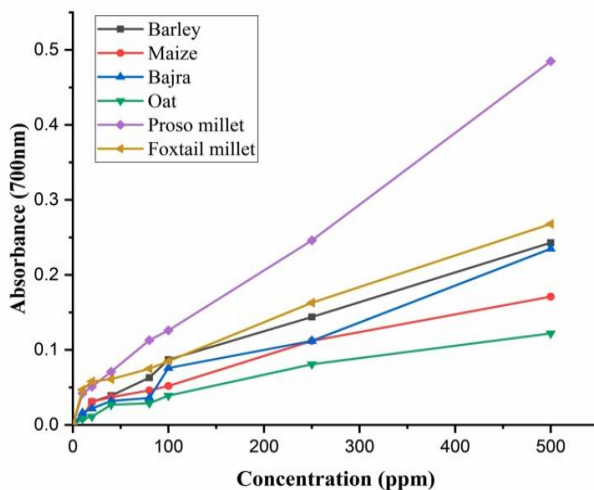


Figure 7.12 FRAP scavenging activity (%) of six minor cereal samples

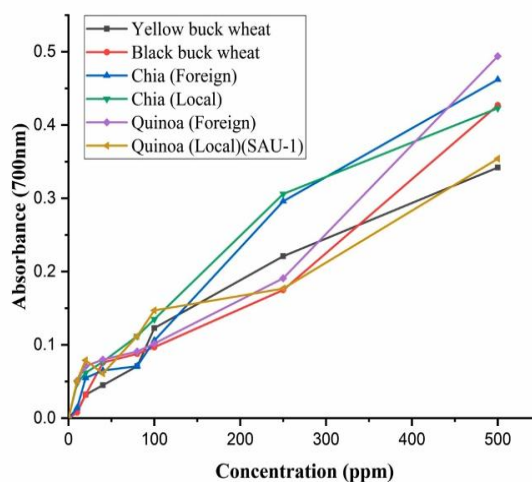


Figure 7.13 FRAP scavenging activity (%) of six pseudograin samples

Table 7.3: Antioxidant capacity of cereal and pseudograin by IC₅₀

Sl. No	Sample name	IC ₅₀ Value	
		ABTS method	DPPH method
	Standard (Ascorbic acid)	1.9	5.58
1.	Red aman rice	19.00	47.97
2.	Black rice	37.50	105.55
3.	Wheat	34.59	-
4.	Barley	46.11	415.36
5.	Maize	88.20	-
6.	Bajra	29.90	141.69
7.	Oat	362.77	-
8.	Proso millet	85.53	-
9.	Fox millet	159.21	-
10.	Black buck wheat	9.35	43.45
11.	Yellow Buck wheat	17.50	80.22
12.	Quinoa (Foreign)	98.11	280.99
13.	Quinoa (Local) (SAU-1)	104.00	355.56
14.	Chia (Foreign)	53.82	80.67
15.	Chia (Local)	71.38	70.57

*Each value represents Mean $\pm$ SD (n=3); (-) = Not Detected.

7.3.3 Total Tanin Content (TTC)

The total tannin content (TTC), expressed as mg of tannic acid equivalent per gram of dry extract (mg TA/g), is presented in Tables 7.4 and 7.5 and standard curve has been illustrated in Figure 7.14. Among the cereal samples analyzed, red aman rice exhibited the highest TTC (176.17 ± 0.60 mg TA/g), followed by oat (149.74 ± 1.12 mg TA/g) and maize (144.17 ± 0.78 mg TA/g), whereas wheat showed the lowest tannin content. Among pseudograins, black buckwheat recorded the highest TTC, exceeding all other pseudograin samples evaluated. The elevated tannin content of red aman rice corroborates earlier reports indicating that red rice varieties are particularly rich in condensed tannins and other polyphenolic compounds, which are mainly concentrated in the outer grain layers (Walter & Marchesan, 2014). The substantial TTC values

observed in oat and maize are notable, as oats are known to contain unique phenolic compounds such as avenanthramides, which contribute to antioxidant, anti-inflammatory, and cardio protective properties (Emmons & Peterson, 2001). Black buckwheat exhibited the highest tannin content among pseudograins, suggesting its strong potential role in oxidative stress reduction and modulation of inflammatory pathways, despite having a slightly lower overall antioxidant capacity. Variations in tannin content among samples may also reflect processing effects, as tannins are largely removed during dehulling and polishing due to their localization in the bran layer (Tang et al., 2015).

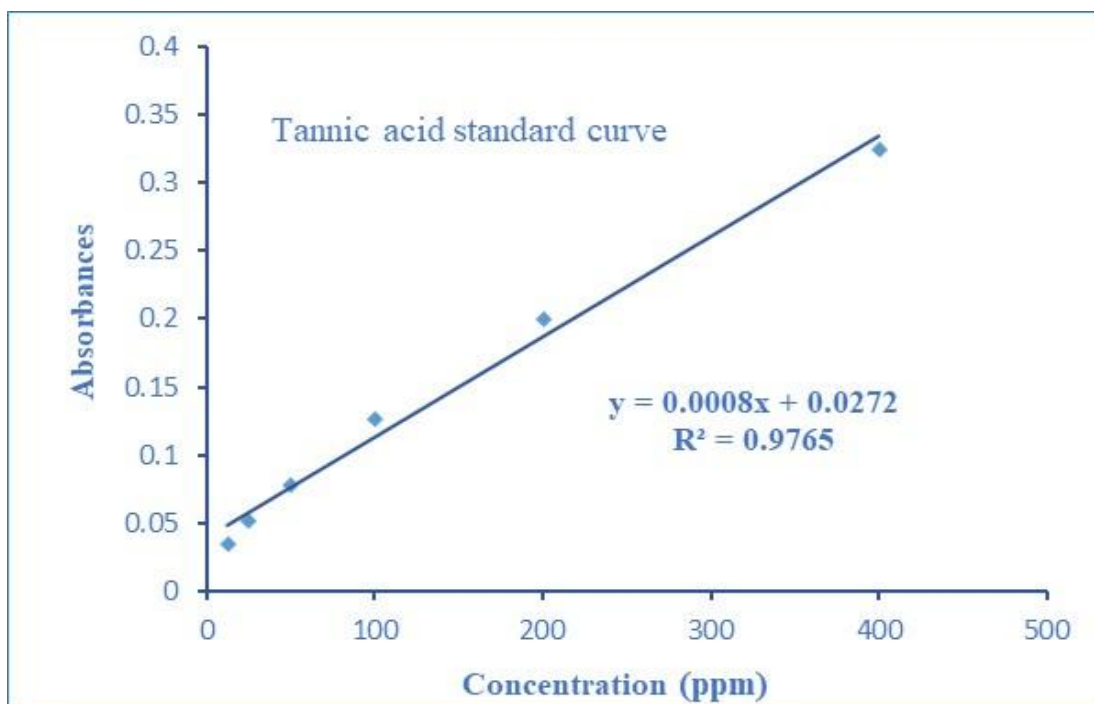


Figure 7.14: Tannic acid standard curve for total tannin content

Table 7.4: Total Tanin content of cereal samples

Sample Name	Total Tanin Content (mg of, TA/100 gm of dry extract)
Red Aman Rice	176.17 ± 0.60
Black Rice	98.31 ± 0.45
Wheat	10.75 ± 1.18
Maize	144.17 ± 0.78
Barley	53.76 ± 0.74
Foxtail Millet	87.12 ± 1.24
Proso millet	96.12 ± 1.00
Oat	149.74 ± 1.12
Bajra	55.37 ± 0.99

Table 7.5: Total Tanin content of pseudograin samples

Sample Name	Total Tanin Content (mg of, TA/100 gm of dry extract)
Yellow buck wheat	175.35 ± 0.63
Black buck wheat	178.37 ± 1.25
Quinoa (foreign)	17.62 ± 1.52
Quinoa SAU-1 (Local)	2.54 ± 0.72
Chia (Foreign)	168.38 ± 1.13
Chia (Local)	56.79 ± 1.52

7.3.4 Lipase inhibition capacity of cereals and pseudograins

7.3.4.1 Lipase inhibition by percentage and capacity index (IC₅₀ value)

The positive control, (–) epicatechin was illustrated in Figure 7.15. Lipase inhibition activity of cereals, minor cereals and pseudograins were presented by Figure 7.16, 7.17 and 7.18. Among cereals, black rice demonstrated the strongest lipase inhibitory activity, with the lowest IC₅₀ value (10.25 ± 1.06 mg/mL), indicating superior bioactivity (Table 7.6). This was followed by barley (21.14 ± 0.92 mg/mL) and red aman rice (25.91 ± 0.17 mg/mL). Moderate inhibitory activity was observed in foxtail millet (30.58 ± 0.69 mg/mL), proso millet (37.33 ± 2.14 mg/mL), and oat (39.36 ± 1.04 mg/mL). In contrast, maize exhibited the lowest inhibitory capacity among cereals, with an IC₅₀ of 65.24 ± 1.02 mg/mL, possibly due to its comparatively lower phenolic concentration or less effective phytochemical profile. Notably, IC₅₀ values for wheat and bajra could not be determined, suggesting negligible inhibition under the experimental conditions or insufficient lipase-inhibiting constituents.

Among pseudograins, yellow buckwheat displayed the highest lipase inhibitory activity, with the lowest IC_{50} value (15.69 ± 1.09 mg/mL), surpassing most cereal samples. This pronounced activity may be attributed to its high content of bioactive flavonoids, including rutin hydrate, quercetin, and catechin. Foreign quinoa (23.70 ± 0.75 mg/mL) showed greater inhibitory activity than local quinoa (SAU-1) (37.97 ± 0.55 mg/mL), indicating possible varietal or environmental effects. Chia seed extracts exhibited moderate inhibition, with local chia showing the lowest inhibitory capacity (48.25 ± 1.17 mg/mL). Data for black buckwheat could not be generated due to assay limitations or insufficient inhibition within the tested concentration range. Overall, pigmented rice samples showed 20–40% inhibition, while minor cereals and pseudograins ranged between 15–30% inhibitions (Figures 7.16–7.18).

The observed lipase inhibitory effects are consistent with earlier findings linking condensed polyphenols and flavonoids to pancreatic lipase inhibition (Thomas et al., 2014). Pancreatic lipase plays a key role in lipid digestion by hydrolyzing tri-, di-, and monoacylglycerols, and its inhibition has been widely explored as a strategy for obesity management (Birari & Bhutani, 2007; Sargent et al., 2012). The strong inhibitory activity of black rice aligns with studies demonstrating the role of anthocyanins, particularly cyanidin-3-glucoside (Cy-3-G) and peonidin-3-glucoside (Pn-3-G), which exhibit low IC_{50} values against pancreatic lipase (Poosri et al., 2019; Shu-Long et al., 2013).

The IC_{50} values obtained for red rice are comparable to those reported for red rice bran phenolics, particularly ferulic acid and catechin, which showed lipase inhibition in the range of 35.95–35.97 mg/mL (Lai & Sung, 2018). The moderate inhibitory activity of barley observed in this study aligns with previous findings reporting significant lipase inhibition by young barley leaf extracts (Kato et al., 2021). Similarly, the inhibitory trends observed in millets correspond well with

reports on proso, foxtail, and pearl millet genotypes, where lipase inhibition ranged from 21–66%, with pigmented varieties showing enhanced activity (Abeysekera et al., 2022).

The moderate lipase inhibition exhibited by chia seed extracts is consistent with earlier findings, where free phenolic fractions of chia seed meal demonstrated the strongest inhibition (IC_{50} = 10.05 mg/mL), while esterified and insoluble-bound fractions showed lower activity (Rahman et al., 2017). The lipase inhibitory capacity of quinoa observed in this study is comparable to previous reports indicating relatively weaker inhibition compared to other functional grains (Herrera et al., 2018). Furthermore, the IC_{50} value recorded for yellow buckwheat aligns with studies demonstrating enhanced lipase inhibition following processing or germination (Yeon et al., 2023).

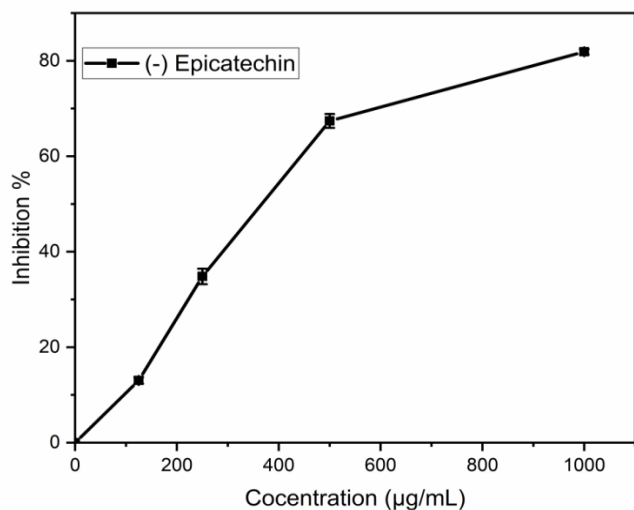


Figure 7.15 Dose dependent lipase inhibition % of (-) Epicatechin as control

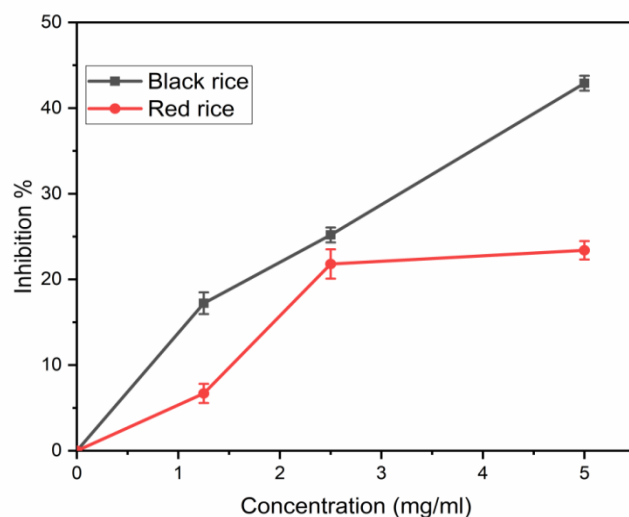


Figure 7.16 Dose dependent lipase inhibition % of black and red aman rice

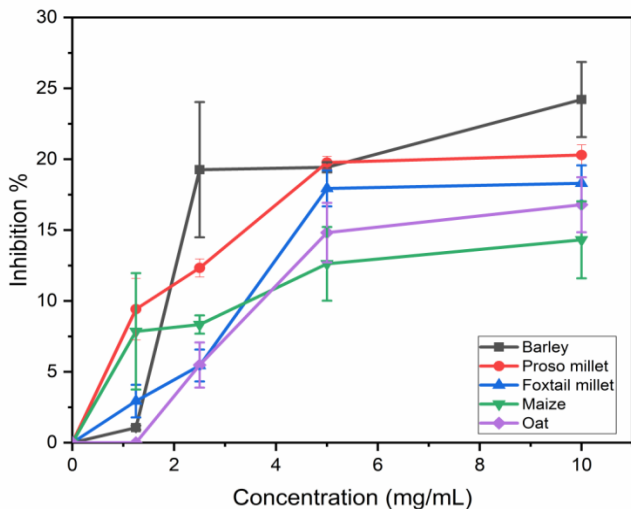


Figure 7.17 Dose dependent lipase inhibition % of minor cereals

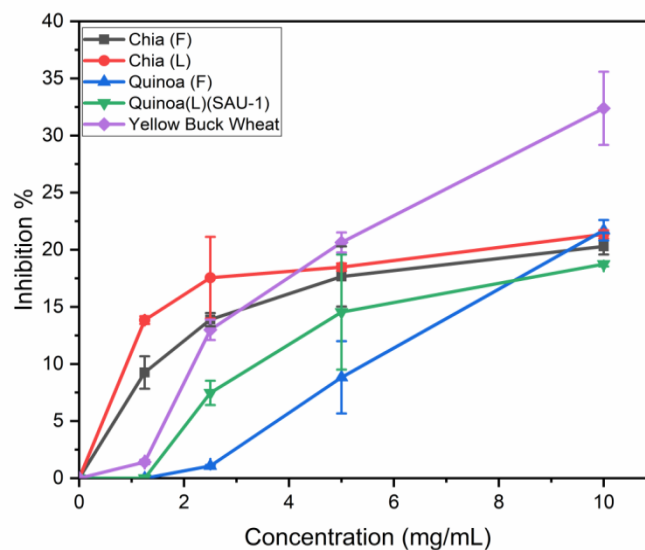


Figure 7.18 Dose dependent lipase inhibition % of pseudograins

The following figures and tables highlight of the lipase inhibition potential of various cereal and pseudograin samples using (-) Epicatechin as a positive control. The key findings are summarized below:

- i. (-) Epicatechin control: (-) Epicatechin showed nearly 80% inhibition activity and an IC_{50} value of 0.320 ± 0.90 mg/mL, confirming its strong inhibitory capacity and serving as a sensitive baseline for comparison (Figure 7.15).
- ii. Highly effective grains: Among the tested cereals, Black rice displayed the highest bioactivity with an IC_{50} of 10.25 ± 1.06 mg/mL (Table 7.6). Other potent inhibitors included Barley (21.14 ± 0.92 mg/mL) and Red aman rice (25.91 ± 0.17 mg/mL).
- iii. Moderate action: Grains like Foxtail millet (30.58 ± 0.69 mg/mL), Proso millet (37.33 ± 2.14 mg/mL), and Oat (39.36 ± 1.04 mg/mL) exhibited moderate inhibitory capabilities (Table 7.6).
- iv. Lowest effectiveness: Maize demonstrated the lowest lipase inhibitory capacity, with an IC_{50} of 65.24 ± 1.02 mg/mL (Table 7.6), perhaps an attribution of its reduced overall phenolic content or a less effective chemical profile.
- v. No Inhibition by wheat and bajra: It is noted that IC_{50} values for wheat and bajra could not be established, perhaps due to inadequate inhibition under the test conditions or the lack of substantial lipase-inhibiting phytoconstituents.
- vi. Lipase inhibition capacity by pseudograins: Yellow buckwheat had the highest lipase inhibition with lowest IC_{50} value (15.69 ± 1.09 mg/mL) (Table 7.6) while Chia (local) displayed the lowest inhibition activity at 48.25 ± 1.17 mg/mL.

Table 7.6: Lipase inhibition capacity of study samples by IC₅₀

	Sample Name	IC ₅₀ (mg/mL)
Standard	Epicatechin	0.32 ± 0.90
Cereal	Black Rice	10.25 ± 1.06
	Red aman rice	25.91 ± 0.17
	Wheat	-
	Proso millet	37.33 ± 2.14
	Foxtail millet	30.58 ± 0.69
	Maize	65.24 ± 1.02
	Barley	21.14 ± 0.92
	Bajra	-
	Oat	39.36 ± 1.04
Pseudograins	Chia (Imported)	36.91± 0.26
	Chia (Local)	48.25 ± 1.17
	Quinoa (F)	23.70 ± 0.75
	Quinoa (L) Sau-1	37.97 ± 0.55
	Yellow buckwheat	15.69 ± 1.09
	Black buckwheat	-

*Each value represents the average of three determinations ±SD (n=3). (-) = Not Detected

7.3.4.2 Correlation between lipase inhibition capacity and inhibitor concentration

The regression analysis indicated a strong statistical relationship between the concentration of bioactive components in most samples and their ability to inhibit lipase *in vitro* as Figure 7.19 and detailed in Table 7.7. The main findings are:

- Strongest inhibition predictability: Red aman rice and foreign quinoa demonstrated the best model fits ($R^2 > 0.96$, adjusted $R^2 > 0.95$, $p < 0.02$) suggesting a highly stable and reliable association between their bioactive components and lipase inhibition efficacy.
- Strong statistical models: (-) Epicatechin, yellow buckwheat, and local quinoa (SAU-1) also showed strong statistical relevance ($R^2 > 0.88$, $p < 0.02$), supporting the effectiveness of their polyphenolic ingredients as enzyme inhibitors.

- c. Moderate correlations: Oat and foxtail millet had modest but reliable predictive power ($R^2 = 0.81$). Other samples, including black rice, proso millet, maize, barley, and foreign chia, showed moderate R^2 values (0.68–0.81) but slightly weaker statistical significance ($p > 0.05$), indicating a need for further validation.
- d. Weakest model: Local chia was the least successful in the regression model ($R^2 = 0.5664$, $p = 0.142$), showing low predictability for lipase inhibition.

Overall, the regression analysis indicates that interaction strengths between lipase inhibition and phytochemical concentration differ substantially across various grain matrices.

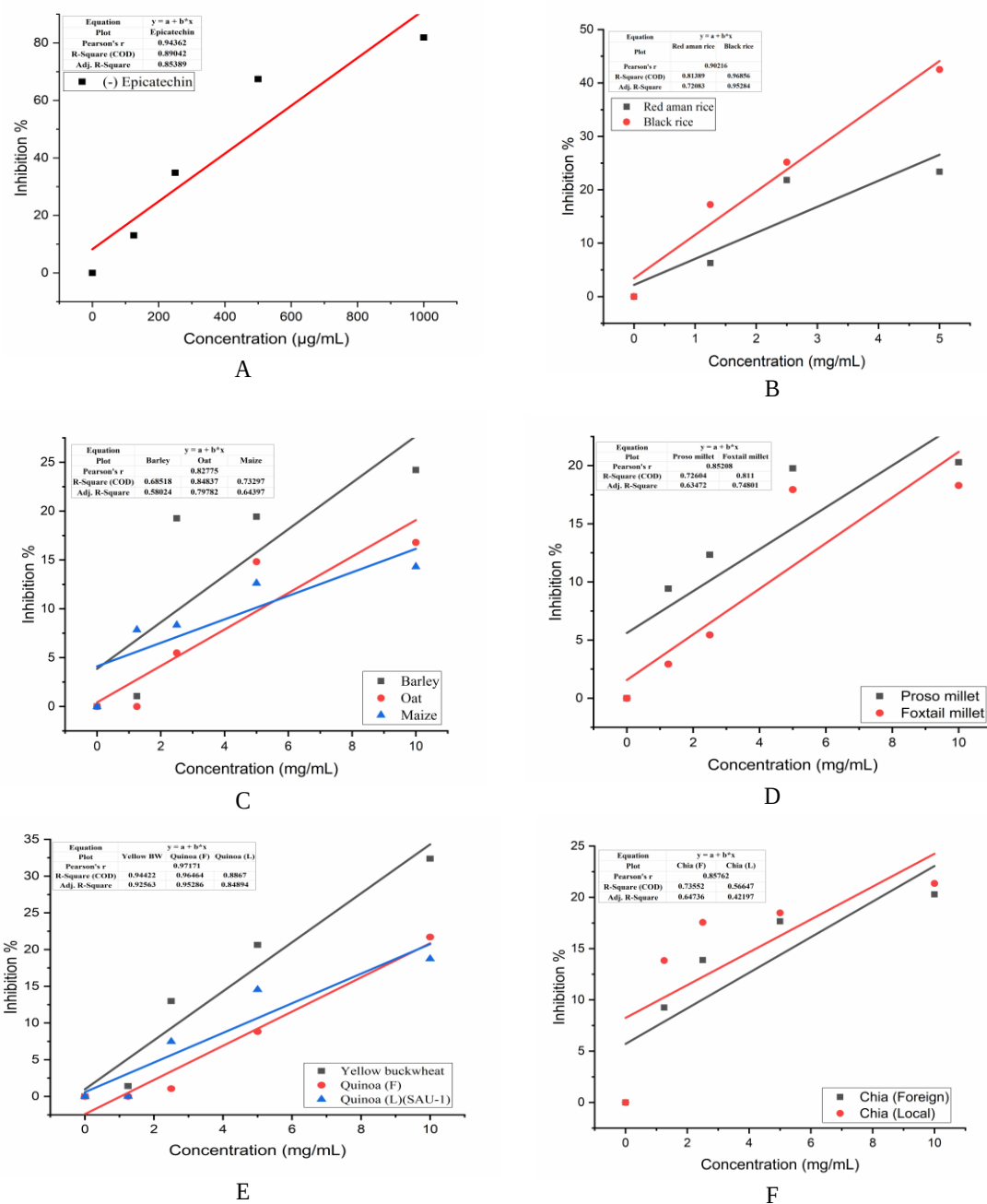


Figure 7.19: Linear correlation between inhibition % and concentration, A = (-) epicatechin, B = red aman rice and black rice, C = oat, maize and barley, D = foxtail and proso millet, E = yellow buckwheat, quinoa (F) and quinoa (L) (SAU-1), F= chia (F) and chia (L).

Table 7.7: Coefficient of determination (R^2), adjusted R^2 and P value of regression curve for the standard (Epicatechin) and samples

Sample Name	Coefficient of determination (R^2)	Adjusted R^2	P value
(-) Epicatechin	0.8904	0.8539	0.0159
Black Rice	0.8138	0.7208	0.0978
Red aman rice	0.9685	0.9528	0.0158
Wheat	-	-	-
Proso millet	0.7260	0.6347	0.0667
Foxtail millet	0.8110	0.7480	0.0370
Maize	0.7329	0.6439	0.0640
Barley	0.6851	0.5802	0.0835
Bajra	-	-	-
Oat	0.8483	0.7978	0.0263
Chia f	0.7355	0.6473	0.0630
Chia L	0.5664	0.4219	0.1420
Quinoa (F)	0.9646	0.9528	0.0028
Quinoa (L)Sau-1	0.8867	0.8489	0.0167
Yellow buckwheat	0.9442	0.9256	0.0056
Black buckwheat	-	-	-

(-) = not detected

7.5 Summary and recommendation

This study identifies pigmented rice, minor cereals, and pseudograins as superior nutritional alternatives to conventional staples in Bangladesh due to their high antioxidant and other functional properties. Key aspects regarding these alternative grains are:

- i. Enriched nutritional value: The research indicates that pigmented rice, minor cereals, and pseudograins offer nutritional profiles superior to commonly consumed staples in Bangladesh. This suggests a potential for dietary diversification to improve overall nutrient intake.
- ii. Rich antioxidant content: Black rice and black buckwheat, in particular, were found to have high Total Antioxidant Capacity (TAC) at 229.61 mg AA/gm. This indicates a

significant presence of compounds that can help protect the body's cells from damage caused by free radicals.

- iii. Identification of bioactive compounds: The study successfully identified specific bioactive compounds present in these grains and these include:
 - a. Rutin hydrate: A flavonoid with various potential health benefits.
 - b. (-) Epicatechin: A compound found in several plant-based foods.
 - c. 3, 4-Dihydroxybenzoic Acid: A phenolic acid.
- iv. Future research implications: The identified polyphenolic compounds provide a foundation for utilization of cereals and pseudograins to make novel, nutrient-dense and gluten-free functional foods. This study also requires enzyme kinetics research to ascertain the exact mechanism of inhibition in the metabolic process. This could lead to developing targeted dietary recommendations or functional food products to aid in managing lipid-related health conditions.

Chapter 8

Study Phase-4:

Data Integration and Discussions

8. Study data integration

In order to better understanding the findings of the present study, data components in different study phases (elaborated in Chapter 5-7) are integrated in this chapter to enabling a consistent view, better analysis, decision-making, and operations by inference data silos.

8.1 Synthesis of Ethnographic data

The low production, distribution, utilization, and consumption of pseudocereals in Bangladesh, despite their significant benefits and official support, can be attributed to several deeply embedded socio-cultural factors, economic challenges, and systemic supply chain limitations, compounded by a lack of localized research data. These issues are investigated in the Ethnographic study (Chapter 5) and summarized in the following sections.

8.1.1 Socio-Cultural Factors and Consumption Patterns

The primary barrier is the deeply inherent dietary habit centered on rice, which is not just a staple food but a cultural symbol in Bangladesh. Key sociocultural factors and consumption trends were identified by this ethnographic study and are the followings:

- a) Dominance of rice: Rice occupies over 96% of the land area under cereal agriculture, and its consumption is synonymous with food in the local tradition, making dietary diversification difficult to achieve.
- b) Perception and prestige: Pseudocereals like buckwheat, amaranth, and millets are often perceived as "minor" or "alternative" foods, sometimes used in special sweet preparations (e.g., kheer or payes) or as animal feed, rather than as primary meal components. In some cases, they may be viewed as food for the poor or as a distress crop, rather than a prestigious, nutritious option.

- c) Lack of awareness: Despite their health benefits (e.g., high protein, gluten-free, rich in micronutrients), there is a general lack of public awareness regarding the nutritional value and appropriate culinary uses of pseudocereals in daily meals.
- d) Traditional knowledge gap: The knowledge and recipes for incorporating these grains into daily diets in a way that is palatable and culturally acceptable are not widely disseminated among the general population and even some farmers.

8.1.2 Production and supply chain limitations

Despite the governmental support and suitable agro-ecological zones, practical issues in the field clog the widespread availability of pseudogamins and, therefore, the main features for the lag of production supply are evident from the ethnographic study as summarized below:

- a) Scanty scientific data: The lack of scientific analytical data within Bangladesh prevents the development of tailored, high-yielding varieties suited to specific local agro-ecological zones and climate challenges (e.g., salinity intrusion, drought). This data gap means that the existing global studies on pseudocereals (Jahan et al., 2023; Kaur et al., 2023) have limited direct application to the specific context of Bangladesh, further slowing adoption and production. Beyond initial experimental production of quinoa and chia, lack of agricultural data causing local farmers' confidence and prevent them to mobilize resources for large-scale, efficient production.
- b) Undeveloped value chains: The supply chain for pseudocereals is underdeveloped compared to the robust, established system for rice and wheat. This result in inefficient distribution channels, lack of proper storage facilities, and price distortions, which make it difficult for both farmers to profit and consumers to access the products consistently.

- c) Market access and profitability: Local producers often sell the majority of their minor cereal crops (e.g., 99% of buckwheat) locally with low profitability due to a limited market and lack of a strong market linkage to urban centers or processing industries.
- d) Infrastructure deficiencies: Inadequate infrastructure for processing, packaging, and marketing pseudocereal-based products were identified which means they cannot compete effectively with processed conventional cereals or "trash food" which is cheaper.
- e) Policy implementation challenges: While official support and good agricultural practices exist on paper, their execution is often hampered by a lack of dedicated personnel, insufficient funding for specific pseudocereal programs and a general prioritization of major cereals within existing agricultural frameworks.

In essence, overcoming the current situation requires a multi-pronged approach that goes beyond official support and addresses the cultural, logistical, and informational barriers preventing the wider adoption of pseudocereals in Bangladesh. Overcoming the existing barriers requires not only continued agricultural research and supply chain improvements but also significant socio-cultural interventions and educational campaigns to shift ingrained perceptions and dietary habits.

8.2 Implication of nutrient and polyphenol composition data

The availability of locally grown cheena (proso millet), kaon (foxtail millet), quinoa, and chia in Bangladeshi markets signals a trend towards functional foods. Because they provide gluten-free, nutrient-dense alternatives to rice and wheat, they provide rich protein, fibre, healthy fats (e.g., omega-3s in chia), antioxidants (polyphenols, flavonoids), vitamins, and minerals, which are essential for managing chronic non-communicable diseases like obesity, diabetes, heart disease, immunity, and more. Ancient super food grains and seeds, rich in bioactive chemicals, boost metabolic health and enhance local cuisines. The "triple burden of malnutrition" (under nutrition,

over nutrition, and micronutrient deficiencies) in Bangladesh can be addressed by these locally grown crops.

In Bangladesh, this study examined macronutrients, total phenolic, flavonoid, antioxidant, free radical scavenging, and HPLC-DAD profiling of polyphenols in selected cereals and pseudograins. These foods produced statistically significant differences. This study found that black and red rice, wheat, oat, and pseudograins, especially chia seeds, may provide dietary fibre, protein, carbs, and phytochemicals that may prevent numerous chronic diseases. Chapter 6 found a strong positive correlation between bioactive components (total phenolic, total flavonoid, and total antioxidant content) and free radical scavenging activities, measured by DPPH, ABTS, and FRAP assays, suggesting potential dietary uses. This study also discovered higher TPC and TFC levels in food samples than previously reported (Ahmed, B. & Rahman, 2020; Milkulajova et al., 2007). This shows that sun exposure, soil composition, and rainfall affect plant phenolic compound concentrations throughout agro-ecological regions (Manach et al., 2004).

