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Development of traditional food products with nutritional assessment for the vulnerable rural population of West Bengal

Thesis

Submitted by

NAJMUN NAHAR

Registration No. D-7/ISLM/61/16 date: 27.07.2016

For the Degree of Doctor of Philosophy (ISLM)

Department of Food Technology and Biochemical

Engineering (FTBE),

Jadavpur University, Kolkata, India

2022

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Under the supervision of

1. **Prof. Utpal Raychaudhuri,** Professor (Retired) Department of Food Technology and Biochemical Engineering, Jadavpur University, Kolkata, India
2. **Dr. Sunita Adhikari (Nee Pramanik),** Associate Professor, Department of Food Technology and Biochemical Engineering, Jadavpur University, Kolkata, India

Dedicated to all who loved and supported me during the work

List of publications

Book Chapter:

(i) **Najmun Nahar,** Utpal Raychaudhuri, and Sunita Adhikari (Nee Pramanik), **"Characterization of black gram nuggets (Bori): Traditional product of Midnapore district, West Bengal, India." Biotechnological Intervention towards Enhancing Food value,** ***Nova Publishers*** (2022).
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Journal:

(i) **Najmun Nahar,** Seyashree Hazra, Utpal Raychaudhuri, and Sunita Adhikari (Nee Pramanik)**,** "**Effect of different drying methods on drying kinetics, modeling, energy-economic, texture profile, color, and antioxidant of lotus rhizomes (Nelumbo nucifera**)." ***Journal of Food Processing and Preservation***, Wiley, (2022). DOI: 10.1111/jfpp.16842

(ii) **Najmun Nahar,** Seyashree Hazra, Utpal Raychaudhuri, and Sunita Adhikari (Nee Pramanik)**, "Development a Novel Poushtic Powder: Nutritional characteristics, organoleptic properties, morphology study, storage, and cost analysis of supplementary food for a vulnerable group in Midnapore."** ***Research Journal of Pharmacy and Technology***,

(iii) **Najmun Nahar,** Utpal Raychaudhuri, and Sunita Adhikari (Nee Pramanik)**, "Effect of drying on kinetics, physiochemical, and antioxidant properties of black gram nuggets."** ***Legume Science***, Wiley, (2022). DOI:10.1002/LEG3.170

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(ii) **Najmun Nahar,** Utpal Raychaudhuri, and Sunita Adhikari (Nee Pramanik), "Characterization of black gram nuggets (Bori): Traditional product of Midnapore district, West Bengal, India." Organized by the University of Engineering and Management (UEM), Kolkata, West Bengal, India, in 2018.

(iii) **Najmun Nahar,** Utpal Raychaudhuri, and Sunita Adhikari (Nee Pramanik), "Scenario of self-help group food products of Midnapore district, West Bengal, India." Organized by Maharajadhiraj Uday Chand Women's College (MUCWC), Burdwan, West Bengal, India, in 2018.

(iv) **Najmun Nahar,** Utpal Raychaudhuri, and Sunita Adhikari (Nee Pramanik), "Modalities delivery of nutritional product towards the vulnerable group in rural areas by organizing attitude development program for sanitation and hygiene (Under Swachh Bharat Abhiyan) of the self-help groups." Organized jointly by Burdwan University (BU) and the Department of Higher Education, Science and Technology and Biotechnology (DHESTBT) Burdwan, West Bengal, India, in 2017.

Statement of Originality

I, Najmun Nahar, registered on, do hereby declare that this thesis entitled "Development of traditional food products with nutritional assessment for the vulnerable rural population of West Bengal" area contains a literature survey and original research work done by the undersigned candidate as part of Doctoral studies. All information in this thesis has been obtained and presented in accordance with existing academic rules and ethical conduct. I declare that, as required by these rules and conduct, I have fully cited and referred all materials and results that are not original to this work. I also declare that I have checked this thesis as per the "Policy on Anti Plagiarism, Jadavpur University, 2022", and the level of similarity as checked by iThenticate software is 5%.

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This is to certify that the NAJMUN NAHAR submitted a thesis entitled "Development of traditional food products with nutritional assessment for the vulnerable rural population of West Bengal" registered on 27th July 2016 for the award of Ph.D. (Science) under the Faculty of ISLM registration no. D-7/ISLM/61/16 date: 27.07.2016)) degree of Jadavpur university under the supervision of Prof. Utpal Raychaudhuri and Dr. Sunita Adhikari (Nee Pramanik). Her thesis or any part of the thesis has not been submitted for any degree/diploma or any other academic award anywhere before.

Signature of the supervisor and date with the official seal.

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Najmun Nahar

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Abstract

Traditional foods play a vital role in human nutrition by being the primary source of carbohydrates, protein, fat, vitamins, and minerals. Besides, it provides bioactive compounds and good bacteria, which are highly critical to human well-being and the prevention of deadly diseases.

Though judging the nutritional quality, we can know how much nutrients a food contains, which increases our awareness about that food and increases the social value of the food. The product development and nutrient extraction processes play a crucial role in realizing the potential of different traditional food. In both cases, the formal process has been mainly used for their cheap set-up, easy scale-up, and control. Novel techniques can provide better performance as they often involve multiple energy transfer pathways. This review summarizes the principal mechanisms involved in different methods and their application.

The Second Chapter of this thesis evaluated the Black gram nuggets (*bori*), a popular traditional pulse-based food item in India, which are prepared from aerated paste (batter) of soaked black gram (*Phaseolus mungo*) and have high nutritional importance. This study collected samples from spinach bori, carrot bori, tomato bori, wax-gourd bori, and daikon bori. Carbohydrates, protein, fat, ash, moisture, antioxidants, and activity were analyzed. The incorporation of vegetables improved the antioxidant content and activity of *bori* samples. Improvement in total phenolic content to the range of 0.76-1.15 mg/g, entire flavonoid content to the field of 0.77-1.33 μg/g. FRAP assay activity to the range of 6.92-11.48 μmol/g, and DPPH assay activity to the range of 7.50-36.04 %, against control was observed. Total carbohydrate and fat content also improved to 0.84-2.39 % and 8.00-15.50 %, respectively. Protein and ash content decreased to 2.82-1.35%-2.82 % and 1.11-10.31 % against control. The moisture content of all samples increased during storage compared to the initial day. Moisture content helps to indicate their shelf life. Principal component analysis

justifies the correlation of characterization parameters and *bori* varieties. A texture profile analyzer helps to analyze their textural properties.

In Part A of the Third Chapter, the effects of moisture content of batter, air integration in batter, and temperature of tray dryer were studied on hardness, whiteness index, water absorption capacity, and oil uptake ratio of black gram nugget (*bori*) and it was optimized using response surface methodology. The optimized conditions were: moisture content 67.01%, air incorporation 21.68% (v/v) of batter and 600C temperature required to attain maximum whiteness index of 81.21, water absorption capacity 41.86 ml/ gm-min, minimum hardness value 44.59 N and oil uptake ratio 14% of nuggets. The carbohydrate, protein, fat, and ash contents of optimized black gram nuggets were 65.49%, 25.70%, 1.45%, and 1.87%. HPLC analysis showed the presence of different antioxidants in it. The color, texture, porosity, and diameter changes of the optimized black gram nuggets during cooking indicated that it was of good quality.

The Part B of the Third Chapter compares the mode of selected drying techniques (hot-air, freeze, microwave drying) on drying kinetics, followed by the development of suitable mathematical modeling for the process. Additionally, the antioxidant, color, and textural properties of dried products were evaluated for their acceptability and associated health benefits. Based on regression parameters, it was discovered that the page model fit better (R2 =0.999 to 0.991 and SSerror = 0.000025 to 0.0424) the experimental data compared with other models. The effective moisture diffusivity exhibited an inverse relation to drying time. Among tested drying, it was found that TB in microwave drying at 450 W had the highest amount of phenolic content (5.27mg / g), flavonoid content (1.72 mg/ 100 g), ferric reducing antioxidant power assay (45.71 μmol/g), 61.42 μmol/g of ABTS assay, and 67.81 μmol/g of DPPH assay values were found. The freeze-drying products were better for physicochemical parameters than other drying process products. The presence of phytochemicals was responsible for the high bioactivity of microwave-dried nuggets.

In the Fourth Chapter, Part A, this study was conducted on lotus rhizomes to find the kinetics of drying and ultrasound-assisted extraction process of antioxidant, energy-economic, quality parameters, and phytochemicals under different drying processes. Milli et al. model was found to be the best-fitted drying model with a low SSerror (0.0145 – 0.0088), RMSE (0.02 to 0.005), and highest R2 (0.999 to 0.992) value. The energy consumption cost (1518.33 Rs) is increased in tray dryers and low in microwave dryers (28.68 Rs). The vacuum-dried lotus rhizomes had a high content of total phenolics of

78.364 mg/g, flavonoids of 10.819 mg/g (dm) content, DPPH of 74.621 μmol/g, ABTS of 104.36 μmol/g, and FRAP of 108.312 μmol/g. Low hardness (12.642 N), resilience (0.468), and high whiteness (61.158) were observed in freeze-dried rhizomes. Microwave and vacuum drying showed a short drying process with better energy economy and higher antioxidant content, but quality parameters are best for a freeze-drying product.

In the Fourth Chapter, Part B, the spongy endosperm of germinated palmyra seed is very nutritious and delicious as a food item. Due to their macro and micronutrient enrichment with antioxidant compounds, it is used to satisfy hunger and promotes good health for vulnerable groups in many developing countries. Morphological analysis and bioactive compounds were also studied to find a suitable time-effective drying process and the effect of this drying method on the quality attributes. WPS Workbench evaluated the kinetics, mathematical modeling, and retention time of the ultrasound-assisted extraction process of different drying methods. Ink software. Color and texture are determined by Hunter Lab colorimeter and TA. XT texture analyzer, respectively. A morphological study was conducted on Field Emission Scanning Electron Microscope (FESEM).

A statistically significant difference was determined by Minitab 19.0 software. The water molecule present in SE-GPS is directly absorbed by electromagnetic energy in microwave drying resulting in quick dehydration in a comparatively short time (6 min). Two-term is the best model with the lowest value of sserror (0.091 – 0.00043), RMSE (0.114 -0.0079), and high R2 (0.969 – 0.999). The free phenolic (6.854 mg/g), free flavonoid contents (1.358 mg/g), DPPH (56.071μmol/g), FRAP (47.841 μmol/g), and ABTS (54.287μmol/g) present in the highest amount in MD 450-W dried product. The minimum retention time (6 to 9 min) was observed in MD 450-W dried product in the UAE process. SEM helps to determine the morphological changes in different drying processes. The freeze-dried product showed an acceptable change in the quality parameters that had less hardness (13.362 N), high porosity (73.793%), high springiness (1.268), and high whiteness (88.522) value. MD at 450-W is the best drying technique in a short time with high moisture evaporating capacity, less retention time of UAE, high amount of antioxidant content, and antioxidant activity. FD is considered as best according to its physical quality parameter. High-temperature long-time exposure to drying can be harmful to bioactive compounds. The low cost-effective short-time microwave drying process was the best drying process with lots of bioactive compounds of SE-GPS, which suggested the potential application in the food and medicinal industry. Retention time helps to determine the maximum free antioxidant content with minimum extraction time and prevent the loss of phytochemicals during the UAE process. Color, texture, and morphology studies helped to determine the physical properties.

In the Fifth Chapter, Ready supplementary food has been the best choice to arrest hunger and malnutrition in developing countries. To create low-cost, highly nutritious additional food with locally available ingredients, those fill-ups up the requirements of nutrients of Indians per day at different age groups according to recommended dietary allowance. To prevent malnutrition and keep children healthy, the ICDS center provides several foods: poushtic laddu, made with rice, wheat, groundnut, gram flour, and sugar. The women of the self-help group mainly make these nutritious laddu ingredients and provide them to the ICDS center. Currently, several ICDS centers offer poushtic powders made by CINI known as Nutrimix, which is advised to feed the children as laddu at home. This laddu powder lags far behind in nutrition and phytochemicals; this is the reason for submitting the report to improve the quality of this laddu in terms of nutrition. Three different poushtic powders were prepared, marked as P, PC, and PI, by healthy and nutritious food ingredients locally available in the market and environment. After experiments, it was found that P, PI, and PC are best for protein (28.315 g), iron (23.77 mg), and calcium (325.502 mg) content, respectively. A sufficient amount of macro and micronutrients is present in all poushtic powders. Phytochemicals like ascorbic acid, gallic acid, chlorogenic acid, valinic acid, routine, trans-cinnamic acid, ferulic acid, quercetin, apigenin, and kaempferol are found to be present. An antioxidant activity like FRAP (12.854 μmol/gm), ABTS (19.217 μmol/gm), and DPPH (19.167 μmol/gm) is high in the PC sample. Every poushtic powder is good in one way or another. SEM determines morphology and particle size with a correlation with hardness and fineness. Different storage containers define the shelf life of the products. In this study cost of the three products is analyzed for product marketing. Locally available ingredients help to prepare the low price with highly healthy and nutritious ready-to supplementary food products that improve human health and nutritional status.

Chapter 1

Introduction

1.1. Introduction of Traditional Food

Traditional food products (TFP) constitute an essential element of Indian culture, identity, and heritage contributing to the development and sustainability of rural areas, protecting them from depopulation, and entailing substantial product differentiation potential for producers and processors (Avermaete et al., 2004) and providing ample variety in food choice for consumers. Consumers often recognize TFPs with characteristics linked to regional identity and sensory quality. An essential part of TFP is sold under different collective trademarks, such as quality labels, and, in general, consumers show a favorable attitude towards such products (Guerrero, 2001). However, producers of TFP still face the challenge of further improving their products' safety, healthiness, and convenience using different innovations, enabling them to maintain and expand their market share in a highly competitive and increasingly global food market. It is, however, essential to get an insight into consumers' perceptions, expectations, and attitudes toward traditional food products and consumers' attitudes to innovations related to TFP. A basis for exploring these dimensions is a need to define the concept of traditional products and innovation related to TFP.

1.1.1. Origin and definition

There are a few definitions in the literature of traditional foods. According to Bertozzi et al. (1998), A traditional food item is a "part of a population, it belongs to a certain location, and it is a component of a tradition that requires the collaboration of the people living in that region." Jordana (2000) derived from this sociological definition following: "An item must be associated with a region which is a group part of customs in to be considered traditional, which ensures its persistence over time." In 2006, the European Commission gave the following definition of "traditional" related to foods: "Traditional means proved usage in the community market for a period showing transmission between generations; this time should be the one generally ascribed as one human generation, at least 25 years" (de Boer et al., 2006).

Recent efforts by The European FIR FP6 Center of Innovation have resulted in the development of an explanation of traditional cuisine. That one definition is detailed and makes claims concerning conventional ingredients, composition, and methods of manufacture and processing (Antonia Trichopoulou et al., 2007). According to the Italian Ministry of Agriculture, the only official definition of traditional food products (TFP) in Europe is "Agri-food items whose techniques of preparation, preservation, and maturation are standardized over time by consistent and regular local use" (Ministero Agricoltura, 1999). Although these definitions make an effort to encompass the various facets of the notion of traditional food products, one perspective still needs to be added, namely an explanation of this concept as seen from the standpoint of the consumers. Fagerberg (2018) claimed that the definition of innovation must be flexible because it relies on the context. According to this author, *innovation* is commonly defined as the successful introduction of something new and helpful. Hence it is possible to identify an ordinary meaning. The definition of innovation in food and drink by Moskowitz et al., (2006) now includes the concept of "recombination of components into new mixes." According to Carayannis et al., (2003), innovations are "the new products and services that arise from technology." However, it is crucial to remember that, in the case of innovation, the customer perspective is again absent. Clear communication using a common language is necessary to properly comprehend consumers' feelings and desires (Sokolow, 2019).

Therefore, to comprehend consumers' attitudes toward innovations in TFP, definitions of TFP and TFP innovation derived from the customers' perspective are required. These emotions and desires are typically influenced by sociocultural factors, which may be affected by the consumers' nation or location of origin. Culture may be one of the most influential factors influencing eating attitudes and behaviors (Rozin, 2004). Cross-cultural studies generally reveal significant variances in food-related elements, even in relatively homogeneous nations like those that makeup India (de Boer et al., 2006; Olsen et al., 2007).

These variations can be seen in dietary preferences, consumption habits, lifestyle choices, attitudes, and beliefs. The diversity of cultural food preferences across Europe has been shown at various levels, including the protein diet composition (de Boer et al., 2006); the significance of food risk communication strategies (Van Dijk et al., 2008), attitudes toward food, nutrition, and health, or food behavior and attitudes.

1.1.2. characteristics

This variety is even more pronounced regarding traditional food items and traditional cuisine, primarily based on the local natural resources. Jordana (2000) asserts that southern European nations have more traditional food characteristics due to a larger market share for small businesses and a better climate, enabling a more comprehensive conventional food distribution. Therefore, examining and contrasting how TFP and innovation are defined in various nations with various cultural backgrounds appears reasonable. As a result, depending on where the customers are from, the meanings of TFP and TFP-related innovation may vary.

While Weatherell et al., (2003) found that rural-based consumers tend to give a higher priority to "civic" issues in food choice, exhibit higher levels of concern over food provisioning issues, and show greater interest in local foods, urban consumers may be more likely to reconnect with their rural roots. Using qualitative research methods, mainly focus group talks, is among the best ways to gain preliminary insights into the concept underpinning traditional food goods and innovation from a consumer's point of view. A focus group discussion is a technique where a select group of people is chosen to learn about their response to concepts and products.

Traditional meals have long piqued people's interest because they are the foundation of nourishment in many different cultures and societies. Nevertheless, since the industrial food growth, or the mass production that started in the middle of the 20th century, a sharp difference in quality was highlighted, especially by consumers, who divided food into two major groups:

those manufactured in mass, standardized, and from which the source of the raw resources with that is produced is unknown, as well as the process of explanation; and products that are made in micro-scale, to a specific extent heterogeneous, and Since the method of elaboration cannot be fully understood, the location of the raw resources can be inferred, which gives consumers greater confidence, we could argue that artisan products have a closer relationship between maker and consumer. Therefore, globalization discouraged and promoted the manufacture and taste of specific meals. As a result, since the 1990s, interest in these meals has increased, mainly focused on enhancing their value and safeguarding them (Cerjak et al., 2014; A. Trichopoulou et al., 2006; Antonia Trichopoulou et al., 2007).

Traditional cuisine reflects culture, history, and way of life. Although we live in a world of globalization, different dietary patterns between countries exist, as Slimani et al., (2002) have reported. Studying traditional foods offers an essential insight into nutritional habits and how these have been shaped through time.

Traditional foods and patterns may have potential health properties that have been tested over time. For instance, this has been shown for the traditional Mediterranean diet based on observational studies and physiological arguments (Willett, 2006) and even randomized trials (Estruch et al., 2006). Because of this, there is a greater demand for traditional foods today, which has piqued the interest of food makers. This increased demand is a result of the current draw of the nation in healthy eating and nutrition. Allende et al., (2006) showed how the industry tried to adjust when consumer pressure was developed toward fresh-cut plant products.

1.2. Vulnerable population

The bulk of people in developing countries is impoverished. They lack sufficient access to fundamental necessities of life like food, shelter, health care, education, employment, security, and equity. The main issue in emerging countries is ensuring that the most disadvantaged populations can participate in social and political life. Governments still need to uphold the rights of citizens at the implementation level. Vulnerable group members are unable to obtain and exercise their rights. In light of this, ICCPR and ICESCR have guaranteed the rights to a sustainable means of subsistence and social, political, and economic development for all people, especially the underprivileged. Many nations have ratified these covenants. The Indian government approved ICESCR in 1979.

All people have a universal right to exist. Identifying marginalized and vulnerable groups within the context of health and human rights was inspired by the urgent situation that resulted from the fact that some groups do not fully enjoy human rights, consisting of the right to political participation, health, and education. Considering the right to life, vulnerability is the deprivation of some people and groups whose rights have been infringed by the agency executing that right (Yamin, 2007). To prevent possible exploitation, certain groups in society frequently experience discrimination. This group of people makes up what is known as Vulnerable Groups. Compared to others, vulnerable people are disadvantaged chiefly due to their limited access to medical care and the fundamental factors that affect health, such as safe and sanitary drinking water, nutrition, housing, and sanitation. People living with HIV/AIDS, for instance, experience numerous forms of discrimination that harm their health and restrict their access to health services. People with disabilities frequently struggle to find a job or receive proper care.

Awareness of vulnerable populations, their health, and their human rights requires understanding participation and avoiding violation. An essential part of implementing the right to health, according to the Economic, Social and Cultural Rights Committee of the United Nations (ESCR Committee), is "improving and advancing population participation the management of the medical sector, the providing of curative and preventive healthcare services, creating and developing self-help groups, the insurance system, and, in particular, when making political choices about the right to wellness."

The connections between health and the human rights of the most disadvantaged people are numerous and intricate. Human rights violations or disregard for some groups might have detrimental health effects (abuse, stigma and discrimination, harmful traditional practices, violence, torture, etc.). The way that health policies and programs are created can either uphold or undermine particular populations' human rights (accessibility to service, provision of information, respect for integrity and privacy, cultural sensitivity, gender and age sensitivity). Sex, class, religion, age, sexual orientation, ethnic identity, disability, health condition (HIV/AIDS), civil, political, social, or other statuses should not unfairly penalize someone's ability to enjoy excellent health. All governments must safeguard and advance the conditions necessary to exercise the right to health.

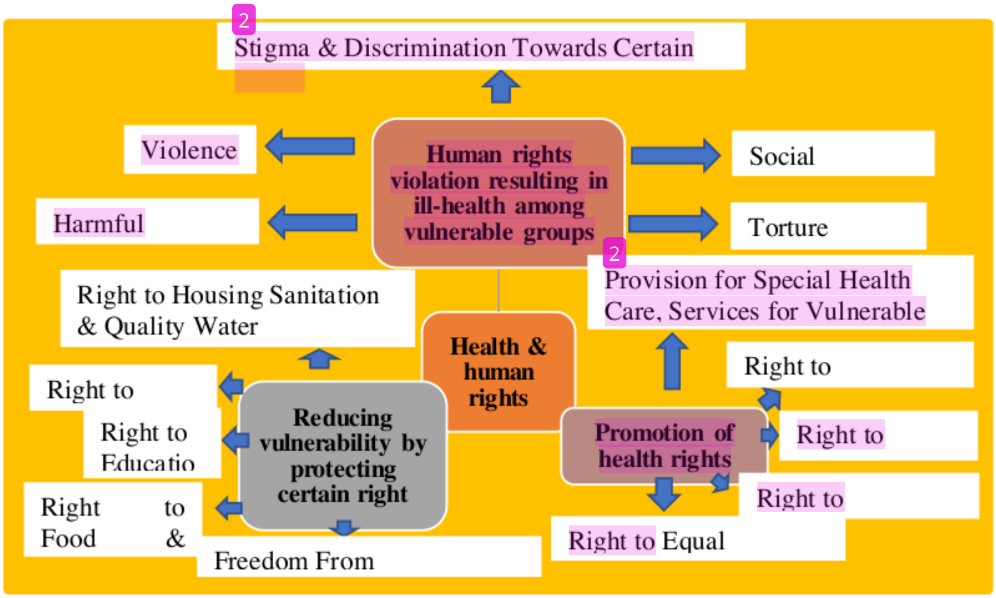

Figure 1.1. Health & human rights of vulnerable groups.

Members of specific communities in India face various socioeconomic constraints that restrict their access to health care. Finding the vulnerable groups to focus on is a difficult undertaking. In addition, many complex vulnerability variables make it difficult to analyze them separately. The current document is based on some of the common grounds for discrimination against individuals or members of groups in India, including structural issues, age, disability, mobility, stigma, and prejudice that prevent access to health care. Women, Scheduled Castes (SC), Scheduled Tribes (ST), children, elderly, disabled, poor migrants, those living with HIV/AIDS, and sexual minorities are among the vulnerable groups that experience prejudice. Due to their diversity of identities, each group occasionally encounters many impediments. For instance, disabled women in patriarchal societies experience double discrimination due to gender and disability.

In India, people who identify as belonging to a particular gender, caste, class, or ethnic group face institutional discrimination that affects their health and ability to receive healthcare. Being a member of a specific caste, class, or ethnic group and having gendered vulnerabilities result in double discrimination for women. Early marriage and childbearing harm women's health in India. In India, about 28% of girls get pregnant and married before the legal age (Reproductive and Child Health – District level Household Survey 2002-04, August 2006). These have detrimental effects on women's health. In India, maternal mortality is very high. The national average maternal mortality rate is 540 deaths per 100,000 live births (National Family Health Survey-2, 2000). Rural-urban balance differs between states and geographical areas.

In contrast to the urban population, where there are 267 maternal deaths per 100,000 live births, there are 617 fatalities of females in rural areas between the ages of 15 to 49 (National Family Health Survey-2, 2000). Most often, deaths are caused by avoidable factors. According to reports, many women did not obtain antenatal care.

Women from lower socioeconomic classes in India deliver babies in hospitals at a lower rate than women from higher classes. Violence against women affects their health. A girl child experiences various types of violence throughout her early years of development, including infanticide and the neglect of her nutritional, educational, and medical needs. Adults who experience violence must deal with domestic abuse, workplace sexual harassment, unplanned pregnancies, rape in marriage, and honor killings. Depending on the women's caste, class, and ethnic identification, different types of violence and their effects on health are experienced. Inequality is also fostered by caste. In Indian civilization, caste is a specific type of social inequality that entails a hierarchy of groups classified according to ritual purity.

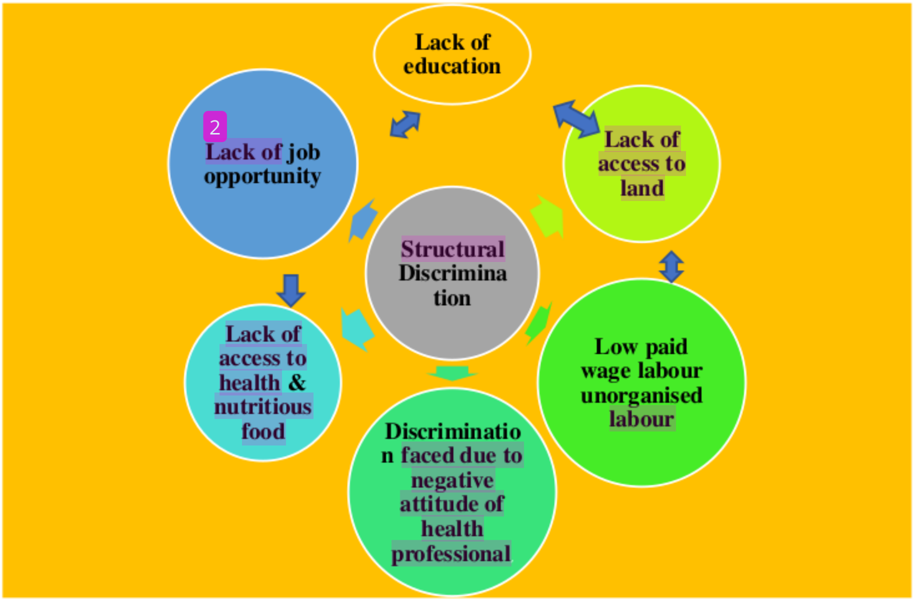

Figure 1.2. Structural Discrimination Faced by Groups

Members of a group or stratum have specific knowledge of common interests and similar identities. The caste system is connected to the ownership of natural resources, sources of subsistence, and in the context of India, especially to land economy and power relations based on land. The hierarchy of occupations, which put tasks linked to leather, cleaning up dead animals from village grounds, work related to burial customs, etc., at the bottom, served as the traditional foundation for caste relations. According to the purity-impurity theory, those individuals or castes responsible for removing the contaminated aspects from society were seen as "untouchables" compared to Brahmins, who were at the top of the social hierarchy. The lower castes were structurally dependent on, the higher castes for economic survival.

Women are crucial in delivering primary healthcare, cleanliness, nutrition, and child care (Balasubramaniam, 2006). Women are essential to food procurement, preparation, storage, and distribution. Nevertheless, they frequently suffer from malnutrition, making them a group that is particularly susceptible to morbidity and mortality from undernutrition.

In India, 36% of females aged 15 to 49 have a BMI below 18.5, indicating poor nutrition, and 16% are moderate to severely underweight. 15% of women identify as overweight or obese (NFHS 3, 2005- 2006).

A woman's poor health affects not just her but also her family. Babies with low birth weight are more likely to be delivered by women who are ill. Additionally, they are less likely to be able to give their kids healthy food and proper care. Lastly, a woman's health impacts the household's financial stability because a sick woman will be less productive at work (Kamalapur & Reddy, 2013).

Microfinance and Self-Help Group (SHG) interventions have significantly improved women's lives in India at the community level by empowering them.

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A Self-Help Group in its present development orientation owed its origin to the starting of the Grameen Bank, founded by Mohamed bonus of Bangladesh, the Nobel prize winner for peace for the year 2006. The experience of Bangladesh proved to the world the banking wisdom in 3 helping women and poor people improve their economic condition and overcome their problem of poverty.

Health is undoubtedly a crucial aspect of women's empowerment and well-being. It is also inextricably tied to how they live in the home and society. Women's health and nutritional status are generally in bad shape, and many efforts are being used to facilitate the situation. Self-help groups are among the best organizations to help enhance women's positions (SHGs).

Self-Help Groups are village-based financial intermediaries, often made up of 10 to 15 local women. The group, which may or may not be legally organized, will come from similar socioeconomic backgrounds and come together thoroughly to save money and use that money to contribute to a pooled fund that will aid them in times of need (Mandal, 2013).

Women have had knowledge and sovereignty over their health for millennia. Our bodies only became the "property" of doctors with the "modernization" of our healthcare system. In terms of their health and other associated issues and solutions, rural women still mostly rely on knowledge gleaned from other females or senior females in their families and community. Although we cannot state that these encounters occur inside a formal SHG organization, helping others has been a tradition for a century. While women of all orientations, races, classes and ages gather in legal self-help groups to discuss various concerns, mostly their financial requirements and commerce, they can converse about and share challenges and wellness info with other participants (Aniket, 2018).

Self-Help Groups provide savings and an efficient credit delivery system to meet members' financial needs, enabling the users to study, collaborate, and perform teamwork (Bassi, 2015). Women need credit because it increases their access to resources and helps them manage their expenditures, which allows them to deal with their poverty and backwardness.

SHGs are essential in raising awareness of health issues by organizing important gatherings of women (Chakravarty & Jha, 2012). SHGs are recognized as a critical method because it empowers women and reduces social inequality. A self-help group (SHG) is a "people's scheme," consequently, the establishment of the group is an essential step in empowering women. Women SHGs are an intervention strategy that significantly differs from the most recent works. These successful techniques include eradicating insecurity, advancing females, and fostering cultural development (Kanti et al., 2013). It is anticipated that SHGs will contribute more to attaining the "Millennium Development Goals" in underdeveloped nations and enhance women's health and empowerment.

A woman's dietary status affects her and her children's health significantly. An undernourished woman, as shown, tends to be lower anemia or other nutritional deficits, lower body-mass index (BMI), is more likely to experience labor complications, have a baby who is born underweight, experience adverse pregnancy outcomes, produce lower-quality breast milk, pass away from a postpartum hemorrhage, and become ill both for herself and her child (NFHS-3, 2005-06).

1.3. Supplementary food product

Taking care of dietary deficiencies has significant economic and societal benefits, such as lowering mortality and morbidity rates, conserving resources for healthcare, enhancing productivity, raising earnings, and improving educational outcomes (SCN, 2004). Dietary diversity, food fortification, dietary supplements, and illness prevention are among the strategies that can be used to combat malnutrition.

Supplements and dietary-based tactics like diet counseling with nutrition enhancement are the most often used techniques to combat malnutrition (Ruel & Levin, 2002). Food-focused interventions are crucial for treating and preventing macro- and micronutrient deficits.

The most fantastic strategy for improving females' nutritional level is through food-based initiatives, mainly through utilizing inexpensive, readily available nutritious foods in the local area. Women must possess the necessary knowledge to choose, prepare, and process foods in the proper combinations. Women need to have enough for that.

Therefore, carefully planned food-based interventions can help poor populations' diets relatively quickly while using nutrients or getting assistance from nutrition and health education (Fanzo et al., 2012).

While food-based tactics like biofortification, proper nutrition, and backyard planting can result in the long-term eradication of micronutrient deficiencies, supplementation measures are crucial in the fight against acute macro and micronutrient deficiencies (Chadha & Oluoch, 2003).

To combat malnutrition, the WHO in 2002 advised increasing the intake of vegetables, fruits, nuts, legumes, and whole grains. Expanding the variety, accessibility, and eventual information of nutrient-dense food providers of nutrients is a crucial method to alleviate macro and micronutrient deficits in resource-poor populations. The formulation of nutrient-rich mixes for SHG women's supplementation was done using inexpensive, locally accessible foodstuffs selected depending upon that SHG female's dietary requirements.

Plant protein products are gaining increased interest as ingredients in food systems worldwide because of their versatile, functional properties or as biologically active components. Besides essential nutrients, they have lower cholesterol levels and incorporate better fiber into the diet (Sirtori & Lovati, 2001).

A bean growing in South Asia is known as Vigna mungo, the black gram, mash Kalai, Uddu (in Kannada), urad legume, uzhunnu parippu, minapa pappu, ulundu paruppu, and black matpe. It has been moved from the Phaseolus genus to the Vigna genus, like its relation, the mung bean. The item was marketed as a black lentil is often the entire urad bean, whereas a white lentil is a split bean with a white interior. Contrast this with the highly tiny real black legume (Lens culinaris).

Black gram has been grown since its inception in South Asia in ancient times and is one of India's most highly prized pulses. Indian cuisine is incredibly prevalent. Among the crucial pulses produced in both the Rabi and Kharif seasons in India is the black gram. This crop is widely farmed in Nepal, Bangladesh's northern region, and southern India. It is referred to as mash daal in Nepal and Bangladesh. It is a well-known legume popular in South Asia, served on a platter with rice and curry. Other tropical regions, including Fiji, the Caribbean, Mauritius, Africa, and Myanmar, have also been exposed to a black gram.

Nugget is a pulse-based popular traditional food item of the Midnapore district, West Bengal, in India. It is mainly prepared in rural areas by women using mashkalai dal during winter. Overnight-soaked pulses are first ground to a smooth paste. It is then aerated to attain proper consistency and density; this form is known as a batter. To create crunchy nuggets with a hollow interior, little portions of batter, each weighing about 10 g, are hand put on mustard oil to spread over a tray, clean cloth, or wooden stage in arrays (Swami et al., 2007a). After oil frying, nuggets are eaten or added to some Indian recipes. In many regions of the nation, there is a strong need for it. Around this product, some micro-business projects have been created.