Various scavenging assays conducted in this study programme indicated noticeably varied contents of phenolic compounds in different cereal, for example, black rice was found to contain maximum amount of total polyphenols, flavonoids and antioxidants. On the other hand, red rice and quinoa have shown highest amount of (-) epicatechin than that of other cereals. Red aman rice and black buckwheat exhibited higher levels of free radical scavenging capacities (% of inhibition indexed by IC_{50} values). Conversely, the free radical scavenging activity of DPPH, ABTS and FRAP with lower IC_{50} values found in Bajra, Chia, and Quinoa (figure no. 7.3, 7.4, 7.5, 7.7, 7.8, 7.9, 7.11, 7.12 and 7.13, page no.128-132 and table no. 7.3, page no.133) is encouraging to use them in diet therapy as well as in habitual diets of the general population. The present research, therefore, highlighted the significance and feasibility of cereals and pseudograins in the development food

products. Specifically, they can serve as a beneficial aspect that promotes the improvement of dietary habits and overall well-being.

8.2.1 Correlation between IC₅₀ value and polyphenolic components

Numerous studies confirm a significant relationship between the total amount of phenolic compounds and the ability of a grain extract to scavenge free radicals or reduce metal ions as measured by their antioxidant activity. Therefore, there is a strong and consistent inverse correlation between TPC and the IC₅₀ value of antioxidants and other biological activity assays (Kwiatkowski et. al., 2022; Shahidi et. al., 2021; Basu & Maier, 2016; Mikulajová et. al., 2007). This means that a higher concentration of polyphenols leads to a lower IC₅₀ value, which in turn indicates greater biological activity and capacity. The primary reason for this inverse relationship is the mechanism of action; polyphenols act as antioxidants by donating electrons or hydrogen atoms to neutralize free radicals. While polyphenols are major contributors to the antioxidant activity of plant extracts, the activity is also influenced by other compounds and potential synergistic effects between different phytochemicals. Nevertheless, this relationship allows researchers to use the total phenolic content (TPC) as a reliable indicator of potential antioxidant capacity in plant extracts.

A Pearson correlation analysis was conducted to examine the impact of individual phenolic constituents on the antioxidant capacity of the chosen cereals and pseudocereals, correlating the concentration of identified phenolic compounds with the IC₅₀ values derived from ABTS and DPPH radical scavenging assays. This technique quantifies the correlation between phenolic quantity and antioxidant efficacy, with a lower IC₅₀ value signifying enhanced radical scavenging ability. The correlations are presented in Table 8.1 and highlight the phenolic compounds most strongly associated with antioxidant performance across the studied samples.

Samples with elevated phenolic concentrations exhibited enhanced antioxidant ability, as evidenced by diminished IC_{50} values in both experiments, signifying a significant enhancement in free radical scavenging efficacy with increasing phenolic content. The majority of phenolic compounds exhibited substantial to very strong correlations ($r = 0.85\text{--}1.00$) with both ABTS and DPPH IC_{50} values, affirming their functional role in antioxidant capacity. Specifically, rutin, catechol, caffeic acid, epicatechin, quercetin, and kaempferol exhibited $r = 1.00$, indicating they are the principal antioxidant agents in the analyzed grains. Buckwheat (black and yellow), foxtail millet, quinoa, and chia demonstrated the most robust connections, suggesting their potential as functional foods for enhancing dietary antioxidants.

Table 8.1: Pearson correlation between polyphenolic compounds and IC₅₀ values obtained from ABTS and DPPH radical scavenging assays

Sample Name	Polyphenolic compounds	Pearson correlations (r) with IC ₅₀ values	
		ABTS	DPPH
Red aman rice	Transcinamic acid	0.8660	
	Syringic acid	0.9692	1.00
Black rice	Trans ferulic, Rosaminic, Myreceptin, kaempferol	1.00	0.96922
Wheat*	3,4-Dihydroxybenzoic acid	0.8703	-
	Syringic acid, kaempferol	1.00	-
Barley	Caffeic acid, Ruti hydrate	1.00	
	p-Coumaric acid and Trans ferulic acid	0.9966	
Maize*	Caffeic acid, Rutin hydrate	1.00	-
	Syringic acid	0.9979	-
Bajra	3,4-Dihydroxybenzoic acid, (-) Epicatechin	1.00	0.54978
Oat*	Rutin hydrate	0.9244	-
	Catechol	0.9991	-
Proso millet*	Syringic acid	0.8660	-
	Rutin hydrate	0.9244	
	3,4-Dihydroxybenzoic acid, Catechin, Catechol, Rutin hydrate	1.00	
Foxtail millet*	(-) Epicatechin	0.6231	-
	kaempferol	0.8982	-
Buckwheat (black)	Catechol, (-) Epicatechin, p-Coumaric, Myreceptin and Quercetin	0.8783	1.00
Buckwheat (yellow)	(-) Epicatechin, Rutin hydrate, Myreceptin	0.8660	1.00
Quinoa (foreign)	(-) Epicatechin, Caffeic, Kaempferol	1.00	-
	p-Coumaric	0.8452	-
	Quercetin	-	0.5736
Quinoa (Local)	Quercetin	1.00	0.9849
	Rutin hydrate	0.8888	0.9597
Chia (Local)	Vanilic acid and Rutin hydrate	0.99258	0.99986
Chia (Foreign)	(-) Epicatechin, Caffeic and p-Coumaric	0.88189	1.00
	3,4-Dihydroxybenzoic acid	0.8665	0.9995

* samples that have IC₅₀ value obtained from ABTS assay, p > 0.05

8.2.2 Visualizing Pearson correlation coefficients by Heat Mapping

The following description outlines a heat map (Figure 8.1) that visualizes Pearson correlation coefficients among fourteen phenolic compounds and two measures of antioxidant activity (IC₅₀-ABTS and IC₅₀-DPPH), thus highlighting the complex dataset connections. The diagonal represents total self-correlation ($r = 1.0$), whereas off-diagonal values show interactions in a color gradient from strong positive (dark orange, $r = 0.92$) to strong negative (dark teal/blue, $r = -0.59$).

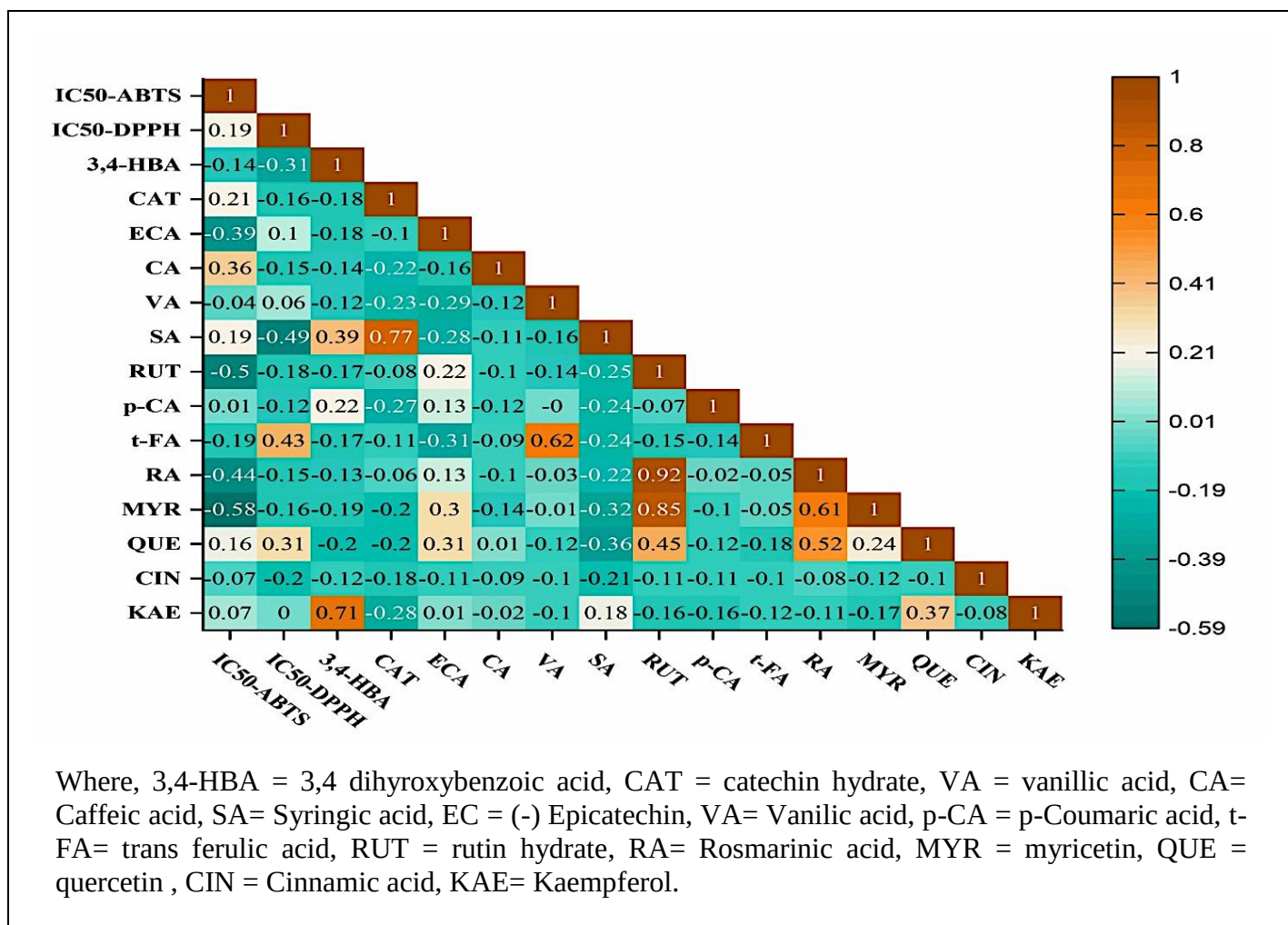


Figure 8.1: Pearson's correlation analysis of polyphenolic compounds identified in the methanolic extracts of 15 samples

The correlation matrix reveals several key insights into the biochemical relationships between phenolic components and their antioxidant efficacy and they are:

I. Key phenolic synergies and co-occurrence

- a) Dataset complexity: The overall pattern of varying correlations (positive, negative, and varying strengths) across the matrix indicates a complex dataset with intricate interconnections between the different phenolic components and their relationship to the measured antioxidant properties.
- b) Strongest association: Rosmarinic Acid (RA) and Myricetin (MYR) exhibit the highest positive correlation ($r = 0.92$), indicating that these two compounds almost always increase or decrease in tandem within the studied plant materials.
- c) Flavonoid clustering: The moderate positive correlation between Myricetin and Quercetin ($r = 0.61$) suggests a shared biosynthetic pathway or simultaneous accumulation of these specific flavonoids.

II. Antioxidant potency indicators (IC₅₀)

- a) Antioxidant drivers: Compounds showing strong negative correlations with IC₅₀. ABTS and IC₅₀-DPPH ($r = -0.59$) are the primary contributors to the radical-scavenging power of the food extracts.
- b) Consistency across assays: The correlation between the two indicators themselves (ABTS and DPPH) typically shows whether the phenolic profile is equally effective at neutralizing different types of free radicals.

III. Interpretation of the color gradient

- a) Dark orange ($r \rightarrow 1.0$): Indicates a "predictive" relationship. If the concentration of one phenolic (like RA) is known, the concentration of its partner (like MYR) can be predicted with high accuracy.
- b) Dark teal/blue ($r \rightarrow -0.59$): These values highlight the inverse relationship between specific phenolics and the IC_{50} values. As these phenolic concentrations rise, the IC_{50} drops, signifying increased antioxidant effectiveness.

This heatmap effectively simplifies a complex 16x16 variable matrix into a visual guide, identifying which specific phenolics are the most reliable markers for the plant's bioactive potentials. Therefore, this type of data visualization is crucial in phytochemical research as it helps researchers understand which compounds might act synergistically or antagonistically, and how these chemical profiles relate to the functional properties (in this case, antioxidant activity) of the studied materials.

8.3 Lipase inhibition potential of cereals and pseudograins

A possible alternative to manufactured medications for obesity management is secondary plant metabolites (SPMs), a large, naturally generated source of digestive enzyme inhibitors that affect nutrition digestion through complicated interactions. These natural inhibitors modulate the digestion process holistically, which may help manage weight and obesity. Plant secondary metabolites inhibit digestive enzymes in different and sometimes synergistic ways, unlike pharmaceutical inhibitors like orlistat. The enzyme-protein structure or enzyme-substrate complexes are commonly involved in these methods. In summary, bioactivity is a common biological strategy of using broad-acting chemical characteristics to disrupt nutrient

digestion and utilization in other organisms. This contrasts with the more specialized processes of several medical synthetic enzyme-inhibitors.

The lipase inhibition assay indicated that various grains, particularly pigmented rice (black and red rice) and yellow buckwheat and quinoa, exhibited potential anti-obesity properties, thereby supporting their incorporation into functional food formulations for the management of metabolic disorders. Red aman rice, foxtail millet, oat, yellow buck wheat and quinoa (both local and foreign) indicated strong association ($P < 0.05$) between dose dependent phytochemical concentrations and lipase inhibition percentages.

The previous research findings of lipase inhibition activity in cereal and pseudocereal closely resemble our current results described in chapter 7 (7.4.3).

The key findings on the lipase inhibition potential study are summarized in the followings:

- a) **Strong association:** Red aman rice, foxtail millet, oats, yellow buckwheat, and quinoa (both local and foreign) showed a strong, dose-dependent relationship between phytochemical concentrations and lipase inhibition percentages (Figure 7.19, Chapter 7).
- b) **Bioactive potential:** The study revealed the significant bioactive potential of cereals and pseudocereals cultivated in Bangladesh (Chapter 6 and 7).
- c) **Dietary and nutritional implications:** While traditional cereals remain popular, pseudocereals, which are rich in bioactive compounds, offer substantial potential for mitigating hyperlipidemia (high levels of fat in the blood) and enhancing dietary diversity.
- d) **Economic benefit:** Expanding the cultivation of these grains offers both nutritional advantages and economic opportunities for sustainable agriculture.

8.4 Summary

Consumers are increasingly conscious of the "triple burden of malnutrition" in Bangladesh, leading to a surge in demand for functional foods like quinoa, chia, and foxtail millet (kaon). Moreover, many minor cereals are deeply rooted in Bangladeshi culture, used in traditional dishes such as kheer, payesh, moa (sweet balls) and pitha using kaon, til, khoi, etc. As a result, while rice and wheat remain the primary staples (averaging 459g and 33.5g per capita daily) the production of pseudocereals is expanding. For example, 99% of buckwheat produced by local farmers is sold for consumption, though newer crops like quinoa and chia are currently more common in research and niche commercial markets (ethnographic study, Chapter 5).

The study confirmed that locally farmed grains are high in beneficial compounds: a) Protein-rich cereals include cheena, kaon, and chia seeds. b) High in fiber and unsaturated fatty acids, chia promotes cardiovascular and digestive health. c) Total phenolics and flavonoids in black rice, red rice, and native bajra constitute the antioxidants. d) HPLC screening indicates (-) epicatechin (high in red rice and quinoa), p-coumaric acid (black rice), and caffeic acid (high in maize) as the primary health benefits (nutrient and polyphenol composition analysis, Chapter 6).

Biochemical analyses of cereals (e.g., wheat, rice), minor cereals (e.g., millets like bajra, cheena and kaon), and pseudograins (e.g., chia, quinoa and buckwheat) demonstrate that they are potent functional foods due to their unique phytochemical and fiber profiles. There is a positive correlation between total phenolic content (TPC) and antioxidant capacity (TAC). Polyphenols found in cereals and pseudograins can inhibit digestive lipase in vitro, which prevents the breakdown and absorption of fats (bioactivity study, Chapter 7).

By integrating the findings of the study revealed a significant connection between the high medicinal potential of cereals and pseudocereals and their nutritional and socio-cultural

acceptance in Bangladesh. Biochemical analyses showed that these grains are rich in health-promoting polyphenols, flavonoids, and fiber, which provide potent antioxidant and anti-lipase effects (Data integration, Chapter 8).

This research successfully bridges the gap between traditional food choice and modern science by proving that ethnographically selected grains possess high nutritional, antioxidant and lipase inhibiting properties, establishing a successful integration of ethno-cultural data and biochemical functionalities.

8.5 Limitations

However, there are some limitations of the study too:

- 1) Plant phenolic concentrations are highly sensitive to local soil composition, rainfall, and sun exposure (as mentioned in section 8.2), the specific "strong correlations" found in this study may not be directly applicable to the same pseudocereal varieties grown in different agro ecological contexts.
- 2) Additionally, the socio-cultural barriers identified (viz., 96% rice dominance) are unique to the Bangladeshi food system, meaning the strategic conclusions may have limited generalizability to other regions with different staple-food cultures.

8.6 Recommendation

While the integration depth was tailored to current laboratory capacities, these results provide an essential benchmark and a clear roadmap for more comprehensive molecular studies as local research infrastructure continues to evolve, ultimately justifying further investment in the large scale cultivation and advanced analysis of these functional super foods.

Chapter 9

Conclusion and Recommendation

9.1 Conclusion

This study examined the nutritional and functional bioactive properties of selected cereals and pseudocereals grown in Bangladesh, emphasizing their potential health and nutritional benefits. The study indicated that these grains are rich in polyphenolic compounds, recognized for their protective properties against hyperlipidemia. The ethnographic investigation, executed via observations, interviews, and field documentation, revealed a notable disparity between the acknowledged value and actual application of pseudocereals in Bangladesh. Despite governmental support and advantageous agro-ecological conditions, the production, distribution, and consumption of pseudocereals remain minimal in comparison to traditional cereals. The results underscore the necessity of incorporating indigenous agricultural expertise, fostering awareness of pseudocereals, and executing focused strategies to facilitate their acceptance as a sustainable and health-promoting crop category. The proximate analysis demonstrated that cereals such as wheat, oat, cheena, and kaon are high in protein, whereas barley, maize, and bajra showed greater dietary fibre content. Chia seeds, both local and foreign, exhibit elevated levels of protein, fat, and fibre among pseudocereals, thereby affirming their potential as nutrient-dense food sources. Phytochemical analysis revealed significant variations in Total Phenolic Content (TPC), Total Flavonoid Content (TFC), Total Antioxidant Capacity (TAC), and Total Tannin Content (TTC). Black rice, red rice, and bajra demonstrated the highest total phenolic content (TPC) among cereals; black rice and bajra exhibited the highest total flavonoid content (TFC); and black rice, red rice, barley, and bajra revealed the highest total antioxidant capacity (TAC) exceeding 100 mg/100g dry weight (DW). In terms of TTC, red rice, oat, and maize were predominant. Among pseudocereals, black buckwheat exhibited the highest total phenolic content (TPC), total flavonoid content (TFC), and total tannin content (TTC), whereas yellow

buckwheat demonstrated the highest total antioxidant capacity (TAC). The HPLC-DAD profiling confirmed the findings by identifying significant polyphenolic compounds. Black rice demonstrated a notable abundance of ferulic acid, whereas red rice and quinoa showed elevated levels of (-) epicatechin. Black buckwheat stands out among pseudocereals due to its significant epicatechin content, which underscores its considerable antioxidant potential. The assessment of bioactivity through DPPH, ABTS, and FRAP assays indicated a significant antioxidant potential in black rice, red rice, and black buckwheat, as evidenced by their lower IC₅₀ values, reflecting strong free radical scavenging capacity. Pseudocereals such as chia, bajra, and quinoa demonstrated notable antioxidant activity. The positive correlations observed among TPC, TFC, TAC, and antioxidant assays support the role of polyphenolic compounds in reducing oxidative stress. The lipase inhibition assay indicated that various grains, particularly pigmented rice (black and red rice) and yellow buckwheat and quinoa, exhibited potential anti-obesity properties, thereby supporting their incorporation into functional food formulations for the management of metabolic disorders. Red aman rice, foxtail millet, oat, yellow buck wheat and quinoa (both local and foreign) indicated strong association (P value < 0.05) between dose dependent phytochemical concentrations and lipase inhibition percentages. This integrated study underscores the substantial nutritional, phytochemical, and bioactive potential of cereals and pseudocereals cultivated in Bangladesh. Traditional cereals remain prevalent; however, pseudocereals, which are abundant in fibre, protein, and bioactive compounds, present significant potential for mitigating hyperlipidemia (*in vitro*) and improving dietary diversity. Encouraging their cultivation and incorporation into national food systems may provide nutritional and economic advantages, enhancing public health outcomes and promoting sustainable agriculture.

9.2 Recommendation

9.2.1 Scope for future research

The study titled "Composition of Plant Polyphenolics in Local Cereals and Pseudograins and Their Bioactivity" represents a developing area of research that presents promising opportunities for further exploration. The following are potential directions for future research.

1. Sustainable agriculture and agro bio-diversity

Further ethno-botanical and agro-ecological studies are needed to assess the adaptability, yield, and sustainability of cereal and pseudograin in diverse agro-climatic zones in Bangladesh. These strategies improve agricultural diversity, food security, and traditional knowledge.

2. Isolation and characterization of bioactive compounds

This study validated the existence of polyphenolic compounds exhibiting antioxidant and lipase inhibitory properties; however, subsequent research should prioritize the isolation, purification, and structural characterization of specific bioactive compounds utilizing advanced analytical methodologies such as LC-MS/MS and NMR. This will facilitate the identification of the most effective bioactive compounds and their structure-function interactions.

3. Lipase inhibition mechanism

To facilitate the functional food application of these grains, comprehensive kinetic studies and mechanistic investigations are required to examine the kinetics and biochemical pathways of lipase inhibition using in vitro and in silico studies.

4. Development of functional food

Bioactivity, particularly lipase inhibition, can be utilized to formulate and improve snacks, breakfast cereals, and meal replacements derived from cereals and pseudocereals. Future research may investigate the bioavailability, sensory acceptability, and stability of these compounds throughout processing and storage.

5. Health economic impact and policy integration

This study emphasizes the necessity for policy-driven initiatives and long-term studies to integrate bioactive-rich pseudocereals into national nutrition programs. Such initiatives may reduce obesity-related disorders and healthcare expenses in Bangladesh.

6. *In vivo* clinical trial

The *in vitro* antioxidant and anti-obesity effects should be validated *in vivo* and clinical trials to confirm the efficacy, safety and dietary relevance of cereal and pseudograins as functional food.

Chapter 10

Bibliography

10. Bibliography

- A.H. Akhi, S.H. Omy, H.B. Saif, F. Akter, A. Anwari, N. Mocarroma, S. Akter, M. M. R. and R. S. (2023). Starting Point Of Buckwheat Breeding In Bangladesh. *International Journal of Agriculture and Environmental Research*, 09(05), 1–16. <https://doi.org/10.51193/IJAER.2023.9505>
- A.K. Al-Suwailem, A.S. Al-Tamimi, M. A. A.-O. and M. S. A.-S. (2006). Safety and Mechanism of Action of Orlistat (Tetrahydrolipstatin) as the First Local Antiobesity Drug. *Journal of APplied Sciences Research*, 2(4), 205–208.
- Abbas, M., Saeed, F., Anjum, F. M., Afzaal, M., Tufail, T., Bashir, M. S., Ishtiaq, A., Hussain, S., & Suleria, H. A. R. (2017). Natural polyphenols: An overview. *International Journal of Food Properties*, 20(8), 1689–1699. <https://doi.org/10.1080/10942912.2016.1220393>
- Abdelaleem, M. A., & Elbassiony, K. R. A. (2021). Evaluation of phytochemicals and antioxidant activity of gamma irradiated quinoa (*Chenopodium quinoa*). *Brazilian Journal of Biology*, 81(3), 806–813. <https://doi.org/10.1590/1519-6984.232270>
- Abdullah, A.T.M., Karim, K.M.R., Rahman, M.M., Sharif, M., Khan, T.A. and Islam, S. . (2024). Chromatographic profiling of bioactive polyphenolic compounds and antioxidant evaluation of ethnobotanical leafy vegetables (*Amaranthus spinosus* and *Glinus oppositifolius*) from the hilly regions of Bangladesh. *Food Research*, 8(6), 305–312.
- Abeysekera, W. K. S. M., Jayathilaka, S. I., Abeysekera, W. P. K. M., Senevirathne, I. G. N. H., Jayanath, N. Y., And, G. A. S. P., & Indika Wijewardana, D. C. M. S. (2022). In vitro determination of anti-oxidant properties and proximate composition of range of millet types and sorghum varieties in Sri Lanka. *Frontiers*, 1–21. <https://doi.org/10.3389/fsufs.2022.884436>
- Adwas, A. A., Ibrahim, A. S., Elsayed, Azab Elsayed Azab, F., & Quwaydir, A. (2019). Oxidative stress and antioxidant mechanisms in human body. *Journal of Applied Biotechnology & Bioengineering*, 6(1), 43–47. <https://doi.org/10.15406/jabb.2019.06.00173>
- Afrin, S. N., Akter, F., Torab, A., & Rahim, M. A. (2024). Vegetable recipe variations in urban and periurban Bangladesh: recipe survey, recipe standardization and nutrient analysis. *BioResearch Communications*, 10(2). <https://doi.org/10.3329/brc.v10i2.74582>
- Agarwal, A., Rizwana, Tripathi, A. D., Kumar, T., Sharma, K. P., & Patel, S. K. S. (2023). Nutritional and Functional New Perspectives and Potential Health Benefits of Quinoa and Chia Seeds. *Antioxidants*, 12(7). <https://doi.org/10.3390/antiox12071413>
- Ahmad, M. (2024). Antioxidant Activity and Bioactive Compounds of Fruits Available in Bangladesh. *Health Dynamics*, 1(1), 22–29. <https://doi.org/10.33846/hd10105>
- Ahmed, B. & Rahman, M. (2020). Food and Food Culture of Early Bengal (in Bangla). *Pratnatattva Journal of the Dept. of Archaeology Jahangirnagar University*, 26, 1–18.

<https://doi.org/10.1007/s12520-019-00991-5>.

- Ahmed, K. S., Farzana, M., Rahman, S. E., Jahan, I. A., Khan, T. A., Al-Mansur, M. A., Sultana, N., & Hossain, H. (2023). *Viscum monoicum*: A New Source of Polyphenolic Compounds Responsible for Antioxidant and Anti-Inflammatory Activities. *Journal of Herbs, Spices and Medicinal Plants*, 29(4), 336–355. <https://doi.org/10.1080/10496475.2023.2182394>
- Ahmed, K. S., Jahan, I. A., Jahan, F., & Hossain, H. (2021). Antioxidant activities and simultaneous HPLC-DAD profiling of polyphenolic compounds from moringa oleifera lam. Leaves grown in Bangladesh. *Food Research*, 5(1), 401–408. [https://doi.org/10.26656/fr.2017.5\(1\).410](https://doi.org/10.26656/fr.2017.5(1).410)
- Akond, M., Government, U. S., Khandaker, L., & Hossain, K. (2010). Total Polyphenol , Polyphenol Oxidase , Antioxidant Activity and Color Profiles of Some Wheat Varieties from Bangladesh. *Research Journal of Agriculture and Biological Sciences*, 6(2), 186–190.
- Alam, M. K., Rana, Z. H., Islam, S. N., & Akhtaruzzaman, M. (2020). Comparative assessment of nutritional composition, polyphenol profile, antidiabetic and antioxidative properties of selected edible wild plant species of Bangladesh. *Food Chemistry*, 320(5), 126646. <https://doi.org/10.1016/j.foodchem.2020.126646>
- Alam, S. A. (2015). *Effects of extrusion process variables on the physical properties of oat-containing extrudates UNIVERSITY OF HELSINKI Department of Food and Environmental Sciences EKT Series 1548 Effects of extrusion process variables on the physical properties of oat-c. May 2012.*
- Alka sharma & Kapoor, A. C. (1996). Levels of antinutritional factors in pearl millet as affected by processing treatments and various types of fermentation. *Plant Foods for Human Nutrition*, 49, 241–252. <https://doi.org/10.1007/bf01093221>
- Amarowicz, R., Pegg, R. B., Rahimi-Moghaddam, P., Barl, B., & Weil, J. A. (2004). Free-radical scavenging capacity and antioxidant activity of selected plant species from the Canadian prairies. *Food Chemistry*, 84(4), 551–562. [https://doi.org/10.1016/S0308-8146\(03\)00278-4](https://doi.org/10.1016/S0308-8146(03)00278-4)
- Antolovich, M., Prenzler, P. D., Patsalides, E., Mcdonald, S., Robards, K., & Robards, K. (2002). ANALYST Methods for testing antioxidant activity. *The Royal Society of Chemistry*, 127, 183–198. <https://doi.org/10.1039/b009171p>
- Archer, D. W., Dawson, J., Kreuter, U. P., Hendrickson, M., & Halloran, J. M. (2008). Social and political influences on agricultural systems. *Renewable Agriculture and Food Szystem*, 23(4), 272–284. <https://doi.org/10.1017/S174217050700169X>
- Association of Official Analytical Chemists, A. (2000). (2000). *Official methods of the analysis of the association of official analytical chemists. 16th editi.*
- Babu, P. D., Subhasree, R. S., Bhakyaraj, R., & Vidhyalakshmi, R. (2009). *Brown Rice-Beyond the Color Reviving a Lost Health Food - A Review*. 2(2), 67–72.