Nelumbo nucifera sometimes referred to as the sacred lotus, the Laxmi lotus, the Indian lotus, or simply the lotus, is one of the two remaining aquatic plant species in the Nelumbonaceae family. It is occasionally referred to as a water lily. However, this term typically refers to Nymphaeaceae family members (Glimn-Lacy & Kaufman, 2006). A *lotus rhizome* is a horizontal underground plant stem that sends roots and shoots from nodes.

Lotus rhizomes are commonly consumed as a vegetable in Japan, China, and India. They can be purchased whole or split into pieces, fresh, frozen, or tinned. They are fried or cooked primarily soaked in syrup, soups, or pickled (Tian et al., 2007). Lotus rhizomes are crisp, have a tangy-sweet flavor, and are a staple at many banquets; they can be deep-fried, stir-fried, packed with meat or preserved fruits, or served as a salad with shrimp, sesame oil, with coriander leaves. A quick rate of browning places restrictions on freshly cut lotus roots (Xing et al., 2010). Tea of lotus root is drunk in Korea.

In Sri Lanka, one popular vegetable is lotus root, often cooked in coconut milk gravy. In India, lotus root (known as Kamal kaki) can be used as a vegetable curry.

Rhizomes are one of Japan's most often used plant parts, accounting for 1% of all ingested vegetables. Although China provides 15,000 tonnes of lotus rhizome annually, Japan must import 18,000 tonnes yearly (Tsuchiya & Nohara, 1989).

Rhizomes contain 31.2% of starch without characteristic taste or odor. The texture resembles a raw potato (Mukherjee et al., 1996). When isolated, Nelumbo starch's binding and disintegration abilities are compared to those of maize and potato starch, and Nelumbo starch is found to be superior as a tablet adjuvant (Mukherjee et al., 1996). Another common usage for Nucifera is flour production after it is dried (Tian et al., 2007).

Common names for the plant Borassus flabellifer include tala or tal palm, doub palm, wine palm, palmyra palm, toddy palm, and ice apple (Johnson, 2011; Lim, 2014). It is indigenous to Southeast and South Asia, particularly Bangladesh and South India (Vindika Sumudunie et al., 2004).

The fruit (palm fruit) is borne in clusters, ranges in diameter from 10 to 18 cm, and has a black husk. To access the delicious jelly seed sockets, which are translucent and pale white and resemble lychees but have a milder flavor and no pit, the top of the fruit should be cut off. The fruit's delectable jelly kernel sockets are clusters of three, two, or four seeds. Thin, yellowish-brown skin covers the fruit's gelatinous portion. These are considered to have a liquid substance inside of their fleshy white bodies. These seed receptacles have given rise to a Bengali form of grief known as jalbhora. The ripe fruit's sweet, dense, and edible mesocarp pulp, which is orange-yellow in color and rich in vitamin A and vitamin C, is edible. Additionally, they contain flabelliferrins, which are steroidal saponins and a bitter substance.

The traditional method of eating this fruit is to consume the seeds and fruit whenever the outer sheath is still immature. However, the fibrous outer covering of palm fruits can also be eaten fresh, cooked, or roasted if the whole fruit is allowed to ripen. The fruit turns purple-blackish and tastes like coconut flesh when this occurs. Similarly, while mango peels are frequently taken along with the fruit, the skin is likewise consumed as a fruit component. Bengalis have mastered the yellow viscous fluid material extracted from mature palm fruit to make various delectable meals. These include taal-er bora and "palmyra vadas," which can also be fried in sunflower or mustard oil or combined with thickened milk to make taal-kheer.

It is referred to as nonku in Kerala and nungu in Tamil Nadu. It is known as tala in Odisha. In Indonesia, ice apples are known as buah lontar and siwalan. It is referred to as "Taati Nungu" in Karnataka." This fruit is called "Thaati Munjalu" in Telangana and Andhra Pradesh.

In the Indian states of Bihar, Andhra Pradesh, Tamil Nadu, Telangana, Jaffna, Bengal, and Sri Lanka, the seeds are sowed and made to sprout. The fleshy stems (below the surface) are then boiled, roasted, and eaten. It is incredibly healthy and fibrous. It is referred to in Tamil as Panai Kizhangu or Panangkizhangu, in Telugu as Thegalu, Gaygulu, or Gengulu (particularly in Telangana), and in Myanmar as htabin myiq.

The hard shell of the germination seed is similarly cracked open to release the crunchy kernel, which has a flavor somewhat akin to a sweeter water chestnut. Tamil refers to it as "thavanai," whereas Telugu calls it "buragunju." In many regions of Bengal, the white core of the mature fruit is utilized as an offering during Lakshmi Puja and is consumed uncooked. One of India's most traditional and popular legumes is roasted Bengal Gram (Cicer arietinum). Compared to other pulses, these proteins are easier to digest and assimilate. Bengal gram protein, which has a high Net - Protein -Utilization value, is generally considered the best pulse protein.

The third most remarkable significant vegetable component proteins and consequently the fourth largest significant origin of edible vegetable oil worldwide are both groundnuts (Arachis hypogaea). Niacin content in groundnuts is exceptionally high. Adding millet, sesame seeds, or milk powder to groundnut and Bengal gram should provide a combination that contains a beneficial amino makeup (Srilakshmi, 2007).

Tomatoes (Solanum Lycopersicum) are consumed as either fresh fruit by themselves, in salads, as ingredients in many recipes, or the form of various processed products such as paste, whole peeled tomatoes, diced products, and multiple forms of juices and soups. The tomato is a beloved garden plant worldwide, a vital source of vitamins and nutrients, and a crucial agricultural product in terms of economic importance (Rothan et al., 2019). In the sixteenth century, Portuguese explorers brought tomatoes to India. From the 18th century onward, it was grown for the British. Even today, the Bengali term for it is "Biliti Begun," which translates as "Foreign Eggplant." Because it grows well in India's environment and Uttarakhand is one of its leading producers, it was then extensively embraced.

Among the most significant antioxidant foods is **spinach (Spinacia oleracea),** which is often eaten after cooking frozen or fresh leaves. Per kg of newly chopped spinach flavonoids contain

1000 mg. In 1943, the possibility of identified spinach chemicals like flavonoids was first noted (Weatherby & Cheng, 1943). Still, it took nearly 20 years before athletic (3,5,7,3′,4′-penthahydroxy-6-methoxy flavone), a flavanol obtained from spinach leaves, was identified and the existence of spinacetin was proven (Zane & Wender, 1961). Additionally, it was observed that a methanolic extract from spinach leaves contained many flavanol glycosides (Aritomi et al., 1985; Aritomi & Kawasaki, 1984).

At least ten flavonoid glycosides are now identified in spinach. These are methylene dioxide derivatives 6-oxygenated flavonol, glucuronides, acylated di- and triglycerides, of methylated (Aritomi et al., 1985; Aritomi & Kawasaki, 1984; Ferreres et al., 1997). Glucuronides are more water-soluble than glycosides and acylated compounds that remain in the tissue after cooking in boiling water. Flavonoids and other phenolic constituents act as antioxidants by the free-radical scavenging properties of their hydroxyl groups. Extensive conjugation across the flavonoid structure and numerous hydroxyl groups enhance their antioxidative properties, allowing them to act as reducing agents, hydrogen or electron-donating agents, or singlet-oxygen scavengers (Kanner et al., 1994; Salah et al., 1995; Vinson et al., 2002). According to the results of the in vitro hydroxyl radical scavenging capacity (ORAC) assay, spinach, strawberry (Cao et al., 1997; H. Wang et al., 1996), and blueberries (Prior et al., 1998) had the highest Oxygen radical absorbance activity among different fruit and vegetable solutions (Prior et al., 1998). The spinach's antioxidant activity, like the DPPH assay (Gil et al., 1999), was compared with that of Trolox, a synthetic analog of vitamin E. The most active products are from patuletin with a three ′,4′-dihydroxyl group. The incorporation of a feruloyl residue increased the free-radical scavenging activity. During the storage of spinach leaves, a decrease in total antioxidant activity was observed. Boiling of fresh-cut spinach leaves extracted approximately 50% of the total flavonoids and 60% of the vitamin C in cooking water; however, flavonoid glucuronides were removed more than other glycosides.

Vegetables with green leaves (VGL) are a gift from the environment to people, being micronutrient packed and offering the highest number of vitamins for each serving of every meal. Utilizing VGL will ensure the consumption of micronutrients because they are well-known for being abundant suppliers of phytonutrients like beta–carotene, vitamin A, and iron. VGL is a low-cost place to get phytonutrients, though various use appears is being restricted anymore because of innumeracy or because they cannot be used for several goods (Gupta & Prakash, 2011).

Even though India ranks 2nd in the world for producing fruits and vegetables, only 2% of the crop is treated, with 30–40% lost owing a not having infrastructure for manufacturing and storage.

Leaves veggies are a nutritious powerhouse, but when examining Indian dietary habits, it is generally known that the populace consumes very little of them. However, a more extensive intake is advised for healthy diets (Tamang, 2016).

1.4. Food product development process

Dehydration is the most basic method of processing and keeping greens fresh, especially if readily accessible (Gupta & Prakash, 2011). Dehydration improves the foods' ability to retain their nutritious worth.

When a person lacks reliable access to enough safe and nourishing food for healthy development and growth and active and healthy life, they are said to be experiencing food insecurity. In the absence of direct measures of food insecurity, the nutritional status of individuals is often used as an outcome measure to reflect the result of all factors affecting the nutritional status, including food security. One of several indicators of food insecurity among adults is underweight (BMI $< 18\cdot5$ kg/m2). Recently, we showed a high prevalence of unhealthy conditions (46.7 % and 60.9 % in men and women) among rural and urban Indians in a population group (Hansen et al., 2011). This indicates that India has to battle the double burden of malnutrition.

Compared to minerals and vitamins, which provide energy, macronutrients are a family of chemical substances that people consume in relatively high amounts. Proteins and carbohydrates have a food energy level of 17 kJ/g (4 kcal/g), whereas fat has a food energy value of 38 kJ/g (9 kcal/g) (Prentice, 2005). There are three main classes of macronutrients: carbohydrates, protein, and fat.

Oxidation, a chemical process that might result in free radicals, is inhibited by antioxidants. This might trigger different chain processes, like polymerization. They are widely added to food to stop deterioration, especially the rancidification of fats and oils, and to industrial items like fuels and lubricants to halt oxidation. Antioxidants like glutathione, mycothiol, and bacillithiol, as well as enzymatic activities such as superoxide dismutase, can stop oxidative stress from harming cells.

The only natural antioxidants are vitamins A, C, and E; however, many other dietary substances with superior antioxidant characteristics in vitro have also been referred to as antioxidants (Adair, 2013). Based on their antioxidant processes, antioxidants could be classified as primary or secondary antioxidants. Antioxidants with dual secondary and primary antioxidant functions are known as multifunctional antioxidants. The significant antioxidants, also known as chain-breaking, can interact quickly with free radicals and convert them into more steady, non-radical products. Therefore, primary antioxidants are crucial in lipid oxidation because they interact with newly produced lipid radicals and change them into non-radicals, which prevents the breakdown of additional lipids (Lee et al., 2002). Due to their capacity to contribute H-atoms to free - radicals, phenolic compounds containing over one hydroxyl (OH) are effective primary antioxidants because resonance stabilisation makes the resulting phenoxyl radicals unreactive. Because they are effective antioxidants that break down chemical chains, synthetic phenolic compounds such as butylated hydroxyanisole (BHA) and butylated hydroxytoluene (BHT) are frequently employed as food preservatives. The effectiveness of naturally occurring phenolic compounds, like tocopherol, ascorbic acid, and caffeic acid, as chain-breaking antioxidants vary depending on the type of food product and are often less than synthetic antioxidants.

The preventative or secondary antioxidants indirectly control lipid oxidation. The binding of metallic elements, singlet-oxygen quenching (during photooxidation), or oxygen scavenging is just a few of the processes that these secondary antioxidants display (Lee et al., 2002). Additionally, secondary antioxidants can collaborate with primary antioxidants to restore their antioxidant activity, ensuring they continue to function as antioxidants. Ascorbic acid is an example hereof. Because food products frequently contain metals, such as iron, which can cause lipid oxidation, the secondary antioxidant in food supply chains must be able to chelate metals. Excellent metal-chelating antioxidants like EDTA (ethylenediaminetetraacetic acid) are employed in the food sector (Haahr & Jacobsen, 2008).

Natural antioxidants are often more expensive and difficult to process than synthetic antioxidants, including EDTA and BHT. However, due to their toxicity and health hazards, regulations on the consumption of synthetic antioxidants were implemented (Branen, 1975). Due to safety concerns, rising consumer interest in natural products, and the possible health advantages of natural antioxidants, there is a lot of interest in and demand for natural plant-based antioxidants to replace synthetic antioxidants (Halliwell, 1996).

Dehydration Besides improving the storage stability and handling of plant materials, dehydration significantly influences the efficacy of the extraction process. Four different types of drying methods are mainly used for improving the pre-extraction steps:

Natural drying is the simplest method involving the sun as the heat source with/without hot air circulation. It is also the cheapest drying method among all drying techniques (Tiwari, 2016).

Convective drying- This method employs higher temperature than natural drying and circulation of hot air within the dehydration chamber to accelerate the moisture removal process. Hot air and tray drying are examples of convective drying methods. It requires a shorter drying time and results in improved product quality compared to natural drying.

Drying at reduced pressure- Drying at reduced pressure decrease the boiling point to ambient room temperature. Freeze-drying involves the sublimation of ice crystals to water vapor. It yields the best products in terms of visual and sensory attributes and retention of phytochemicals. Among all drying processes, the cost of drying is the highest for this drying technique.

Radiative drying- This method uses electromagnetic radiation for heat transfer, resulting in a much faster dehydration process. Microwave and infrared (IR) drying are examples of radiative drying methods.

The selection of drying methods primarily depends on the characteristics of the plant material. Freeze drying is most suitable for fruit pulp, where antioxidants are mainly present in an accessible form. On the other hand, high-temperature drying techniques are ideal for lignocellulosic plant materials such as cereal grain, fruit pulp, seed, and bark, where mostly bound antioxidants are present. Vashisth et al., (2011) observed that retention of polyphenols was significantly higher for freeze-dried and vacuum-dried muscadine pomace than for hot air-dried products. López et al., (2017) analyzed the effects of various drying processes on the quality attributes of murta berries. They observed that only the freeze-drying process caused a nonsignificant variation in the free flavonoid and anthocyanin content compared to fresh ones. The antioxidant concentration was lowered by as much as 54% during more excellent processes such as convective drying, IR drying, and sunlight. However, the content of bound flavonoids was higher for sun and IR-dried samples. Polyphenols are most stable at a temperature below 60° C but rapidly disintegrates with the increase in temperature by irreversible chemical reaction, the extent of which depends on the period of exposure to high temperature (Goula et al., 2016). Cellular degradation processes occurring during high-temperature dehydration process degrades thermolabile polyphenols. However, these processes also release bound antioxidants attached to carbohydrate and proteinaceous moieties, resulting in better extraction of bound antioxidants (Vashisth et al., 2011). Applying microwave drying improved the extraction of bound antioxidants from germinated corn, corn cob, and barley grain, all of which are lignocellulosic and contain bound antioxidants (Bualuang et al., 2017; Ragaee et al., 2014; Saha et al., 2019). Additionally, that helps to deactivate polyphenol oxidase (PPO) by exposing them to high temperatures (Mphahlele et al., 2016; Vashisth et al., 2011).

Extraction with the aid of ultrasound (USE) has been regarded as a potential replacement for conventional solvent infusion due to the enhanced extraction efficacy, budget with resources, usage, mechanization, and monitoring (C. Chen et al., 2015; M. Chen et al., 2015). When ultrasonic (US) energy is delivered to a liquid media, the sonic occurrence is called surface scraping, disintegration, disruption of the Detexturization, vegetal tissue membrane, and improved dryness-contributes to an improvement in extraction rate. It promotes solvent absorption cellular and the leaking of specific chemicals by enhancing the surface area, availability, and consequently permeability of solvent. As a result, the substances are more directly and significantly solubilized (Chemat et al., 2017). The use of ultrasound improved performance and efficiency when compared to traditional extraction methods like distillation and solvent extraction to isolate phenolics, isoflavone, flavonoids, and chlorogenic acids from strawberries (Herrera & Luque De Castro, 2004), soybean (Rostagno et al., 2003) (Rostagno et al., 2003), euonymus alatus (Yang & Zhang, 2008), olives (Li et al., 2005) respectively. Corncob is so resistant that any preparation to break up the natural plant structure can significantly impact extraction efficiency and antioxidant activity. The degradation of thermo-labile phenolics was triggered by extended exposure to the US wave and high temperature in some cases, even after only 20 minutes of extraction. It will be sufficient to assume that both the corn cob and the kernel will be rich in bound antioxidants due to their similar nature and structure. Drying processes should be evaluated to create an outcome that includes powerful phytonutrients or promising target substances (Lopez-Martinez et al., 2009; López et al., 2017).

Pre-extraction of plants involves grinding, drying, and of plant tissues, aiming to improve bioactive molecules' extractability. Grinding reduces the particle size resulting in better surface contact between solvent and plant material. Extraction yield for smaller particle sizes (≤ 0.4mm) was considerably higher than other sizes. Similar results were also observed for solid-liquid extraction of antioxidants from grape by-products and grape seeds. The surface area per unit mass of plant material is increased proportionately with the decrease in particle size, reducing the mass transfer distance between solid and solvent. Hence, the extraction time is shortened, and the yield is improved. However, too-small particle size may cause difficulty in efficiently segregating extract from the residue, necessitating additional cleaning-up steps. The particle size of around 0.3-0.6 mm was suitable for an efficient extraction process.

1.5.Supplementary feeding program

As part of the MWCD's Integrated Child Development Services (ICDS) Program, pregnant and lactating mothers receive supplemental nutrition as meals powered or enriched with micronutrients as turn food rations, total energy 600 Kcal, and protein 18–20 g each day. As a part of their Home Take Ration (HTR), children between six months to three years are given a supplement containing 500 Kcal and protein 12 to 15 g of every day, fortified with micronutrients or foods that are labeled "ICDS Food Supplement." Children aged three to six years are given a dietary supplement daily that contains 500 calories of energy and 12 to 15 g of protein. The dissemination of accurate knowledge is not enough of a goal in and of itself to enhance nutrition. Education about food that is effective moves beyond the primary acquisition of facts and toward constructive action.

Women participating in self-help groups could exercise sway on their substance possessions, information, and judgment in their homes and communities. There has yet to be any investigation into how these economic advantages affect changes in women's health conditions. Women's involvement in income-generating activities raises their status and influences their decision-making ability. To empower women, it is crucial to maintain good health and nutrition. The SHG ladies must be educated immediately. The influence of health and dietary viewpoints in Self-help groups would open the door, such as improving rural women's nutritional profiles. With this context, the following goals were set for investigating the frequency of dietary problems across women in self-help groups and the effects of treatments.

Table 1.1. Traditional food items in different countries.

Food name	**Processing**	**Countries**	**Reference**
Khaman	Chickpeas are soaked for 4 to 6 hrs. Then the smooth batter is prepared and fermented for 10–12h. The fermented batter is poured into greased cups and steam heated in a larger pan for 10 min. The steamed khaman is cooled and cut into small pieces.	India	(Frias et al., 2017)
Uttapam	A batter is prepared from the soaked rice and urad dhal), then materials are fermented at room temperature for 5–6 hrs. The fermented batter is spread over a buttery/greased pan into a round shape. Toppings like chopped vegetables, paneer, capsicum, and onion are added over the flat batter and cooked on a low flame	South India	(Blandino et al., 2003; Saraniya & Jeevaratnam, 2014)

Idli	Rice and black gram dhal are soaked for prepared the batter. Therefore the slurry is allowed to ferment for an entire night at ambient temperature. Add the table salt and fenugreek seeds. Or it's too spoilt; the fermented slurry is then made into steamed cakes.	South India	(Mukherjee et al., 1965; Steinkraus, 2018)
Doenjang	Black soybeans, local pulses Mashed cooked seeds in ball shape are wrapped in rice straw and fermented for 1–6 months.	Korea	(Frias et al., 2017)
Chakuli	Rice and black gram dhal are soaked for prepared the batter; then batter is left for 4 to 5 hrs. at room temperature (summer) for fermentation. Add the spices for tasting. Then the fermented batter is fried over a hot, greased pan into a round-shaped flat cake.	Orissa, India	(Roy et al., 2007)
Dhokla	Prepared the batter of Bengal gram dhal, rice, and leafy vegetables, then overnight fermented the batter and prepared pancakes.	South India	(Blandino et al., 2003; Ramakrishnan et al., 1976; Roy et al., 2007)
Siddhu or khobli	Wheat flour is mixed with water and malera or yeast powder. Prepared dough left for 4 to 5 hrs. for fermentation in a warm place. The fermented dough is given an oval shape and stuffed with spices mixed with opium seed; black walnut gram is steamed and cooked.	Himachal Pradesh, India	(Thakur & Bhalla, 2004)

Ugba	Locust bean and local pulses are Boiled, then mashed and prepared, sliced, wrapped in banana leaves, and fermented naturally for 4–5 days	Nigeria	(Frias et al., 2017)
Enduri pitha, munha pitha	A turmeric leaf containing fermented batter (as is done to make chakali) with the leaf being folded in the middle. Additionally, it is filled with sugar, coconut, and dahi-chhana fillings. The batter -filled folded leaves are then cooked over steam.	Orissa, India	(Roy et al., 2007)
Taotjo	Making soy paste involves boiling yellow soybeans, crushing them, combining them with a roast wheat meal and glutinous rice flour, and fermenting them. The fermentation process is accelerated by soaking the soy paste in salt water, which is then dried in the sun for several weeks until the paste turns yellow-reddish.	East India, Chinese Indonesian, and Malaysian	(Blandino et al., 2003)
Mor Kuzhambu	Rice and dals were soaked together for 15–20 min. Green chilies, ginger, garlic, and coconut were grinded with the soaked rice and dal to a fine paste. In a pan, a half cup of water and veggies were added and halfway cooked, after which the ground paste and salt were added. Buttermilk curd was whisked/beated with turmeric powder and added to the curry. It took a day for this Mor Kuzhambu to ferment at ambient temperature.	South India	(Kumar et al., 2010)

Hummus	Lemon juice, citric acid, tehineh, garlic, salt, and chickpeas (Cicer arietinum L).	The region	(Al-Holy et al., 2006; Amr & Yaseen, 1994)
Shana Jhiej	Bengal gram should be soaked in water for an hour before blending with ginger and green chilies to make a coarse pulp. Transfer the fine mixture to a bowl at this point, and stir in the sesame seeds and salt. Make cakes out of them in the shape of the Vedas and have them on hand. These vadas should be deep-fried until both sides are golden brown. Serve them hot.	Meghalaya	(Blah & Joshi, 2013)
Papad	Papad is often prepared with dough or paste from potatoes, rice, black gram, lentils, or chickpeas. To create a dough, salt or peanut oil is added. The dough can then be spiced with chili, cumin, garlic, and black pepper. Slaked lime or baking soda may also be included on occasion. Depending on the texture desired, the dough is formed into thin, circular flatbreads, dried (traditionally mainly in the sun), and prepared by frying, roasting over an open fire, toasting, or microwaving.	India, Pakistan, Bangladesh, Nepal, Sri Lanka	(Aidoo et al., 2006; Roy et al., 2007)
Probiotic food	The mung bean seeds were soaked for 12 hrs. in distilled water at ambient temperature. After that, soaked beans were drained and dispersed into distilled water to make a slurry using a homogenizer. The slurry was filtered, the supernatant of mung bean milk was obtained, and L. Plantarum B1-6 was applied for fermentation for 5 to 7 hrs.	China	(Wu et al., 2015)

Sepubari	overnight soaked black grams were grounded to a soft dough, and the batter was whipped till fluffy or left to ferment for 1-2 days. Fermented batter is rolled in fresh leaves of Butia sp. and cooked in boiling water for 15 to 20 min. Steamed cooked rolls are cut into 5×5" cm cubes and deep-fried for further use.	India	(Sharma et al., 2013)
Teliye mah	Soaked the horse gram for 4 hrs, then boiled. Heat a Kadai with ghee, add all the whole spice, and add the cooked horse gram and spice powders. Once it begins to boil, stir, lower the heat to medium, and gradually whisk in the curd. Simmer the curry and add cream; check for salt and serve hot.	India	(Thakur & Bhalla, 2004)
Tempeh	Soybeans, chickpeas, groundnut, and local pulses were Soaked, and steamed seeds were inoculated with spores of Rhizopus oligosporus and fermented for 24–48h	Indonesia, Guinea, Surinam	(Frias et al., 2017)
Tempe Benguk	soybeans, velvet beans (*Mucuna pruriens)*, or *kara benguk*, have been soaked, steamed, and inoculated with fungi of the *Rhizopus* genus. The seeds are then wrapped in banana or teak leaves and stored in a well-ventilated, dry area. After two days, the product can be fried or further processed.	Indonesia	(Chatzipavlidis et al., 2013)
Wari / Nuggets / Bori / Masyaura / Mashbari / Dangalbari /	Black gram, Bengal gram, and lentils are soaked for 4 to 6 hrs. Then the smooth paste is prepared using a stone mortar, wet grinder, or mixer grinder, and different types of seasonal vegetables and spices are added to the batter. Prepared the aliquots,	India, Pakistan, Nepal, Bangladesh	(Dahal et al., 2003; Dahal et al., 2005; Frias et al., 2017; Kulkarni et al., 1997; Tewary & Muller, 1992)

	small balls are poured on trays greased with mustard oil or on a clean cloth or a wooden stage in arrays and sun-dried for two to three days until crispy nuggets with hollow inner cores are obtained.		
Dawadawa	Locust bean and local pulses are spread calabash tray, covered with a cloth, and fermented for 2–4 days	West and Central Africa	(Frias et al., 2017)
Adai dosa	A batter is prepared of boiled rice and soaked black gram, red gram, Bengal gram, and green gram dhal, then fermenting. It is steamed as pancakes prepared by fermenting batter.	South India	(Chavan & Kadam, 1989)
Cheonggukjang	Black soybeans, local pulses Soaked and steamed seeds are inoculated with spores of Bacillus and fermented for 1–3 days	Korea	(Frias et al., 2017)
Dosa	Raw and parboiled rice and black gram dhal are soaked for prepared the batter. After the batter fermentation for 6 to 8 hours, Add the table salt. They were prepared as dosa.	South India	(Chavan & Kadam, 1989; kaur & Kawatra, 1986; Steinkraus, 2018)
Natto	Soybeans and local pulses are inoculated with spores of B. natto and fermented for 15–24h	Japan	(Frias et al., 2017)

1.6. The background for selecting the topic

Food insecurity, chronic hunger, starvation, and malnutrition continue to plague millions of people throughout the developing world, especially in the rural area (Omueti et al., 2009). Vulnerable groups are part of our community, state, or country which would be defenseless under any circumstances, e.g., economically, physically, mentally, socially, gender or age basis and nutritionally. Malnutrition and undernutrition are the significant causes of morbidity and mortality among vulnerable groups in most developing countries (Ejigui et al., 2007). These are problems that cannot be tackled individually but can be better solved through group efforts.

Today these groups, known as Self-help groups, have become the vehicle of change for the poor and marginalized. India's Self-Help Group (SHG) movement has emerged as the world's largest and most successful network of community-based organizations (CBOs). A self-help group (SHG) organizes poor people (economically weaker vulnerable groups) and the marginalized section of our community to solve their problems.

However, the self-help group (SHG) performs several works in health, nutrition, and manufacturing different food items. In this context, at present, my attention has been focussed on to standardized some nutritional food product indices related to the below-mentioned subject concern; at present, there is a plethora of information in this field in West Bengal state (*Study on District Human Development Report Paschim Medinipur, West Bengal. 2015*,). Hence the outcome of the present study will be beneficial to formulate or modify the Govt policy regarding SHG in connection with the upliftment of the lifestyle in the marginalized sections of specific communities.

Some traditionally nutritional food is consumed on a large scale by a vulnerable group suffering from economic, chronic hunger, food insecurity, and starvation. These food materials are worthless and destroyed parts of plants which maximum time smashed in agricultural land, but it is nutritious.

The Moto of the proposed study is to standardize some nutritional food product-related index among rural women workers of SHG and vulnerable communities in rural areas at Paschim Medinipur district in West Bengal in India.

The proposed study is to be carried out from different dimensions. Data concerning SHG and vulnerable communities will be collected by survey and nutritional analysis to be studied using the standard laboratory method. Results are to be analyzed using a relevant statistical package.

1.7. Importance of proposed work

This work will have very high social value. To develop and nutritional evaluation of vulnerable groups in rural areas and SHGs working women own products which help us economically and socially up gradation of our district and our state. Research values are also the most important in this work to identify the causative factors or agents that may lead to improving a food product. Analysis and calculation of the nutritional value of their created food products and study to co-relation with health benefits. Supply some healthy supplementary food products through SHG in a different field (especially vulnerable groups) to prevent the several health problems in our community.

1.8. Aims and Objective

The proposed study would be carried out to fulfill the following aims -

- To search out the nutritional value of different food or products the women workers make of SHGs. These food items' ingredients are analyzed through calorie and protein content.
- Nutritional assessment of the numerical value of food products with a different statistical and mathematical model.
- Quality evaluation of locally available food materials generally consumed by vulnerable groups using a numerical stool and statistical model.
- To search the nutritional value of the product supplemented to the vulnerable group through supplementary feeding programs (ICDS, Mid-day-meal) and gradation of the nutritional quality through technical and market survey basis.

The ultimate objective of the proposed work is to develop and nutritional evaluation of the food items of self-help groups and vulnerable groups in a rural area of west Bengal in

India in respect of availability, low cost, and rich in nutritional and phytochemicals.

1.9. Parameters to be studied

- To select the area where a presence of food made SHG women and some vulnerable groups.
- To identify and collect the nutritional product based on low cost and availability.
- Development of food products by using different drying processes.
- Optimization of product parameters by response surface methodology.
- To determine the drying kinetics using the thin layer drying models.
- Analysis and calculation of how much macronutrients are present, such as carbohydrates, proteins, fat (saturated/unsaturated), the energy present in 100 gm of food or food product, and micronutrients.
- Determine phytochemicals like antioxidant content and antioxidant activity, phenolic, and flavonoid compound by HPLC study.
- Analysis of their self-life period.
- Analysis of their textural profile
- Analysis of their color profile.
- Evaluation of sensory parameters.
- Analysis the cost
- Analysis of their other physiochemical properties

Chapter 2

To search out the nutritional value of food or products that the women workers make of SHGs. These food items' ingredients are analyzed through calorie and protein content

2.1. Introduction

"Annaath Bhavanthi Bhoothani," which means all beings evolved from food, is a sacred verse from the Bhagwat Geeta. Food has been a component of man's life on our planet and is one of his basic needs. What we eat has influenced human civilization since the beginning; food has been linked to good health. The Rig Vedic dietary regulations, based on Ayurvedic principles, highlight the strong links between fruits and vegetables, long life, and excellent health. The physical counterpart and prerequisite for mental engagement, health is excellence in and of itself. It is fuelled by diet. According to the WHO, health is "a condition of full physical, mental, social, and emotional well-being and not only the absence of sickness."

Today's nutrition research is looking for a solution to improving global health. A traditional Indian diet consists mainly of grains, pulses, and various locally grown fruits and vegetables. Green leafy vegetables (GLV) are often utilized as multicultural ingredients in Indian cuisine. Consuming fruits and vegetables decrease the risk of developing illnesses like cancer, cardiovascular disease, and cerebrovascular disease. Leading nutrition researchers have endorsed GLV as a complete supply of micronutrients for the Indian population's better health.

The food-related businesses include those that manage tea booths, offer snacks (black gram nuggets, locally known as "*Bori*") and vegetables, mill flour, sell rice and flowers, and grocery goods including pulses, sugar, incense, candles, limestone, and paper products. Toiletry preparation, including the production of liquid blue, phenyl, and detergent powder, is also present. Women in West Bengal have engaged in a variety of businesses. Clothing, terracotta, Pathamadai mats, silk mats, handloom sarees, sanitary napkins, paper cups, vermicompost, ornamental items, various foods, and pickles are among the things that certain SHGs create. Other SHG goods include flower vases, hot onion pickles, hanging flower vases, herbal mosquito sticks, mango jam, mango squash, cashew nuts, and Krishna dolls. God: a clay Ganesh doll, a clay Gowri doll, a sweater, a metal vinayagar, a money pouch, a multi-colored foot mat, a pineapple squash, a silk sari, a tomato pickle, an umbrella, soft toys, gift goods, and edible decorations.

Legumes are a valuable source of plant protein and other nutritional compounds. Black gram (*Phaseolus mungo*) is widely consumed for protein, fiber, vitamins, and minerals. Additionally, it is an excellent source of disease-preventing antioxidants such as flavonoids, polyphenols, and phytosterols (Sreerama et al., 2010). Common names of a black gram are urad dal (Hindi), mashkalai dal (Bengali), Biri dal (Odia), adad (Gujaratis), manha di dal (Punjabi), uluntu (Tamil), and kalo dal (Nepalis), etc. Mashkalai dal belongs to the Leguminosae family. Although it is highly consumed all over Asia and Europe, very few studies have been performed on the nutritional benefits of these legumes (Bhattacharya et al., 2004). Dehusked cotyledon of black gram is used in many Indian dishes, especially in fermented dishes such as idli, dosa, and non-fermented foods like hopper, papad, waries (spicy hollow balls), and *bori*.

Nugget is a pulse-based popular traditional food item of the Midnapore district, West Bengal, in India. It is mainly prepared in rural areas by women using mashkalai dal during winter. Overnight-soaked pulses are first ground to a smooth paste. It is then aerated to attain proper consistency and density; this form is known as a batter. Small aliquots of batter of approximately 10 g weight are manually poured on mustard oil to rub over the tray, clean cloth, or wooden stage in arrays and sun-dried for two to three days (Swami et al., 2007b).