- Bangladesh Agricultural Research Institute (BARI), (2020). *Krishi Projukti Hatboi*, 9th edition. file:///C:/Users/ashik/Downloads/Krishi Projukti Hatboi 2019 (9th Edition) Final Book.pdf
- Banik, S., Rahman, M. (2018). No Title Prevalence of Overweight and Obesity in Bangladesh: a Systematic Review of the Literature. *Curr Obes Rep* 7, 247–253 (2018). *Curr Obes Rep*, 7, 247–253. <https://doi.org/https://doi.org/10.1007/s13679-018-0323-x>
- Bansal AB, Patel P, A. K. Y. (2024). *Orlistat*. Treasure Island (FL): StatPearls Publishing. www.ncbi.nlm.nih.gov/books/NBK542202/
- Barbara Kupikowska-Stobba, Hui Niu, Iveta Klojdov, Ruben Agregan, Jose Manuel Lorenzo, M. K. (2025). Controlled lipid digestion in the development of functional and personalized foods for a tailored delivery of dietary fats. *Food Chemistry*, 466(July 2024). <https://doi.org/10.1016/j.foodchem.2024.142151>
- Bartosz Kulczynski , Joanna Kobus-Cisowska, Maciej Taczanowski, D. K. and A. G.-M. (2019). The chemical composition and nutritional value of chia seeds – current state of knowledge. *Deutsche Lebensmittel-Rundschau*, 115(9), 1–16.
- BBS. (2023). *Summary crop Statistics: Bangladesh Bureau of Statistics 2021-22 and 2022-23*.
- Beitane, I., Krūmina-Zemture, G., Krūma, Z., & Cinkmanis, I. (2018). Phenolics content in buckwheat flour. *Proceedings of the Latvian Academy of Sciences, Section B: Natural, Exact, and Applied Sciences*, 72(2), 75–79. <https://doi.org/10.2478/prolas-2018-0012>
- Belfort, R., Mandarino, L., Kashyap, S., Wirfel, K., Pratipanawatr, T., Berria, R., Defronzo, R. A., & Cusi, K. (2005). *Dose-Response Effect of Elevated Plasma Free Fatty Acid on Insulin Signaling*. 54(June).
- Bianca, D., Ficco, M., Petroni, K., & Mistura, L. (2024). Polyphenols in Cereals : State of the Art of Available Information and Its Potential Use in Epidemiological Studies. *Nutrients (MDPI)*, 16(2155), 1–20. <https://doi.org/10.3390/nu16132155>
- Birari, R. B., & Bhutani, K. K. (2007). *Pancreatic lipase inhibitors from natural sources : unexplored potential*. 12(October), 879–889. <https://doi.org/10.1016/j.drudis.2007.07.024>
- Biswas, P., & Tanni, Z. (2020). Quinoa (Chenopodium Quinoa Willd.) – a Potential New Crop in Bangladesh: Agronomic Performance With Sowing Date. *Bangladesh Agronomy Journal*, 23(1), 67–73. <https://doi.org/10.3329/baj.v23i1.50121>
- Bolea, C. A., & Vizireanu, C. (2017). Polyphenolic content and antioxidant properties of black rice flour. *Annals of the University Dunarea de Jos of Galati, Fascicle VI: Food Technology*, 41(2), 75–85.
- Borkwei Ed Nignpense , Nidhish Francis, C. B. and, & Santhakumar, A. B. (2021). Bioaccessibility and Bioactivity of Cereal Polyphenols:A Review. *Foods*, 10(1595), 3–25.
- Bottger, A. (2018). Plant Secondary Metabolites and Their General Function in Plants. In *Plant Secondary Metabolites and Their General Function in Plants* (pp. 3–17). Springer Nature

Switzerland AG. <https://doi.org/10.1007/978-3-319-99546-5>

- Bouis, H. E., & Welch, R. M. (2010). Biofortification — A Sustainable Agricultural Strategy for Reducing Micronutrient Malnutrition in the Global South. *Crop Science*, 50(March 2010), S-20-S-32. <https://doi.org/10.2135/cropsci2009.09.0531>
- Boz, H. (2015). p-Coumaric acid in cereals: Presence, antioxidant and antimicrobial effects. *International Journal of Food Science and Technology*, 50(11), 2323–2328. <https://doi.org/10.1111/ijfs.12898>
- Brahmi, F., Lounis, N., Mebarakou, S., & Guendouze, N. (2022). Impact of Growth Sites on the Phenolic Contents and Antioxidant Activities of Three Algerian Mentha Species (*M. pulegium* L ., *M. rotundifolia* (L .) Huds ., and *M. spicata* L .). *Frontiers*, 13(June), 1–13. <https://doi.org/10.3389/fphar.2022.886337>
- Bray, G. A. (2004). Medical Consequences of Obesity. *The Journal of Clinical Endocrinology & Metabolism*, 89(6), 2583–2589. <https://doi.org/10.1210/jc.2004-0535>
- Buchholz, T., & Melzig, M. F. (2015). Polyphenolic Compounds as Pancreatic Lipase Inhibitors. 771–783.
- Carey, M. C. (1983). LIPID DIGESTION. *Annual Review of Physiology*, 45, 651–677.
- Chandrasekara, A., & Shahidi, F. (2010). Content of insoluble bound phenolics in millets and their contribution to antioxidant capacity. *Journal of Agricultural and Food Chemistry*, 58(11), 6706–6714. <https://doi.org/10.1021/jf100868b>
- Chen, X. Q., Nagao, N., Itani, T., & Irifune, K. (2012). Anti-oxidative analysis , and identification and quantification of anthocyanin pigments in different coloured rice. *FOOD CHEMISTRY*, 135(4), 2783–2788. <https://doi.org/10.1016/j.foodchem.2012.06.098>
- Cheng, Y., & Prusoff, W. H. (1973). Relationship between the inhibition constant (K_i) and the concentration of inhibitor which causes 50 per cent inhibition (I₅₀) of an enzymatic reaction. *Biochemical Pharmacology*, 22(23), 3099-3108.
- Cheng, H., Xu, N., Zhao, W., Su, J., Liang, M., Xie, Z., & Wu, X. (2017). (-) -Epicatechin Regulates Blood Lipids and Attenuates Hepatic Steatosis in. *Molecular Nutrition & Food Research*, 1–43. <https://doi.org/10.1002/mnfr.201700303>
- Cheynier, V. (2012). Phenolic compounds : from plants to foods. *Phytochemistry Revolution*, 000(1962). <https://doi.org/10.1007/s11101-012-9242-8>
- Cosme, F., Aires, A., Pinto, T., Oliveira, I., & Vilela, A. (2025). A Comprehensive Review of Bioactive Tannins in Foods and Beverages : Functional Properties , Health Benefits , and Sensory Qualities. *Molecules*, 30, 1–28.
- Cremonini, E., Iglesias, D. E., Kang, J., Lombardo, G. E., Mostofinejad, Z., Wang, Z., Zhu, W., & Oteiza, P. I. (2020). (–)-Epicatechin and the comorbidities of obesity. In *Archives of Biochemistry and Biophysics* (Vol. 690). Academic Press Inc.

<https://doi.org/10.1016/j.abb.2020.108505>

- De Aguiar, Etienne & Garcia dos Santos, Fernanda & Centeno, Ana & Capriles, V. (2021). Influence of pseudocereals on gluten-free bread quality: A study integrating dough rheology, bread physical properties and acceptability. *Food Research International*, 150. <https://doi.org/10.1016/j.foodres.2021.110762>.
- De La Garza, A. L., Milagro, F. I., Boque, N., Campi3n, J., & Mart3nez, J. A. (2011). Natural inhibitors of pancreatic lipase as new players in obesity treatment. *Planta Medica*, 77(8), 773–785. <https://doi.org/10.1055/s-0030-1270924>
- Deng, G. F., Xu, X. R., Guo, Y. J., Xia, E. Q., Li, S., Wu, S., Chen, F., Ling, W. H., & Li, H. Bin. (2012). Determination of antioxidant property and their lipophilic and hydrophilic phenolic contents in cereal grains. *Journal of Functional Foods*, 4(4), 906–914. <https://doi.org/10.1016/j.jff.2012.06.008>
- Dikkumburage, H., Madhuranga, T., & Lanka, S. (2023). *Advancing In vitro Antioxidant Activity Assessment : A Comprehensive Methodological Review and Improved Approaches for DPPH , FRAP and H 2 O 2 Assays. December.* <https://doi.org/10.23880/jonam-16000431>
- Dixit, V., Kamal, S. W. J., Chole, P. B., Dayal, D., Chaubey, K. K., Pal, A. K., Xavier, J., Manjunath, B. T., & Bachheti, R. K. (2023). Functional Foods : Exploring the Health Benefits of Bioactive Compounds from Plant and Animal Sources Functional Foods : Exploring the Health Benefits of Bioactive Compounds from Plant and Animal Sources. *Journal of Food Quality*, August, 1–22. <https://doi.org/10.1155/2023/5546753>
- Elshafie, H. S., & Camele, I. (2023). A Comprehensive Review on the Biological , Agricultural and Pharmaceutical Properties of Secondary Metabolites Based-Plant Origin. *Molecular Sciences*, 24(3266), 1–20.
- Emmons, C., & Peterson, D. M. (2001). Antioxidant Activity and Phenolic Content of Oat as Affected by Cultivar and Location. *Crop Science*, 41, 1676–1681. <https://doi.org/10.2135/cropsci2001.1676>
- Emu, Sifat & Dulal, Md & Kali, Tiluttama & Chadni, Mahmuda & Rasul, Md & Mondal, Md. Nurunnabi & Ahsan, Md. Emranul & Khan, Murshida & Shah, A. K. M. A. (2023). Effects of extracting solvents on phytochemical, antioxidant, and antibacterial activity of some seaweeds from the Bay of Bengal offshore Island. *Food and Humanity*, 1(1). <https://doi.org/10.1016/j.foohum.2023.09.005>.
- EROL, Z., ERDEMLİ KÖSE, S. B., GARLI, S., & KOCASARI, F. (2021). The Antioxidant Effect of p-Coumaric Acid Against Toluene-Induced Oxidative Stress in Rats. *Kahramanmaraş Sütçü İmam Üniversitesi Tarım ve Doğa Dergisi*, 24(3), 473–478. <https://doi.org/10.18016/ksutarimdog.vi.765193>
- Fang, Y. Z., Yang, S., & Wu, G. (2002). Free radicals, antioxidants, and nutrition. *Nutrition*, 18(10), 872–879. [https://doi.org/10.1016/S0899-9007\(02\)00916-4](https://doi.org/10.1016/S0899-9007(02)00916-4)

- Filho, A. M. M., Pirozi, M. R., Borges, J. T. D. S., Pinheiro Sant'Ana, H. M., Chaves, J. B. P., & Coimbra, J. S. D. R. (2017). Quinoa: Nutritional, functional, and antinutritional aspects. *Critical Reviews in Food Science and Nutrition*, 57(8), 1618–1630. <https://doi.org/10.1080/10408398.2014.1001811>
- Foster-schubert, K. E., & Cummings, D. E. (2006). *Emerging Therapeutic Strategies for Obesity*. 27(7), 779–793. <https://doi.org/10.1210/er.2006-0041>
- FPMU. (2025). *BANGLADESH FOOD SITUATION REPORT* (Issue July-September, Volume-142). www.fpmu.gov.bd
- Francesca, I., Mera, G., Estefanía, D., Falconí, G., & Córdova, V. M. (2020). *Secondary metabolites in plants : Main classes , phytochemical analysis and pharmacological activities Secondary metabolites in plants : main classes , phytochemical analysis and pharmacological activities . November 2019*. <https://doi.org/10.21931/RB/2019.04.04.11>
- Francis Raguindin, P., Adam Itodo, O., Stoyanov, J., Dejanovic, G. M., Gamba, M., Asllanaj, E., Minder, B., Bussler, W., Metzger, B., Muka, T., Glisic, M., & Kern, H. (2021). A systematic review of phytochemicals in oat and buckwheat. *Food Chemistry*, 338(August 2020), 127982. <https://doi.org/10.1016/j.foodchem.2020.127982>
- Gabal, A. M. S. (2024). *Biological and Biomedical Journal*. 2, 1–17. <https://doi.org/10.21608/BBJ.2024.262948.1016>
- Ganachari, A., As, P. P., Reddy, M., & Pf, Mathad, H. K. and B. R. (2022). Physical properties of Chia (*Salvia hispanica* L .) seeds required for the design of equipment. *The Pharma Innovation*, 11(3), 2253–2256.
- Geetha, K., Yankanchi, G. M., Hulamani, S., & Hiremath, N. (2020). Glycemic index of millet based food mix and its effect on pre diabetic subjects. *Journal of Food Science and Technology*, 57(7), 2732–2738. <https://doi.org/10.1007/s13197-020-04309-5>
- Georgescu, C., Frum, A., Virchea, L. I., Sumacheva, A., Shamtsyan, M., Gligor, F. G., Olah, N. K., Mathe, E., & Mironescu, M. (2022). Geographic Variability of Berry Phytochemicals with Antioxidant and Antimicrobial Properties. *Molecules*, 27(15). <https://doi.org/10.3390/molecules27154986>
- Gezici, K. D. and S. (2019). Secondary plant metabolites , their separation and identification , and role in human disease prevention Secondary plant metabolites , their separation and identification , and role in human disease prevention. *Annals of Phytomedicine*, 7(2)(December 2018), 13–24. <https://doi.org/10.21276/ap.2018.7.2.3>
- Gondoin, A., Grussu, D., Stewart, D., & Mcdougall, G. J. (2010). White and green tea polyphenols inhibit pancreatic lipase in vitro. *Food Research International*, 43(5), 1537–1544. <https://doi.org/10.1016/j.foodres.2010.04.029>
- González, M. I., Wells, G., & Fischer, S. (2014). Chemical characteristics and mineral composition of quinoa by near infrared spectroscopy. *Journal of the Science of Food and*

Agriculture, 94(5). <https://doi.org/10.1002/jsfa.6325>

- Gordillo-Bastidas E, Diaz Rizzolo DA, Roura E, M. T. and G. R. (2017). Quinoa (*Chenopodium quinoa* Willd), from Nutritional Value to Potential Journal of Nutrition & Food Sciences Quinoa (*Chenopodium quinoa* Willd), from Nutritional Value to Potential Health Benefits : An Integrative Review. *Journal of Nutrition & Food Sciences*, 6(3), 100497. <https://doi.org/10.4172/2155-9600.1000497>
- Gorinstein, S., Medina, O. J., Jaramillo, N. O., Arnao, I., Leticia, A., Ayala, M., Toledo, P. A. F., Katrich, E., & Trakhtenberg, S. (2007). The total polyphenols and the antioxidant potentials of some selected cereals and pseudocereals The total polyphenols and the antioxidant potentials of some selected cereals and pseudocereals. *European Food Research and Technology*, 225, 321–328. <https://doi.org/10.1007/s00217-006-0417-7>
- Grande, T., Souid, A., Ciardi, M., Della Croce, C. M., Frassinetti, S., Bramanti, E., Longo, V., & Pozzo, L. (2023). Evaluation of antioxidant and antimicrobial activities of whole flours obtained from different species of *Triticum* genus. *European Food Research and Technology*, 249(6), 1575–1587. <https://doi.org/10.1007/s00217-023-04238-5>
- Grove, K. A., Sae-tan, S., Kennett, M. J., & Lambert, J. D. (2012). *Pancreatic Lipase and Reduces Body Weight Gain in High Fat-Fed Obese Mice*. 20(11), 2311–2313. <https://doi.org/10.1038/oby.2011.139>
- Guerriero, G., Berni, R., Muñoz-sanchez, J. A., Apone, F., Abdel-salam, E. M., Qahtan, A. A., Alatar, A. A., & Cantini, C. (2018). Production of Plant Secondary Metabolites : Examples , Tips and Suggestions for Biotechnologists. *Genes (MDPI)*, 9(309), 1–22. <https://doi.org/10.3390/genes9060309>
- Hales, C. M., Carroll, M. D., Fryar, C. D., & Ogden, C. L. (2020). Prevalence of Obesity and Severe Obesity Among Adults: United States, 2017-2018. *NCHS Data Brief*, 360, 1–8.
- Hammersley, M., & Atkinson, P. (2009). *Ethnography principles in practice third addition*. 1–236.
- Haque, U., Alam, A. H. M. K., Shovon, T. I., Sujon, K. M., Maruf, M. H., Kabir, S. R., Hoque, K. F., & Reza, A. (2024). Unveiling the apoptotic potential of antioxidant-rich Bangladeshi medicinal plant extractives and computational modeling to identify antitumor compounds. *HELIYON*, October, e38885. <https://doi.org/10.1016/j.heliyon.2024.e38885>
- Hasan, M., Roy, P., Alam, M., Hoque, M., & Zzaman, W. (2022). Antimicrobial activity of peels and physicochemical properties of juice prepared from indigenous citrus fruits of Sylhet region , Bangladesh Heliyon Antimicrobial activity of peels and physicochemical properties of juice prepared from indigenous citrus fr. *Heliyon*, 8(July), e09948. <https://doi.org/10.1016/j.heliyon.2022.e09948>
- Herrera, T., Navarro, J., Fornari, T., & Martin, D. (2018). Inhibitory effect of quinoa and fenugreek extracts on pancreatic lipase and α -amylase under in vitro traditional conditions or intestinal simulated conditions. *Food Chemistry*.

<https://doi.org/10.1016/j.foodchem.2018.07.145>

- Hithamani, G., & Srinivasan, K. (2014). Effect of domestic processing on the polyphenol content and bioaccessibility in finger millet (*Eleusine coracana*) and pearl millet (*Pennisetum glaucum*). *FOOD CHEMISTRY*. <https://doi.org/10.1016/j.foodchem.2014.04.107>
- Hossain, M., & Yunus, M. (2017). Estimates of Per Capita Consumption of Food Grains in Bangladesh Estimates of Per Capita Consumption of Food Grains in Bangladesh. *Bangladesh Development Studies*, XXXIX(June 2016 No, 1 & 2). <https://doi.org/10.57138/IHCI9560>
- Ilyasov, I. R., Beloborodov, V. L., Selivanova, I. A., & Terekhov, R. P. (2020). *ABTS / PP Decolorization Assay of Antioxidant Capacity Reaction Pathways*.
- Islam, Md. Rafiqul, Md Abiar Rahman, Asif Reza Anik, S. A. (2022). *Book_minorcereals*.
- Islam, A., Khalil, I., Islam, N., Moniruzzaman, M., & Mottalib, A. (2012). Physicochemical and antioxidant properties of Bangladeshi honeys stored for more than one year. *BMC Complementary and Alternative Medicine*, 12(1), 1. <https://doi.org/10.1186/1472-6882-12-177>
- Islam, S., Rahman, O., Hossain, M., & Khaleque, A. (2015). Antioxidant Activity of Some Common Seasonal Fruits of Bangladesh. *Bioresearch Communications*, 1(1), 28–31.
- Jahan, F., Islam, B., & Prosad, S. (2023). Nutritional characterization and antioxidant properties of various edible portions of *Cucurbita maxima* : A potential source of nutraceuticals *Heliyon*, 9(6), e16628. <https://doi.org/10.1016/j.heliyon.2023.e16628>
- Jan, R., Asaf, S., Numan, M., & Kim, K. (2021). Plant Secondary Metabolite Biosynthesis and Transcriptional Regulation in Response to Biotic and Abiotic Stress Conditions. *Agronomy*, 11, 1–31.
- Jawed, A., Singh, G., Kohli, S., Sumera, A., Haque, S., Prasad, R., & Paul, D. (2019). Therapeutic role of lipases and lipase inhibitors derived from natural resources for remedies against metabolic disorders and lifestyle diseases. *South African Journal of Botany*, 120, 25–32. <https://doi.org/10.1016/j.sajb.2018.04.004>
- Jenny B, Maneka M, Joanne S, Lovemore M, T. N. and S. J. (2022). Health Benefits of Cereal Grain- and Pulse-Derived Proteins. *Molecules*, 27(12), 3746.
- Jones, D. B. (1931). *Factors for converting percentages of nitrogen in foods and feeds into percentages of proteins*.
- Jun, H. Il, Song, G. S., Yang, E. I., Youn, Y., & Kim, Y. S. (2012). Antioxidant Activities and Phenolic Compounds of Pigmented Rice Bran Extracts. *Journal of Food Science*, 77(7), 1–6. <https://doi.org/10.1111/j.1750-3841.2012.02763.x>

- Kabir MH, Rahman SA, K. M. (2023). General and abdominal obesity and dietary nutrient intake among university students in Bangladesh: A cross-sectional study targeting potential risk factors. *Clinical Nutrition ESPEN*, 57, 587–597. <https://doi.org/doi:10.1016/j.clnesp.2023.08.006>.
- Kato, E., Tsuruma, A., Amishima, A., & Satoh, H. (2021). Proteinous pancreatic lipase inhibitor is responsible for the antiobesity effect of young barley (*Hordeum vulgare* L .) leaf extract. *Bioscience, Biotechnology and Biochemistry*, 85(8), 1885–1889. <https://doi.org/10.1093/bbb/zbab096>
- Kaur H, Shams R, Dash KK, and D. A. (2023). A comprehensive review of pseudo-cereals: Nutritional profile, phytochemicals constituents and potential health promoting benefits. *Applied Food Research*, 3(2): 1003. <https://doi.org/https://doi.org/10.1016/j.afres.2023.100351>.
- Khade, O. S., Sruthi, K., Sonkar, R. M., Gade, P. S., & Bhatt, P. (2023). Plant secondary metabolites : Extraction , screening , analysis and their bioactivity. *International Journal of Herbal Medicine*, 11(2), 1–17. <https://doi.org/10.22271/flora.2023.v11.i2a.855>
- Khan, J., Khan, M. Z., Ma, Y., Meng, Y., Mushtaq, A., & Shen, Q. (2022). Overview of the Composition of Whole Grains ' Phenolic Acids and Dietary Fibre and Their Effect on Chronic Non-Communicable Diseases. *International Journal of Environmental Research and Public Health*, 19(3042), 1–21. <https://doi.org/10.3390/10.3390/ijerph19053042>
- Khatun, S., & Mollah, M. M. I. (2024). Analysis of black rice and some other cereal grains for protein, sugar, polyphenols, antioxidant and anti-inflammatory properties. *Journal of Agriculture and Food Research*, 16(April), 101121. <https://doi.org/10.1016/j.jafr.2024.101121>
- Khursheed, T., Fatima, T., Qadri, T., Rafiq, A., Malik, A., Naseer, B., & Hussain, S. Z. (2023). Biochemical, nutraceutical and phytochemical characterization of chia and basil seeds: A comparative study. *International Journal of Food Properties*, 26(1), 1–13. <https://doi.org/10.1080/10942912.2022.2151617>
- Klepacka, J., & Najda, A. (2021). Effect of commercial processing on polyphenols and antioxidant activity of buckwheat seeds. *International Journal of Food Science and Technology*, 56(2), 661–670. <https://doi.org/10.1111/ijfs.14714>
- Klop, B., Elte, J. W. F., & Cabezas, M. C. (2013). Dyslipidemia in Obesity: Mechanisms and Potential Targets. *Nutrients*, 5, 1218–1240. <https://doi.org/10.3390/nu5041218>
- Lai, S. C. J., & Sung, J. L. J. (2018). In vitro inhibition of lipase , α -amylase , α -glucosidase , and angiotensin-converting enzyme by defatted rice bran extracts of red-pericarp rice mutant. *Cereal Chemistry*, May, 167–176. <https://doi.org/10.1002/cche.10025>
- Lázaro Cañizares, Silvia Meza, B. P., Rodrigues, L., Jappe, S. N., & Paulo Carteri Coradi, and M. de O. (2024). Functional Foods from Black Rice (*Oryza sativa* L.): An Overview of the Influence of Drying, Storage, and Processing on Bioactive Molecules and Health-Promoting

- Effects. *Foods*, 13, 1088. <https://doi.org/10.3390/foods13071088>
- Li, T., Owsley, E., Matozel, M., Hsu, P., Novak, C. M., & Chiang, J. Y. L. (2010). *Transgenic Expression of Cholesterol 7 α -Hydroxylase in the Liver Prevents High-Fat Diet-Induced Obesity and Insulin Resistance in Mice*. 678–690. <https://doi.org/10.1002/hep.23721>
- Lin, D., Xiao, M., Zhao, J., Li, Z., & Xing, B. (2016). An Overview of Plant Phenolic Compounds and Their Importance in Human Nutrition and Management of Type 2 Diabetes. *Molecules*, 21(1374), 1–19. <https://doi.org/10.3390/molecules21101374>
- Liu, Y., Chen, P., Zhou, M., Wang, T., Fang, S., Shang, X., & Fu, X. (2018). Geographic variation in the chemical composition and antioxidant properties of phenolic compounds from cyclocarya paliurus (batal) iljinskaja leaves. *Molecules*, 23(10). <https://doi.org/10.3390/molecules23102440>
- Lunagariya, N. A., Patel, N. K., Jagtap, S. C., & Bhutani, K. K. (2014). *Review article : INHIBITORS OF PANCREATIC LIPASE : STATE OF THE ART AND CLINICAL PERSPECTIVES*. 897–921.
- Mamari, H. H. and Al. (2021). *Phenolic Compounds: Classification, Chemistry and Updated Techniques of Analysis and Synthesis*. Intech Open.
- Mamun, S., Shaheen, N., A, B. T., & Cp, B. (2012). Hydrophilic antioxidant capacities and total phenol content of seasonal fruits of Bangladesh Hydrophilic Antioxidant Capacities and Total Phenol Content of Seasonal Fruits of Bangladesh. *Malaysian Journal of Nutrition*, 18(3), 355–362.
- Manach, C., Scalbert, A., Morand, C., Rémésy, C., & Jiménez, L. (2004). Polyphenols: Food sources and bioavailability. *American Journal of Clinical Nutrition*, 79(5), 727–747. <https://doi.org/10.1093/ajcn/79.5.727>
- Martín-Diana, A. B., García-Casas, M. J., Martínez-Villaluenga, C., Frías, J., Peñas, E., & Rico, D. (2021). Wheat and oat brans as sources of polyphenol compounds for development of antioxidant nutraceutical ingredients. *Foods*, 10(1), 1–21. <https://doi.org/10.3390/foods10010115>
- Martinez-gonzalez, A. I., Alvarez-parrilla, E., & Díaz-sánchez, Á. G. (2017). *In vitro Inhibition of Pancreatic Lipase by Polyphenols : A Kinetic , Fluorescence Spectroscopy and Molecular Docking Study*. 55(4), 519–530. <https://doi.org/10.17113/ftb.55.04.17.5138>
- Martínez-Villaluenga, C., Peñas, E., & Hernández-Ledesma, B. (2020). Pseudocereal grains: Nutritional value, health benefits and current applications for the development of gluten-free foods. *Food and Chemical Toxicology*, 137, 111178. <https://doi.org/10.1016/j.fct.2020.111178>
- Matar, D. B., Zhra, M., Nassar, W. K., Altemyatt, H., & Abotouk, N. (2025). Adipose tissue dysfunction disrupts metabolic homeostasis : mechanisms linking fat dysregulation to disease. *Frontiers*, June, 1–33. <https://doi.org/10.3389/fendo.2025.1592683>

- Mazumdar, A., Bhatt, D., Author, C., & Ga, A. (2022). Utilization of black rice and red rice in value added products: A review. ~ 1661 ~ *The Pharma Innovation Journal*, 11(7), 1661–1665. www.thepharmajournal.com
- Mcdougall, G. J., & Stewart, D. (2018). *Berry polyphenols inhibit pancreatic lipase in vitro*. July 2009. <https://doi.org/10.1016/j.foodchem.2008.11.093>
- Melzig, M. (2023). Plant Polyphenols as Inhibitors of Hydrolases are Regulators of Digestion. *Complementary Medicine Research*, 30(5). <https://doi.org/10.1159/000531745>
- Mili, Fatema Tuj Jahan and Rahim, A. T. M. A. (2024). Nutrient composition of nine festival dishes obtained from a recipe survey among lower to middle-class households in selected urban areas. *Bioresearch Communications*, 10(2). <https://doi.org/doi.org/10.3329/brc.v10i2.74573>
- Milkulajova, A., Takacsova, M., Rata, P., Brindzová, L., Zalibera, M., & Németh, K. (2007). Total phenolic contents and antioxidant capacities of cereal and pseudocereal genotypes. *Journal of Food and Nutrition Research*, 46(4), 150–157.
- Mondal, N.A., Moniruzzaman, A.F.M., Abedin, M.Z., Hamid, A. and Sarder, N. A. (1992). Effect of seeding dates and seed rates on buckwheat (*Fagopyrum esculentum*). *Annals of Bangladesh Agriculture*, 2(2), 117–121.
- Moniruzzaman, M., An, C. Y., Rao, P. V., Nurul, M., Hawlader, I., Amirah, S., Mohd, B., Sulaiman, S. A., & Gan, S. H. (2014). Identification of Phenolic Acids and Flavonoids in Monofloral Honey from Bangladesh by High Performance Liquid Chromatography : Determination of Antioxidant Capacity. *BioMed Research International*, 2014, 1–11. <https://doi.org/10.1155/2014/737490>
- Most, A. (2022). Anti-Inflammatory Medicinal Plants of Bangladesh — A Pharmacological Evaluation. *Frontiers*, 13(March), 1–24. <https://doi.org/10.3389/fphar.2022.809324>
- Mounika, D., Sangeetha, U., & Sireesha, G. (2022). Estimation of phytochemicals in Millets and selected Millet products. *Indian J. Applied & Pure Bio*, 37(3), 810–820.
- Namrata, S ; Haripriya, A. (2022). Effect of germination on selected phytochemicals and antioxidant activity of quinoa (*Chenopodium quinoa*). *SIIndian Journal of Traditional Knowledge (IJTK)*, 21(4). <https://doi.org/http://op.niscair.res.in/index.php/IJTK/article/view/33004>
- Nashrurrokhman, M., Sayekti, P. R., Safitri, A. Y. U., Purwestri, Y. A., & Pratiwi, R. (2019). Macronutrient and mineral contents of five local black rice (*Oryza sativa*) cultivars in Indonesia. *Biodiversitas*, 20(12), 3647–3653. <https://doi.org/10.13057/biodiv/d201225>
- Nasim, M., Shahidullah, S. M., Saha, A., Muttaleb, M. A., Aditya, T. L., & Kabir, M. A. A. and M. S. (2017). Distribution of Crops and Cropping Patterns of Bangladesh. *Bangladesh Rice Journal*, 21(2), 1–55.
- Nazrul, M., Bhuiyan, I., & Hossain, S. J. (2020). Comparison of physicochemical and

antioxidant properties of edible fruits in the Sundarbans ' mangrove forest , Bangladesh
 COMPARISON OF PHYSICOCHEMICAL AND ANTIOXIDANT PROPERTIES OF
 EDIBLE FRUITS IN THE SUNDARBANS '. *Bangladesh Journal of Botany*, 49(3), 671–
 678. <https://doi.org/10.3329/bjb.v49i3.50009>

- Neacsu, M., Sampaio, S. D. L., Hayes, H. E., Duncan, G. J., Vaughan, N. J., Russell, W. R., & Raikos, V. (2022). Nutritional Content , Phytochemical Profiling , and Physical Properties of Buckwheat (*Fagopyrum esculentum*) Seeds for Promotion of Dietary and Food Ingredient Biodiversity. *Crops, MDPI*, 2, 287–305.
- Nibir, Y. M., Sumit, A. F., Akhand, A. A., Ahsan, N., Hossain, M. S., & Ph, D. (2017). Tea extracts. *Asian Pacific Journal of Tropical Biomedicine*, 7(4).
<https://doi.org/10.1016/j.apjtb.2017.01.005>
- Onzere, K. N. O.-D. and S. N. (2019). Ethnography in Agricultural Research: A Tool Diagnosis Problems and Sustaining Solutions. *African Journal of Food Agricultural And Nutrition*, 19(1), 14090–14112. <https://doi.org/10.18697/ajfand.84.BLFB1032>
- Paiva, E. P. D. E., Torres, S. B., & Leite, M. D. E. S. (2019). *GERMINATION OF CHIA SEEDS IN DIFFERENT SUBSTRATES AND WATER*. 2125, 270–275.
- Pandey, K. B., & Rizvi, S. I. (2009). Plant polyphenols as dietary antioxidants in human health and disease. *Oxidative Medicine and Cellular Longevity*, 2(5), 270–278.
<https://doi.org/10.4161/oxim.2.5.9498>
- Pandurangan, P., Na, R., Nagarajan, S., & Samrot, A. V. (2021). Evaluation of Antioxidants , Antidiabetic , Antiinflammatory Active Compounds from *Leptogium rivurale* Through In-Vitro and In-Silico Studies. *Applied Nano Bioscience*, 11(4), 4192–4200.
<https://doi.org/10.33263/LIANBS114.41924>
- Pasko, P., Sajewicz, M., & Gorinstein, S. (2008). Analysis of Selected Phenolic Acids and Flavonoids in *Amaranthus cruentus* and *Chenopodium quinoa* Seeds and Analysis of Selected Phenolic Acids and Flavonoids in *Amaranthus cruentus* and *Chenopodium quinoa* Seeds and Sprouts by HPLC. *Acta Chromatographica*, 20(4), 661–672.
<https://doi.org/10.1556/AChrom.20.2008.4.11>
- Poonia, A., Upadhayay, A. (2015). *Chenopodium album* Linn: review of nutritive value and biological properties. *Journal of Food Science and Technology*, 52, 3977–3985.
<https://doi.org/10.1007/s13197-014-1553-x>
- Poosri, S., Thilavech, T., Pasukamonset, P., & Suparpprom, C. (2019). Studies on Riceberry rice (*Oryza sativa* L .) extract on the key steps related to carbohydrate and lipid digestion and absorption : A new source of natural bioactive substances. *NFS Journal*, 17(October), 17–23. <https://doi.org/10.1016/j.nfs.2019.10.002>
- Pradipta, S., Ubaidillah, M., & Siswoyo, T. A. (2020). Physicochemical, functional and antioxidant properties of pigmented rice. *Current Research in Nutrition and Food Science*, 8(3), 837–851. <https://doi.org/10.12944/CRNFSJ.8.3.15>