Vegetables are potent antioxidants, nutrients, and elements (Kaur & Kapoor, 2002). Tomatoes, carrots, and spinach are rich sources of antioxidants, vitamins like lycopene, beta carotene, vitamin-A, vitamin C, vitamin K, folate, and minerals like potassium, iron, calcium, etc. (Bhowmik et al., 2012; Sharma et al., 2012; Tewani et al., 2016). Radish and wax gourd are rich sources of polyphenol compounds; isothiocyanate compounds like sulforaphane, alpha-lipoic acid, vitamin-C, dietary fiber, iron, vitamin-B1, phosphorus, zinc, etc. (Abdullah et al., 2012; Jurica & Petříková, 2014). These vegetables can decrease the possibility of cancer, diabetes mellitus, and heart disease and promote wellness (Bhowmik et al., 2012). Vegetables are incorporated in the *bori* primarily to enhance their nutritional and antioxidant capacity. To our best knowledge and belief, this study has yet to be done before. The objectives of the studies were to analyze the nutritional characteristics like carbohydrates, protein, fat, etc., antioxidant content and activity, and textural properties of different *bori* specimens. These *bori* specimens are traditional products of the Midnapore district, West Bengal, India.

2.2. Materials and methods

2.2.1. Sample collection

Six varieties of nuggets (bori), black gram bori (BB), spinach bori (SB), carrot bori (CB), wax gourd bori (WB), tomato bori (TB), and daikon bori (DB) were collected from several blocks in East and West Midnapore and were stored in an airtight container at room temperature for further study.

2.2.2. Reagents

Unless otherwise stated, most chemicals obtained were received from Sigma-Aldrich (Mumbai, India).

2.2.3. Extraction of Antioxidants

2.2.3.1. Ultrasound-assisted extraction (UAE)

Ultrasound-assisted extraction (UAE) was performed in a sonication water bath (D150 IH, ultrasonic power-100 watts and frequency-50 kHz, heater power-200 watts, AC 220-240 V 50 Hz, Trans-o-sonic, Shanti Industrial Estate, India). Flasks were always positioned at the same distance from the transducer, and no agitation was applied. Ultrasound power and extraction time were modified according to the experimental design. A 100 mL Conical flask containing 1g of material was filled with 20 mL of 80% methanol (HPLC grade). It was centrifuged at

8900 rpm for 10 minutes at 4 °C after being sonicated in an ultrasonic bath for 20 minutes. The antioxidant activity and content of the supernatant were subsequently analyzed.

2.2.3.2. Determination of antioxidant content

2.2.3.2.1 Phenolic content (Total)

Following the method outlined by Ray et al., (2017), phenolic components were determined spectrophotometrically. 0.2 ml of the extracted sample was mixed with 1.8 ml of distilled water. After that, 0.2 ml of Folin-Ciocalteu reagent was added and manually shaken for 5 minutes to ensure appropriate mixing. Then 7% of the sodium carbonate mixture was added. The next step was to add distilled water at 0.8 ml.

The spectrophotometer determined the mixture's sensitivity at 750 nm following a 90-minute incubation period in the dark (machine details). As a calibration standard, gallic acid (5 - 40 μg/ml) was utilized (calibration equation: absorbance = 0.0236 concentration + 0.0017 (R2 = 0.9998)). The outcomes were given as mg of equivalent gallic acid (GAE) for every gram of the sample's dry basis.

According to Ray et al., (2017), the total flavonoid content of the samples was calculated. 1 ml of the extracted material, 4 ml of distilled water, and 3 ml of NaNO2 were combined. Then, 2 ml (1 M) NaOH and 0.3 ml AlCl3 were added. Following a 25-minute incubation period under light, the mixture's absorbance at 510 nm was measured using a spectrophotometer. Here quercetin (mg/ g db.) was used as a standard. Quercetin (25−200 µg/ml) was used as the calibration standard (calibration equation: Absorbance = 0.0005 × Concentration + 0.0019 (R^2 = 0.9925)).

2.2.3.3. Antioxidant activity determination

The ferric-reducing antioxidant power (FRAP) was assessed, followed by Ray et al., (2017). The sample extract was combined with 2.5 ml phosphate buffer (0.2 M, pH 6.6) and 2.5 ml potassium ferricyanide (1%), respectively. Twenty minutes were spent heating the mixture to 50 °C. Add 2.5 ml of trichloroacetic acid (10%); then, the mixture was incubated and centrifuged for 10 min at 3000 rpm. Then 2.5 ml of the solution's upper layer was combined with 2.5 ml of distilled water, adding 0.5 ml of 0.1% ferric chloride. At 700 nm, the mixture's absorbance was determined. A higher absorption indicates a higher reducing power. The results were expressed in terms of ascorbic acid equivalent per milligram of extract. The ascorbic acid was used as a standard (0.25–2 μmol/ml) (Calibration curve: Absorbance = 0.8294 × Concentration − 0.0007 (R^2=0.9988)).

According to Yu et al., (2003), the ability of sample extracts to scavenge free radicals was assessed. A volumetric flask combined 0.002 g of the 2,2-diphenyl-1-picrylhydrazyl radical (DPPH) with 50 ml of ethanol. The flask was then kept extremely cold and in the dark. In a test tube, 0.1 ml of the sample was taken and combined with 3.9 ml of the ready-made DPPH solution. After 45 minutes of incubation in a dark cabinet, the absorbance at 515 nm was measured using a spectrophotometer.

$$Total\ antioxidant\ activity = \frac{Blank - Sample}{Blank} \times 100 \quad (2.1)$$

2.2.4. Nutritional analysis

The crude carbohydrate content was determined, followed by Akindahunsi & Oyetayo (2006). 0.5 g of all *bori* powder was taken in a 250 ml digestion flask, and 50 ml of HCl (2.5N) solution was added. Hydrolysis was done by boiling the answer in a water bath for three hrs at 70 °C. After cooling, it was filtered using Whatman filter paper, neutralized by NaOH solution, and pH was adjusted to 7. The supernatant was stored for analysis. 4 ml anthrone reagent was added to all samples, followed by heating for eight min in a water bath. After cooling, absorbance was measured by UV Visible spectrophotometer at 630 nm. Glucose was used as standard (200–1000 mg/ml) (Calibration curve: Absorbance = 0.0008 × Concentration + 0.2178 (R^2 = 0.9849)).

$$Carbohydrate\ (\%) = \frac{weight\ of\ glucose\ (g)}{weight\ of\ sample\ (g)} \times 100 \qquad (2.2)$$

The Folin Lowry method was applied to determine the sample's protein concentration (Lowry et al., 1951). 0.5 g of all sample flour was retrieved in 10 ml of phosphate buffer (0.1 M, pH - 6.5) in a rotary shaker for one hour. Then the solution was centrifuged at 1500 rpm for 30 min, and the supernatant was used for protein estimation. 1 ml of distilled water was used as a blank in a test tube. 4.5 ml reagent I (0.1 N NaOH added in 48 ml 2% Na_2CO_3 in water + 1 ml of NaK tartrate in 1 % in water + 1 ml $CuSO_4.5H_2O$ in 0.5 % in water) was taken in all sample test tubes, then incubated for 10 min. Add reagent II (0.5 ml) following incubation. 30 minutes of incubation came next. At 660 nm, the Spectrophotometer determined the absorbance. Here, the standard was bovine serum albumin (200–1000 mg/ml) (Calibration curve: Absorbance = 0.0003 × Concentration + 0.0153 (R^2 = 0.9976)).

$$Protein\ (\%) = \frac{weight\ of\ albumin\ (g)}{weight\ of\ sample\ (g)} \times 100 \qquad (2.3)$$

Fat, moisture and ash content were measured by the method *AOAC: Official Methods of Analysis*, (2005). 5 g of all samples were taken in thimbles and sealed with cotton, then transferred to Soxhlet apparatus, and 250 ml petroleum ether was filled into a bottle and then placed over a mantle heater. The process is continued for 6 hr at 60-70 ℃. After completing the process, the flask was wholly dried, placed in a desiccator, and reweighed.

$$Fat\ (\%) = \frac{weight\ of\ the\ fat\ (g)}{weight\ of\ sample\ (g)} \times 100 \qquad (2.4)$$

A 5 g sample was placed in a crucible until the ash was obtained and heated to 550 °C in a muffle furnace for 5 hrs. After that, the ash's weight was calculated.

$$Ash\ (\%) = \frac{weight\ of\ ash\ (g)}{weight\ of\ the\ sample\ (g)} \times 100 \qquad (2.5)$$

A 3 g sample was placed in a metal dish and heated to 105 °C in a hot air oven for 3 hours to achieve a consistent weight. The sample was then chilled for 10 minutes in a desiccator.

After that, the sample's weight was calculated.

$$Moisture\ content = \frac{Initial\ weight\ of\ sample - final\ weight\ of\ sample}{Initial\ weight\ of\ sample} \times 100 \quad (2.6)$$

The moisture content of the samples was measured on the first day and after 15 days, one month, and two months of storage while they were kept at room temperature.

2.2.5. Textural profile analysis (TPA)

TPA of *bori* Nugget was performed using a TA.XT. Plus texture analyzer (Stable Micro System Ltd., UK), following the procedure described by Swami et al., (2007). A 36 mm diameter (P/36R) aluminum cylindrical probe was used. The nugget was placed centrally under the compression plate, and texture profile analysis was performed five times. They maintained the compression height by 30%. The test, pre-test, and post-test speeds were 1 mm/s, respectively, and 5s was the pause time. Texture profile analysis was carried out using a TA. XT texture analyzer (Stable Micro System Ltd., UK, model TA. XT Express). The analyzer was linked to a computer that recorded data via a software program called Exponent Light Express (Stable Micro System Ltd., UK); the software was used for a data recorder that generated a graph of force (grams) versus time (s). A cylindrical probe (aluminum, P/36R) was used to analyze the specimens' texture profile.

2.2.6. Principal component analysis (PCA)

PCA is a statistical tool that is widely used for numerical data statistics that condenses the unique set of independent variables (i.e., characteristics) into a reduced set of essential variables (i.e., factors) (Rajalahti & Kvalheim, 2011). Ratings from the sensory analysis were used to collect data. The primary components are obtained by determining the eigenvalues and eigenvectors of the data matrix. Since the eigenvectors are orthogonal, the primary components show concurrent perpendicular orientations throughout the initial parameters' space. The eigenvector with the highest eigenvalue, among others, determines the direction of the most significant change. The summation of the principal component scores is uncorrelated. The model's least-squares solution is provided by the first i main components (Srivastava & Fujikoshi, 2006).

$$Y = XA + E \tag{2.7}$$

In this scenario, Y has a "np" centered matrix of observed parameters, X is a "ni" first I scores matrix of principal components, A uses using ip eigenvectors matrix, and E is an "np" residuals matrix.

2.2.7. Statistical analysis

All values were presented in triplicate (n = 3), and data were presented as mean and standard deviation. The statistical analysis of results was done by the R. (3.4.3) (R Development Core Team, 2017, Vienna, Austria) for principal component analysis (PCA).

2.3. Results and discussion

2.3.1. Antioxidant properties

From Table 1, it was observed that incorporating vegetables in bori improved the TPC content to the range of 0.76-1.15 mg/g and TFC content to the field of 0.77-1.33 μg/g compared to plain bori. FRAP activity, too, was improved to the range of 6.92-11.48 μmol/g. However, in the case of DPPH, all samples showed a marked increase in free radical scavenging activity, around 7.50 to 36.04 %. SB is high in TPC (1.15 μg/g), FRAP (11.48 μmol/g), and DPPH (23.93 %) as compared to other vegetable bori. DB has a high TFC (1.33 μg/g) value compared to the other vegetable nuggets.

2.3.2. Nutrition

From Table 1, it was observed that incorporating vegetables in *bori* improved their nutritional value, such as carbohydrate, protein, and fat content. Total carbohydrate content was improved to the range of 0.84-2.39 %, but in the case of SB, carbohydrate content was decreased by 3.34 % compared to BB. Leafy vegetable spinach had a shallow carbohydrate content (2.9 g /100 g) but was a plentiful supply of protein and minerals compared to vegetables (Gopalan et al., 1980).

Table 2.1. Antioxidant, carbohydrate, protein, fat, and ash content analysis of all *bori* samples. The control *bori was* designated as black gram *bori* (BB), other vegetable *bori* were designated as spinach *bori* (SB), carrot *bori* (CB), wax gourd *bori* (WB), tomato *bori* (TB), and daikon *bori* (DB). The values present the mean of independent experiments ± SD

ID	TPC	TFC	FRAP	DPPH (%)	Carbohydrate (%)	Protein (%)	Fat (%)	Ash (%)
BB	0.54 ± 0.010	0.55 ± 0.030	3.04 ± 0.005	17.59 ± 0.010	59.30 ± 2.300	23.03 ± 1.398	2.00 ± 0.050	9.89 ± 0.900
SB	1.15 ± 0.050	1.01 ± 0.020	11.48 ± 0.500	23.93 ± 0.020	57.32 ± 1.690	24.93 ± 0.498	2.25±0.059	10.10 ± 0.700
CB	0.76 ± 0.029	0.95 ± 0.010	9.46 ± 0.300	23.50 ± 0.010	60.20 ± 1.149	22.38 ± 0.798	2.00±0.010	8.90 ± 0.800
TB	0.96 ± 0.019	1.17 ± 0.050	8.28 ± 0.010	20.86 ± 0.050	60.20 ± 1.513	23.21 ± 0.598	2.16±0.020	9.01 ± 0.700
WB	1.03 ± 0.010	0.77 ± 0.100	10.39 ± 0.010	18.91 ± 0.010	59.80 ± 0.987	22.63 ± 0.980	2.31±0.010	8.87 ± 0.500
DB	0.99 ± 0.010	1.33 ± 0.050	6.92 ± 0.030	23.72 ± 0.040	60.72 ± 1.199	22.72 ± 0.750	1.99±0.019	9.78 ± 0.398

The protein content of the SB sample increased to 8.25%, and the TB sample increased to 0.78% compared to BB. Similarly, the other sample's value decreased to 1.35-2.82 % compared to BB. Fat content was improved, too, for all samples, from about 8.00 to 15.50 %. The Ash content of all samples was decreased to about 10.31-1.11 % compared to BB. Compared to the control, Ash content improvement (2.12%) was observed in SB. DB had higher carbohydrate content than the other vegetable nuggets. SB had a higher protein and ash content than other *bori*. Fat content was higher in WB than in different nugget samples.

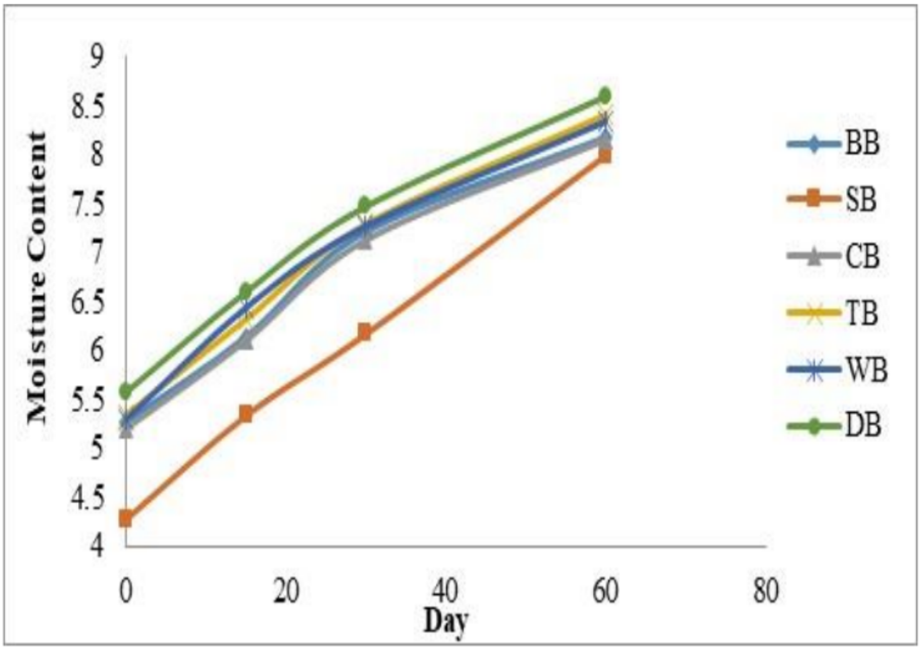

Figure 2.1. The moisture level of various samples depends on storage duration. The control bori was designated as black gram bori (BB), other vegetable bori were designated as spinach bori (SB), carrot bori (CB), wax gourd bori (WB), tomato bori (TB), and daikon bori (DB). The values were presented as the mean of independent experiments ± SD.

2.3.3. Moisture content

Quality and storage characteristics of a food product depend on moisture content since the growth of spoilage organisms was favored by high moisture content (Swami et al., 2005). There was a finding that for BB first moisture was 5.26 %. After 15 days of storage, the humidity was increased to 16.54 % on the initial day. After 60 days, the moisture content of BB was 55.51 %. All samples showed high moisture content after 60 days of storage, and the rate of water uptake was also increased for all samples except SB. SB samples took water at a greater rate, i.e., 82.67 % (60 days) compared to the initial day.

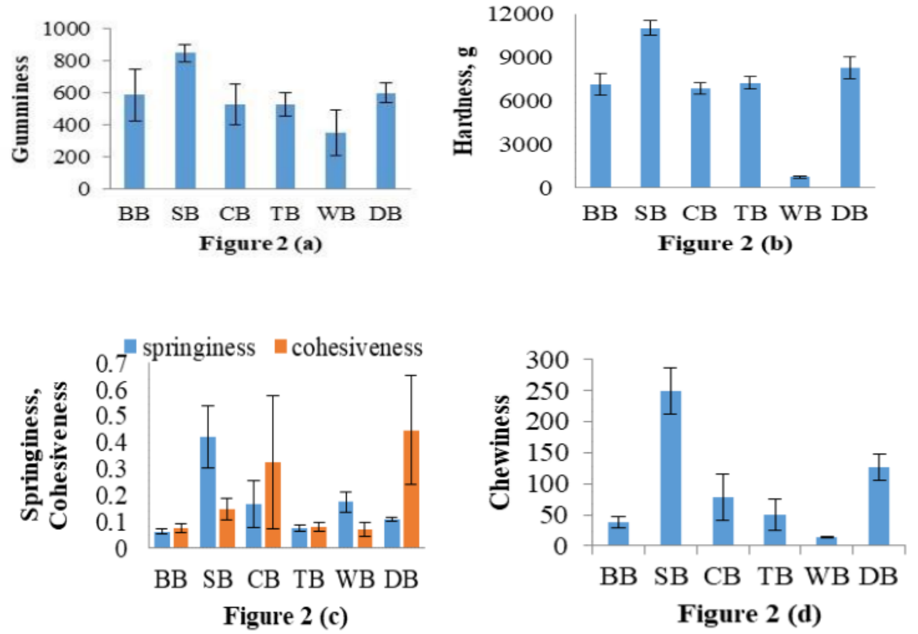

Figure 2.2. (a, b, c, d) Analysis of variance for gumminess, hardness, springiness, cohesiveness, and chewiness of different *bori* samples. The control *bori was* designated as black gram *bori* (BB), other vegetable *bori* were designated as spinach *bori* (SB), carrot *bori* (CB), wax gourd *bori* (WB), tomato *bori* (TB), and daikon *bori* (DB). The values were presented as the mean of independent experiments ± SE.

2.3.4. Analysis of textural properties (TPA)

Figure 2 (a) illustrates the gumminess of different varieties of *bori* samples. Gumminess values were increased for SB and DB and decreased for CB, TB, and WB against control. The gumminess for the SB sample was high, and WB was low for other samples. Figure 2 (b) shows the hardness of the nugget samples. Hardness increased in SB, TB, and DB but decreased in WB and CB compared to BB (control). Figure 2 (c) shows the springiness and cohesiveness of all samples. Springiness and cohesiveness values were increased for all samples compared to the power, but cohesiveness was decreased only for WB. Figure 2 (d) shows the chewiness of all black gram nuggets. Chewiness values were increased in all samples except WB compared to the control. SB (Spinach *bori*) had higher gumminess, hardness, chewiness, and springiness values than other samples. Cohesiveness values were increased in DB compared to others. WB had low gumminess, hardness, chewiness, and cohesiveness values compared to different samples, but springiness was high in TB. The TB and BB samples were similar in all parameter studies of texture profiles.

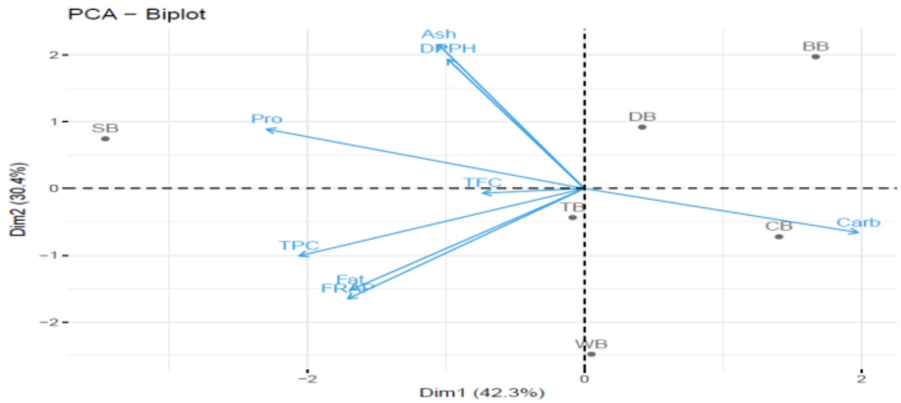

Figure 2.3. PCA – Bi-plot of all samples with their parameters. The control bori was designated as black gram bori (BB), other vegetable bori were designated as spinach bori (SB), carrot bori (CB), wax gourd bori (WB), tomato bori (TB), and daikon bori (DB). The values were presented as the mean of independent experiments ± SD.

2.3.5. Principal component analysis

It was concluded from the analysis of the six principal components (PC) produced and the percentage of variation observed that the first three PC would explain the variance caused by different ingredients. PC1 showed a positive correlation with carbohydrates, while PC2 showed a positive correlation with protein, ash, and DPPH and a negative correlation with others. The Bi-plot showed that BB, DB, TB, and CB samples were similar with high carbohydrate content and lower fat, protein, ash, and antioxidant value. In contrast, SB had elevated protein, fat, ash, and antioxidant values. WB sample was characterized by high TPC, FRAP, fat and carbohydrate values, and lower protein, ash, and DPPH activity.

2.4. Conclusion

On the nutrient profile, antioxidant qualities, and moisture content, all bori used to have a considerable impact. All vegetable *bori* showed improvement in their antioxidant and antioxidant activity (TPC content: 0.76-1.15 mg/g, TFC content: 0.77-1.33 μg/g, FRAP activity: 6.92-11.48 μmol/g and DPPH activity 7.50-36.04 %) compared to BB. SB had the highest TPC content (1.15 mg/g), DPPH (36.04 %), and FRAP activity (11.48 μmol/g), whereas WB contained more TFC (1.33 μg/g) than all other samples. Carbohydrate and fat content were improved to the range of 0.84-2.39 % and 8.00-15.50 %, respectively, but in the case of SB, carbohydrate content was decreased to 3.34 % compared to BB used as a control. SB was good for nutrition. It was a rich source of protein (8.25 %), fat (15.50 %), and ash (2.12 %) but a poor source of carbohydrates. Its moisture absorption was higher than the other samples, so its shelf life was meager. The Ash content of all samples decreased to about 1.11-10.31% compared to BB. The principal component analysis confirmed the findings of the characterization parameters. With the help of analyses of texture characteristics, this was concluded that SB showed high attributes for all parameters except cohesiveness; similarly, WB had low values for all parameters except springiness. Cohesiveness was high in DB. PCA did the correlation of characterization parameters. We may infer from this research that adding specific vegetables to *bori* preparation improved their antioxidant content and nutritional values.

Chapter 3

Nutritional assessment of the numerical value of food products with different statistical and mathematical models

Part -A

3A.1. Introduction

Black gram (*Vigna Mungo*) is among the essential pulse crops grown throughout India. It is widely consumed for protein, essential amino acids, fiber, vitamins, and minerals. It is a rich source of antioxidants like polyphenols, flavonoids, and phytosterols that prevent several diseases (Sreerama et al., 2010). Although it is widely consumed throughout Asia and Europe, few studies on the nutritional benefit of these legumes have been performed(Bhattacharya et al., 2004). Dehusked cotyledon of black gram (Dhal) is used for many Indian dishes, especially for fermented dishes such as idli and dosa and non-fermented foods like *bori*, hopper, papad, and waries (spicy hollow balls).

More than 1000 ethnic fermented and non-fermented food cultures are present in India (Tamang, 2016). In India, especially in West Bengal, *Bori* is one of the most important ethnic foods that have been highly demanded locally and globally. Black gram pulses are soaked for 3 to 4 hrs in the water, then prepared the batter by using a wet grinder or stone-made mortar or pestle. Then it is aerated to achieve the right thickness and uniformity. Minuscule portions of batter of approximately 10gm weight are manually poured on trays greased with mustard oil or on a clean cloth or a wooden stage in arrays and sun-dried for two to three days until crunchy nuggets with internally porous core are obtained (Swami et al., 2006).

Our study was conducted on ethical food prepared by a self-help group of women in the East and West Midnapore district in West Bengal, India. In general, self-help groups consist of a maximum of women involved in making the *bori* and alleviating their poverty by selling this food product. The batter's right thickness and uniformity during production determine the product's quality, i.e., level of added water content (initial moisture content of batter) and air incorporation that results from porosity in it. However, SHG women have yet to learn about preparing batter properly. To overcome this problem, the optimized value of the different parameters of the batter prepared was determined by Response Surface Methodology (Swami et al., 2006). Response Surface Methodology (RSM) was used as a mathematical and statistical combination tool for designing experiments that described the affinity of independent variables and other parameters (Witek-Krowiak et al., 2014).

From November to July, bori is traditionally sun-dried outside. The product dries unevenly and slowly, with other problems like environmental contamination, weather dependence, and a time-consuming process. Introduction to equipment drying enables maintenance consistency in product quality and hygienic practices to resolve these issues and continue large-scale production. Tray dryers were employed to create better-quality products (Giri & Prasad, 2007).

Hardness, yellowness, oil uptake ratio, and water absorption capacity are crucial qualitative characteristics of this *bori*. This essay examines how the three distinct variables of moisture, air inclusion, and temperature influence the quality of the product above. The independent factors were then optimized for reasonable variable feature values. In this study, *bori* was developed and optimized to the best settings for process parameters using the response surface methodology, followed by an analysis of the physicochemical and nutritional properties of the developed *bori*.

3A.2. Materials and methods

3A.2.1. Raw materials

Black gram (*Vigna Mungo*) pulses (without husk) were collected at “Sasya Shyamala Krishi Vigyan Kendra” (SSKVK), Sonarpur, South 24 Parganas, Kolkata in India. The name of this variety is “WBU-109,” also called “Sulota” locally.

3A.2.2. Batter and nuggets preparation process

The initial moisture content of collected black gram pulses was around 12%, determined by the AOAC method (2005). It was soaked in drinking water at room temperature (23±2 °C) for

4 hrs. The moisture content of soaked pulses was approximately 54%. After draining, the water of soaked pulses was ground to prepare the batter using a wet grinder (Panasonic MK-SW200BLK we grinder, India) by adding drinking water in the amount of 30, 35, and 40 ml per 100 grams of the wet pulse. The grinding was completed in 45 minutes for all samples. After that, the batter was passed through the 60-mesh size sieve, where 90% of the batter passed out. The moisture content of the prepared batter was 64.72±0.22, 65.94±0.55, and 67.16±0.38 % (wb). A pre-weighed 10 ml beaker was loaded to the capacity with ready batter, or any air pockets were removed by entering the beaker. The beaker, along with the batter weight, was recorded. After that, the batter was whipped or beaten at the speed of 1350 min^{-1} at various time duration, 60, 75, and 90 s, to achieve the different levels of air incorporation. The volume of air incorporation (AI) in percentage was calculated according to equation 1.

$$AI\ \% = \frac{BB - BA}{BB - BE} \qquad (3A.1.)$$

Where BB is the combined (non-whipping) weight (g) of the batter-beaker, whipped beaker weight denoted "BA"; BE is the weight of the empty 10 ml beaker. Air incorporation was estimated at 18.13±0.29, 21.21±0.26, and 24.29±0.49 % (v/v).

3A.2.3. Drying Process of black gram nuggets (*bori*)

5±1 mL of batter was placed on fine cotton cloths laid out on trays to make bori, which was then dried in a tray dryer at various temperatures (50, 60, and 70 °C). All samples' weights at these three different temperatures were measured every 30 minutes until a consistent weight was attained. The bori samples' final moisture content was 3.5±0.5 (%).

3A.2.4. Quality measurement of dried black gram nuggets (*bori*)

3A.2.4.1. Whiteness index

Each group's five dried nuggets were crushed into flour using a mortar and pestle before being sieved through 60 mesh screens. The flour was kept in a zip-top bag for two days and dried out in a desiccator. The desiccators' moisture-absorbing material was blue silica gel. The flour was placed in a hunting beaker to prevent light from passing through and filled to the top. After that, it was placed on top of the Hunter colorimeter, wherein values L* denote brightness or whiteness.

3A.2.4.2. Hardness

Each dried nugget group comprised five nuggets, and each was compressed. The TA. XT Express texture analyzer's measurement of hardness (Stable Microsystem, Surry, UK). The target mode distance was 10 mm, while the aluminum probe's diameter was 36 mm. This test moved at a speed of 5.00 mm/sec. The hardness (N) of the nuggets was the first peak of the compressor.

3A.2.4.3. Oil uptake ratio (O.U.R)

The dried black gram nuggets were fried in hot oil at 140 °C to 160 °C for 1 minute, and the oil content was measured by the Soxhlet method using petroleum ether solvent. The oil uptake ratio was defined as formula 2 by the method of Pinthus et al., (1993).

$$\%\ Oil\ Uptake\ Ratio\ (O.U.R) = \frac{Final\ total\ Oil\ Content}{Weight\ of\ dry\ sample} \times 100 \qquad (3A.2.)$$

3A.2.4.4. Water absorption capacity (W.A.C)

The water absorption capacity of cooked nuggets was measured using the following formula Bhattacharya & Sowbhagya (1971).

$$WAC = \frac{water\ intake\ of\ \ cooked\ nuggets\ (ml)}{weight\ of\ uncooked\ nuggets\ (gram) \times cooking\ time\ (\min)} \qquad (3A.3.)$$

The absence of a white core confirmed the cooking of the nuggets upon pressing between colorless transparent glass slides after cooking in a 2% NaCl solution.

3A.2.4.5. Optimization of batter parameters and drying temperature

Response Surface Methodology (RSM) was used in designing this experiment. Three independent variables, namely the temperature of tray dryers (x_1), moisture content of batter (x_2), and air incorporation content of batter (x_3), were chosen. The independent variable had 3 levels coded as +1, 0, and −1 instead of actual factor values (Daneshi et al., 2010). Experiment results were transformed into coded values using the following equation.

$$X_i = \frac{Xi - Xi\ (mean)}{Xi(mean) - Xi(min)} \qquad (3A.4.)$$

Where Xi is the actual value of the factor, i; Xi (mean) is the mean of high and low levels of the factor, i; and Xi (min) is the minimum value of the factor, i.

A total of 17 different combinations (including three replicates of the center point, which were signed the coded value 0) were chosen in random order according to a CCD configuration for three factors (Table 3A.1.). The moisture's impact content, the batter's assimilation of air and dried temperature of tray dryer was studied on the various parameters of dried nuggets, i.e., hardness, whiteness, water absorption capacity, and oil uptake ratio. These were assessed through central composite design (CCD) of Response Surface Methodology (RSM) (Swami et al., 2007a) and executed through MINITAB 17.0 (Minitab, Inc., Pennsylvania, PA) software. The experimental design in the coded (y) and actual (Y) levels of variables are shown in Table 3A.1. The response function (z) measured were hardness, whiteness, water absorption capacity, and oil uptake ratio of nuggets. These values have been related to coded variables zi, (i= 1, 2, and 3) by an order two polynomial. In this study, we selected the 2nd quadratic model because this one would give a decent estimation of the interrelation.

$$z = b_0 + b_1y_1 + b_2y_2 + b_3y_3 + b_{12}y_1y_2 + b_{13}y_1y_3 + b_{23}y_2y_3 + b_{11}y_1^2 + b_{22}y_2^2 + b_{33}y_3^2 \qquad (3A.5.)$$

The parameters determined the best quality of the nuggets: high water absorption capacity, low oil-uptake ratio, high whiteness index, and minimum hardness. Optimizing independent parameters, including moisture content, air inclusion in batter, and tray dryer temperature, was done using MINITAB 17.0.

Table 3A.1. The central composite experimental design (in the coded level of three variables) employed for Black gram nuggets (*bori*).

Serial No	Independent variables			Dependent variables			
	Temperature (°C) Y_1 (y_1)	Moisture (%) Y_2 (y_2)	Air Incorporation (%) Y_3 (y_3)	Hardness (N) z_1	Whiteness z_2	WAC (ml/gm-min) z_3	OUR (%) z_4
1	50(-1)	65.94(0)	21.21(0)	46.523	79.173	26.687	8.1
2	50(-1)	67.16(+1)	24.29(+1)	61.807	78.187	30.920	9.9
3	60(0)	65.94(0)	21.21(0)	42.520	80.993	40.472	9.6
4	60(0)	64.72(-1)	21.21(0)	70.622	80.433	34.596	10.1
5	60(0)	65.94(0)	21.21(0)	47.520	80.493	39.472	10.6
6	70(+1)	64.72(-1)	18.13(-1)	100.063	78.087	40.890	12.6
7	50(-1)	67.16(+1)	18.13(-1)	63.186	78.593	26.606	8.6
8	60(0)	65.94(0)	18.13(-1)	78.321	79.690	36.744	13.5
9	60(0)	67.16(+1)	21.21(0)	49.684	81.460	42.385	10.9
10	50(-1)	64.72(-1)	24.29(+1)	116.595	79.047	34.286	8.2
11	70(+1)	67.16(+1)	18.13(-1)	103.790	80.477	49.742	35.4
12	70(+1)	64.72(-1)	24.29(+1)	75.677	78.543	35.318	18.5
13	70(+1)	67.16(+1)	24.29(+1)	27.881	78.980	40.589	28.5
14	70(+1)	65.94(0)	21.21(0)	43.866	79.043	39.844	16.9
15	60(0)	65.94(0)	21.21(0)	37.520	81.493	41.472	8.6
16	50(-1)	64.72(-1)	18.13(-1)	30.304	78.853	20.340	7.4
17	60(0)	65.94(0)	24.29(+1)	62.704	80.760	37.302	10.6

The coefficient of the polynomial was represented by b_0 (constant term), b_1, b_2, *and* b_3 (linear effects), b_{11}, b_{22} *and* b_{33} (quardratic effects) and b_{12}, b_{13} *and* b_{23} (interaction effects).