- Puangpraphant, Sirima, E.-O. C.-R., & Oseguera-Toledo, M. (2022). Chapter 9- Anti-inflammatory and antioxidant phenolic compounds. In C. M.-V. Blanca Hernández-Ledesma (Ed.), *Current Advances for Development of Functional Foods Modulating Inflammation and Oxidative Stress* (pp. 165–180). Elsevier. <https://doi.org/10.1016/B978-0-12-823482-2.00018-2>
- Rahim, A. T. M. A., Takahashi, Y., & Yamaki, K. (2015). Mode of pancreatic lipase inhibition activity in vitro by some flavonoids and non-flavonoid polyphenols. *Food Research International*, 75(May 2015), 289–294. <https://doi.org/10.1016/j.foodres.2015.05.017>
- Rahman, J., Costa, A., Camargo, D., & Shahidi, F. (2017). Phenolic and polyphenolic profiles of chia seeds and their in vitro biological activities. *Journal of Functional Foods*, 35, 622–634. <https://doi.org/10.1016/j.jff.2017.06.044>
- Rahman, S., Hasnat, A., Hasan, C. M., & Rashid, M. A. (2001). Pharmacological Evaluation of Bangladeshi Medicinal Plants — a Review Pharmacological Evaluation of Bangladeshi Medicinal Plants for Antioxidant. *Pharmaceutical Biology*, 46(10), 704–709. <https://doi.org/10.1076/phbi.39.1.1.5939>
- Rahman, W. (2021). *Quinoa now made in Bangladesh*. <https://www.dhakatribune.com/business/246942/quinoa-now-made-in-bangladesh>
- Rathore, S., Singh, K., & Kumar, V. (2016). Millet Grain Processing , Utilization and Its Role in Health Promotion : A Review. *International Journal of Nutrition and Food Sciences*, 5(5), 318–329. <https://doi.org/10.11648/j.ijnfs.20160505.12>
- Repo-carrasco-valencia, R. A., & Serna, L. A. (2011). Quinoa (*Chenopodium quinoa* , Willd .) as a source of dietary fiber and other functional components. *Cienc. Technol. Aliment., Campinas*, 31(1), 225–230. <https://doi.org/https://doi.org/10.1590/S0101-20612011000100034>
- Rhaman, M., Shoeb, M., & Islam, N. (2022). Evaluation of Total Phenolic , Flavonoid Content and Antioxidant Capacity of Different Parts of Averrhoa carambola L . *Dhaka University Journal of Pharmaceutical Sciences*, 21(2), 147–151. <https://doi.org/10.3329/dujps.v21i2.63115>
- ROBERTA RE, NICOLETTA PELLEGRINI, ANNA PROTEGGENTE, ANANTH PANNALA, MIN YANG, C. R.-E. (1999). Antioxidant activity applying an improved ABTS radical. *Free Radical Biology & Medicine*, 26(98), 1231–1237.
- Rocchetti, G., Lucini, L., Rodriguez, J. M. L., Barba, F. J., & Giuberti, G. (2019). Gluten-free flours from cereals, pseudocereals and legumes: Phenolic fingerprints and in vitro antioxidant properties. *Food Chemistry*, 271, 157–164. <https://doi.org/10.1016/j.foodchem.2018.07.176>
- Rodríguez, J. P., Rahman, H., Thushar, S., & Singh, R. K. (2020). Healthy and Resilient Cereals and Pseudo-Cereals for Marginal Agriculture : Molecular Advances for Improving Nutrient Bioavailability. *Frontiers*, 11(February), 1–29. <https://doi.org/10.3389/fgene.2020.00049>

- Romania, A. M., Crina, C. M., Anamaria, P., Georgina, S. M., Andruta, E. M., Andreea, P., Alina, N. P., Florina, S., Ioana, C. C., Ionut-Dumitru, V., & Roxana, N. R. (2025). *Dietary Fibers and Their Importance in the Diet*. WEB of Science, Intech Open. <https://doi.org/http://dx.doi.org/10.5772/intechopen.115461> 2.
- Roopashree, K. M., & Naik, D. (2019). Advanced method of secondary metabolite extraction and quality analysis. *Journal of Pharmacognosy and Phytochemistry*, 8(3), 1829–1842.
- Rupa, A. Z., Akhter, K. T., & Rahim, A. T. M. A. (2024). *Nutritive , Polyphenolic , and Antioxidative Properties of Locally Produced Cereals and Pseudograins*. 06(01).
- Rupa, A. Z., & Rahim, A. T. M. A. (2023). Ethnographic survey on cereal and pseudocereal in Bangladesh perspective. *Food Research*, 7(2), 222–229. [https://doi.org/10.26656/fr.2017.7\(2\).669](https://doi.org/10.26656/fr.2017.7(2).669)
- Rupa, A. Z., A., Torab, A., Rahim, M. A., Hossain, H., & Shahin, K. (2025). *Nutritional , phytochemical and antioxidant properties of Bangladeshi pigmented rice (red and black), grains and pseudograins*. 6(December 2024).
- Schwartz, S. L. (2006). *Diabetes and dyslipidaemia*. 355–364. <https://doi.org/10.1111/j.1463>
- Sehwag, S., & Das, M. (2014). Nutritive , therapeutic and processing aspects of Jamun , *Syzygium cuminii* (L .) Skeels- An overview. *Indian Journal of Natural Product and Resources*, 5(4), 295–307.
- Sekhvatizadeh, S. S., Hosseinzadeh, S., & Mohebbi, G. (2021). *Nutritional , antioxidant and polyphenol content of quinoa (Chenopodium quinoa Willd .) cultivated in Iran*. 9(May).
- Sergent, T., Vanderstraeten, J., Winand, J., Beguin, P., & Schneider, Y. (2012). Phenolic compounds and plant extracts as potential natural anti-obesity substances. *Food Chemistry*, 135(1), 68–73. <https://doi.org/10.1016/j.foodchem.2012.04.074>
- Shaheen, Nazma, Masao Goto, J. W. and Y. T.-I. (2012). Antioxidant Capacity and Total Phenol Content of Commonly Consumed Indigenous Foods of Asian Tropical Regions. *Journal of Food Science and Engineering*, 2, 187–195. <https://doi.org/10.17265/2159-5828/2012.04.001>
- Shaheen, N., Bari, L., & Mannan, M. A. (2013). *Food Composition Table for Bangladesh*. <https://www.researchgate.net/publication/268520007>
- Shaheen, N., Tukun, A. B., Islam, S., & Akhter, K. T. (2021). Polyphenols profile and antioxidant capacity of selected medicinal plants of Bangladesh. *BioResearch Communication*, 7(1), 947–954.
- Sharma, A., Tiwari, V. K., Suman, S., & Nagaraju, M. (2020). Nutritional and Nutraceutical Importance of Minor Millets: A Review. In *Int.J.Curr.Microbiol.App.Sci (2020) Special Issue* (Vol. 11). <http://www.ijcmas.com>
- Sharma, S., Kataria, A., & Singh, B. (2022). Effect of thermal processing on the bioactive

- compounds, antioxidative, antinutritional and functional characteristics of quinoa (*Chenopodium quinoa*). *Lwt*, 160(February), 113256. <https://doi.org/10.1016/j.lwt.2022.113256>
- Shela Gorinstein, Antonin Lojek, Milan Ciz, Elke Pawelzik, Efren Delgado-Licon, Oscar J. Medina, Marlen Moreno, I. A. S. & I. G. (2008). Original article Comparison of composition and antioxidant capacity of some cereals and pseudocereals. *International Journal of Food Science and Technology*, 43, 629–637. <https://doi.org/10.1111/j.1365-2621.2007.01498.x>
- Shen, N., Wang, T., Gan, Q., Liu, S., Wang, L. and Jin, B. (2022). Plant flavonoids: Classification, distribution, biosynthesis, and antioxidant activity. *Food Chemistry*, 383, 132531. <https://doi.org/10.1016/j.foodchem.2022.132531>
- Shu-Long Yao, Ying Xu, Yan-Yan Zhang, Y.-H. L. (2013). Black Rice and Anthocyanins Induce Inhibition of Cholesterol Absorption in Vitro. *Food & Function*. <https://doi.org/10.1039/C3FO60196J>
- Shykh Seraj. (2019). *Black rice, a magical variety*. Retrieved from *The Daily Star*. <https://www.thedailystar.net/country/news/black-rice-magical-variety-1845295>
- Sinay, H., Mahulette, F., & Yáñez, J. A. (2022). Determination of free radical scavenging activity, phenolic and flavonoid content of seven corn cultivars from the Southwest Maluku District, Indonesia. *Biodiversitas*, 23(11), 5974–5981. <https://doi.org/10.13057/biodiv/d231151>
- Slavin, J. (2004). Whole grains and human health. *Nutrition Research Reviews*, 17, 99–110. <https://doi.org/10.1079/NRR200374>
- Smith, C. E., & Tucker, K. L. (2011). Health benefits of cereal fibre: A review of clinical trials. *Nutrition Research Reviews*, 24(1), 118–131. <https://doi.org/10.1017/S0954422411000023>
- Stefoska-needham, A., Beck, E. J., & Johnson, S. K. (2015). Sorghum : An Underutilized Cereal Whole Grain with the Potential to Assist in the Prevention of Chronic Disease. *Food Reviews International*, 31, 401–437. <https://doi.org/10.1080/87559129.2015.1022832>
- Sugiura, Y., Nu, G., Kim, Y., Tomioka, S., Seki, N., Sugiura, Y., Akiyama, M., Uchiyama, J., & Yamaguchi, G. (2022). Report Cooperative action of gut-microbiota-accessible carbohydrates improves host metabolic function II Cooperative action of gut-microbiota-accessible carbohydrates improves host metabolic function. *Cell Reports*, 40(111087). <https://doi.org/10.1016/j.celrep.2022.111087>
- Sulaiman, S. A., Kassum, A. L., & Sanusi, S. N. (2020). Proximate analysis and mineral compositions of different cereal grain varieties available in Kano state, Nigeria. In *International Journal of Food Science and Nutrition*. www.foodsciencejournal.com
- Sumi, S. S., Shorna, S. I., Hossain, A., & Hossain, A. (2023). *Effect of Planting Density on*

Growth and Yield of Chia (Salvia hispanica L .). 21(4), 472–480.

- Tahiri, K. (2020). Estimation of some Nutrient Values of Quinoa, Chia ,Teff, Mung Bean and Buckwheat Seeds for Ruminants by In vitro Methods. *Arastirma Makalesi*, 57(4), 519–527. <https://doi.org/10.20289/zfdergi.670262>
- Talha, S., Us, T., Saad, S., Islam, T., Us, T., & Talha, S. (2023). Prevalence , pattern , and correlates of dyslipidemia in Bangladeshi individuals Prevalence , pattern , and correlates of dyslipidemia in Bangladeshi individuals. *Journal of Clinical Lipidology*, 17(6), 788–799. <https://doi.org/10.1016/j.jacl.2023.09.007>
- Tang, Y., Li, X., Zhang, B., Chen, P. X., Liu, R., & Tsao, R. (2015). Characterisation of phenolics , betanins and antioxidant activities in seeds of three Chenopodium quinoa Willd . genotypes. *FOOD CHEMISTRY*, 166, 380–388. <https://doi.org/10.1016/j.foodchem.2014.06.018>
- Tchang, B. G., Aras, M., Kumar, R. B., & Aronne, L. J. (2021). CURRENT PHARMACOLOGIC TREATMENT OF OVERWEIGHT AND OBESITY IN Principles of Obesity Pharmacotherapy. *EndoText, Cvd*.
- Teoh, E. S. (2016). Secondary Metabolites of Plants. *Springer International Publishing*, 59–73. <https://doi.org/10.1007/978-3-319-24274-3>
- Thitipramote, N., Pradmeeteekul, P., Nimkamnerd, J., Chaiwut, P., Pintathong, P., & Thitilerdecha, N. (2016). Bioactive compounds and antioxidant activities of red (Brown Red Jasmine) and black (Kam Leum Pua) native pigmented rice. *International Food Research Journal*, 23(1), 410–414.
- Thomas, E., Manuel, S., Sigrid, F., & Klaus, K. (2014). In-Vitro Inhibition of Human Lipase PS by Polyphenols From Kiwi Fruit. *Journal of Food Research*, 3(4), 71–77. <https://doi.org/10.5539/jfr.v3n4p71>
- Thomson, A.B.R., De Pover, A., Keelan, M., Jarocka-Cyrta, E., & Clandinin, M.T. (1997). Inhibition of lipid absorption as an approach to the treatment of obesity. *Methods in Enzymology*, 286, 3–44.
- Tian, S., Sun, Y., Chen, Z., Yang, Y., Wang, Y., & Trabelsi, N. (2019). Functional Properties of Polyphenols in Grains and Effects of Physicochemical Processing on Polyphenols. *Journal of Food Quality*, 2019. <https://doi.org/10.1155/2019/2793973>
- Tomczyk, M. O. (2021). How to express the antioxidant properties of substances properly ? *Chemical Papers*. <https://doi.org/10.1007/s11696-021-01799-1>
- Tribune, T. D. (2021). *Foreign vegetables gaining ground inPanchagarh*.
- Tsao, R. (2010). Chemistry and Biochemistry of Dietary Polyphenols. *Nutrients*, 2, 1231–1246. <https://doi.org/10.3390/nu2121231>
- Tucci SA, Boyland EJ, H. J. (2010). The role of lipid and carbohydrate digestive enzyme

- inhibitors in the management of obesity: a review of current and emerging therapeutic agents. *Diabetes Metabolic Syndrome & Obesity.*, 3, 125–143.
<https://doi.org/10.2147/dmsott.s7005>.
- Uddin, M. R., Li, X., Park, W. T., Kim, Y. B., Kim, S. J., Kim, Y. S., Lee, M. Y., Park, C. H., & Park, S. U. (2013). Phenolic compound content in different organs of KOREan common buckwheat cultivars. *Asian Journal of Chemistry*, 25(1), 424–426.
<https://doi.org/10.14233/ajchem.2013.13141>
- US Department of Agriculture. (2018). *USDA food data center*. <https://fdc.nal.usda.gov/>
- Vani, S. N., & Soni, D. (2024). Nutritional Profile and Health Benefits of Buckwheat : A Miracle Pseudo Cereal. *Centre for Advanced Research in Agricultural Sciences*, 15(05), 1204–1209.
- Vega-g, A., Miranda, M., Vergara, J., Uribe, E., Puente, L., & Mart, E. A. (2010). Nutrition facts and functional potential of quinoa (*Chenopodium quinoa willd.*), an ancient Andean grain : a review. *Journal of Science , FOOD & Agriculture*, 90(September), 2541–2547.
<https://doi.org/10.1002/jsfa.4158>
- Walter, M., & Marchesan, E. (2014). Phenolic Compounds and Antioxidant Activity of Rice. *Brazilian Archives of Biology and Technology*, 54(1), 371–377.
<https://doi.org/10.1590/S1516-89132011000200020>
- Welch, R. M., & Graham, R. D. (2004). Breeding for micronutrients in staple food crops from a human nutrition perspective. *Journal of Experimental Botany*, 55(396), 353–364.
<https://doi.org/10.1093/jxb/erh064>
- Xie, F. Y., Bi, W. W., Wang, X. J., Zhang, X. L., Zhang, X. N., Zhao, G. X., & Liu, Q. Q. (2017). Extraction and Identification of Black Rice Polyphenolic Compounds by Reversed Phase High Performance Liquid Chromatography–Electrospray Ionization Mass Spectrometry. *Journal of Food Processing and Preservation*, 41(5).
<https://doi.org/10.1111/jfpp.13119>
- Yang, M. H., Chin, Y., Yoon, K. D., & Kim, J. (2014). *Phenolic compounds with pancreatic lipase inhibitory activity from Korean yam (Dioscorea opposita)*. 6366.
<https://doi.org/10.3109/14756366.2012.742517>
- Yang, X. S., Wang, L. L., Zhou, X. R., Shuang, S. M., Zhu, Z. H., Li, N., Li, Y., Liu, F., Liu, S. C., Lu, P., Ren, G. X., & Dong, C. (2013). Determination of protein, fat, starch, and amino acids in foxtail millet [*Setaria italica* (L.) Beauv.] by Fourier transform near-infrared reflectance spectroscopy. *Food Science and Biotechnology*, 22(6), 1495–1500.
<https://doi.org/10.1007/s10068-013-0243-1>
- Yeon Ju Lee, Hye Jee Kang, Su Hyung Yi, and Y. H. J. (2023). Antioxidant Properties of Kombucha Made with Tartary Buckwheat Tea and Burdock Tea. *Preventive Nutrition and Food Science*, 28(3), 347–352.
- Yunus, M., Rashid, S., & Chowdhury, S. (2019). *Per Capita Rice Consumption in Bangladesh:*

Available estimate and IFPRI's validation survey results (003; Issue February).
<https://www.ifpri.org/publication/capita-rice-consumption-bangladesh-available-estimates-and-ifpris-validation-survey>

- Zeng, Y., Pu, X., Du, J., Yang, X., Li, X., Mandal, M. S. N., Yang, T., & Yang, J. (2020). Molecular Mechanism of Functional Ingredients in Barley to Combat Human Chronic Diseases. *Oxidative Medicine and Cellular Longevity*, 2020, 1–26.
<https://doi.org/10.1155/2020/3836172>
- Zhang Ming-Wei, Guo Bao-jiang, Zhang Rui-fen, Chi Jian-wei, Wei Zhen-Cheng, Xu Zhi-hong, Z. Y. and T. X. (2006). Separation , Purification and Identification of Antioxidant Compositions in Black. *Agricultural Sciences in China*, 5(6), 431–440.
[https://doi.org/http://10.1016/S1671-2927\(06\)60073-4](https://doi.org/http://10.1016/S1671-2927(06)60073-4)
- Zhang, R., Huang, L., Deng, Y., Chi, J., Zhang, Y., Wei, Z., & Zhang, M. (2017). Phenolic content and antioxidant activity of eight representative sweet corn varieties grown in South China. *International Journal of Food Properties*, 20(12), 3043–3055.
<https://doi.org/10.1080/10942912.2016.1270964>
- Zhong, L., Lin, Y., Wang, C., Niu, B., Xu, Y., Zhao, G., & Zhao, J. (2022). Chemical Profile, Antimicrobial and Antioxidant Activity Assessment of the Crude Extract and Its Main Flavonoids from Tartary Buckwheat Sprouts. *Molecules*, 27(2).
<https://doi.org/10.3390/molecules27020374>

Chapter 11

Annexure

Annexure 1

CASE STUDY-1: **Date:** August, 2021

Interviewee: Owner and farmer of black rice and red rice agro farm

Location: Monagram, Cumilla, Bangladesh

Descriptions: This case study highlights a pioneering effort in diversifying Bangladeshi agriculture through high-nutrient specialty crops.

Quick Stats: Black vs. Red Rice (Monjur Agro Farm)		
Feature	Black Rice	Red Rice
First cultivated	2017 (Cumilla)	2017 (Cumilla)
Seed source	SE Asia & Japan (Vietnam, Indonesia, etc.)	BRRI & Local Farmers
Yield (per bigha)	17 Mon	13 Mon
Production cost	~15,000 BDT per bigha	(Not specified)
Seasonal cycle	Aman & Boro	Aman & Boro
Crop diversification	Successful cultivation of 4 variety only (out of 21 attempted)	4 variety out of 21

Key Takeaways:

- i. **Market Niche:** The farm targets health-conscious consumers, specifically those managing diabetes or obesity, and sells primarily through organic food distributors in Dhaka.
- ii. **Innovation vs. Support:** Despite successful cultivation of 21 varieties and expansion into mustard oil, dairy, and palm oil, the owner reported a lack of government extension services or funding from local Upazila agriculture offices as of 2021.
- iii. **Knowledge Sharing:** The farm acts as a local hub, having already supplied seeds to 15 other farmers to encourage the spread of these varieties.
- iv. **Lack of interest:** Nutritional quality of the grain.

Summary of the statement:

This case illustrates private entrepreneurial initiative in colored rice farming in Bangladesh. Despite positive market response, the lack of institutional support and extension-based promotion poses barriers to scaling up cereal production.

CASE STUDY-2: **Date:** December, 2021

Interviewee: Researcher, Bangladesh Agricultural University (BAU),
Mymensingh

Location: Mymensingh, Bangladesh

Descriptions: This case study highlights the early-stage introduction and research-led adoption of chia (a pseudograin) in Bangladesh, focusing on agronomic feasibility, institutional interest, and challenges to commercialization.

Quick Stats: Chia Research and Cultivation (Bangladesh)

Feature	Chia seed
Crop Category	Pseudograin with high nutritional value
Research started	2016 (BAU, seeds sourced from Canada)
First successful cultivation	2017 (Manirampur, Jashore)
Current cultivation zones	Dinajpur, Mymensingh, Gaibandha & Jashore (trial plots)
Growing seasons	Rabi Season (Oct–Nov sowing)
Input	1–2 irrigations, low pesticides, natural fertilizers
Farmers engagement	Limited to research-driven experimental plots
Government approval	Not yet approved; no registered varieties
Status	Research-based crop; not commercialized

Key Takeaways:

- i. **Research-driven introduction:** Chia was introduced through university research initiatives rather than commercial farming or import-based market demand.
- ii. **Agronomic Suitability Identified:** Trials indicate chia can grow in Bangladesh’s Rabi season with low input requirements, making it a potentially sustainable crop.
- iii. **Institutional vs. Market Gap:** While academic sectors recognize chia’s health benefits and global market value, farmer and consumer awareness remains limited due to lack of commercial exposure.
- iv. **Regulatory Barriers:** Absence of formal government approval, seed registration, and dedicated policy support restricts expansion beyond experimental plots.
- v. **Future Potential:** If approved and promoted, chia could contribute to agricultural diversification and niche health-food markets, but currently shows no socioeconomic impact at farm level.

Summary of the statement:

Chia cultivation in Bangladesh remains in its preliminary research phase. Despite favorable agronomic performance and recognized health benefits, commercialization is constrained by regulatory gaps, low awareness, and limited institutional support.

Annexure 2

Minerals and vitamin compilation Excel sheet

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
1		fat from my souece	Fat from ref. source	source	FC	MCF	Water soluble vitamin																		
2				FCT			C	tia + MC	nia*mc	Folate *MC	B6 *MC	Rib *MC	thiamine	riboflavin	niacin	folate	B6 micro	Vit A *FCA	Vit E * FCA	A		Bcarotene	etinol	D	E
3	Red rice	2.23	2.3		1.000716	0.99		0.17424	2.7027	9.9	0.29106	0.03861	0.176	0.039	2.73	10	0.294	0	1.401003071						1.4
4	black rice	3.66	3.08		0.994016	0.98		0.7252	2.009	0.10094	4.018	0.2156	0.74	0.22	2.05	0.103	4.1	0	0.045724721		0	0		0	0.046
5	wheat	2.33	2.1		0.997651	1.01		0.4949	5.555	38.38	0.303	0.1212	0.49	0.12	5.5	38	0.3	0	1.895536261		0	5			1.9
6	oat	1.67	7.2		1.059591	0.94		0.188	0.846	0	0	0.094	0.2	0.1	0.9			0	0.953631466						0.9
7	corn	5.08	3.4		0.982609	1		0.39	2	20	0.622	0.11	0.39	0.11	2	20	0.622	10.80869565	0.481478261		11	129			0.49
8	bajra	2.73	3.3		1.005895	0.99		0.2475	0.8514	35.7489	0.2673	0.198	0.25	0.2	0.86	36.11	0.27	0	0.241414685					5.56	0.24
9	cheena	1.62	4.2		1.026931	1.01		0.4242	6.767	85.85	0.38784	0.202	0.42	0.2	6.7	85	0.384	0	0.051346555						0.05
10	kaon	1.5	4.3		1.029258	1.02		0.6018	3.264	87.72	0.39168	0.1122	0.59	0.11	3.2	86	0.384	5.146290491	0.051462905		5	60			0.05
11	chia	29.67	30.7		1.014863	0.99		0.6138	8.7417	48.51	0	0.1683	0.62	0.17	8.83	49	0	16.44077922	0.507431457		16.2				0.5
12	quinoa	4.38	6.3		1.020491	0.98		0.8134	1.666	0.2058	169.54	0.2156	0.83	0.22	1.7	0.21	173	0	0						
13	buckwheat	2.34	3.4		1.010973	0.98		0.098	6.8796	29.4	0.2058	0.4214	0.1	0.43	7.02	30	0.21	0	0						
14	Barley	1.65	2.2		1.005624	0.99		0.4653	7.722	33.66	0.3762	0.198	0.47	0.2	7.8	34	0.38	1.005623722	0		1	13			
15																									

Annexure-3

Table I: HPLC chromatogram of standard, cereal samples and Pseudograin samples

Sl No.	HPLC Chromatograms
-----------	--------------------

1.

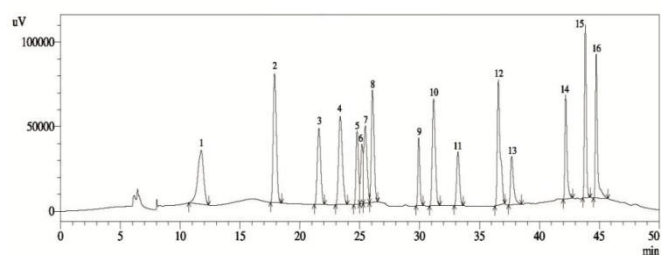


Figure i: HPLC chromatogram of Mixed Standard

2.

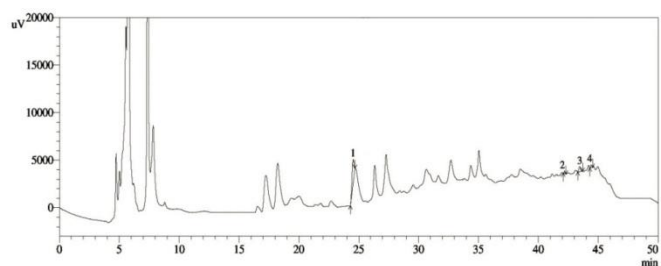


Figure ii: HPLC chromatogram of Red Aman Rice

3.

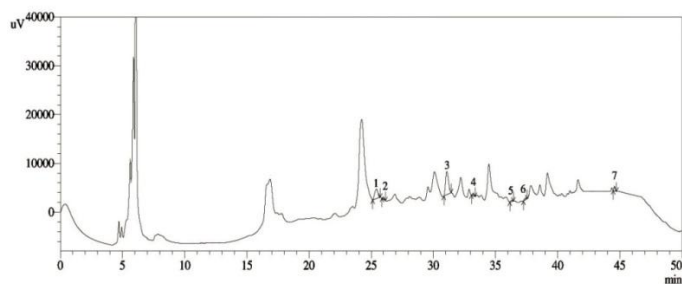


Figure iii: HPLC chromatogram of Black rice

4.

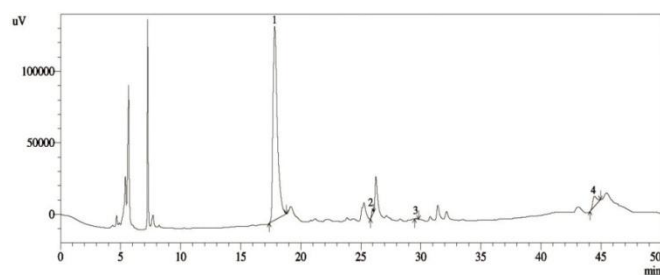


Figure iv: HPLC chromatogram of Wheat

5.

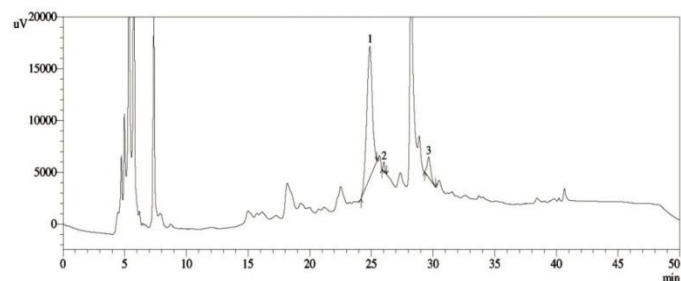


Figure v: HPLC chromatogram of Maize

6.

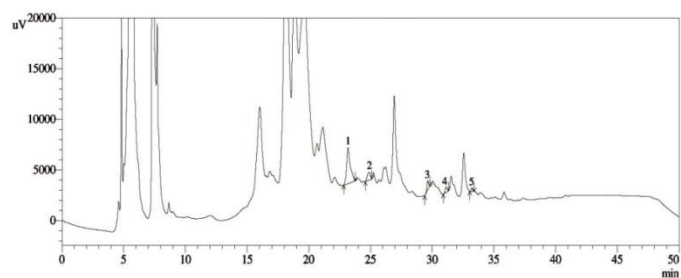


Figure vi: HPLC chromatogram of Barley

7.

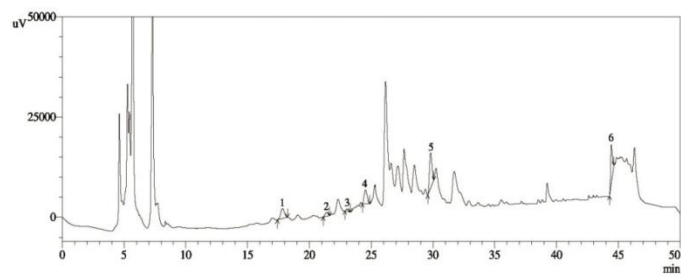


Figure vii : HPLC chromatogram of Foxtail millet

8.

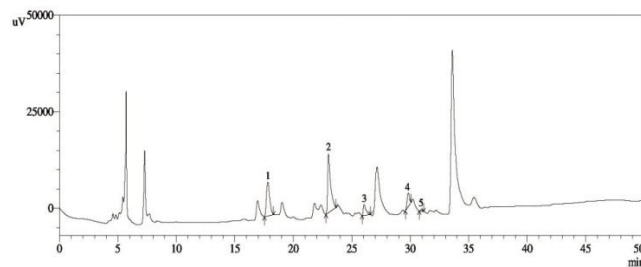


Figure viii: HPLC chromatogram of Proso millet

9.

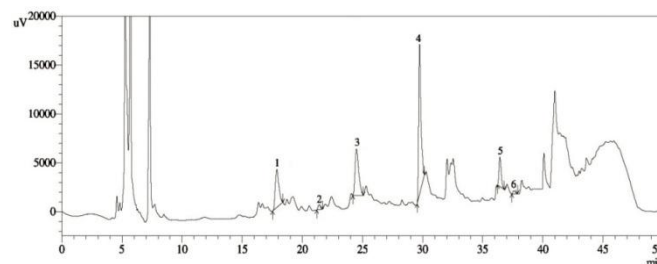


Figure ix: HPLC chromatogram of Oat

10.

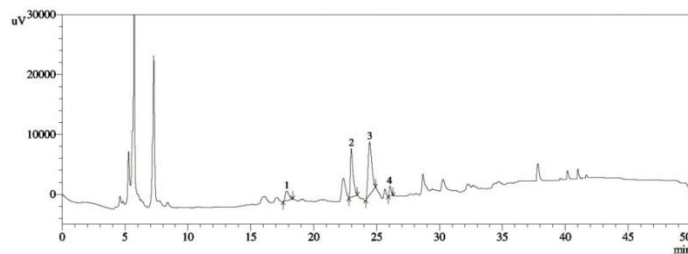


Figure x: HPLC chromatogram of Bajra

11.

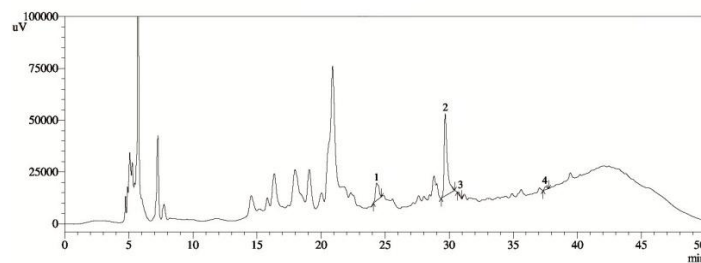


Figure xi: HPLC chromatogram of Yellow buck wheat

12.

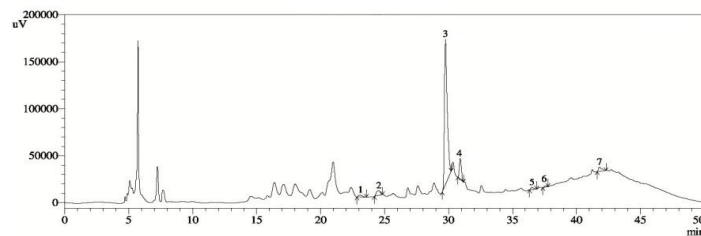


Figure xii: HPLC chromatogram of black buck wheat

13.

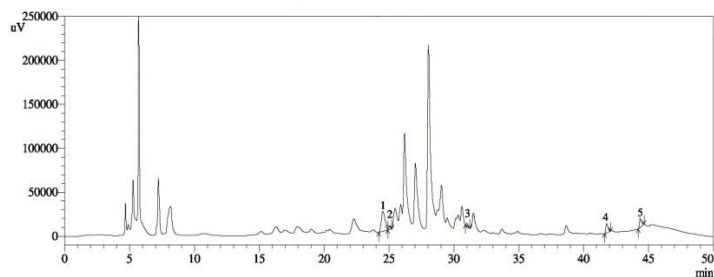


Figure xiii: HPLC chromatogram of Quinoa (Commercial)

14.

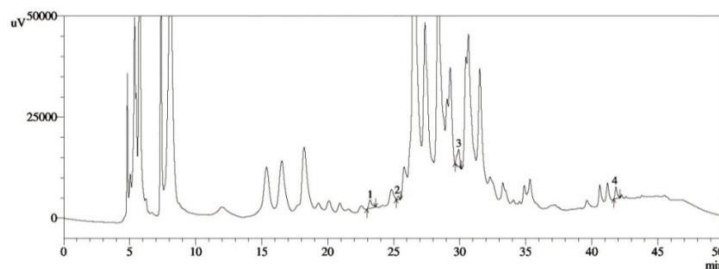


Figure xiv: HPLC chromatogram of Quinoa (SAU-1, local)

15.

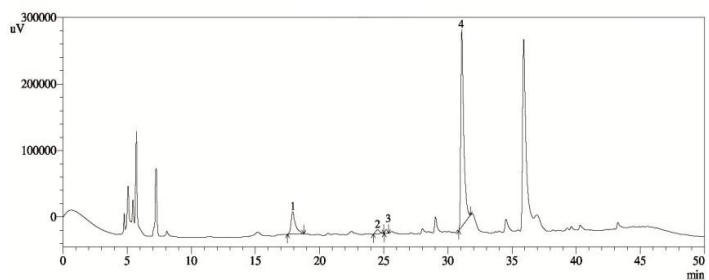


Figure xv: HPLC chromatogram of Chia (Commercial)

16.

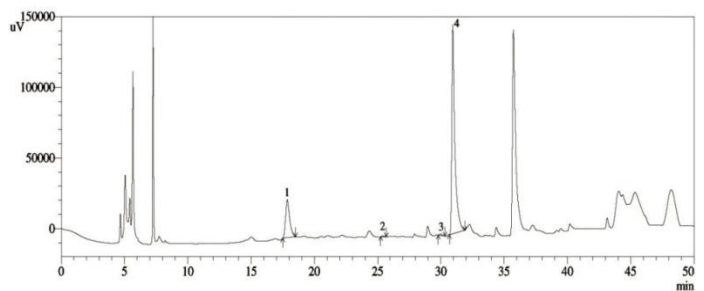


Figure xvi: HPLC chromatogram of Chia (Local)

Annexure 4

Study Deliverables

1. Rupa, A.Z. and Rahim, A.T.M.A. (2023). Ethnographic survey on cereal and pseudocereal in Bangladesh perspective, Food Research 7 (2) : 222 - 229 (April 2023).
[https://doi.org/10.26656/fr.2017.7\(2\).669](https://doi.org/10.26656/fr.2017.7(2).669)
2. Anjum Zerine Rupa, Kazi Turjaun Akhter and Abu Torab M A Rahim (2024). Nutritive, Polyphenolic, and Antioxidative Properties of Locally Produced Cereals and Pseudograins, Journal of Scientific and Industrial Research, Volume 06 (01), page: 89-98, 2024. <https://doi.org/10.3329/jscitr.v6i1.77380>
3. Anjum Zerine Rupa, Abu Torab M.A. Rahim, Md. Hemayet Hossain, Khondoker Shahin Ahmed (2025). Nutritional, phytochemical and antioxidant properties of Bangladeshi pigmented rice (red and black), grains and pseudograins, Food Chemistry Advances 6 (2025). <https://doi.org/10.1016/j.focha.2024.100862>

Ethnographic survey on cereal and pseudocereal in Bangladesh perspective

¹Rupa, A.Z. and ^{2,*}Rahim, A.T.M.A.

¹Bangladesh Council of Scientific and Industrial Research (BCSIR), Dhaka-1205, Bangladesh

²Institute of Nutrition and Food Science (INFS), University of Dhaka, Dhaka-1000, Bangladesh

Article history:

Received: 1 September 2021

Received in revised form: 28 October 2021

Accepted: 25 February 2022

Available Online: 14 April 2023

Keywords:

Ethnography,
Survey,
Cereal,
Pseudocereal,
Bangladesh

DOI:

[https://doi.org/10.26656/fr.2017.7\(2\).669](https://doi.org/10.26656/fr.2017.7(2).669)

Abstract

Numerous studies have proven that cereal and pseudo cereal could be a great source of polyphenols that help to prevent different lifestyle diseases like hyperlipidemia. The ethnographic survey represents production, uses and consumption of cereal in Bangladesh due to well-developed agronomy. On the other hand pseudo cereal (buckwheat, quinoa, amaranth and chia) production, consumption and research actions are limited. This study aimed to conduct an ethno-graphic survey of local cereals and pseudo grains will provide the knowledge and current information of their availability and uses in Bangladesh for advance research. A qualitative, inductive, exploratory and longitudinal study was conducted. Bangladesh Institute of Development Studies (BIDS) and Bangladesh integrated Household Survey (BIHS) investigated that people intake maximum 459 g and 33.5 g per capita rice and wheat in National level. Approximately 85% of black rice, 80% of red rice and 99% of buckwheat were sold by local producers, identified by focus group discussion. On the other hand 100% of experimental quinoa and chia production were used for research purpose. Serious studies on Buckwheat, chia, millets, oat and sorghum are conducting for their excellent nutritional value. The government of Bangladesh conducted various developmental, agricultural, food and nutrition security programs which indicate a positive social and political impact on the farming system. In spite of having Governmental support, good agricultural practices, huge health and agro-economic benefits, pseudo cereal production, distribution, use and consumption data are very scanty in Bangladesh compared to other cereals.

1. Introduction

Ethnography is a qualitative adaptive measuring tool in order to face future challenges of agriculture by scientists and policymakers. Ethnographic study broadly frames out the production, social perceptions and acceptability, market situation, vulnerability overall social and political impact in the case of the agricultural sector (Kwame *et al.*, 2019). David *et al.* (2008) describe that the agricultural system can be influenced by the social and political environment. External factors, internal factors and political factors leave an impact on cultivation. A scientific analysis report of those factors could help to promote a guideline for policymaking and enhance agricultural sustainability. The uses of functional foods and their bioactive components have been considered as a new approach in the prevention and management of lifestyle diseases *viz.*, obesity. In search of biologically active enzyme inhibitors from natural resources, plant secondary metabolites have been

screened for their biological properties. For example, a growing number of literatures have suggested that polyphenols from vegetables, fruits, and cereals can inhibit digestive lipase *in vitro* (Garza *et al.*, 2011).

Humans consume 85% of rice, 70% of wheat and 15% of maize production over the world. In developing countries, 27% of per capita calories come from rice consumption (Regional Office for Latin America and the Caribbean, 2011). Chen *et al.* (1993) suggested that people in developing countries consume sorghum and millet as minor whole grains, which lower chronic disease incidences than wheat. On the other hand, the annual production of buckwheat in Europe is 56%, Asia 36% and America 7%, whereas Bolivia, Peru and Ecuador have grown the world's most quinoa production. The Andean region produces 70,000 tons of quinoa in 2009. Amaranth grain, consider a nutritious food from the early 1970s. Latin America mostly uses amaranth flour as inclusion of various bakery products

*Corresponding author.

Email: torabrahim@gmail.com

(Rosentrator and Evers, 2018). An ethnographic survey of local cereals and pseudo grains can be beneficial for coping with lifestyle diseases.

2. Methodology

Ethnography considers a research methodology because it has a well-built foundation in experimentation and literalism (Hammersley and Atkinson, 2007). Methodological viewpoints of ethnography are fieldwork (interview, individual perception) and ethnohistoric study (reports, personal and organizational documents, journals, diaries).

2.1 Planning of access and ethics

Ethnographic studies require accomplishing approval from proper legal authorities for access to an experimental setting and ethical endorsement (Hammersley and Atkinson, 2007). Written applications were submitted to the in-charged authority of BARI, BRRI and Bangladesh National Herbarium for a visit, open discussion to participants, information and sample collection.

2.2 Interviews

Focused and in-depth interviews were conducted during the ethnographic survey that produced answers to many research inquiries unfounded in the literature. An unstructured questionnaire was the key tool for the interviews of selected resource personnel (Table 1). The main aim of the conversation was to engage the interviewee to evoke their perceptions and interpretations about particular research-related topics which was not available in literature search. Moreover, the respondents of the FGD were able to disclose the current agricultural practices of crops and their socioeconomic benefits. They also opined revitalization policies and priorities to ensure household level food security using pseudocereals in the crop diversification basket.

Table 1. Key questions for Focus Group Discussions (FGD)

Unstructured questionnaires	Expected Outcome
1. What is the pattern of cereal and pseudocereal farming in Bangladesh?	Pattern of comparative farming system.
2. Do farmers have interest in farming pseudograins?	Current scopes of pseudograins farming.
3. What kinds of cereals/pseudograins are cultivated more?	Pattern of significantly produced crops.
4. Why is pseudocereal cultivation undeveloped?	Problems of pseudocereal cultivation.
5. Do farmers know the health benefits of pseudograins?	Knowledge on the role of a healthy food.
6. Is there any socioeconomic and political impact of farming cereals/pseudocereals?	Socioeconomic and political policy revitalization on agroecological farming.
7. Are there any initiatives for encouraging farmers/researchers for pseudocereal cultivation?	Status of agricultural extension initiatives of pseudocereal research.
8. How many registered varieties of crops are there in Bangladesh?	Record of crop varieties released for field cultivation.

2.3 Data collection

Primary information was collected from focus group discussions with scientists, professors, technicians and people associated with agriculture. Secondary data were taken from internet websites, books, BBS, DAE, FAO stat, journal/ articles, research reports of different organizations, and annual reports of BARI and BRRI.

3. Results and discussion

3.1 Cereals

According to Table 2, farmers in Bangladesh grow rice (aus, aman and boro), and wheat as major crops and barley, jower, bazra, maize, cheena and kaon as minor cereals (Bangladesh Bureau of Statistics, 2020). Crops in Bangladesh are widely classified into two groups according to growing seasons; they are Kharif crops and Rabi crops (Table 3). From Table 3 it could be obtain that Kharif crops are cultivated in the spring or summer season and harvested in late summer or early winter. On the other hand, Rabi crops are sown in winter but

Table 2. Cereal production in Bangladesh

Crops	Yield kg/acre
Rice (Aus)	Local 557
	HYV 1103
Aman	T. Local 588
	HYV 1136
Boro	Local 756
	HYV 1598
	Hybrid 1950
Wheat	1245
Barley	333
Jower	443
Bazra	535
Maize	3245
Cheena and Kaon	400
Other cereals	18

Source: BBS (2019).

HYV: High Yielding Variety, T. local: Total local

Table 3. Farming seasons in Bangladesh identified by focus group discussion

Crop Name	Time of sowing	Time of harvesting
Aus rice (Local, HYV)	Mid March- Mid April	July to August
Aman rice (Local)	End June – Early September	December -early January
Aman rice (HYV)	Late June- Mid August	December- early January
Boro rice (Local)	Mid November- Mid January	April - May
Boro rice (HYV/Hybrid)	December – Mid February	Mid April-June
Wheat	November- December	March- Mid April
Maize	Mid October- Late December	Early April-End May
Jowar	Mid April- June	Mid August- Mid October
Kaon	November- December (Low land)	Mid March- Mid June
	Mid March- Mid May (Hilly Land)	Mid June- Mid August
Cheena	November-Mid December	Mid February- Mid April
Barley	Mid October-Mid December	Mid February- Mid April
Buckwheat	Beginning September-October	Late October-December
Chia	Beginning September-October	Late October-December
Quinoa	Beginning September-October	Late October-December

harvested in early summer or spring.

3.1.1 Rice (*Oryza sativa*)

Bangladesh Rice Research Institute (BRRI) developed 102 modern varieties of high yielding rice, which sustain in both favourable and unfavourable environments. Among them BR 5, BR 22, BRRI 34, BRRI 37, BRRI 38 and BR 7, BR 16, BRRI 28, BRRI 29, BRRI 50 are analysed for evaluating total polyphenolic content, IC₅₀ of DPPH radical scavenging activity and ferric reducing antioxidant power (FRAP). Comparatively higher total polyphenolic compounds and antioxidant property found in aman dhan BR 5 and boro dhan BRRI 28 than in other rice varieties (Alak *et al.*, 2012). Functional food such as whole grain brown rice is a popular tool for disease prevention. Both bran/embryo fraction and endosperm fraction of brown rice contains gallic acid, ferulic acid, syringic acid, coumaric acid, salicylic acid, 2-hydroxycinnamic acid as free and bound phenolic compounds (Ti *et al.*, 2014).

Shykh (2019), reported in The Daily Star (newspaper) that magnificent and nutritious black rice harvested 5.5 tons/hectare in Cumilla, Bangladesh. A farmer collected seeds from Vietnam, Indonesia, the Philippines, Japan, Thailand and Cambodia. According to Table 4 producers should be more conscientious on black and red rice farming and alternatively farmers over the country cultivated 10 acres of land and use 15 % for research purpose and sold 85% of total production of black rice (Table 5). Table 5 also represent that the local farmer harvested 13 mon/bigha red rice and sold 80% of total production but kept rest of the 20% for research purpose. Black rice flour, sieved with 140 µm showed

the highest value of anthocyanin, flavonoids, total polyphenolic content and antioxidant activity in the DPPH scavenging method (Carmen *et al.*, 2017). HPLC assay identified the presence of free Gallic (GA) and Ferulic acids (FA) in black rice, a potential source of lipase inhibitors (Rahim *et al.*, 2015).

3.1.2 Wheat (*Triticum aestivum*)

It is noticeable from Table 2 that the second highest calorie given cereal is wheat (*Triticum aestivum*) and harvesting in March to mid April (Table 3) in Bangladesh as well as in Asia. Bangladesh Agricultural research institute (BARI) developed 33 high yielding varieties of wheat and distribute the seeds among farmers (Table 4) across the country. Among them, 9 hybrid varieties of wheat were analysed for evaluating total polyphenol (TP), polyphenols oxidase activity (PPO) and antioxidant activity. The wheat variety named Shatabdi showed the highest (1.316 mg/g) and Akbar found in the lowest (1.269 mg/g) total phenolic content, whether PPO and antioxidant activity are less significant over nine varieties of wheat (Masum *et al.*, 2010).

3.1.3 Barley (*Hordeum vulgare*)

There are nine types of high yielding hybrid barley cultivated over 471 acres of the area of Bangladesh as a minor crop (Table 2), harvesting mid February to mid April (Table 3) and BARI has developed seven high yielding varieties of barley for local farming and research (Table 4). Sixteen years (from 2004 to 2020) tremendous research studies by PubMed, CNKI, Bangladesh Wheat and Maize Research institute and ISI Web of Science have proved that the barley grain extract

Table 4. Opinion survey results of respondents identified by focus group discussion

Referred Cereal/Pseudograins	Opinion
1 Red rice, Black rice	Red and Black rice farming should be spread more.
2 Wheat, Barley, Corn	BARI will provide all available released grains varieties.
3 Antioxidant-rich rice, Red, and Black rice	Helpful for people to keep them in good health and boost immune system.
4 Pseudograins	a) Very scanty information about pseudograins, however, they are cultivated in scatter in several Agro Ecological Zone. b) Lipase inhibitor identification will be helpful for people.
5 Buckwheat	Buckwheat should be cultivated governmentally.
6 Quinoa	Quinoa should cultivate more
7 Chia	Chia is a easily grown grain, but it needs government support
8 Teel and Tisi	Chemical analysis of Teel and Tisi will help in research
9 Cheena, Kaon, Sorghum	Sorghum, Cheena and Kaon are popular seeds for consumption and research

Table 5. Case studies with cereal and pseudo cereal

Case study	Occupation	Area	Production	Use
Black Rice	Farmer and Entrepreneur	10 acres in Cumilla	17 mon/bigha	Self-15% Sell- 85%
Red Rice	Farmer and Entrepreneur	Cumilla	13 mon/bihga	Self-20% Sell-80%
Chia	Cereal Researcher	Dinajpur, Jashore Mymensingh, and Gaibandha	Not available	Research-100%
Quinoa	Cereal Researcher	Sher-E-Bangle AURF Kurigram, Lalmonirhat, Kuakata	700/800-1.5 ton/ hector Sher-E-Bangla AURF 2 ton/hector -Kurigram RF, 1.5 ton/hector -Lalmonirhat RF, 1 ton/hector -Kuakata RF	Research-100%
Buckwheat	Entrepreneur	Sayedpur, Jessore, and Potuakhali	15-20 mon/bigha	Sell-99% Research-1%

is rich in Phytosterols, polyphenols, arabinoxylan, tocots, β -glucans and resistant starch. More than 20 chronic diseases could prevent by the referred ingredients of barley (Yawen *et al.*, 2020).

3.1.4 Maize (*Zea mays*)

BARI released 19 types of high yielding maize, including waxy corn, popcorn and sweet corn varieties. Among three white kernel maize varieties, the quality protein maize (QPM) is specifically developed for consumption as ruti/ chapatti. Maize potentially yields higher (Table 2) in Rabi season than Kharif (Table 3) over 963 acres of land in Bangladesh. A Major cropping system of maize is Maize-*T. aman* (monsoon) rice, however, rice could be replaced by any other crops, such as potato, mung bean or mustard (Salahuddin *et al.*, 2017). Zhang *et al.* (2016) determined the free form of phenolics and flavonoids but found there were bounded forms of ferulic acid in nine varieties of sweet corn.

3.1.5 Cheena (*Setaria italica*) and Kaon (*Panicum miliaceum*)

According to Table 2 Bangladesh cultivates Cheena and Kaon on over 1063 hectares of land as minor crops

and their conjugal production are 1058 MT/year. According table 3, Cheena is in between crop of rabi and kharif but kaon is a rabi seasoned grain. Bangladesh Agriculture Research Institute (BARI) invented one hybrid cheena variety named 'Tushar' and two kaon varieties known as 'Titas' and 'Kaon-2' and are very popular for consume occasionally (Table 4). Cheena and kaon are grown on the unfertilized land of Char Anchali and used for making various local foods which could provide food security in the vulnerable social or environmental situation of Bangladesh (Bangladesh Agriculture Research institute, 2019). Nazma *et al.* (2012) showed 24 times higher lipophilic antioxidant L-ORACFL (19.40 μ mol TEG-1) fraction than the hydrophilic (0.80 μ mol TEG-1) of Cheena.

Table 6 presents that International Food Policy Research Institute (IFPRI) published statistical data on per capita major grains consumption validation survey report in the national perspective of Bangladesh (Mohammad, 2019). A survey summary from three reputed organizations showed that rice is the topmost-consumed grain in Bangladesh.

Table 6. Per capita daily food grain consumption (in grams) from HIES, BIDS and IFPRI-BIHS, 2016

Institute	Type	Rural	Urban	National
BBS	Rice	386.1	316.7	367.2
(From HIES),	Wheat	17.4	26.2	19.8
BIDS	Rice	540.5	249.5	459.4
	Wheat	23.8	89.0	41.5
IFPRI	Rice	447.8	367.3	425.9
BIHS	Wheat	29.4	44.3	33.5

BBS: Bangladesh Bureau of Statistics, HIES: Household Income and Expenditure survey

BIDS: Bangladesh Institute of Development Studies, IFPRI: International Food Policy Research Institute, BIHS: Bangladesh integrated Household Survey.

3.2 Pseudo-cereal

Buckwheat, quinoa and amaranth seeds are known as gluten-free and fabulous protein (amaranth 16.5 g/100 g, quinoa 14.5 g/100 g and buckwheat 12.5 g/100 g) content pseudocereal. Referred cereals are an excellent source of phytochemicals and have higher nutritive value. Pseudocereal flours are used as a nutritious ingredient in diversified bakery products, worldwide (Alencar and de Carvalho Oliveira, 2019).

3.2.1 Buckwheat (*Fagopyrum esculentum*)

Buckwheat (*Fagopyrum esculentum*) is a tropical ancient crop that mainly originated in China. Europe produces the world's highest buckwheat (50%) production and the second-most production region is Asia (43%). Table 3 shows that buckwheat is a winter crop. In Bangladesh, Panchagarh Department of Agricultural Extension (DAE) informed that the buckwheat cultivation demand is graphically growing for its lucrative price, nutritional value and disease prevention functions. Buckwheat cultivated on five hectares of land in the Rajshahi district does not require fertilizer, but untrained and limited knowledge of farming decreased the production (Nishi, 2018). Table 4 suggested government support for buckwheat farming. An Entrepreneur of an organic farm has started cultivating buckwheat as an organic product since 2013 (Table 5). In his project buckwheat is cultivated as a winter-seasoned partner crop in Sayedpur and Panchagarh. From Table 5 it has been shown that every year 15-20 Mon/Bigha buckwheat has been produced and buyers bought 99% of them as rice while local people eat buckwheat leaves as a vegetable. Mondal (1992) evaluated buckwheat yields during different sowing dates with significant seed rates. In 1988-89 and 1989-90 during the dry season (November to March) highest crop yield was given due to the sowing of 20 kg seed/hac.

3.2.2 Quinoa (*Chenopodium quinoa*)

In the 37th conference, FAO supported the submitted report that designated 2013 as an 'International year of quinoa' by Bolivia. Quinoa grain, steam, and leaves have frequent medicinal use in abscesses, bleeding, dislocations, nausea, insomnia and other vital diseases (Regional Office for Latin America and the Caribbean, 2011). Around the World, estimated quinoa production is almost 510 tons or 102,745 hectares. Rabi crop quinoa (Table 3) should farming seriously in Bangladesh (Table 4) due to public requirement and research purpose. A cereal researcher of Bangladesh collected quinoa seeds from Denmark and started research on cultivation in 2017. Bangladeshi quinoa seeds achieved registration from the Ministry of Seed Board, known as SAU-1. SAU-1 is a Rabi crop, with low moisture and salinity tolerance; needs no chemical fertilizers and pesticides (Porimal and Tanni, 2020). According to Table 5, 700/800-1.5 ton/ hector seeds produced in Sher-E-Bangla agricultural research field, 2 ton/hector in Kurigram, 1.5 ton/hector in Lalmonirhat and 1 ton/hector in Kuakata research field. 100% of quinoa production was used for research purpose (Table 5).

3.2.3 Chia seed (*Salvia hispanica*)

Chia (*Salvia hispanica*) belongs to the Lamiaceae family and is a good source of omega-6, omega-3, fatty acids, proteins, soluble and insoluble dietary fibre, antioxidants and polyphenols (Anacleto *et al.*, 2018). Masudul *et al.* (2015), found higher seed production of chia in November and good potential for chia production in the local framework. Mohsin (2020) reported in UNB news (the online newspaper) that a Bangladeshi Professor in Bangladesh Agricultural University, Mymensingh collected chia seeds from Canada and started research on them in 2016. In 2017 chia grew successfully in Manirampur upozilla, Jashore. From Table 3, it has been showed that Bangladeshi chia is a Rabi crop (October-December) that needs one or two irrigations, fewer pesticides, natural fertilizer and also need government support (Table 4). Chia seeds are cultivated as an experimental crop in Dinajpur, Mymensingh, Gaibandha and Jashore and use 100% of production in research (Table 5).

3.3 Ongoing research on buckwheat (*Fagopyrum esculentum*), oat (*Avena Sativa*) and sorghum (*Sorghum bicolor*)

Table 2 presents 18 yield kg/acre of other cereals except for major and minor cereals. BARI experimented with genotypes of buckwheat, oat and sorghum for developing high yielding seed varieties and production growth (Tables 3 and 4). Four buckwheat genotypes

were collected from RCBD, Bogura, one oat genotype (BD-4271) and four foxtail millet genotypes received from Plant Genetic Resource Center (PGRC), Gazipur were analysed for a high yield rate. Among four genotypes germplasm gE3 found a promisingly higher seed yield (268.8 g) during Rabi 2018-2019 and a BD-4271 oat line produced 11.0 kg of seed. Three sorghum genotypes (IS-29468, IS-21891 and IS-9745) were experimented with for salinity tolerance and finally selected for advanced evaluation (BARI, 2018).

3.4 Social and political impact on agriculture

David *et al.* (2008) categorized three broad groups that affect the farming system are:

External social factors - consumer demands for locally produced foods, varieties and low prices, food safety and environmental concerns, genetically modified foods, fair market price and labour concerns.

Internal social factors - farm/field management policy (including risk management), safety strategies for workers, legal concerns of landowners and property rights.

Political factors - International trade policy, state-funded agricultural research and development programs, agricultural policy for commodity bills and others, food and nutrition security policy, and national dietary guideline policy.

The above reference and ethnographic survey indicate the positive and advanced social and political impact on Bangladesh's agriculture. Bangladesh Agricultural Research Institute (BARI) developed a total of 545 high yielding crop varieties and 505 evolving technologies for crop production. The Government of Bangladesh adopted different development and

implementation program for agriculture, food and nutrition security.

Table 7 shows that the government of Bangladesh (GoB) has serious, concerns about agricultural policy-making, research and development. GoB work on fertilizer and seed distribution, bank loan for small stakeholders, agricultural diversification, storage and market trade, climate change strategy etc for achieving agricultural challenge.

4. Conclusion

Functional bioactive polyphenolic compounds of cereals and pseudocereals could prevent acute and chronic diseases like hyperlipidemia, Cancer, diabetes, atherosclerosis and many more. Developed and some developing countries have advanced research on both kinds of cereals, but scientific-analytical information is very scanty in Bangladesh. Ethnography is a qualitative, inductive and longitudinal study generated from observational data, documentation and interviews. From the ethnographic survey, it could be concluded that in spite of having Governmental support, good agricultural practices, huge health and agro-economic benefits, pseudocereal production, distribution, use and consumption are unpleasant in Bangladesh compared to other cereals. Pseudocereal production could be the most potential supplementary equipment for preventing nutrition and other health problems. Particular agricultural knowledge and technology should be acknowledged for the expansion and development of pseudocereal production.

Conflict of interest

The authors declare no conflict of interest.

Table 7. Government programs for agriculture, food and nutrition security and their objectives

Sl. no	Program Name	Objectives
1	Vision 2021 and National perspective plan (2010-2021)	To achieve national level of nutritional requirements and self-competence in crop production.
2	Sixth Five Year Plan (6 th FYP 2011-2015)	Main goal was to increase agricultural production
3	Seventh five-year plan (7 th FYP2016-2020)	Five-year future plan to achieve-
		a. sub-sector crop production development
		b. Ensure food and nutritional security
4	National Agricultural Policy (NAP-2013)	c. Make national and international market for farming community
		The aim was to ensure improved food and nutritional safety for the whole nation and enhance rural life through agricultural productivity and diversification
5	Country Investment Plan for Agriculture, Food Security and Nutrition (CIP, 2011-2015)	Mobilized internal and external funds for monitoring and evaluating agricultural investment and ensuring food safety.
6	National Agricultural Extension Policy (2015)	Service provider of extension programs for different agricultural departments
7	Strategic Plan for Health, Population and Nutrition Sector Development Program (HPNSDP 2011-2016)	To provide nutrition security and social protection.
8	Nutrition Policy (2015)	Nutrition and food security for a vulnerable group.

Acknowledgements

The authors acknowledged the Bangabandhu Science and Technology Fellowship Trust, Ministry of Science and Technology, Bangladesh, for financing the research program.

References

- Alak, K.D., Partha, S.G., Subrata, B., Sukh, M., Muhammad, A.S. and Yearul, K. (2012). Antioxidant properties of ten high yielding rice varieties of Bangladesh. *Asian Pacific Journal of Tropical Biomedicine*, 2(1), S99-S103. [https://doi.org/10.1016/S2221-1691\(12\)60137-3](https://doi.org/10.1016/S2221-1691(12)60137-3)
- Alencar, N.M.M. and de Carvalho Oliveira, L. (2019). Advances in Pseudocereals: Crop Cultivation, Food Application, and Consumer Perception, p. 1696-1708. In Mérillon, J.M. and Ramawat, K. (Eds.) *Bioactive Molecules in Food. Reference Series in Phytochemistry*. Cham, Netherlands: Springer.
- Anacleto, S.B., Guadalupe, R.I., Raúl René, R.T., Reyna, R.L. and Aurora, M.L. (2018). The chia (*Salvia hispanica*): past, present and future of an ancient Mexican crop. *Australian Journal of Crop Science*, 12(10), 1626-1632. <https://doi.org/10.21475/ajcs.18.12.10.p1202>
- Bangladesh Agriculture Research Institute (BARI). (2018). BARI Annual report 2017-2018. Retrieved from BARI website: [http://bari.portal.gov.bd/sites/default/files/files/bari.portal.gov.bd/annual_reports/74f4b5f6_827f_4c92_8082_6cd466ca8b0c/BARI%20Annual%20Report%202017-18%20\(for%20BARI%20Website\).pdf](http://bari.portal.gov.bd/sites/default/files/files/bari.portal.gov.bd/annual_reports/74f4b5f6_827f_4c92_8082_6cd466ca8b0c/BARI%20Annual%20Report%202017-18%20(for%20BARI%20Website).pdf)
- Bangladesh Agriculture Research institute (BARI). (2019). Agriculture Technology Handbook (Krishi Projukti Hatboi). (2019). Bangladesh: Bangladesh Agriculture Research institute.
- Bangladesh Bureau of Statistics (BBS). (2020). Yearbook of Agriculture Statistics-2019. 31st series. Bangladesh: Bangladesh Bureau of Statistics.
- Carmen, B. and Camelia, V. (2017). Polyphenolic content and antioxidant properties of black rice flour. The Annals of the University Dunarea de Jos of Galati, Fascicle VI, *Food Technology*, 41(2), 75-85.
- David, W.A., Julie, C.D., Urs, P.K., Mary, H. and John, M.H. (2008). Social and political influences on agricultural systems. *Renewable Agriculture and Food Systems*, 23(4), 272-284. <https://doi.org/10.1017/S174217050700169X>
- Fabio, A. and Parraga, G. (2016). Origin, production and utilization of pseudocereals. In Haros, C.M. and Schonlechner, R. (Eds.) *Pseudocereals: chemistry and technology*. 1st ed., p. 1-27. Chichester, United Kingdom: Wiley. <https://doi.org/10.1002/9781118938256.ch1>
- Garza, A.L., Milagro, F.I., Boque, N., Campion, J. and Martinez, J.A. (2011). Natural inhibitors of pancreatic lipase as new players in obesity treatment. *Planta Medica*, 77(8), 773-785. <https://doi.org/10.1055/s-0030-1270924>
- Hammersley, M. and Atkinson, P. (2007). *Ethnography: Principles in practice*. 3rd ed. London, United Kingdom: Taylor and Francis. ISBN—203-94476-3, Master-ebook.
- Kwame, N., Owusu, D. and Sheila, N. (2019). Ethnography in Agricultural Research: A Tool for Diagnosing Problems and Sustaining Solutions. *African Journal of Food, Agriculture and Nutrition Development*, 19(1), 14090-14112. <https://doi.org/10.18697/ajfand.84.BLFB1032>
- Masudul, K., Mohammad, A. and Alamgir, H. (2015). Article Effect of planting time on the growth and yield of chia (*Salvia hispanica* L.). *Asian Journal of Medicine and Biological Research*, 1(3), 502-507. <https://doi.org/10.3329/ajmbr.v1i3.26469>
- Masum, A., Laila, K., Khwaja, H. and Furuta, Y. (2010). Total polyphenol, polyphenol oxidase, antioxidant activity and color profiles of some wheat varieties from Bangladesh. *Research Journal of Agriculture and Biological Sciences*, 6(2), 186-190.
- Mohammad, Y., Shahidur, R. and Sulin, C. (2019). Per capita rice consumption in Bangladesh: Available estimates and IFPRI's validation survey results. Washington, DC, USA: International Food Policy Research Institute (IFPRI). <https://doi.org/10.2499/p15738coll2.133124>
- Mohsin, A. (2020). Chia cultivation gives hope to Jashore farmer. Retrieved from United News of Bangladesh website: <https://unb.com.bd/category/Special/chia-cultivation-gives-hope-to-jashore-farmer/42488>
- Mondal, N.A., Moniruzzaman, A.F.M., Abedin, M.Z., Hamid, A. and Sarder, N.A. (1992). Effect of seeding dates and seed rates on buckwheat (*Fagopyrum esculentum*). *Annals of Bangladesh Agriculture*, 2(2), 117-121.
- Nazma, S., Masao, G., Jun, W. and Yuko, T.I. (2012). Antioxidant Capacity and Total Phenol Content of Commonly Consumed Indigenous Foods of Asian Tropical Regions. *Journal of Food Science and Engineering*, 2, 187-195. <https://doi.org/10.17265/2159-5828/2012.04.001>
- Nishi. (2018). Buckwheat farming gains popularity in Panchagarh. Retrieved from Daily Bangladesh

- website: <https://www.daily-bangladesh.com/english/country/2087> [In Bangladeshi].
- Porimal, K.B. and Tanni, Z.A. (2020). Quinoa (*Chenopodium quinoa* Willd.) – A Potential new crop in Bangladesh: agronomy performance with sowing date. *Bangladesh Agronomy Journal*, 23(1), 67-73. <https://doi.org/10.3329/baj.v23i1.50121>
- Rahim, A.T.M.A., Yoko, T. and Kohji, Y. (2015). Mode of pancreatic lipase inhibition activity *in vitro* by some flavonoids and non-flavonoid polyphenols. *Food Research International*, 75, 289-94. <https://doi.org/10.1016/j.foodres.2015.05.017>
- Regional Office for Latin America and the Caribbean. (2011). Quinoa: An ancient crop to contribute to world food security. Retrieved from FAO website: <https://www.fao.org/3/aq287e/aq287e.pdf>
- Rosentrater, K.A. and Evers, A.D. (Eds.) (2018). Introduction to cereals and pseudocereals and their production. In Kent's Technology of Cereals, 5th ed. USA: Woodhead Publishing. <https://doi.org/10.1016/B978-0-08-100529-3.00001-3>
- Salahuddin, A., Monayem, M. and Amiruzzaman, A. (2017). Scaling-up of Proven Technology for Maize Improvement through Participatory Approach in Bangladesh. In Pandey, P.R. and Koirala, K.B. (Eds.) Best Practices of Maize Production Technologies in South Asia. **Bangladesh**: SAARC Agriculture Centre.
- Shela, G., Oscar, J.M.V., Nicolas J.O. and Ines, A.S. (2007). The total polyphenols and the antioxidant potentials of some selected cereals and pseudocereals. *European Food Research and Technology*, 225(3), 321-328. <https://doi.org/10.1007/s00217-006-0417-7>
- Shykh, S. (2019). Black rice, a magical variety. Retrieved from The Daily Star website: <https://www.thedailystar.net/country/news/black-rice-magical-variety-1845295>
- Ti, H., Li, Q., Zhang, R., Zhang, M., Deng, Y., Wei, Z., Chi, J. and Zhang, Y. (2014). Free and bound phenolic profiles and antioxidant activity of milled fractions of different indica rice varieties cultivated in southern China. *Food Chemistry*, 159, 166–174. <https://doi.org/10.1016/j.foodchem.2014.03.029>
- Yawen, Z., Xiaoying, P., Juan, D., Xiaomeng, Y., Xia, L., Siddikun, N.M., Tao, Y. and Jiazhen, Y. (2020). Molecular Mechanism of Functional Ingredients in Barley to Combat Human Chronic Diseases. *Hindawi Oxidative Medicine and Cellular Longevity*, 2020, 3836172. <https://doi.org/10.1155/2020/3836172>
- Zhang, R., Huang, L., Deng, Y., Chi, J., Zhang, Y., Wei, Z. and Zhang, M. (2016). Phenolic Content and Antioxidant Activity of Eight Representative Sweet Corn Varieties Grown in South China. *International Journal of Food Properties*, 2017, 1532-2386. <https://doi.org/10.1080/10942912.2016.1270964>



Nutritive, Polyphenolic, and Antioxidative Properties of Locally Produced Cereals and Pseudograins

Anjum Zerin Rupa², Kazi Turjaun Akhter¹ and Abu Torab M A Rahim^{1*}

¹Institute of Nutrition and Food Science (INFS), University of Dhaka, Dhaka-1000, Bangladesh

^{1 2}Chemical Research Division, BCSIR Laboratories Dhaka, Bangladesh Council of Scientific & Industrial Research (BCSIR), Dhaka-1205, Bangladesh

Abstract

Cereals and pseudograins are known for their bioactive components and hence used as functional food worldwide. Recently, locally grown cheena, kaon, quinoa, and chia are available in Bangladeshi markets. The study aimed to determine the macronutrients, polyphenols, and flavonoids contents of selected cereals (bajra, zob, cheena, and kaon) and pseudograins (quinoa and chia) along with their antioxidant properties. Cheena (13.48%) and kaon (13.55%) showed higher protein content among cereals, whereas chia of commercial and local sources showed high quantities of protein (22.40% and 22.35%, respectively) among pseudograins. A high amount of carbohydrate was found in kaon and quinoa (64.57% and 59.79%, respectively), whereas chia contained a high amount of fat (20.88 to 29.77%) and dietary fiber (31.46% to 36.85%). Locally grown bajra exhibited a markedly higher concentration of total phenolics (135.75 ± 0.33 mg/g GAE dw) and total flavonoids (17.44 ± 0.05 mg/gm QE dw) compared to other foods studied. Regarding antioxidant activity determined by 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay and half-maximal inhibitory (IC_{50}) values, chia from Dinajpur field showed the best results. Therefore, cereals and pseudograins studied and reported here could provide utilizable nutritional and functional bioactive polyphenolic components that may have the potential in the nutritional management of noncommunicable diseases.