Individual linear, quadratic, and interaction terms were achieved, and regression coefficients were calculated using an ANOVA Table 3A.2. By determining the F and p-value, the statistical importance of each term in the polynomial was determined. The resolution and classification of stationary points while taking into account the sign of the roots of the characteristic (λ) of the associated regression equations allowed for the completion of the identification of the optimal condition (Swami et al., 2006).

3A.2.5. Nutritional, Antioxidant, and physiochemical analysis of optimized black gram nuggets 3A.2.5.1. Nutritional Analysis

The total carbohydrate, protein, and ash content were measured according to section 2.2.4. Stored the Samples at room temperature and measured the moisture at 20 days, 40 days, and 60 days.

3A.2.5.2. Antioxidant Content and Antioxidant Activity

The total phenolic, flavonoid content, and antioxidant activity (FRAP, DPPH, ABTS assay) of all samples was determined as per section 2.2.3.

3A.2.5.3. Analysis of HPLC assay

The phenolic compound of black gram nuggets was analyzed by a reversed-phase high-performance liquid chromatography system (Alliance 2695 HPLC system, Water Corporation, Massachusetts, MA) fit out with a binary pump, a dual λ absorbance 2487 UV detector, and in line with a degasser and permit with two software. The segregation was conducted by symmetry reversed-phase C-18 column (150 mm × 4.6 mm, and size of particle 5μm) at 30 °C. system of gradient solutions A and B had been as a 0.5% phosphoric acid and 90% methanol. The elution chart had the pursuing content: A 100% and B 0% for 0 to 1 min, A 80% and B 20% at 1 to 4 min, A 70% and B 30% at 4 to 15 min, A 80% and B 20% at 15 to 20 min, A 100% and B 0% at 20 to 30 min till the finish of the run. The injector volume was 10 μL. 1mL/ min was the flow rate, and the peak was observed at 280 nm. 10 times dilute the extract with methanol before evaluation. Here mentioned, standard compounds were used to characterize and quantify black gram nuggets phenolic. The standards used were gallic acid, ferulic acid, quercetin, caffeic acid, vanillic acid, protocatechuic acid, epicatechin, (+) catechin, chlorogenic acid, sinapinic acid, syringic acid, apigenin, rutin, kaempferol, rosmarinic acid, p-coumaric acid, elachic acid, and trans-cinnamic acid. The phenolic component concentration was calculated as mg/g of nugget flour.

3A.2.5.4. Texture Profile Evaluation (TPE)

All Nugget texture profile was measured according to 2.2.5. section.

3A.2.5.5. Analysis of color

Hunter Lab colorimeter (45/0 of color flex, Hunter Associates Laboratory Inc, USA) was used to measure the color parameters of the samples. The Color analysis of the sample was done according to the process mentioned by Ray et al., (2017). A white standard plate was used for instrument calibration (where L* = 93.49, a* = −1.07, b* = 10.6). The samples were closely poured into optical glass up to 3cm in length, then placed on the port and covered by a black color cup. The color of the sample was seen through the bottom optical glass. Generally, this process is done repeatedly two to three times to get an accurate result. The results were expressed as lightness L* (0 to 100; black to white), redness a* (+ to – t; red to green), and yellowness b* (+ to –; yellow to blue) values. The color changes of the sample were measured by the ΔE* (Saha et al., 2019).

$$\Delta E^* = \sqrt{(L^* - L_0^*)^2 + (a^* - a_0^*)^2 + (b^* - b_0^*)^2} \quad (3A.6.)$$

Where subscript 0 is the color of the batter.

3A.2.5.6. Measurement of bulk density and porosity

The black gram nuggets' bulk density was measured by the procedure described by Gursoy et al., (2013). This formula calculated the percentage of porosity of black gram nuggets.

$$Porosity\ (\%) = [1 - (BD / PD)] \times 100 \quad (3A.7.)$$

BD was the bulk density, and PD was the particle density of the black gram nuggets.

3A.2.5.7. Dimension expansion

The dimension of the cooked nuggets was changed and determined by the following formula given by Math et al., (2004).

$$Dimension\ expansion = \frac{D.A.C - D.B.C}{D.B.C} \times 100 \quad (3A.8.)$$

D.A.C was a dimension of nuggets after cooking, and DBC was a dimension of (uncooked) nuggets before cooking.

3A.2.5.8. Statistical analysis

All parameters' mean (n = 5) and standard deviation values were calculated and presented. Significant differences at $p \leq 0.05$ were assessed by one-way analysis of variance and Tukey's test. Statistical, Non-linear regression and optimization analysis were conducted by Minitab 19.0 (MINITAB, INC., PA).

3A.3. Result and discussion

3A.3.1. Influence of moisture content, trapped air of batter, and temperature of tray dryer on product quality

3A.3.1.1. Whiteness index

3D surface plots presented in Figure 3A.1.(A) illustrate variables' effect on the maximum whiteness index of dried nuggets. The whiteness index varied between 78.09 to 81.76. It was increased up to a specific temperature at 60 °C then with a further increase of the temperature whiteness index was decreased. Increased temperature exposed more heat to the product, resulting in nuggets with a darker color. According to the ANOVA, E_1*E_1, and E_1*E_2 significantly affected the parameter. Temperature content in the batter is the primary variable affecting the whiteness attribute of the sample. Temperature and moisture content interaction had a significant effect on the parameter. Equations (9) express the correlation with the whiteness index and coded parameters:

$$L = 517 - 0.58E_1 - 15.6E_2 + 8.26E_3 - 0.01667E_1^2 + 0.115E_2^2 - 0.0580E_3^2 + 0.0404E_1E_2 - 0.00336E_1E_3 - 0.0849E_2E_3 \quad (3A.9.)$$

Where E_1; is temperature, E_2; is moisture content, and E_3; is air incorporation. The constructed model of the whiteness index was able to describe 91% of the total variation, according to the R2 value of 91.13%.

3A.3.1.2. Hardness

3D surface plots presented in Figure 3A.1.(B) expressed the effect of minimum hardness of dried sample at different moisture content, the batter's assimilation of air, and different drying temperatures of tray dryers. The hardness varied between 27.88 to 116.59 N. The parameter was significantly affected by E2, E3*E3, E1*E3, and E2*E3, according to the ANOVA. The batter's moisture content and air inclusion are the most important component affecting the sample's hardness characteristic. While increasing the moisture content diminished the texture characteristics of nuggets, incorporating air in higher volume helped preserve it. Temperature, trapped air, and moisture content substantially impacted the parameter. Hardness was noted minimum while increasing these three parameters of batter. Equations (10) express the correlation with the hardness and coded parameters:

$$H = 23311 + 36.7E_1 - 814E_2 + 256.7E_3 - 0.0458E_1^2 + 6.97E_2^2 + 2.186E_3^2 - 0.227E_1E_2 - 0.7516E_1E_3 - 4.630E_2E_3 \quad (3A.10.)$$

Where E_1; is temperature, E_2; is moisture content, and E_3; is air incorporation. A strong correlation (R2 = 95.88%) showed that the hardness model established could explain 96% of the overall variation.

3A.3.1.3. Oil uptake ratio (O.U.R)

3D surface plots presented in Figure 3A.1.(C) expressed the effect of the minimum oil uptake ratio of dried samples at different moisture content, temperature, and air incorporation. The oil uptake ratio varied from 7.4 to 35.4%. According to the ANOVA, the parameter was affected significantly by E1, E2, and E1*E1. The sample's oil uptake ratio is most strongly influenced by temperature and moisture content.

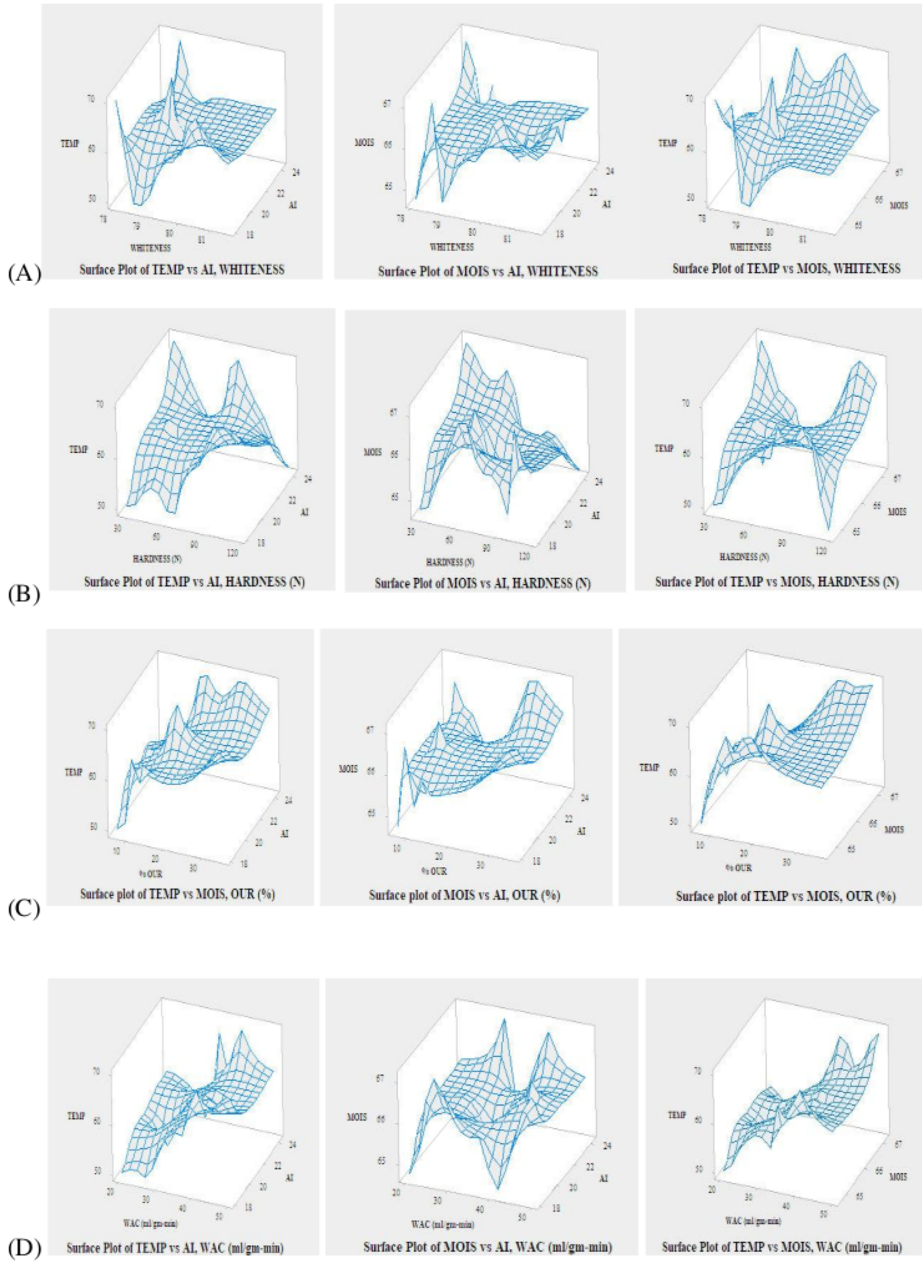

Figure 3A.1. Surface plot for the effect of moisture content (64.72 – 67.16 % wb), air incorporation (18.13 – 24.29% v/v) of batter and drying temperature (50 – 70 °C) of tray dryers on (A) whiteness index of nuggets; (B) hardness of the nuggets, N; (C) oil uptake ratio of nuggets, %+; (D) water absorption capacity of nuggets, ml/gm-min;

The oil uptake ratio of the nuggets decreased when the temperature and moisture content increased, assisting in its preservation. Increased air incorporation increased the oil uptake ratio in a specific volume of air incorporation. After that, it grew. Temperature and moisture content interaction had a significant effect on the parameter. Equation (11) shows their correlation:

$$O = 3586 - 22.85E_1 - 97E_2 + 16.2E_3 + 0.0301E_1^2 + 0.68E_2^2 + 0.27E_3^2 + 0.3064E_1E_2 - 0.0126E_1E_3 - 0.409E_2E_3 \quad (3A.11.)$$

Where E_1; is temperature, E_2; is moisture content, and E_3; is air incorporation. With a value of $R^2$was 92.50%.

3A.3.1.4. Water absorption capacity (W.A.C)

3D surface plots presented in Figure 3A.1.(D) expressed the effect of water absorption capacity of dried bori at various temperatures, air incorporation, and moisture content. The percentage of water absorption capacity varied between 20.34 to 49.742 ml per gram per min. Water absorption capacity was positively correlated with temperature, moisture content, and air incorporation. Equation (12) shows their correlation:

$$W = 1616 + 1.27E_1 - 65E_2 + 40.2E_3 - 0.0445E_1^2 + 0.524E_2^2 - 0.073E_3^2 + 0.1150E_1E_2 - 0.1339E_1E_3 - 0.440E_2E_3 \quad (3A.12.)$$

Where E_1; is temperature, E_2; is moisture content, and E_3; is air incorporation. With a value of R^2 96.48%. All parameters significantly affect the water absorption capacity of black gram nuggets at a 5% significance level.

3A.3.1.5. Optimization of variables by response surface methodology (RSM)

Using the method outlined by Gunst et al., (1996), the maximum value of air inclusion of batter, moisture content, and temperature of tray dryers were obtained while preparing samples. The data were fitted with a quadratic polynomial model using MINITAB 17.0.

Table 3A.2. Shows the result of a quadratic polynomial model in the form of an analysis of variance (ANOVA). With a very low p-value from the analysis of variance (ANOVA), the quadratic polynomial model was highly significant and sufficient to represent the relationship between the response and the critical variables (Table 3A.2.).

Table 3A.2. Variance Analysis (ANOVA) of dried black gram nuggets (*bori*).

Source	Sum of square value	Degree of freedom	Mean square value	*F*-value	*p*-value
(a) Whiteness index					
E_1	0.1631	1	0.16307	0.62	*0.456*
E_2	0.7475	1	0.74748	2.85	*0.135*
E_3	0.0033	1	0.00335	0.01	*0.913*
$E_1^*E_1$	7.4468	1	7.44677	28.42	*0.001*
$E_2^*E_2$	0.0787	1	0.07865	0.30	*0.601*
$E_3^*E_3$	0.8109	1	0.81095	3.09	*0.122*
$E_1^*E_2$	1.9474	1	1.94735	7.43	*0.030*
$E_1^*E_3$	0.0859	1	0.08591	0.33	*0.585*
$E_2^*E_3$	0.8147	1	0.81473	3.11	*0.121*
Error	1.8343	7	0.26204		
$R^2 = 0.9113$					
(b) Hardness					
E_1	108.0	1	107.99	1.70	0.233
E_2	755.4	1	755.39	11.90	0.011
E_3	96.1	1	96.1	1.51	0.258
$E_1^*E_1$	56.3	1	56.32	0.89	0.378
$E_2^*E_2$	288.3	1	288.34	4.54	0.071
$E_3^*E_3$	1151.7	1	1151.73	18.14	0.004
$E_1^*E_2$	61.4	1	61.4	0.97	0.358
$E_1^*E_3$	4287.7	1	4287.68	67.53	0.00
$E_2^*E_3$	2421.9	1	2421.87	38.15	0.00
Error	444.4	7	63.49		
$R^2 = 0.9588$					
(c) Oil uptake ratio					
E_1	485.809	1	485.809	47.84	0.000
E_2	133.225	1	133.225	13.12	0.008
E_3	0.324	1	0.324	0.03	0.863
$E_1^*E_1$	24.329	1	24.329	2.40	0.166
$E_2^*E_2$	2.751	1	2.751	0.27	0.619
$E_3^*E_3$	17.605	1	17.605	1.73	0.229
$E_1^*E_2$	111.751	1	111.751	11.00	0.013
$E_1^*E_3$	1.201	1	1.201	0.12	0.741
$E_2^*E_3$	18.911	1	18.911	1.86	0.215
Error	71.090	7	10.156		
$R^2 = 0.9250$					
(d) Water absorption capacity					
E_1	456.219	1	456.219	113.01	0.000
E_2	61.564	1	61.564	15.25	0.006
E_3	1.675	1	1.675	0.41	0.540
$E_1^*E_1$	52.946	1	52.946	13.11	0.008
$E_2^*E_2$	1.628	1	1.628	0.40	0.546
$E_3^*E_3$	1.268	1	1.268	0.31	0.593
$E_1^*E_2$	15.744	1	15.744	3.90	0.089
$E_1^*E_3$	136.001	1	136.001	33.69	0.001
$E_2^*E_3$	21.823	1	21.823	5.41	0.053
Error	28.260	7	4.037		
$R^2 = 0.9648$					

The value of the determination coefficient R^2 were 91.13%, 95.88%, 92.50%, and 96.48%, which implied that 91.%, 96%, 92.5%, and 96.5% of the sample variation in the nuggets preparation was attributed to the independent variables (Table 3A.2.) (Imandi et al., 2007).