Received: 04.04.2024

Revised: 02.06.2024

Accepted: 22.06.2024

Keywords: Cereals, Pseudograins, Macronutrients, Polyphenols, Antioxidant Property.

Introduction

The World Health Organization estimated that overweight and obesity kill more people than underweight around the world. Obesity raises various health risks, including cardiovascular disease, cancer, diabetes, osteoarthritis, and chronic renal disease (Hales *et al.*, 2020). Bangladesh currently faces a triple burden of malnutrition: undernutrition, overnutrition, and micronutrient deficiencies. Banik *et al.* (2018) conducted a

comprehensive review of the literature and discovered a growing trend in overweight and obesity among Bangladeshi children, adolescents, and adults across time.

The use of bioactive dietary components has recently been proposed as a novel method to the prevention and control of lifestyle illnesses, specifically obesity. The most typical tactic for these approaches is the development of inhibitors of nutritional digestion and absorption. For example, a growing body of

*Corresponding author e-mail: torabrahim@gmail.com

research suggests that polyphenols found in vegetables, fruits, cereals, and pseudograins can inhibit digestive lipase *in vitro* (De La Garza et al., 2011). Plant secondary metabolites were evaluated for biological features in order to find biologically active Lipase inhibitors from natural resources (Scalbert et al., 2005; Pandey et al., 2009; Rahim et al., 2015).

Although the beneficial effects of polyphenols on human health are well recognized, it is critical to analyze them quantitatively and qualitatively in local agricultural produce. There are several studies on cereals and pseudocereals (Kaur et al., 2023); however, investigations on locally cultivated pseudograins are few. It is worth noting that pseudocereals, often known as pseudograins, are non-grass seeds with grain-like applications around the world. A recent ethnographic investigation (Rupa and Rahim, 2023) found that, despite Bangladesh's government support for good agricultural practices and significant agroeconomic benefits, pseudograin production, distribution, use, and consumption remain subpar when compared to other cereals. However, a significant amount of land has been used locally to grow buckwheat (*Fagopyrum esculentum*), quinoa (*Chenopodium quinoa*), and chia (*Salvia hispanica*). Furthermore, they are now widely available in retail markets as imported goods.

This analytical note describes the compositional data and bioactive properties of polyphenols in locally grown and selected cereals and pseudograins. The data presented here may be useful for nutritional management of noncommunicable diseases through diet therapy.

Materials and Methods

Sample Collection

Food samples were collected from the grower's field from different parts of the country. The collected samples were fresh, well-shaped, and free from insect bites and other deformities. They were selected at random from the cultivation fields or from a stockpile of traders. Emphasis was given to collecting food samples during their pick seasons. zob, cheena, and kaon were collected from Bangladesh Agricultural Research Institute (BARI), but bajra was collected from a commercial source. Chia seeds were collected from the research field of BARI located in Bogra, Mymensingh, and Dinajpur, while quinoa was collected from the Bangladesh Agricultural University (BAU) research field. Lists of collected samples were presented in Table 1.

Laboratory Sample Preparation

Figure 1 describes the flow diagram of laboratory sample preparation for chemical analysis. Briefly, collected food samples were cleanly washed with tap water, and edible portions were separated, followed by drying in open air for half an hour. For moisture, ash, and TDF estimations on a fresh weight basis, clean and air-dried sample pieces were weighed, grinded to powder, and processed for laboratory analysis. Powdered samples were sieved and distributed in small ziplock sachets, and kept in desiccators at room temperature until analysis.

Table 1. Description of collected foodstuffs

Food Type	Food Name		Botanical Name	Sources
	Local Name	English Name		
Cereals	Bajra	Pearl millet	<i>Pennisetum glaucum</i> (L.) R. Br.	Market
	Zob	Barley	<i>Hordeum vulgare</i> L.	Field
	Cheena (BARI)	Proso/White millet	<i>Panicum miliaceum</i> L.	Field
	Kaon	Foxtail millet	<i>Setaria italica</i> (L.) P. Beau vois	Field
Pseudograins	Chia seeds	Chia seed	<i>Salvia hispanica</i> L.	Field and Market
	Quinoa	Quinoa	<i>Chenopodium quinoa</i> willd.	Field and Market

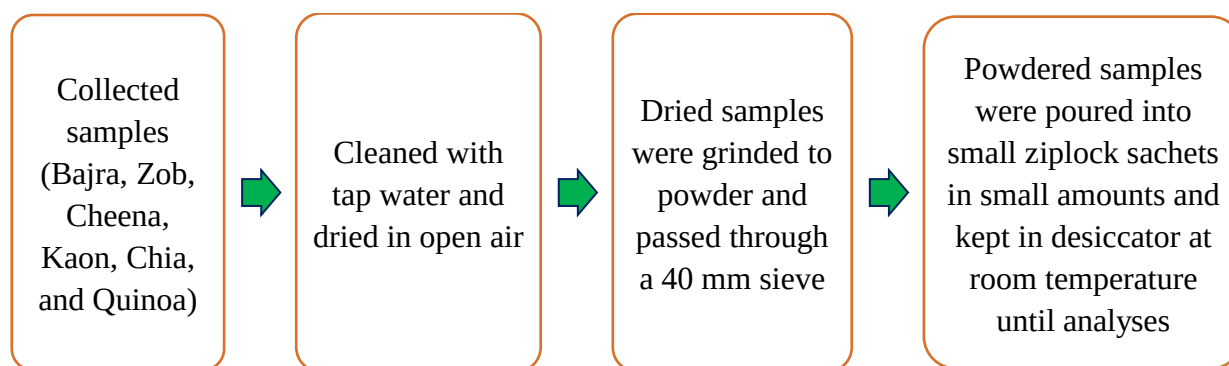


Figure 1. Flow chart showing the preparation of sample flours for lab analyses.

Analyses of Proximate Composition

All methods used for proximate analyses were recommended methods (AOAC, 2000). The moisture content (method no. 925.09) was determined by weight loss on drying of the sample in an oven at 105 °C for 4 hours (h). Following repeated weighing after each 30 minutes (min) until the weight becomes constant. Ash content (method no. 923.03) was estimated by heating the moisture-free sample at 200 °C for charring about 2 h, followed by heating at 600 °C for 5 h in a muffle furnace. The nitrogen content was determined by the micro-Kjeldahl method of AOAC (2000). The protein content was then calculated by multiplying the nitrogen values with Jones factors (XN) for cereals, *i.e.*, 6.25. Crude fat content (method no. 991.36) was derived by the continuous extraction method using Soxhlet apparatus. Total dietary fiber (TDF) was determined by using a total dietary fiber assay kit based on enzymatic-gravimetric determination of both soluble and insoluble non-starch polysaccharides of Prosky methods (methods no. 985.29). Available carbohydrate content of each sample was calculated by difference using Atwater's conversion factors (Atwater and Bryant, 1902). Finally, the energy content was determined applying the following equation:

$$\text{Energy (Kcal/g)} = [4 \times \text{protein (g)} + 4 \times \text{carbohydrates (g)} + 9 \times \text{fat (g)} + 2 \times \text{TDF (g)}]$$

Determination of Total Phenolic Content (TPC) and Total Flavonoid Content (TFC)

Solvent extraction of solid samples is one of the most commonly used and easiest methods of extraction for phenolics (Pekić *et al.*, 1998; Lapornik *et al.*, 2005). Briefly, 50 g of sample flour was added to 125 mL of HPLC-graded 99.9% methanol. The mixture was then shaken repeatedly and rested for maximization of phenolic extraction. Followed by filtration through Whatman No. 1 filter paper, the extraction process was repeated two more times, and the final extract was stored in a dark glass bottle. After 72 h, the total extract was collected and immediately evaporated by a rotary evaporator at 40 °C to get crude methanol extract. Finally, collected concentrated extracts were stored in a refrigerator at 4 °C for further determination of total contents of phenolics, flavonoids, and antioxidant activity.

Total soluble phenolics in the extracts were determined with Folin-Ciocalteu reagent using gallic acid as a standard according to the method of Singleton (1965) with suitable modification. About 1 mg of extract was mixed with 1 mL of ethanol. After that, 15.8 mL of deionized water and 0.1 mL of 50% of Folin-Ciocalteu reagent were added into 0.2 mL of ethanol-extract solution. The mixture was then shaken and left to stand for 8 min, followed by adding 3 mL of 2% sodium carbonate and shaken for 3 min. The mixture was then kept in the dark for 2 h at room temperature. Finally, the absorbance was taken using a UV-Vis spectrophotometer (Uviline 9400, Secomam, France) at 765 nm.

TPC was determined in gallic acid equivalents (GAE) from the following formula and expressed as mg of gallic acid equivalent (GAE) per 100 g of sample: $A = (C \times V)/M$. Where A = total phenolic content of extract equivalent to gallic acid; C = concentration of the gallic acid obtained from the calibration curve (mg/mL); V = volume of extract solution (mL); M = weight of extract (g).

Total flavonoid content (TFC) was determined after Sinay *et al.* (2022) with slight modification. About 0.5 mg of extract was mixed with 2 mL of 96% methanol, followed by adding 2 mL of 2% aluminum chloride. Subsequently, the absorbance of the mixture was measured using a UV-Vis spectrophotometer (Uviline 9400, Secomam, France) at 430 nm. Quercetin was used as a standard. TFC was measured by the following equation and expressed as mg of quercetin equivalent (QE) per 100 g of sample: $A_1 = (C_1 \times V_1)/M_1$. Where A_1 = total flavonoid content of extract equivalent to quercetin; C_1 = concentration of the quercetin obtained from the calibration curve (mg/mL); V_1 = volume of extract solution (mL); M_1 = weight of extract (g).

Determination of Antioxidant Activity of the Study Samples

activity test (Sinay *et al.*, 2022) with a slight adjustment. About 2.5 mL of methanol extract of the sample at different concentrations (2.5 $\mu\text{g mg}^{-1}$, 5.0 $\mu\text{g mg}^{-1}$, 10 $\mu\text{g mg}^{-1}$, 20 $\mu\text{g mg}^{-1}$, 40 $\mu\text{g mg}^{-1}$, 60 $\mu\text{g mg}^{-1}$, 80 $\mu\text{g mg}^{-1}$, 100 $\mu\text{g mg}^{-1}$, 250 $\mu\text{g mg}^{-1}$, and 500 $\mu\text{g mg}^{-1}$) was added to 1.0 mL of 0.3 mM DPPH methanol solution. For the blank, 2.5 mL of methanol replaced the methanol extract of the sample. The sample and the blank were then allowed to stand in a dark chamber at room temperature for 30 min. After changing the color from deep violet to light yellow, the absorbance was measured at 514 nm

using a UV-Vis spectrophotometer (Uviline 9400, Secomam, France). Ascorbic acid was used as a control for its antioxidant activity. The free radical sequestering ability was expressed as a percent inhibition of oxidation of the radical and calculated according to the following equation:

$$\text{Inhibition (\%)} = \frac{\text{ABS}_{\text{control}} - \text{ABS}_{\text{sample}}}{\text{ABS}_{\text{control}}} \times 100$$

The half-maximal inhibitory (IC_{50}) value expresses the sample concentration required to scavenge 50% DPPH radical. It was calculated from the plot of inhibition (%) against the concentration of the sample extract. The inhibition (%) was plotted against the methanol extract of the sample. The IC_{50} was calculated after developing a linear regression graph, which means the amount of sample necessary to decrease the absorbance of DPPH by 50%.

Statistical Analyses

Data analysis was performed using a statistical package for the social sciences version 25.0 for Windows (SPSS Inc., Chicago, USA). The values were expressed as mean $\pm$ standard deviation. One-way analysis of variance (ANOVA) with Tukey's test was used to determine the significant differences among the samples. The values of $P < 0.05$ were considered as statistically significant.

Results and Discussion

Food Description

Table 1 presented in the 'Materials and Method' section described general food descriptions that were collected for chemical analysis. On the other hand, an example of a herbarium sheet for quinoa seeds is presented in Figure 2, which summarizes the botanical profile of the plant. Similar herbarium sheets were prepared for all collected food samples that described the local name, English name, binomial name, collector's name, herbarium identification number, and related descriptions.

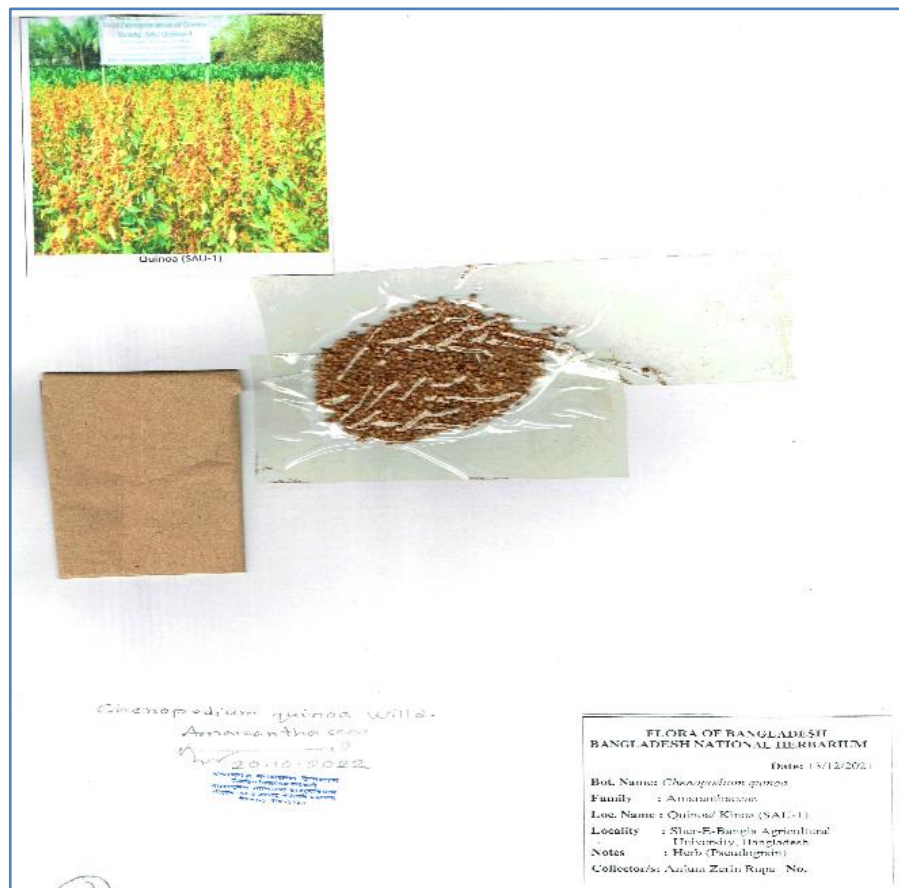


Figure 2. Herbarium sheet of Quinoa.

Nutritional Analysis

Tables 2 and 3 show the content of proximate nutrient values of the cereals and pseudograins studied. Results are expressed as the mean of the duplicate analysis of each sample and expressed as grams per 100 grams of

edible portion (EP). Notable values are shown in bold letters. Both cheena and kaon were found to be rich in protein, while zob was rich in dietary fiber. These values are in well agreement with literature values (Shaheen *et al.*, 2014).

Table 2. Proximate compositions of cereals (g/100 g EP)

Food Description	Energy (Kcal)	Moisture (g)	Protein (g)	Fat (g)	Dietary Fiber (g)	Available CHO (g)	Ash (g)
Bajra (Commercial/Local)	334.63	12.93	9.47	2.73	10.83	62.63	1.41
Zob (BARI-6 Field)	322.38	11.69	11.65	1.64	15.11	57.70	2.21
Cheena (BARI Field)	339.49	10.77	13.47	1.65	9.88	62.75	1.48
Kaon (BARI Field)	344.90	9.48	13.65	1.50	9.26	64.57	1.54

EP = Edible parts.

Table 3. Proximate compositions of local pseudograins (g/100 g EP)

Food Description	Energy (Kcal)	Moisture (g)	Protein (g)	Fat (g)	Dietary Fiber (g)	Available CHO (g)	Ash (g)
Chia (Bogra Field)	418.65	7.10	19.25	28.93	31.44	04.60	8.68
Chia (Dinajpur Field)	383.84	10.00	20.44	20.88	31.40	12.84	4.44
Chia (BAU Field)	436.03	7.00	22.35	29.77	32.41	03.47	5.00
Quinoa (SAU-1 Field)	328.13	12.36	16.04	4.39	13.37	49.06	4.41

EP = Edible parts. SAU = Sher-e-Bangla Agricultural University.

Buckwheat (*Fagopyrum esculentum*), chia (*Salvia hispanica*), and quinoa (*Chenopodium quinoa*) are well-known pseudograins in Bangladesh (Rupa and Rahim, 2023). Protein (20.44 to 22.57%), fat (20.88 to 29.77%), and dietary fiber contents (31.40 to 36.85 g%) of locally grown chia seeds were found to be almost similar to the ranges reported by Bartosz *et al.* (2019). Comparing to other pseudograins, quinoa contained lower proximate nutrients (Table 3). However, similar amounts of protein (12.43 to 16.04%) and fat (4.3 to 5.17%) in quinoa have been reported earlier (Filho *et al.*, 2017). Local chia seeds were thus revealed to be a good source of protein, fat, and dietary fiber compared among pseudograins cultivated and available in Bangladesh (Rupa and Rahim, 2023). Smith *et al.* (2011) reported that whole grains, especially cereal fiber, reduced mortality, cardiovascular disease, and type-2 diabetes. Genotypes and cultivation conditions had direct influence on the nutritional and polyphenolic composition of plants (Ghimire *et al.*, 2021). Apart from rich phytochemical content (Table 5), these two

pseudograins showed excellent amounts of macronutrients (Table 3) also.

Total Polyphenol Content (TPC) and Total Flavonoid Contents (TFC)

Tables 4 and 5 show the TP and TF contents of selected minor cereals and pseudograins. Among the minor cereals studied, bajra was found to be rich in both TPC (135.75±0.33) and TFC (17.44±0.05) (Table 4). Samaila *et al.* (2022) found 20.14±0.14 mg/100 g TPC and 6.36±0.07 mg/100 g TFC in non-germinated pearl millet. Lower TPC was observed in cheena (22.97±0.04) while kaon showed lower TF (7.12±0.01) content (Table 4). A study analyzed twenty-five genotypes of Proso millet and found a maximum 0.10 mg/g dw TFC among them (Balli *et al.*, 2020). A recent study revealed that the methanolic extract of Foxtail millet flour exhibited significantly elevated amounts of TPC and TFC (51.35±1.35 mg GAE/100 g and 68.26±1.51 mg QE/100 g, respectively) in comparison to the other solvent extracts (Abedin *et al.*, 2022).

Table 4. Total polyphenols and flavonoids content in cereals (Mean±SD)

Sample	Total Polyphenols Content (TPC) (mg of, GAE*/gm of dry extract)	Total Flavonoids Content (TFC) (mg of QE**/gm dry extract)
Bajra	135.75±0.33	17.44±0.05
Zob	57.75±0.37	0.45 ±0.01
Cheena	22.97±0.04	7.71 ±0.01
Kaon	61.24±0.03	7.12±0.01

*Gallic acid equivalent; **Quercetin equivalent.

Table 5. Total polyphenols and flavonoids content in pseudograins (Mean±SD)

Sample	Total Polyphenols (mg of, GAE*/gm of dry extract)	Total Flavonoids (mg of QE**/gm dry extract)
Chia DP [#]	79.75±0.19	3.65±0.075
Quinoa SAU 1 [§]	28.55±0.06	6.66±0.01

*Gallic acid equivalent; **Quercetin equivalent; [#]DP- Chia seeds from Dinajpur field; [§]SAU 1- Quinoa from Sher-e-Bangla Agricultural University.

The TPC (79.75±0.19) of Chia seeds was higher than quinoa, but interestingly, a higher content of TF (6.66±0.01) was found in quinoa than chia seeds (Table 5). These values are relatively higher than reported values in chia (2.6 mg GAE/gm of TPC and 1.17 mg QE/gm of TFC), but quinoa was shown to contain a very low amount of TPC (1.4 mg GAE/gm) and 0.9 mg QE/gm of TFC (Brend *et al.*, 2012). These reported values are much lower than the values obtained in this study.

Agronomic conditions (Naczek *et al.*, 2006) and extraction methods (Chandrasekara *et al.*, 2010) could be the reasons for these differences in the content of TPC and TFC in the seeds of chia and quinoa. Low temperatures may increase the production of phenolics by enhancing the synthesis of phenylalanine ammonia-lyase (PAL) in plants, while high altitude and long sunlight exposure with high UV radiation positively affect the synthesis of phenolic compounds (Kishore *et al.*, 2010). Thus, the differences in TPC and TFC content of the pseudograins in this study with the earlier studies may be due to the variations in the geographical location, different extraction/cultivation/sample processing used, and so forth (Ghias *et al.*, 2013). The relatively higher contents of TP and TF in locally grown minor cereals and pseudograins generates optimism to use them as healthful foods for the management of noncommunicable diseases.

Free Radical Scavenging Activity by DPPH

The capability of scavenging free radicals by antioxidants is to neutralize them from being able to reactively damage cellular lipids, proteins, enzymes,

carbohydrates, and DNA (Fang *et al.*, 2002). Some phenolic compounds and flavonoids possess antioxidant activities because they are able to act as scavengers of singlet oxygen and free radicals in biological systems (Rice-Evans *et al.*, 1997). Phenolics are among the major phytochemicals that have been considered as bioactive compounds with health benefits based on clinical trials and epidemiological studies of oxidative stress-related diseases.

Therefore, assaying the free radical scavenging activity of chia and quinoa by DPPH was considered vital, and the data resulted in is presented in Table 6. The half-maximal inhibitory concentration (IC₅₀) value was chosen as an index of DPPH activity. It has been demonstrated that commercial bajra is more active, as evidenced by its lower IC₅₀ value (141.11±5.33) compared to cultivated zob (415.27±1.09). The ethanolic extract of pearl millet (bajra) exhibited a comparable value (152.586 µg/mg) to the findings of the current study (Krishnan *et al.*, 2022). The findings of Fouad *et al.* (2021) showed IC₅₀ values of four different zob extracts in acetone ranged from 2.031 to 3.428 mg/mL, which denoted much lower values compared to our results. The present study also observed higher antioxidant activity (low IC₅₀ values) in chia than the study of Khursheed *et al.* (2023). However, lower IC₅₀ values (3.6 mg/mL), *i.e.*, high antioxidant activity, for chia are in India (Namrata and Haripriya, 2022).

Table 6. Antioxidant activity of selected cereals and pseudograins by DPPH (% of inhibition by substrate concentration in $\mu\text{g mg}^{-1}$)

DPPH Index/ Food	Bajra	Zob	Chia DP	Quinoa SAU 1	Standard (Ascorbic acid)
*IC ₅₀	141.11±5.33	415.27±1.09	70.57±2.33	355.56±3.77	5.58

*The half-maximal inhibitory concentration (IC₅₀) represents the concentration (mg/ML) at which a substance exerts half of its maximal inhibitory effect.

Quinoa has been shown about 80% DPPH radical scavenging activity (Namrata and Haripriya, 2022), which is comparatively higher than the findings of the present study (Table 6). Relatively higher free radical inhibition (IC₅₀ = 70.57±2.33) was observed in chia from Dinajpur field, compared to other foodstuffs studied.

It is worth noting that comparing results obtained from the different geographical locations using different extraction methods is difficult as it may influence the chemical and functional properties of the pseudograins, which might be a possible reason behind the quite different findings of DPPH antioxidant activity in the present study compared to other reported studies (Klepacka *et al.*, 2021). Lower the IC₅₀ value, more potent is the substance in food materials at scavenging DPPH, thereby, implies a more potential health benefit of these food materials in health and diseases. It has been reviewed that an additional strategy for lowering body weight and managing adipose tissue mass could be the use of phytochemicals with anti-obesity potential (Roy *et al.*, 2020).

Conclusions

TPC and TFC of the food samples studied were relatively higher than other reported values, indicating the effects of environmental factors such as sun exposure, soil type, and rainfall on the phenolic contents of plants (Manach *et al.*, 2004) across different agro-ecological regions. Within the stipulated opportunity, all collected food samples were not possible to analyze their TP and TF profiles. However, the free radical scavenging activity of DPPH found in Bajra, Chia, and Quinoa (Table 6) is encouraging to use them in diet therapy as well as in habitual diets of the general population.

Acknowledgements

The authors acknowledged the Ministry of Science and Technology, Government of the People's Republic of Bangladesh, for financial assistance (SRG-221229, 2022–2023).

Declaration

The authors declare no conflict of interest.

Authors' Contributions

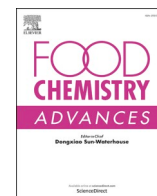
ATMAR conceived and designed the experiments, analyzed and interpreted the data, wrote the manuscript, contributed reagents, materials, and intellectual inputs; AZR conducted the experiments, analyzed and interpreted the data, and wrote the draft manuscript; KTA analyzed and interpreted the data. The completed manuscript has been read and approved by all authors.

References

- Abedin MJ, Abdullah ATM, Satter MA and Farzana T 2022. Physical, functional, nutritional and antioxidant properties of foxtail millet in Bangladesh. *Heliyon* **8**(10): e11186. doi: 10.1016/j.heliyon.2022.e11186
- AOAC 2000. *Official Method of AOAC International* (16th Edition). Association of Official Analytical Chemists, Washington DC., USA. pp. 200–210.
- Banik S and Rahman M 2018. Prevalence of overweight and obesity in Bangladesh: A systematic review of the literature. *Current Obesity Reports* **7**: 247–253.
- Balli D, Bellumori M and Orlandini S 2020. Optimized hydrolytic methods by response surface methodology to accurately estimate the phenols in cereal by HPLC-DAD: The case of millet. *Food Chemistry* **303**: 125393.
- Bartosz k, Joanna KS, Maciej T, Dominik K and Anna GM 2019. The chemical composition and

- nutritional value of chia seeds – current state of knowledge. *Nutrients* (MDPI) **11**(6): 1242.
- Brend Y, Liel G and Shmuel G 2012. Total phenolic content and antioxidant activity of red and yellow quinoa (*Chenopodium quinoa* Willd.) seeds as affected by baking and cooking conditions. *Food and Nutrition Sciences* **3**(8):1150–1155.
- Chandrasekara A and Shahidi F 2010. Content of insoluble bound phenolics in millets and their contribution to antioxidant capacity. *Journal of Agricultural and Food Chemistry* **58**(11): 6706–6714.
- De La Garza AL, Milagro FI and Boque N 2011. Natural inhibitors of pancreatic lipase as new players in obesity treatment. *Planta Medica* **77**(8): 773–785.
- Fang YZ, Yang S and Wu G 2002. Free radicals, antioxidants, and nutrition. *Nutrition* **18**: 872–879.
- Filho AMM, Pirozi MR and Borges JTDS 2017. Quinoa: Nutritional, functional, and antinutritional aspects. *Critical Review of Food Science and Nutrition* **57**: 1618–1630.
- Fouad ELM, Miguel PL, Hannadi EIF, Halima O and Jamal B 2021. Extraction, analysis of polyphenols and antioxidant properties of morrocan barley seed extracts (*Hordeum vulgare* L.). *Materials Today Proceedings* **43**(4): 1896–1902.
- Ghias U, Abdur R and Sumaira G 2013. Proximate chemical composition and biological profile of fatty acids of *Withania somnifera* L. dunal. *Journal of Medicinal Plants Research* **7** (27): 2034–2039.
- Ghimire CP, Zwartendijk BW and Pde F 2021. Changes in soil hydraulic conductivity and preferential flow pathways after assisted forest restoration on degraded land in the Khasi Hills (Meghalaya , NE India), EGU general assembly, EGU 21-6559, pp. 4–6.
- Hales CM, Carroll MD and Fryar CD 2020. Prevalence of Obesity and Severe Obesity Among Adults: United States, 2017–2018. NCHS Data Brief, No. 360, pp. 1–8. <https://www.cdc.gov/nchs/products/index.htm>
- Kaur H, Shams R, Dash KK and DA 2023. A comprehensive review of pseudo-cereals: Nutritional profile, phytochemicals constituents and potential health promoting benefits. *Applied Food Research* **3**(24): 100351.
- Khursheed T, Fatima T and Qadri T 2023. Biochemical, nutraceutical and phytochemical characterization of chia and basil seeds: A comparative study. *International Journal of Food Properties* **26** (1): 1–13.
- Khursheed T, Tabasum F, Tahiya Q, Asima R, Ajaz M, Bazila N and Syed ZH 2022. Biochemical, nutraceutical and phytochemical characterization of chia and basil seeds: A comparative study. *International Journal of Food Properties* **26**(1): 1–13
- Kishore K, Pathak KA and Shukla R 2010. Studies on floral biology of passion fruit (*Passiflora* spp.). *Pakistan Journal of Botany* **42**: 21–29.
- Klepacka J and Najda A 2021. Effect of commercial processing on polyphenols and antioxidant activity of buckwheat seeds. *International Journal of Food Science and Technology* **56**(2): 661–670.
- Krishnan V, Piyush V, Supriyo S, Bhupinder S, Vinutha T, Kumar RR, Ankur K, Singh SP, Tara S, Archana S and Shelly P 2022. Polyphenol-enriched extract from pearl millet (*Pennisetum glaucum*) inhibits key enzymes involved in post prandial hyper glycemia (α -amylase, α -glucosidase) and regulates hepatic glucose uptake. *Biocatalysis and Agricultural Biotechnology* **43**(26): 102411
- Lapornik B, Prošek M and Wondra AG 2005. Comparison of extracts prepared from plant by-products using different solvents and extraction time. *Journal of Food Engineering* **71**(2): 214–222.
- Nacz M and Shahidi F 2006. Phenolics in cereals, fruits and vegetables: Occurrence, extraction and analysis. *Journal of Pharmaceutical and Biomedical Analysis* **41**(5): 1523–1542.
- Namrata S and Haripriya A 2022. Effect of germination on selected phytochemicals and antioxidant activity of quinoa (*Chenopodium quinoa*). *Indian Journal of Traditional Knowledge* **21**(4): 876–882.
- Nazma S, Abu TMR, Md M, Cadi PB, Md LB, Avonti BT, MA M, Lalita B and Barbara S 2014. Food composition table for Bangladesh. pp 1–11.
- Pandey KB and Rizvi SI 2009. Plant polyphenols as dietary antioxidants in human health and disease. *Oxidative Medicine and Cellular Longevity* **2** (5): 270–278.
- Pekić B, Kovač V and Alonso E 1998. Study of the extraction of proanthocyanidins from grape seeds. *Food Chemistry* **61**(1–2): 201–206.
- Rice-Evans CA, Miller NJ and Paganga G 1997. Antioxidant properties of phenolic compounds. *Trends in Plant Science* **2**(4): 152–159.
- Roy M 2020. Phytochemicals for controlling obesity related cancers. *Novel Approaches of Cancer Study* **4**(5):423–437.
- Rupa AZ and Rahim ATMA 2023. Ethnographic survey on cereal and pseudocereal in Bangladesh perspective. *Food Research* **7**: 222–229.
- Samaila J, Suleiman YB, Suleiman AJ, Caleb YM, Amina IB, Adobu I and Abdullazeez O 2022. Total phenolic, flavonoid and antioxidant capacities of processed pearl millet and sorghum flours. *Croatian Journal of Food Science and Technology* **14**(2): 12.
- Scalbert A, Johnson IT and Saltmarsh M, 2005.

- Polyphenols: antioxidants and beyond. *American Journal of Clinical Nutrition* **81**: 215–217.
- Sinay H, Mahulette F and Yáñez JA 2022. Determination of free radical scavenging activity, phenolic and flavonoid content of seven corn cultivars from the Southwest Maluku District, Indonesia. *Journal of Biological Diversity* **23**: 5974–5981.
- Singleton VL and Joseph AR 1965. Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagents. *American Journal of Enology and Viticulture* **16**(3): 144–158
- Smith CE and Katherine LT 2011. Health benefits of cereal fibre: a review of clinical trials. *Nutrition Research Review* **24**(1): 118–131.



Nutritional, phytochemical and antioxidant properties of Bangladeshi pigmented rice (red and black), grains and pseudograins

Anjum Zerin Rupa^a, Abu Torab M.A. Rahim^{b,*}, Md. Hemayet Hossain^a, Khondoker Shahin Ahmed^c

^a Chemical Research Division, BCSIR Laboratories, Dhaka, Bangladesh Council of scientific and Industrial Research (BCSIR), Dhaka-1205, Bangladesh

^b Institute of Nutrition and Food Science (INFS), University of Dhaka, Dhaka-1000, Bangladesh

^c Institute of Food Science and Technology (IFST), Dhaka, Bangladesh Council of scientific and Industrial Research (BCSIR), Dhaka-1205, Bangladesh

ARTICLE INFO

Key words:

Nutrient value
Pigmented rice
Pseudograins
Polyphenolic composition
Antioxidant potential

ABSTRACT

A comprehensive nutritional and phytochemical study of Bangladeshi cereals and pseudograins is required to demonstrate their significance as functional foods. Black and red aman (rainy to winter season) rice (*Oryza sativa*), wheat (*Triticum aestivum*), maize (*Zea mays*), oat (*Avena sativa*), black and yellow buckwheat (*Fagopyrum esculentum*), chia (*Salvia hispanica*) and quinoa (*Chenopodium quinoa*) have been analysed for their proximate composition, total phenolics, flavonoid and antioxidant capacity, DPPH activity, ABTS activity, FRAP assay and HPLC polyphenol profiling. Chia showed highest protein, fat and dietary fibre contents among all samples. Black rice extract contained higher amounts of TAC, TPC, and TFC while yellow buckwheat exhibited the highest TAC (176.33 mg AAE/100 g) activity. Black rice among cereal samples revealed the most TPC (90.58 mg GAE/100 g) and TFC (58.84 mg QE/100). The HPLC profiling of polyphenol revealed that red aman rice and quinoa contained highest epicatechin concentration (13.05 and 104.26 mg/100 gm in dry extract). On the other hand, red aman rice and black buckwheat extracts showed the lowest IC₅₀ values in ABTS (19.00 and 9.35 µg/mL) and DPPH (9.35 and 43.45 µg/mL) assays. In FRAP test, methanolic grain extracts depicted significantly higher reducing power compared to the standard. Therefore, these cereals and pseudograins showed bioactive polyphenolic compounds that may be useful in dietary management of various diseases.

1. Introduction

Low glycemic index, easily digestible, non-acid forming and gluten free characteristics of grains are highly recommended as a suitable option in diabetic and celiac disease conditions (Geetha et al., 2020). Numerous recent epidemiological studies showed that consumption of cereals and pseudograins that have bioactive and nutritional potentiality are associated with reduce incidence of non-communicable diseases (Kaur et al., 2023; Khan et al., 2022; Shahbaz et al., 2022). The antioxidant activity of grain polyphenols is enhanced in the body due to the synergistic effect of many bioactive compounds, resulting in the elimination of excessive free radicals following intestinal digestion (Tian et al., 2019). In addition to these, polyphenols, non-nutritive secondary plant metabolites, showed antioxidant activity in whole grain varieties using DPPH, ABTS, FRAP, and ORAC tests in vitro. The antioxidant properties of these grains have been attributed to the content their ferulic acid, oxalic acid, p-coumaric acid, and caffeic acid, other

polyphenols and anthocyanin Deng et al. (2012). Moreover, polyphenols have been reported to possess inhibitory actions on various lipogenic enzymes (Rahim et al., 2015; Alejandra et al., 2017). Whole grains in particular are a good source of dietary polyphenols and their biological properties have long been underestimated in comparison to fruits and vegetables (Tian et al., 2019). Since these compounds are secondary plant metabolites, their effects on human physiology depends upon their consumption through everyday diet.

The agricultural wing of the Bangladesh Bureau of Statistics (BBS) categorizes rice and wheat as major crops while maize and oat as minor cereals in their crop statistics (BBS, 2023). Pseudograins are also called as pseudocereals because their seeds mimic grains like rice, wheat and barley in functionality, nutrient composition or both and also called the grains of the twenty first century (Das et al., 2019; Martínez-Villaluenga et al., 2020). Our recent study by Rupa and Rahim (2023) disclosed that local wheat output reached 1245 kg/acre, while maize production reached 3245 kg/acre in 2019, thereby indicating a significant rise in

* Corresponding author.

E-mail address: torabrahim@gmail.com (A.T.M.A. Rahim).

<https://doi.org/10.1016/j.focha.2024.100862>

Received 7 August 2024; Received in revised form 22 November 2024; Accepted 3 December 2024

2772-753X/© 2024 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

minor cereal production in Bangladesh. Currently, agricultural experts in Bangladesh are investigating the cultivation of pigmented rice, oats and pseudograins (chia, quinoa and buckwheat) due to their notable nutritional and bioactive advantages. Black and red rice are two most prevalent local types of pigmented rice. Pigmented rice possess remarkable nutritional and phytochemical properties that contribute significantly to human health, surpassing other varieties of rice (Bolea & Vizireanu, 2017; Mazumdar et al., 2022; Pradipta et al., 2020). On the other hand buckwheat, quinoa and chia contain high amounts of macro (protein, dietary fibers, and lipids), micro (vitamins and minerals) and phytonutrients (e.g., phenolic, flavonoid, sterol), which poses numerous health beneficial functions; moreover, they are suggested for gluten-sensitive people due to its low gluten content (Agarwal et al., 2023; Francis Raguindin et al., 2021).

As pigmented rice, cereals and dicotyledonous pseudograins have been reported to contain bioactive components their potential health benefits have not been explored with local varieties. A lack of comprehensive physico-chemical analytical data on locally grown and available cereals and pseudograins in Bangladesh is a limitation to their potential health uses. In this context, the present study analysed and reporting the nutritional content, phytochemical components and antioxidant status of some selected grains found in Bangladesh. The aim is to emphasize their significance as conceivable healthy food sources.

$$\text{carbohydrate (\%)} = 100 - (\% \text{ water} + \% \text{ protein} + \% \text{ fat} + \% \text{ dietary fiber} + \% \text{ ash}) \dots \quad (1)$$

2. Materials and methods

2.1. Chemicals and reagents

The following chemicals were obtained from Sigma-Aldrich (St. Louis, MO, USA): Gallic acid, 3,4-Dihydroxybenzoic acid, Catechin hydrate, Catechol, (-) Epicatechin, Caffeic acid, Vanillic acid, Syringic acid, Rutin hydrate, p-Coumaric acid, trans-Ferulic acid, Rosmarinic acid, Myricetin, Quercetin, trans-Cinnamic acid, Kaempferol, Folin-(FC) Ciocalteu's reagent, DPPH (1,1-diphenyl-2-picryl-hydrazyl), and ascorbic acid. Acetonitrile (HPLC), methanol (HPLC), acetic acid (HPLC), acetone, aluminium nitrate, ammonium molybdate, disodium hydrogen phosphate, methanol, iron (III) chloride, potassium acetate, potassium ferricyanide, sodium carbonate, sodium nitrite, sulfuric acid, sodium dihydrogen phosphate, trichloroacetic acid, and ethanol were acquired from Merck (Darmstadt, Germany).

2.2. Preparation of sample flour

The red aman rice and black rice were obtained from an agricultural area in Managram village, Cumilla, Bangladesh. The other samples are (BARI maize-7, BARI wheat-26, BARI oat-1) collected from the agricultural field of Bangladesh Agricultural Research Institute (BARI). Yellow buck wheat, black buckwheat, chia and quinoa) were collected local commercial sources (Supplement 1). The samples were washed gently with tap water after collection, and the inedible parts (stone, broken seeds and others) were later separated and were dehydrated for 3–4 h in the open air. Clean and air-dried samples were weighed and analysed for moisture, ash and TDF content as described in our earlier studies (Afrin et al., 2024; Tuj & Mili, 2024). The moisture-free, dehydrated materials were grounded to flour with a domestic grinder followed by passing through a 100 mm sieve. Samples were kept in small zip lock packets and stored in desiccators at room temperature until further analysis.

2.3. Macronutrient assessment

All methods used for proximate analysis were 'Association of Official Analytical Chemists, AOAC' recommended methods (AOAC, 2000). The proximate components, which include water or moisture, protein, fat, ash, and total dietary fiber, were estimated according to the procedures reported earlier (Afrin et al., 2024; Mili & Rahim, 2024). Briefly, moisture content (method no. 925.09) was determined by weight loss on drying of the sample in an oven at 105 °C for 4 h. Ash content (method no. 923.03) was estimated by heating the moisture free sample at 200 °C for charring about 2 hrs followed by heating 600 °C for 5 h in a muffle furnace. Nitrogen content was determined by micro-Kjeldahl method of AOAC (2000). The crude protein content was then calculated by multiplying the nitrogen values with Jones factor (XN) for cereals i. e., 6.25. Crude fat content (method no. 991.36) was derived by the continuous extraction method using Soxhlet apparatus. The total dietary fibre (TDF) was determined by using the total dietary fiber assay kit based on enzymatic-gravimetric determination of both soluble and insoluble non-starch polysaccharides of Prosky methods (method no. 985.29). Available Carbohydrate content of each sample was calculated by difference using the Atwater's conversion factors (Atwater, W.O. & Bryant, 1900) shown in Eq. (1) and, finally, the energy content was determined by Eq. (2).

The total energy values of the samples were determined by using the formula:

$$\text{Total energy} \left(\frac{\text{Kcal}}{100\text{g}} \right) = (\% \text{ carbohydrate} \times 4) + (\% \text{ protein} \times 4) + (\% \text{ fat} \times 9) + (\% \text{ Dietary fiber} \times 2) \quad (2)$$

2.4. Antioxidant activity

2.4.1. Extraction procedure

Each flour sample was extracted using 99.9 % HPLC grade methanol, with a quantity of 50g for each sample. The combination was subjected to mechanical agitation on a shaker for a period of 48 h. It was filtered and drying under decreased pressure using a rotary evaporator (Stuart, UK) (Ahmed et al., 2021). The concentrated extracts were stored at a temperature of 4 °C. The antioxidant activities of the extracts were assessed by dissolving them in methanol at a concentration of 1 mg/mL. The absorbance was measured using a UV spectrophotometer (Specord 205, Analyticjena, Germany).

2.4.2. Total antioxidant capacity, total phenolic and flavonoid content

The quantification of total antioxidant capacity, total phenolic and flavonoid was conducted using the modified colorimetric technique using the UV-Visible spectrophotometric procedure (Ahmed et al., 2023). A reagent solution of 0.6 M H₂SO₄, 28 mM sodium phosphate, and 4 mM ammonium molybdate was added to 0.1 mL of the extract (1 mg/mL) in a test tube. The tubes were incubated at 95 °C for 90 min. After cooling to room temperature, the solution's absorbance at 695 nm was compared to a blank sample for assessing the TAC.

For determination of TPC, each test tube received 1 ml (1000 µg/mL) of plant extract, 5 mL of Folin-ciocalteu reagent (diluted 1:10 v/v with distilled water) and 4 mL (75 g/L) of sodium carbonate. After a 30 min reaction, absorbance was measured against the blank at 765 nm.

Separate extracts of 5 mL (1000 µg/mL) were mixed with 2.5 mL of

AlCl₃ solution for determination of TFC. The test tubes were left at room temperature for 30 min while the reaction mixture's absorbance was measured at 430 nm. A standard ascorbic acid, gallic acid and quercetin calibration curve was used to calculate the total antioxidant, phenolic and flavonoid content in milligrams of ascorbic acid, gallic acid and quercetin equivalent per gram of dry extract. Three readings per sample yielded reproducible findings.

2.4.3. DPPH free radical scavenging activity

DPPH radical scavenging activity was measured by established method (Ahmed et al., 2023). Each sample extract at varied concentrations (2.5ppm-500 ppm) was combined with 0.1 mM DPPH in 2 ml. After vortexing, the solution incubates for 30 minutes in darkness and absorbance was measured at 517 nm relative to a blank. To measure radical scavenging activity, the inhibition percentage (I %) was calculated using the equation:

$$I (\%) = \frac{A_{\text{blank}} - A_{\text{sample}}}{A_{\text{blank}}} \times 100 \quad (3)$$

Where A blank = absorbance of the control (containing all the reagents except the testing compound), and A sample = absorbance of the experimental sample with all reagents.

2.4.4. ABTS (2,2'-azino-bis 3-ethylbenzothiazoline-6-sulfonic acid) radical scavenging activity test

The ABTS radical scavenging activity assay was utilized to assess the antioxidant activity, with specific modifications (Ahmed et al., 2021). ABTS radical scavenging activity was measured by mixing a 7 mM ABTS solution with 2.45 mM potassium per-sulfate at room temperature for 16 h without illumination. The ABTS solution was diluted with ethanol to achieve a consumption absorbance of 0.70 ± 0.02 at 734 nm. Samples were vigorously mixed with 1 mL of ABTS solution at concentrations from 10 to 500 µg mL⁻¹. The same spectrophotometer showed 734 nm absorbance after 6 min of cooling the reaction mixture. To quantify ABTS radical scavenging activity, the equation provided the inhibition percentage (I %):

$$I (\%) = \frac{A_{\text{blank}} - A_{\text{sample}}}{A_{\text{blank}}} \times 100 \quad (4)$$

Where A blank = absorbance of the control (containing all the reagents except the testing compound), and A sample = absorbance of the experimental sample with all reagents.

The plot of inhibition (%) against extract concentration yielded the IC₅₀ value (the sample concentration needed to scavenge 50 % DPPH and ABTS radical). The average of all triplicate determinations was taken. The conventional antioxidant used was ascorbic acid.

2.4.5. Ferric reducing antioxidant power (FRAP) assay

The ferric reducing antioxidant power (FRAP) of the methanolic extracts were quantified by using a method developed by Pushparaj and Urooj (2014). 2.5 mL extract was treated with 0.2 M phosphate buffer (pH 6.6) and 1 % (w/v) potassium ferricyanide. After cooling, 2.5 mL 10 % w/v trichloroacetic acid was added. The mixture was centrifuged 10 min at 3000 rpm. 2.5 mL supernatant, 2.5 mL deionized water, and 0.5 mL 0.1 % FeCl₃ was added. Spectrophotometer 700 nm absorbance was recorded after 10 min. The reaction mixture's high absorbance showed the sample extracts' reducing power.

2.5. HPLC method

2.5.1. Preparation of working standard solutions

Stock standard solutions were made by dissolving 16 phenolic compounds in methanol in a 25 mL volumetric flask. Stock solutions had values of 4.0–5.0 µg/mL. For working standard solutions, the required volumes of each stock solution were combined and diluted serially. All

solutions were refrigerated.

2.5.2. HPLC analysis

HPLC-DAD analysis was used to identify and evaluate polyphenolic compounds in grain extracts, following Ahmed et al. (Ahmed et al., 2023) with some modifications. A Japanese Shimadzu LC-20A HPLC system with a binary solvent delivery pump (LC-20AT), auto sampler (SIL-20A HT), column oven (CTO-20A), and photodiode array detector was employed. LC solution software (Lab) analyzed. Methanol standard calibration curves were made from stock solution. The solutions contained Gallic acid (20 µg/mL), 3,4-Dihydroxybenzoic acid (15 µg/mL), Catechin hydrate (50 µg/mL), Catechol, (-) Epicatechin, Rosmarinic acid (30 µg/mL), Caffeic acid, Vanillic acid, Syringic acid, Rutin hydrate, p-Coumaric acid, trans-Ferulic acid, Quercetin (10 µg/mL), Myricetin, Kaempferol (8 µg/mL), and trans-Cinnamic acid (4 µg/mL).

2.6. Statistical analysis

The data were presented as the mean ± SD (standard deviation) for three replications. An analysis of variance (one-way ANOVA) was conducted using SPSS software (version 22.0) and Origin 8.3 to identify any significant differences in the mean values.

3. Results

3.1. Content of proximate nutrients

Table 1 represents cereal, minor cereals and pseudo grain macro-nutrient content. Oat and red aman rice had slightly higher moisture content and chia seed had the least moisture. Black and red aman rice had above 8 % of protein, respectively. The highest protein concentration was found in oat and wheat (above 12 %) among the cereal samples, and in chia (above 20 %) among the pseudo grain samples. Result revealed that chia seeds and maize showed higher fat contents and energy values respectively. The oat grain flour exhibited the lowest amount of dietary fibre compared to the other cereal samples analyzed. Oats were found to have the highest available carbohydrate content at (73.68 g/100 g EP) while chia seeds, black buckwheat and maize had the high dietary fibre content correspondingly.

3.2. Total flavonoid content, phenolic content and antioxidant capacity

Table 2 shows total flavonoid content (TFC), total phenolic content (TPC) and total antioxidant capacity (TAC) of selected grains that were extracted using methanol (supplement 3 contains standard curves). Total flavonoid, phenolic and antioxidant content found higher in methanol extracts of black rice flour followed by red rice, maize, oat and wheat. This study demonstrates that wheat has a relatively low content of TFC (Total Flavonoid Content) and TPC (Total Phenolic Content). Among pseudograins, Total antioxidant content observed rich in yellow buckwheat when black buckwheat found to be high in total phenolic and flavonoid content. Chia, quinoa and black buckwheat flour extracts are also showed good quantity of TAC respectively.

3.3. Free radical scavenging activity by DPPH (2,2-Diphenyl-1-picrylhydrazyl)

The DPPH free radical scavenging activity of rice (black and red), wheat, maize, and oat is depicted in Fig. 2(a). The DPPH free radical scavenging activity of various pseudograins (black buckwheat, yellow buckwheat, quinoa, and chia) is illustrated in Fig. 2(b). Fig. 1(a) demonstrates the standard curve of ascorbic acid for measuring the activity of DPPH free radical scavenging. With the increase of extract concentration from 0.005 mg/mL to 0.5 mg/mL, the antioxidant activity of the five cereal and four pseudograins showed notable increments [Fig. 2(a) and 2(b)]. At an extraction concentration of 0.5 mg/mL, the antioxidant

Table 1

Proximate composition of cereal and pseudograins (g/100 g of edible portion EP).

Major cereal	Sample Name	Energy (Kcal)	Moisture (g)	Protein (g)	Fat (g)	Available CHO (g)	Dietary Fiber (g)	Ash (g)
Minor Cereals	Red Aman Rice	338.78 ± 6.20	12.66 ± 0.34	10.33 ± 0.05	2.23 ± 0.39	66.44 ± 0.176	6.85 ± 1.57	1.50 ± 0.18
	Black Rice	351.71 ± 5.01	12.00 ± 0.28d	8.24 ± 0.45	3.66 ± 0.47	67.89 ± 1.16	7.09 ± 1.03	1.10 ± 0.13
	Wheat	345.32 ± 2.95	10.86 ± 0.95	12.04 ± 0.92	2.43 ± 0.48	64.53 ± 3.26	8.54 ± 1.41	1.57 ± 0.31
	Maize	358.57 ± 4.93	10.50 ± 0.62	10.80 ± 0.96	5.08 ± 0.25	62.33 ± 1.83	10.15 ± 0.36	1.13 ± 0.15
	Oat	343.69 ± 8.11	12.43 ± 1.52	13.65 ± 0.62	1.67 ± 0.31	66.07 ± 1.04	4.90 ± 0.36	1.28 ± 0.25
Pseudograins	Chia	391.38 ± 2.77	9.16 ± 0.54	22.09 ± 0.37	23.43 ± 0.41	4.78 ± 1.05	36.51 ± 0.33	4.02 ± 0.89
	Quinoa	361.20 ± 0.76	9.88 ± 0.38	11.95 ± 0.92	5.32 ± 0.55	61.48 ± 1.67	9.78 ± 0.35	1.57 ± 0.39
	Yellow Buck wheat	343.15 ± 3.98	11.31 ± 0.34	14.70 ± 0.71	1.86 ± 0.41	63.42 ± 0.58	6.96 ± 1.17	1.74 ± 0.29
	Black Buckwheat	321.27 ± 2.20	12.11 ± 0.88	11.34 ± 0.71	2.23 ± 0.27	54.54 ± 1.31	18.36 ± 0.89	1.30 ± 0.42

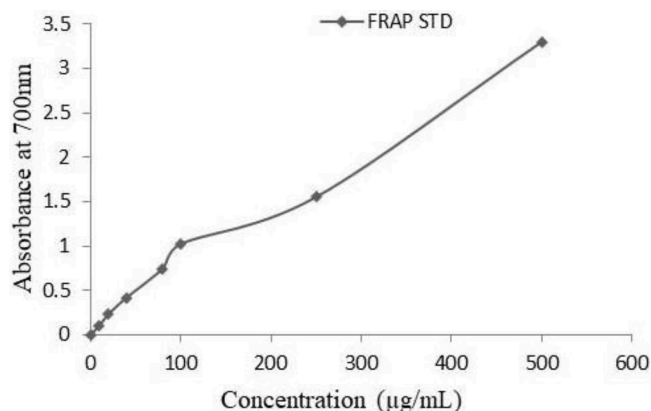
*Each value represents the average of three determinations ±SD (n = 3).

Table 2

Total antioxidant capacity (TAC), total phenolic (TPC) and total flavonoid (TFC) content.

Sl. No	Sample Name	TPC (mg/100 gm)	TF (mg/100 gm)	TAC (mg/100 gm)
1.	Red Aman Rice	156.18 ± 2.16	13.78 ± 3.27	169.04 ± 40.43
2.	Black Rice	276.69 ± 3.14	20.22 ± 2.84	229.88 ± 13.39
3.	Wheat	42.17 ± 2.10	10.29 ± 3.13	96.17 ± 2.00
4.	Maize	86.25 ± 3.14	6.09 ± 2.86	98.17 ± 1.98
5.	Oat	57.65 ± 3.31	4.46 ± 2.19	94.31 ± 2.11
6.	Chia	79.54 ± 1.78	3.77 ± 1.84	124.27 ± 3.91
7.	Quinoa	29.38 ± 2.02	5.84 ± 1.84	85.64 ± 2.01
8.	Yellow Buck wheat	54.11 ± 2.00	39.74 ± 2.80	176.33 ± 2.88
9.	Black Buck wheat	90.38 ± 1.81	58.84 ± 5.61	128.19 ± 4.03

*Each value represents the average of three determinations ±SD (n = 3).

**Fig. 1(c).** Standard curve of Ascorbic Acid as FRAP standard.

activity of cereal and pseudograins follows the order: red aman rice > black rice > maize > wheat > oat, and black buckwheat > yellow buckwheat > chia > quinoa, respectively. In this regard, standard ascorbic acid inhibited 95.2 % free radical at the concentration of 0.5 mg/mL.

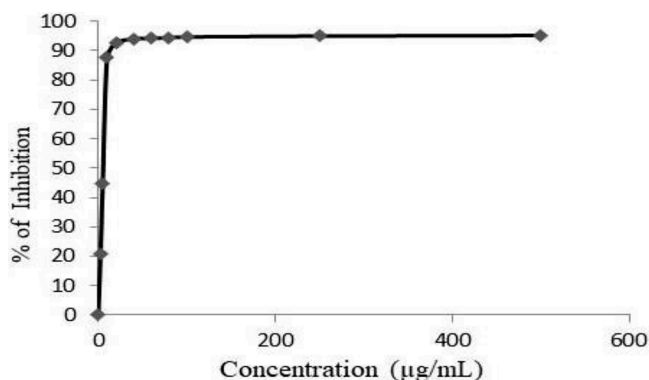
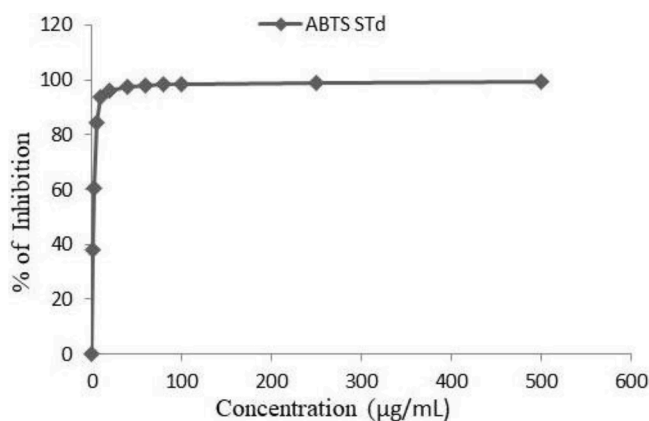
3.4. Free radical scavenging activity by ABTS (2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid))

The scavenging powers of the cereal and pseudograins were relatively increasing with the concentrations (Fig. 3a and 3b). Fig. 1(b) illustrates the standard curve of ABTS assay measured with ascorbic acid. At a minimum concentration (20 µg mL⁻¹), the extract of red aman rice and black buck wheat (10 µg mL⁻¹) showed greater inhibition than that of standard ascorbic acid (Table 3). The IC₅₀ values of the red aman rice and black buckwheat extracts were much lower inhibition capacity compared to ascorbic acid. On the contrary, yellow buckwheat exhibited a much lower IC₅₀ value compared to the other food samples. Wheat showed the lowest IC₅₀ value (Table 3) in the ABTS analysis among the three crops examined, followed by oat and maize. Black buck wheat, red aman rice, quinoa, and black rice all had significantly higher maximal reduction capacities than the other samples.

The IC₅₀ values indicates the capacity of the sample extract which measures the lowest concentration of it required to inhibit 50 % of DPPH free radicals. According to Table 3, IC₅₀ values of the red aman rice, black buckwheat, yellow buckwheat and chia were significantly different from each other, which reveal that red aman rice and black buckwheat posed more potent antioxidant activity than that of other samples.

3.5. Ferric reducing antioxidant power (FRAP) assay

Methanol extracts of selected samples were subjected to the ferric reducing power (FRAP) test, with notable variations seen in Fig. 4(a)

**Fig. 1(a).** Standard curve of Ascorbic Acid as DPPH standard.**Fig. 1(b).** Standard curve of Ascorbic Acid as ABTS standard.

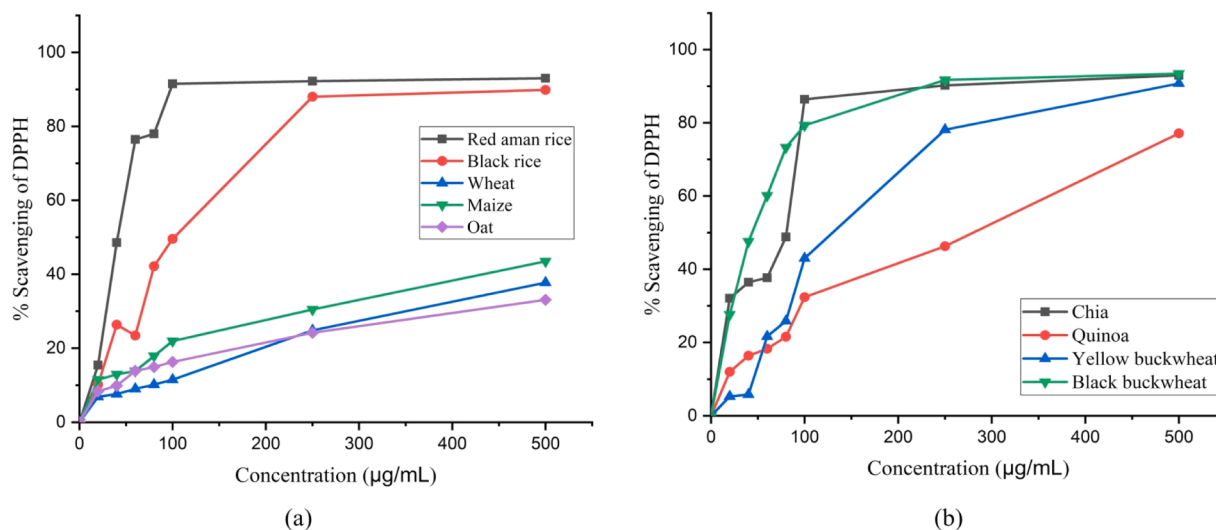


Fig. 2. (a). DPPH free radical scavenging capacity of cereal sample extracts ($n = 3$). (b). DPPH free radical scavenging capacity of pseudo-grain sample extract ($n = 3$).

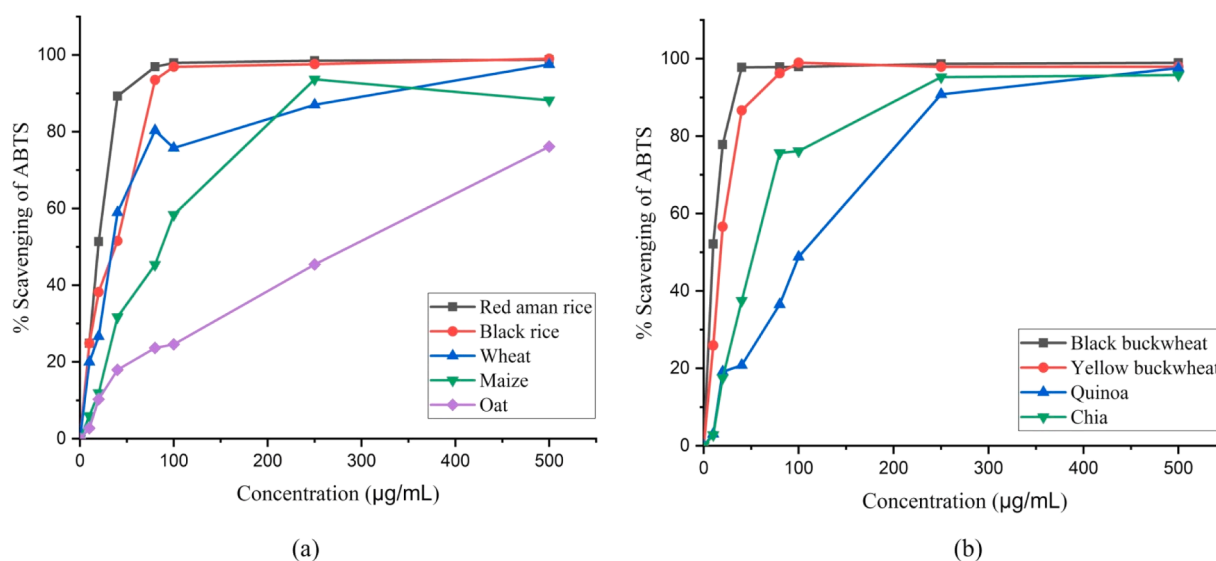


Fig. 3. (a). ABTS free radical scavenging capacity of cereal sample extracts ($n = 3$). (b). ABTS free radical scavenging capacity of cereal sample extracts ($n = 3$).

Table 3

IC₅₀ values of DPPH and ABTS methods.

Sample Name	IC ₅₀ values (µg/mL)	
	DPPH	ABTS
Standard (Ascorbic acid)	5.58	1.9
Red Aman Rice	47.97	19.00
Black Rice	105.55	37.50
Wheat	ND*	34.59
Maize	ND	88.20
Oat	ND	362.77
Chia	80.67	9.35
Quinoa	280.99	17.50
Black Buck wheat	43.45	98.11
Yellow Buck wheat	80.22	53.82

ND*, Not detected.

and 4(b). Fig. 1(c) displays the standard curve of the FRAP assay.

3.6. Polyphenolic compounds

The results of Polyphenolics compounds obtained from 99.9 % methanol extracts were analyzed by HPLC-DAD chromatographic screening and the findings expressed in mg/100 gm dry weight is shown in Table 4a and b (corresponding sample chromatograms are attached in supplement 2). The (-) Epicatechin in red aman rice, p-coumaric acid in black rice, 3,4-dihydroxybenzoic acid in wheat, caffeic acid in maize while (-) epicatechin and rutin hydrate in oat showed to be the prime contributors among fourteen polyphenolic compounds compared with standard (Table 4a).

Table 4b also represents the amount of the phenolic compounds present in the black buckwheat, yellow buckwheat, quinoa and chia. Rutin hydrate, a great contributor to the antioxidant activities of buckwheat, was observed as the major phenolic compound in both buckwheat varieties while (-) Epicatechin and p-coumaric acid were the common phenolic compounds found in the four pseudograins studied. Epicatechin and p-coumaric acid content were observed both in quinoa

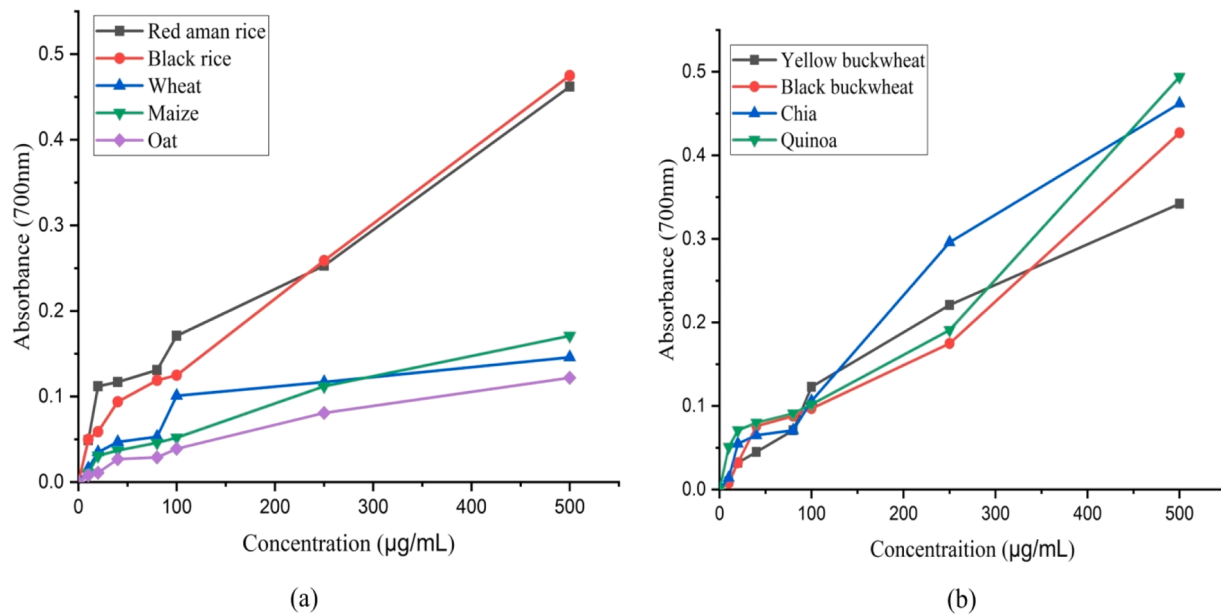


Fig. 4. (a). FRAP assay of cereal sample extracts ($n = 3$). (b). FRAP assay of pseudo grain sample extracts ($n = 3$).

Table 4a
Polyphenolic compound Screening by HPLC (mg/100 g dry extract).

Name of standard compounds	Red Aman Rice	Black rice	Wheat	Maize	Oat
Gallic acid	–	–	–	–	–
3,4-Dihydroxybenzoic acid	–	–	249.97 ± 0.54	–	7.98 ± 0.39
Catechin hydrate	–	–	–	–	3.85 ± 0.05
Catechol	–	–	–	–	–
(-) Epicatechin	13.05 ± 0.47	–	–	–	44.10 ± 0.05
Caffeic acid	–	–	–	59.94 ± 0.38	–
Vanillic acid	–	3.95 ± 0.12	–	–	–
Syringic acid	–	0.45 ± 0.02	3.14 ± 0.03	0.79 ± 0.02	–
Rutin hydrate	–	–	1.42 ± 0.06	8.07 ± 0.07	42.44 ± 0.05
p-Coumaric acid	–	6.89 ± 0.08	–	–	–
trans-Ferulic acid	–	0.63 ± 0.05	–	–	–
Rosmarinic acid	–	0.62 ± 0.01	–	–	9.27 ± 0.07
Myricetin	–	0.54 ± 0.04	–	–	0.65 ± 0.02
Quercetin	0.41 ± 0.02	–	–	–	–
trans-Cinnamic acid	0.45 ± 0.02	–	–	–	–
Kaempferol	0.36 ± 0.01	0.76 ± 0.06	11.37 ± 0.27	–	–

*Each value represents the average of three determinations ±SD ($n = 3$), (–) = not detected.

and chia ($p < 0.05$) [Table 4b]. High concentration of ($p < 0.05$) rutin hydrate, p-coumaric acid and lower concentration of epicatechin were observed in black buckwheat.

Table 4b
Polyphenolic compound Screening by HPLC of pseudograins (mg/100 g dry extract).

Name of standard compounds	Black BW	Yellow BW	Chia	Quinoa
Gallic acid	–	–	–	–
3,4-Dihydroxybenzoic acid	–	–	81.91 ± 0.33	–
Catechin hydrate	–	–	–	–
Catechol	12.26 ± 0.02	–	–	–
(-) Epicatechin	47.08 ± 0.87	66.22 ± 0.26	60.12 ± 0.30	104.26 ± 0.98
Caffeic acid	–	–	0.87 ± 0.04	10.79 ± 0.13
Vanillic acid	–	–	–	–
Syringic acid	–	–	–	–
Rutin hydrate	274.86 ± 1.45	112.64 ± 0.57	–	–
p-Coumaric acid	22.38 ± 0.24	0.89 ± 0.05	217.47 ± 0.40	2.23 ± 0.03
trans-Ferulic acid	–	–	–	–
Rosmarinic acid	8.32 ± 0.16	–	–	–
Myricetin	2.41 ± 0.07	2.84 ± 0.01	–	–
Quercetin	10.86 ± 0.05	–	–	15.33 ± 0.17
trans-Cinnamic acid	–	–	–	–
Kaempferol	–	–	–	8.41 ± 0.28

*Each value represents the average of three determinations ±SD ($n = 3$). (–) = not detected.

4. Discussion

Low moisture content increase the shelf life and storage period of food while high moisture content encourage microbial growth (Obeta et al., 2020). The current findings of moisture and protein content were found align with previously published reports (Cremonini et al., 2020; Khurshed et al., 2023; Sulaiman et al., 2020). The maize type contains a greater amount of fat and carbohydrates compared to other kinds of wheat and sorghum (Sulaiman et al., 2020) whereas fiber content of oat is consistent with the results reported in a recent study (Alam, 2015).

Several observational studies show that whole grains, especially cereal fibre, reduce mortality, cardiovascular disease, and type-2 diabetes. Research has examined how different forms of fibre and grains may improve obesity, cardiovascular disease, and type 2 diabetes measures (Smith & Tucker, 2011).

However, recent research has discovered that eight genotypes of wheat possess a range of TPC and TFC (Grande et al., 2023), five black rice and seven red rice varieties showed higher total phenolic (TPC) and total flavonoid (TFC) contents, (Deng et al., 2012) which are close to current study. Higher TPC and TFC have been reported in buckwheat collected from Italy (Rocchetti et al., 2019) and Latvia (Beitane et al., 2018) than the present study. The low TPC in chia seeds found in this study may be due to free phenolics or coupled to sugars by glycosidic bondage, which increases water solubility but decreases bioavailability (Khurshed et al., 2023). A study in Italy showed black and red quinoa TPC values similar to our study (Rocchetti et al., 2019). In addition, (Sharma et al., 2022) found approximately 1327 mg QE 100 g⁻¹ TFC in quinoa purchased in Mumbai.

Lower IC₅₀ values found in buckwheat sprouts than in the present study (Zhong et al., 2022). DPPH radical scavenging activity found 80 % and 36 % in Indian quinoa and chia (Khurshed et al., 2023; Namrata & HariPriya, 2022), which is higher than the current observation. Comparing results from different geographical locations and extraction methods is difficult because it may affect the chemical and functional properties of the pseudograins, which may explain why the present study found different DPPH antioxidant activity than previous studies (Klepcka & Najda, 2021).

The highest antioxidant content in black rice neutralizes ABTS free radicals with minimal extract which was significantly different from white and brown rice, wheat, and barley ($P < 0.05$) (Khatun & Mollah, 2024). Regardless of the various varieties of rice and the bran of red rice showed considerably higher ($P < 0.05$) ABTS radical scavenging activity compared to the bran of white rice (Thitipramote et al., 2016). A recent study demonstrated that wheat grain and wheat bran exhibit a greater capacity to inhibit free radicals compared to oat grain and oat bran, as determined by the ABTS method (Martín-Diana et al., 2021). Higher radical scavenging capacity by ABTS ($\mu\text{mol TE/g dw}$) of total phenolic compound was demonstrated by mean value of thirteen types of quinoa compared with frap, orac, and dpph method (Li et al., 2021). According to a study, chia seeds had an inhibitory effect of TEAC per gram on ABTS (Sargi et al., 2013).

Due to the presence of antioxidants in the methanol extracts, the ferric-ferricyanide complexes was reduced to the ferrous form (Amarowicz et al., 2004) and higher frap activity in red and black rice varieties were found than white rice (Thitipramote et al., 2016).

The principal phenolic acids found in whole black rice bran and BF1 were ferulic acid, p-coumaric acid, gallic acid, and vanillin, respectively (Lázaro Cañizares, Silvia Meza et al., 2024). Ferulic acid, vanillic acid and p-coumaric acid were the primary phenolic acids found in red rice bran (Jun et al., 2012) similar polyphenolic compounds were found in this study. Resorcinol, tyrosol, caffeic acid, syringic acid, and ferulic acid were found in significant quantities in an 80 % ethanol solution of five wheat genotypes (Grande et al., 2023). Caffeic acid and ferulic acids were detected higher in twenty one cultivars of oat (Sinay et al., 2022) by HPLC-DAD quantification method among thirteen polyphenolic compounds. Literature reported that the concentration of rutin hydrate is positively correlated with the total phenolic content in buckwheat and total phenolic content was reported to be strongly associated with the antioxidant capacity (Beitane et al., 2018) and play a vital role in cellular defense either by scavenging reactive oxygen species or by responding to pro-inflammatory stimuli (EROL et al., 2021; Qu et al., 2021). Caffeic acid and p-coumaric acid content was observed to be higher and quercetin and kaempferol content was found to be lower in quinoa in the present study than in the previous study (Abdelaleem & Elbassiony, 2021) conducted in Egypt. Gramineous plant cell walls contain 4-hydroxy-cinnamic acid and P-coumaric acid, which decreases

LDL oxidation, has antioxidant and antimicrobial activity and improves human health (Boz, 2015). Recent study has shown that (-) epicatechin improves muscular performance, reduces cardiovascular and cerebrovascular symptoms, prevents diabetes, and protects the nervous system. The observed differences in the presence and content of individual phenolic compounds from the previous studies may derived from several factors, for example, geographic variation, harvest time, environmental and agronomic conditions, the botanical parts of plants, and extraction methods, etc. (Georgescu et al., 2022; Liu et al., 2018).

5. Conclusion

This study reported the macro nutrient analysis, total phenolic, flavonoid, antioxidant content, free radical scavenging assays and HPLC-DAD profiling of selected cereals and pseudograins in Bangladesh. We found statistically significant different results of mentioned parameters. The current study's findings suggest that black and red rice, wheat, oat and pseudograins, especially chia seeds may serve as potential sources of dietary fibre, protein, carbs, and phytochemicals, which could contribute to the prevention of many chronic disorders. The variables TPC (Total Phenolic Content), TFC (Total Flavonoid Content), and TAC (Total Antioxidant Capacity) exhibited significant positive associations with the free radical scavenging activities measured by DPPH (2,2-diphenyl-1-picrylhydrazyl), ABTS (2,2'-azino-bis-3-ethylbenzothiazoline-6-sulfonic acid) and FRAP (Ferric Reducing Antioxidant Power). Owing to noticeably varied phenolic compounds content, different cereal responses in different scavenging assays. Black rice was found maximum content of total phenolic, flavonoid and antioxidant but red rice and quinoa showed highest (-) epicatechin than that of other cereals. Red aman rice and black buckwheat exhibited higher levels of free radical scavenging abilities (% of inhibition) as assessed through DPPH, ABTS and FRAP assays with lower IC₅₀ values. The present research highlights the significance and feasibility of grains and investigates their potential for developing food products. Specifically, they can serve as a beneficial aspect that promotes the improvement of dietary habits and overall well-being.

Funding statement

This study received funding from Bangabandhu Science and Technology Fellowship Trust, Ministry of Science and Technology, Bangladesh.

CRediT authorship contribution statement

Anjum Zerine Rupa: Writing – original draft, Software. **Abu Torab M.A. Rahim:** Writing – review & editing, Methodology, Formal analysis, Data curation, Conceptualization. **Md. Hemayet Hossain:** Formal analysis. **Khondoker Shahin Ahmed:** Formal analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors acknowledged the Bangabandhu Science and Technology Fellowship Trust (BSTFT) and Bangladesh Council of Scientific and Industrial Research (BCSIR), Ministry of Science and Technology, Bangladesh, for supporting to conduct the research program.

Supplementary materials

Supplementary material associated with this article can be found, in

the online version, at [doi:10.1016/j.focha.2024.100862](https://doi.org/10.1016/j.focha.2024.100862).

Data availability

Data will be made available on request.

References

- Abdelaleem, M. A., & Elbassiony, K. R. A. (2021). Evaluation of phytochemicals and antioxidant activity of gamma irradiated quinoa (*Chenopodium quinoa*). *Brazilian Journal of Biology*, 81(3), 806–813. <https://doi.org/10.1590/1519-6984.232270>
- Afrin, S. N., Akter, F., & Rahim, A. T. M. A. (2024). Vegetable recipe variations in urban and periurban Bangladesh: Recipe survey, recipe standardization and nutrient analysis. *Bioresearch Communications*, 10(2). <https://doi.org/10.3329/brc.v10i2.74582>
- Agarwal, A., Rizwana, Tripathi, A. D., Kumar, T., Sharma, K. P., & Patel, S. K. S. (2023). Nutritional and functional new perspectives and potential health benefits of quinoa and chia seeds. *Antioxidants*, (7), 12. <https://doi.org/10.3390/antiox12071413>
- Ahmed, K. S., Farzana, M., Rahman, S. E., Jahan, I. A., Khan, T. A., Al-Mansur, M. A., et al. (2023). *Viscum monoicum*: A new source of polyphenolic compounds responsible for antioxidant and anti-inflammatory activities. *Journal of Herbs, Spices and Medicinal Plants*, 29(4), 336–355. <https://doi.org/10.1080/10496475.2023.2182394>
- Ahmed, K. S., Jahan, I. A., Jahan, F., & Hossain, H. (2021). Antioxidant activities and simultaneous HPLC-DAD profiling of polyphenolic compounds from moringa oleifera lam. Leaves grown in Bangladesh. *Food Research*, 5(1), 401–408. [https://doi.org/10.26656/fr.2017.5\(1\).410](https://doi.org/10.26656/fr.2017.5(1).410)
- Alam, S. A. (2015). *Effects of extrusion process variables on the physical properties of oat-containing extrudates* UNIVERSITY OF HELSINKI Department of Food and Environmental Sciences EKT Series 1548 Effects of extrusion process variables on the physical properties of oat-c. May 2012.
- Alejandra, I., Martinez-Gonzalez, Emilio, A. P., Angel, G. D. S., Laura, A. D. L. R., Jose, A. N. G., Alma, A. V. F., et al. (2017). In vitro inhibition of pancreatic lipase by polyphenols: A kinetic, fluorescence spectroscopy and molecular docking study. *Food Technology and Biotechnology*, 55(4), 519–530. <https://doi.org/10.17113/ftb.55.04.17.5138>
- Amarowicz, R., Pegg, R. B., Rahimi-Moghaddam, P., Barl, B., & Weil, J. A. (2004). Free-radical scavenging capacity and antioxidant activity of selected plant species from the Canadian prairies. *Food Chemistry*, 84(4), 551–562. [https://doi.org/10.1016/S0308-8146\(03\)00278-4](https://doi.org/10.1016/S0308-8146(03)00278-4)
- Association of Official Analytical Chemists, A.O.A.C (2000). *Official methods of the analysis of the association of official analytical chemists*. 16th editi.
- Atwater, W. O., & Bryant, A. P. (1900). The availability and fuel of food materials, Storrs, CT, USA. *Agriculture Experiment Stations 12th Annual Report*.
- BBS. (2023). *Summary crop statistics: Bangladesh Bureau of Statistics 2021-22 and 2022-23*.
- Beitane, I., Krümina-Zemtura, G., Krüma, Z., & Cinkmanis, I. (2018). Phenolics content in buckwheat flour. *Proceedings of the Latvian Academy of Sciences, Section B: Natural, Exact, and Applied Sciences*, 72(2), 75–79. <https://doi.org/10.2478/prolas-2018-0012>
- Bolea, C. A., & Vizireanu, C. (2017). Polyphenolic content and antioxidant properties of black rice flour. *Annals of the University Dunarea de Jos of Galati, Fascicle VI: Food Technology*, 41(2), 75–85.
- Boz, H. (2015). Coumaric acid in cereals: Presence, antioxidant and antimicrobial effects. *International Journal of Food Science and Technology*, 50(11), 2323–2328. <https://doi.org/10.1111/ijfs.12898>
- Cremonini, E., Iglesias, D.E., Kang, J., Lombardo, G.E., Mostofinejad, Z., Wang, Z. et al. (2020). (–)-Epicatechin and the comorbidities of obesity. In *Archives of biochemistry and biophysics* (Vol. 690). Academic Press Inc. [10.1016/j.abb.2020.108505](https://doi.org/10.1016/j.abb.2020.108505).
- Das, S., Khound, R., Santra, M., & Santra, D. K. (2019). Beyond bird feed: Proso millet for human health and environment. *Agriculture (Switzerland)*, 9(3). <https://doi.org/10.3390/agriculture9030064>
- Deng, G. F., Xu, X. R., Guo, Y. J., Xia, E. Q., Li, S., Wu, S., et al. (2012). Determination of antioxidant property and their lipophilic and hydrophilic phenolic contents in cereal grains. *Journal of Functional Foods*, 4(4), 906–914. <https://doi.org/10.1016/j.jff.2012.06.008>
- Erol, Z., Erdemli Kose, S. B., Garli, S., & Kocasari, F. (2021). The antioxidant effect of p-coumaric acid against toluene-induced oxidative stress in rats. *Kahramanmaraş Sütçü İmam Üniversitesi Tıp ve Doğa Dergisi*, 24(3), 473–478. <https://doi.org/10.18016/ksutarimdog.vi.765193>
- Francis Raguintin, P., Adam Itodo, O., Stoyanov, J., Dejanovic, G. M., Gamba, M., Asllanaj, E., et al. (2021). A systematic review of phytochemicals in oat and buckwheat. *Food Chemistry*, 338, Article 127982. <https://doi.org/10.1016/j.foodchem.2020.127982> (August 2020).
- Geetha, K., Yankanchi, G. M., Hulamani, S., & Hiremath, N. (2020). Glycemic index of millet based food mix and its effect on pre diabetic subjects. *Journal of Food Science and Technology*, 57(7), 2732–2738. <https://doi.org/10.1007/s13197-020-04309-5>
- Georgescu, C., Frum, A., Virchea, L. I., Sumacheva, A., Shamsyan, M., Gligor, F. G., et al. (2022). Geographic variability of berry phytochemicals with antioxidant and antimicrobial properties. *Molecules (Basel, Switzerland)*, (15), 27. <https://doi.org/10.3390/molecules27154986>
- Grande, T., Souid, A., Ciardi, M., Della Croce, C. M., Frassinetti, S., Bramanti, E., et al. (2023). Evaluation of antioxidant and antimicrobial activities of whole flours obtained from different species of Triticum genus. *European Food Research and Technology*, 249(6), 1575–1587. <https://doi.org/10.1007/s00217-023-04238-5>
- Jun, H. II, Song, G. S., Yang, E. I., Youn, Y., & Kim, Y. S. (2012). Antioxidant activities and phenolic compounds of pigmented rice bran extracts. *Journal of Food Science*, 77(7), 1–6. <https://doi.org/10.1111/j.1750-3841.2012.02763.x>
- Kaur, H., Shams, R., Dash, K. K., & Dar, A. H. (2023). A comprehensive review of pseudo-cereals: Nutritional profile, phytochemicals constituents and potential health promoting benefits. *Applied Food Research*, 3(2), Article 100351. <https://doi.org/10.1016/j.afres.2023.100351>
- Khan, J., Khan, M. Z., Ma, Y., Meng, Y., Mushtaq, A., Shen, Q., et al. (2022). Overview of the composition of whole grains' phenolic acids and dietary fibre and their effect on chronic non-communicable diseases. *International Journal of Environmental Research & Public Health*, 19(5), 3042. <https://doi.org/10.3390/ijerph19053042>
- Khatun, S., & Mollah, M. M. I. (2024). Analysis of black rice and some other cereal grains for protein, sugar, polyphenols, antioxidant and anti-inflammatory properties. *Journal of Agriculture and Food Research*, 16, Article 101121. <https://doi.org/10.1016/j.jafr.2024.101121> (April).
- Khurshed, T., Fatima, T., Qadri, T., Rafiq, A., Malik, A., Naseer, B., et al. (2023). Biochemical, nutraceutical and phytochemical characterization of chia and basil seeds: A comparative study. *International Journal of Food Properties*, 26(1), 1–13. <https://doi.org/10.1080/10942912.2022.2151617>
- Klepcka, J., & Najda, A. (2021). Effect of commercial processing on polyphenols and antioxidant activity of buckwheat seeds. *International Journal of Food Science and Technology*, 56(2), 661–670. <https://doi.org/10.1111/ijfs.14714>
- Cañizares, Lázaro, Silvia Meza, B. P., Rodrigues, L., Jappe, S. N., Coradi, Paulo Carteri, & de O, M. (2024). Functional foods from black rice (*Oryza sativa* L.): An overview of the influence of drying, storage, and processing on bioactive molecules and health-promoting effects. *Foods (Basel, Switzerland)*, 13, 1088. <https://doi.org/10.3390/foods13071088>
- Li, L., Lietz, G., & Seal, C. J. (2021). Phenolic, apparent antioxidant and nutritional composition of quinoa (*Chenopodium quinoa* Willd.) seeds. *International Journal of Food Science and Technology*, 56(7), 3245–3254. <https://doi.org/10.1111/ijfs.14962>
- Liu, Y., Chen, P., Zhou, M., Wang, T., Fang, S., Shang, X., et al. (2018). Geographic variation in the chemical composition and antioxidant properties of phenolic compounds from cyclocarya paliurus (batal) jinskaja leaves. *Molecules (Basel, Switzerland)*, (10), 23. <https://doi.org/10.3390/molecules23102440>
- Martín-Diana, A. B., García-Casas, M. J., Martínez-Villaluenga, C., Frías, J., Peñas, E., & Rico, D. (2021). Wheat and oat brans as sources of polyphenol compounds for development of antioxidant nutraceutical ingredients. *Foods (Basel, Switzerland)*, 10 (1), 1–21. <https://doi.org/10.3390/foods10010115>
- Martínez-Villaluenga, C., Peñas, E., & Hernández-Ledesma, B. (2020). Pseudocereal grains: Nutritional value, health benefits and current applications for the development of gluten-free foods. *Food and Chemical Toxicology*, 137, Article 111178. <https://doi.org/10.1016/j.fct.2020.111178>
- Mazumdar, A., Bhatt, D., Author, C., & Ga, A. (2022). Utilization of black rice and red rice in value added products: A review. ~ 1661 ~ *The Pharma Innovation Journal*, 11 (7), 1661–1665. www.thepharmajournal.com.
- Namrata, S., & Haripriya, A. (2022). Effect of germination on selected phytochemicals and antioxidant activity of quinoa (*Chenopodium quinoa*). *Indian Journal of Traditional Knowledge*, 21(4), 876–882. <https://doi.org/10.56042/ijtk.v21i4.33004>
- Obeta, N.A., Oti, C.E., Ugwuona, F.U., & Peter, E.S. (2020). *Processing Treatments of Beniseed (Sesamum indicum Linn) on Nutrients, Anti-Nutrients Composition and Functional Properties of Flour*. 314–325. <https://doi.org/10.4236/fofs.2020.114023>
- Pradipta, S., Ubaidillah, M., & Siswoyo, T. A. (2020). Physicochemical, functional and antioxidant properties of pigmented rice. *Current Research in Nutrition and Food Science*, 8(3), 837–851. <https://doi.org/10.12944/CRNFSJ.8.3.15>
- Pushparaj, F. S., & Urooj, A. (2014). Antioxidant activity in two pearl millet (*Pennisetum typhoidum*) cultivars as influenced by processing. *Antioxidants*, 3(1), 55–66. <https://doi.org/10.3390/antiox3010055>
- Qu, Z., Liu, A., Li, P., Liu, C., Xiao, W., Huang, J., et al. (2021). Advances in physiological functions and mechanisms of (–)-epicatechin. *Critical Reviews in Food Science and Nutrition*, 61(2), 211–233. <https://doi.org/10.1080/10408398.2020.1723057>
- Rahim, A. T. M. A., Takahashi, Y., & Yamaki, K. (2015). Mode of pancreatic lipase inhibition activity in vitro by some flavonoids and non-flavonoid polyphenols. *Food Research International*, 75, 289–294. <https://doi.org/10.1016/j.foodres.2015.05.017> (May 2015).
- Rocchetti, G., Lucini, L., Rodriguez, J. M. L., Barba, F. J., & Giuberti, G. (2019). Gluten-free flours from cereals, pseudocereals and legumes: Phenolic fingerprints and in vitro antioxidant properties. *Food Chemistry*, 271, 157–164. <https://doi.org/10.1016/j.foodchem.2018.07.176>
- Rupa, A. Z., & Rahim, A. T. M. A. (2023). Ethnographic survey on cereal and pseudocereal in Bangladesh perspective. *Food Research*, 7(2), 222–229. [https://doi.org/10.26656/fr.2017.7\(2\).669](https://doi.org/10.26656/fr.2017.7(2).669)
- Sargi, S. C., Silva, B. C., Santos, H. M. C., Montanher, P. F., Boeing, J. S., Santos Júnior, O. O., et al. (2013). Antioxidant capacity and chemical composition in seeds rich in omega-3: Chia, flax, and perilla. *Food Science and Technology*, 33(3), 541–548. <https://doi.org/10.1590/S0101-20612013005000057>
- Shahbaz, M., Raza, N., Islam, M., Imran, M., Ahmad, I., Meyyazhagan, A., et al. (2022). The nutraceutical properties and health benefits of pseudocereals: A comprehensive treatise. *Critical Reviews in Food Science and Nutrition*, 63(29), 10217–10229. <https://doi.org/10.1080/10408398.2022.2071205>
- Sharma, S., Kataria, A., & Singh, B. (2022). Effect of thermal processing on the bioactive compounds, antioxidative, antinutritional and functional characteristics of quinoa (*Chenopodium quinoa*). *Lwt*, 160, Article 113256. <https://doi.org/10.1016/j.lwt.2022.113256> (February).
- Sinay, H., Mahulette, F., & Yáñez, J. A. (2022). Determination of free radical scavenging activity, phenolic and flavonoid content of seven corn cultivars from the Southwest

- Maluku District, Indonesia. *Biodiversitas*, 23(11), 5974–5981. <https://doi.org/10.13057/biodiv/d231151>
- Smith, C. E., & Tucker, K. L. (2011). Health benefits of cereal fibre: A review of clinical trials. *Nutrition Research Reviews*, 24(1), 118–131. <https://doi.org/10.1017/S0954422411000023>
- Sulaiman, S.A., Kassum, A.L., & Sanusi, S.N. (2020). Proximate analysis and mineral compositions of different cereal grain varieties available in Kano state, Nigeria. In *International journal of food science and nutrition*. www.foodsciencejournal.com.
- Thitipramote, N., Pradmeeteekul, P., Nimkamnerd, J., Chaiwut, P., Pintathong, P., & Thitilerdecha, N. (2016). Bioactive compounds and antioxidant activities of red (Brown Red Jasmine) and black (Kam Leum Pua) native pigmented rice. *International Food Research Journal*, 23(1), 410–414.
- Tian, S., Sun, Y., Chen, Z., Yang, Y., Wang, Y., & Trabelsi, N. (2019). Functional properties of polyphenols in grains and effects of physicochemical processing on polyphenols. *Journal of Food Quality*. <https://doi.org/10.1155/2019/2793973>. 2019.
- Mili, F. T. J., & Rahim, A. T. M. A. (2024). Nutrient composition of nine festival dishes obtained from a recipe survey among lower to middle-class households in selected urban areas. *Bioresearch Communications*, 10(2). <https://doi.org/10.3329/brc.v10i2.74573>
- Zhong, L., Lin, Y., Wang, C., Niu, B., Xu, Y., Zhao, G., et al. (2022). Chemical profile, antimicrobial and antioxidant activity assessment of the crude extract and its main flavonoids from tartary buckwheat sprouts. *Molecules (Basel, Switzerland)*, (2), 27. <https://doi.org/10.3390/molecules27020374>