The point of maximum whiteness index, minimum hardness, minimum oil uptake ratio, and maximum water absorption capacity was within the range, and due to mixed variables, it isn't easy to arrive at a meaningful conclusion in terms of moisture content, the volume of air incorporation and drying temperature fulfills the criteria of optimum condition. Thus, these response optimization plots could identify the point of maximum whiteness index, minimum hardness, minimum oil uptake ratio, and maximum water absorption capacity. Based on the examination, the whiteness index of 81.21±0.31, hardness of 44.59±4.85 (N), oil uptake ratio of 14±0.02 (%), and water absorption capacity of 41.86±1.22 (ml/g-min) appears to fulfill the criteria of the set optimum condition at the initial moisture content of 67.01%, air incorporation of 21.68% and drying temperature of 60.51 °C. The graphical results significantly affect the process variables that correspond to the response above parameters and show the best values for various moisture content levels, air inclusion volume, and tray dryer drying temperature.

Table 3A.3. The predicted and experimental values of whiteness index, hardness (N), oil uptake ratio (ml/gm-min), and water absorption capacity (ml/gm-min) for bori samples at the optimum condition of process variables moisture content 67.01% (wb), air incorporation 21.68% (v/v) and drying temperature at 60 °C.

Response's parameters	Predicted values	Experiment values
Whiteness index	80.47-81.94	80.48±0.78
Hardness (N)	33.11-56.06	51.76±5.60
Oil uptake ratio (%)	9-18	13±0.03
Water absorption capacity (ml/gm-min)	38.97-44.76	40.09±1.58

The entire relationship between process variables and response parameters would be better understood by examining the surface plots (Figure 3A.1.) generated from the predicted model equation by moisture content (wb), incorporated air (v/v), and temperature of driers (°C) at 65.94%, 21.21%, and 60 °C. The experimental values met the estimated optimal value. The sample was prepared by containing the batter moisture content of 67.01% (wb), 21.21% (v/v) air incorporation, and drying temperature of tray dryers at 60 °C. Table 3A.3 shows and compares the experimental and predicted values at the optimum condition.

3A.3.2. Nutritional, Antioxidant content, antioxidant activity, and other physicochemical properties analysis of optimized black gram nuggets (*bori*)

3A.3.2.1. Moisture Content

A food product's quality and storage characteristics depend on moisture content since the growth of spoilage organisms is favored by high moisture (Burguet et al., 1999). The initial moisture content of black gram nuggets (bori) was observed to be 3.47 %. After 20 days of storage, the moisture content was increased by 15.54 %. After 40 days, the moisture content of *bori* was 32.51 %. Moisture content after 60 days of storage of bori was 46.51% compared to the initial day. Moisture content was increased because environment humidity was high for a food product (*bori*) water content.

3A.3.2.2. Nutritional analysis

It was observed that black gram nugget (*bori*) has 65.49% carbohydrate, 25.70% protein, 1.45% fat, 1.87% ash content, and moisture content was 3.47%, and black gram (dhal) 58.92% carbohydrate, 23.12% protein, 1.31% fat, 3.19% ash and 12.69% moisture respectively. When preparing the *bori* with the black gram (dhal), carbohydrate, protein, and fat content were increased because dried foods have more calories on a weight-for-weight basis because of their nutrient concentration and decreased ash content because soaking reduces the phytic acid, some minerals like calcium and some heavy metals like cadmium, arsenic, and lead (Hotz & Gibson, 2001; Karkle & Beleia, 2010; Liu et al., 2018).

3A.3.2.3. Antioxidant content and antioxidant activity

Total phenolic content (TPC) and total flavonoid content (TFC) are the most important

Group of substances that support the antioxidant qualities (Kaur & Kapoor, 2002). The phenolic and flavonoid content of black gram nuggets (*bori*) was 0.87 mg GAE per gram (dry weight) and 0.81 mg QE per 100 g (dry weight). Black beans contain about 46% of the total bound phenolic. The phenolic compound is free when processed by several germinating methods, soaking, and drying (Wang et al., 2016). The antioxidant and drying temperature negatively correlate, especially for hot air oven drying, tray drying, or convective hot air drying (Saha et al., 2019). Several researchers reported that polyphenols retained be stat below 60 °C temperature. Still, the extent of damage to polyphenol compounds increases the chemical changes irreversibly, increasing the time duration and temperature (60 to 85 °C) (Goula et al., 2016).

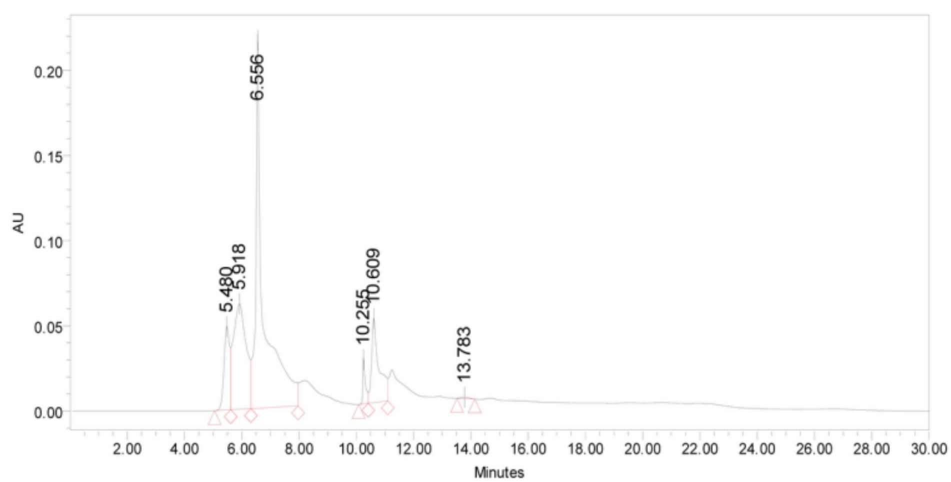

Figure 3A.2. HPLC chromatogram of black gram nuggets (*bori*): dihydroxy benzoic acid (5.480 min), catechin (5.918 min), ferulic acid (6.556 min), quercetin (10.255 min), apigenin (10.609 min) and kaempferol (13.783min).

The significant phenolic and flavonoids identified in the black gram nuggets were dihydroxybenzoic acid (RT = 5.480 min), catechin (RT = 5.918 min), ferulic acid (RT = 6.556 min), quercetin (RT = 10.255 min), apigenin (RT = 10.609 min) and kaempferol (RT = 13.783min) (Figure 3A.2.). Benzie & Strain, (1996) originally developed the ferric reducing antioxidant power (FRAP) for measuring the reducing power in plasma, but subsequently, this assay used for the assay of antioxidant in botanicals as it is a simple and quick process for the determination of antioxidant activity. It was observed that for black gram nuggets, FRAP activity was 9.77μmol AAE per gram (dry weight). 2,2-Diphenyl-1-picrylhydrazyl (DPPH) is a stable free organic nitrogen radical with a deep purple color and is frequently used to evaluate how well different antioxidants can scavenge free radicals (Shimoji et al., 2002). Black gram nugget, DPPH scavenging activity was 9.01μmol AAE per gram (dry weight). ABTS is also used for free radical scavenging activity determination of food samples. The radical has blue and is used for antioxidant activity. In a black gram nugget, ABTS free radical scavenging activity was 8.88μmol AAE per gram (dry weight). Black gram nugget, antioxidant content, and antioxidant activity were gradually decreased concerning black gram (dhal) but not significant (P≥0.05).

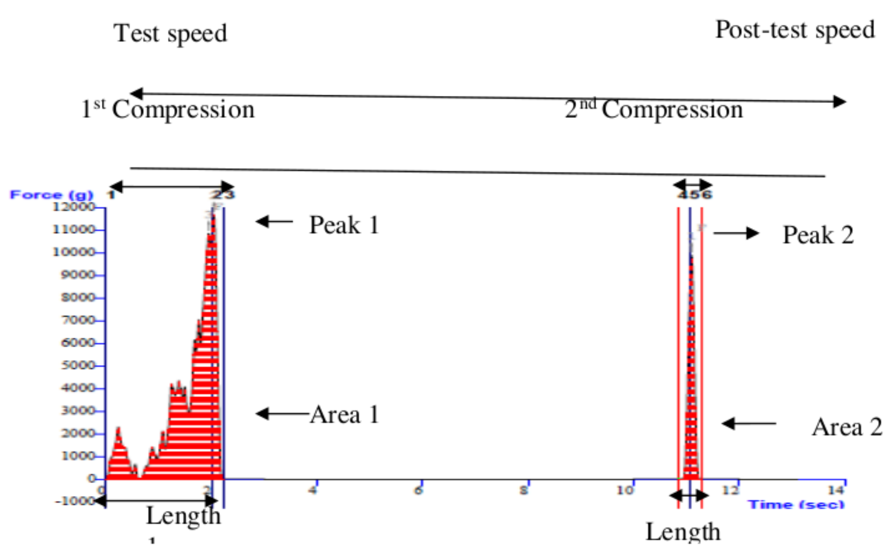

Figure 3A.3. Graph showing the textural profile of black gram nuggets.

3A.3.2.4. Texture profile analysis

Food texture was defined by the general state that "texture is the functional and sensory manifestation of the mechanical, structural, and surface properties of foods measured by the sense of vision, hearing, touch, and kinetics"(Szczesniak, 2002). Food texture is an essential parameter for sensory property evaluation. Some parameters of food texture can be observed and appraised by texture testing instruments (Van Vliet et al., 2009). It is a multiplied characteristic defined by many words, of which cohesiveness, hardness, and thickness are examples. Figure 3A.3 outlines the nuggets with an average textural profile after completing one run. Where Hardness (N) = is possibly the highest compression force, Cohesiveness = Ratio of area of 2^{nd} and 1^{st} compression, Springiness = Length 2 / Length 1, Gumminess (N) = Hardness × Cohesiveness, Chewiness (N) = Hardness × Cohesiveness × Elasticity and Adhesiveness (g.s) = The graph's negative area. In an analysis of the texture profile of black gram nuggets *(bori)*, it was observed that the hardness value was 51.76±5.600 N, the Springiness value was 0.13±0.055, the cohesiveness value was 0.15±0.014, gumminess value was 7.49±0.766 N, chewiness value was 2.57±0.690 N and adhesiveness (g.s) value was −0.92±0.055.

3A.3.2.5. Analysis of color

Food color is the property to evaluate the external characteristics of a product (Barrett et al., 2010). Color is the second perception of food products after consumer appearance. Customer acceptability of different color food or food products may be affected by undesirable color changes and developed by the Maillard browning reaction (Nahar et al., 2022). It was observed that the black gram nuggets (*bori*) and *bori* preparing batter L^*, a^*, and b^* values were 80.48, 81.87, 1.59, 0.59, and 27.68, 22.58, respectively. This drying process decreased the whiteness and yellowness value and increased the redness value of *bori* concerning the batter. Drying induces color changes in *bori* via a nonenzymatic browning reaction.

3A.3.2.6. Another physicochemical parameter's analysis

Black gram nuggets have 39.95% porosity, bulk density of 0.51gm/cm^3, and normal density of 0.85gm/cm$^{3.}$ and after cooking the nuggets, the dimension expansion was 72.43 %with respect to dried black gram nuggets.

3A.4. Conclusion

The current study leads to the following finding. The effect of moisture content, air incorporation into the batter, and tray dryer drying temperature significantly impacted the hardness, whiteness, water absorption, and oil uptake ratio of samples. The ideal moisture level, batter's air incorporation, and tray dryer temperature were 67.01% (w/b), 21.68% (v/v) and 60 °C, obtaining the maximum whiteness index, water absorption capacity, a minimum level of hardness and oil uptake ratio. The optimum values of these response quality parameters would be 80.47 to 81.94 (whiteness index), 33.11 to 56.06 N (hardness), 9 to 18 % (oil uptake ratio), and 38.97 to 44.76 ml/ g-min (water absorption capacity) respectively. Prepared the black gram nuggets by optimized parameters (67.01% w/b, 21.68% v/v, and 60 °C), and their quality response parameters were 80.48±0.78 (whiteness index), 51.76±5.60 N (hardness), 13±0.03 % (oil uptake ratio) and 40.09±1.58 ml/g-min (water absorption capacity). The optimized nuggets have improved their macronutrient content, i.e., carbohydrate, protein, and fat content concerning black gram (dhal). These nuggets were rich in antioxidant content and antioxidant activity. This study experiments developed traditional food by technology and analyzed their nutritional values, which have health benefits.

Part -B

3B.1. Introduction

Most people worldwide use pulses as essential protein and other nutrient sources. It has also been reported that certain phytochemicals such as polyphenols, flavonoids, and phytosterols are found in legumes with health benefits (Sreerama et al., 2010). Protein-rich food consumption per capita in industrialized countries is high. However, the composition varies by geographical area (de Boer et al., 2006). Typically, Europeans consume 70% more animal-based protein than the recommended daily allowance (The Netherlands Environmental Assessment Agency, 2017). It causes health-risk because of the presence of higher cholesterol and other harmful fats, offering a threat to the development of a variety of diet-related diseases such as cardiovascular disease, cancer, diabetes, and others (Boada et al., 2016; Nadathur et al., 2017). Enhancing the nutrient content of food and protein from the plant could be a good choice as nutritional enhancers or replace animal proteins. Plant proteins boost energy, support the immune system, lower the risk of cardiovascular disease, and aid weight loss. However, a mix of plant-based foods such as grains and legumes, which are commonly used in traditional diets such as the Mediterranean diet (de Boer et al., 2006; Martínez-González et al., 2017), can offer vital amino acids and enhance vascular health (Agnoli et al., 2017; McCarty et al., 2016).

The maximum protein of the plant black gram (*Vigna mungo)* is Leguminosae, which plays an essential role in the human diet with proven health benefits. The black gram can be used with or without the husk. The de-husked cotyledon of black gram, known as dal, is used to make dishes like idli, dosa, papad, nuggets, etc. On the other hand, the portions with husk, known as 'kaloi,' contain a high amount of fiber, protein, vitamins, iron, and calcium, which helps to make some traditional cuisine. So many products have shown potential industrial applications in the quality improvement of buffalo meat burgers, beef sausages, and biscuits (Modi et al., 2004). The husk (seed coat, aleurone layer, and plumule) is a waste generated by the black gram processing industry. However, it contains various nutrients, including dietary fiber and bioactive compounds, and has potential in functional foods.

Nuggets are a pulse-based traditional food item that is quite popular in the Indian subcontinent. Overnight soaked, pulses are first ground to a smooth paste. It is then aerated to attain the proper consistency and density, and this form is known as a batter. Small aliquots of batter of approximately 10 g in weight are manually poured on mustard oil to rub over the tray, clean cloth, or wooden stage in arrays and sun-dried for two to three days until crispy nuggets with a hollow inner core are obtained. To produce the nuggets commercially, a mechanical drying system is required. Hot air, freeze-drying, and microwave drying are the most common available drying methods. The most popular and effective methods of drying food are hot air drying or tray drying, which destroy the squishy microstructure and reduce the amount of bioactive thermolabile compounds in plant products

(Salim et al., 2017). Additional benefits of microwave drying include increased evaporation rate, decreased drying temperature, homogenous energy transfer on the product, development of optimal final product features, improved space usage, devastating impact on food, and better process control (Demiray et al., 2017). As mentioned earlier, microwave drying is much more effective in freeze-drying and tray drying due to the antioxidant activity of cereals, pulses, and lignocellulose plant materials (Ozcan-Sinir et al., 2019; Saha et al., 2019). Mathematical models play a vital role in designing and optimizing the drying processes widely used to define the properties of dried food (Ozcan-Sinir et al., 2019; Saha et al., 2019).

Several studies have been conducted on different aspects of nuggets, such as the preparation of nuggets from a batter, characteristics of the batter, and nuggets (Swami et al., 2005, 2006, 2007a, 2007b). Previous research has been conducted on the preparation of nuggets from the only cotyledon part of a black gram by sunlight, convective air dryers, and textural profile analysis only. However, a minimum number of studies focus on the drying kinetics, different drying processes, color profiles, and antioxidant profiles of nuggets. Therefore, the objectives of the work were to compare drying techniques, namely, hot-air, microwave, and freeze-drying of black gram nuggets, followed by drying kinetics and mathematical modeling. Additionally, the antioxidant (total phenolic content, total flavonoid content, FRAP assay, DPPH assay, and ABTS assay), color, and textural properties of dried products were evaluated for their acceptability and health benefits.

3B.2. Materials and methods

3B.2.1. Raw materials

Black gram (*Vigna Mungo*) (Cultivar: “WBU-109”) was procured locally (Dinesh Dal mill, Kolkata, West Bengal, India).

3B.2.2. Chemicals

They purchased gallic acid from an Alfa Aesar supplier. Sodium carbonate, distilled water, folin-ciocalteu reagent, sodium hydroxide, quercetin, aluminum chloride, sodium nitrate, ascorbic acid, potassium ferricyanide, trichloroacetic acid, 2,2-diphenyl-1-picryl-hydrazyl-hydrate (DPPH), ethanol, 2,2'-azino-bis-3-ethylbenzothiazoline-6-sulfonic acid (ABTS) were purchased from SRL (Mumbai, India). SD Fine chemicals supply the methanol, acetone, ferric chloride, phosphate buffer, and potassium persulfate. Ferulic acid, quercetin, caffeic acid, vanillic acid, protocatechuic acid, epicatechin, (+) catechin, chlorogenic acid, sinapinic acid, syringic acid, apigenin, rutin, kaempferol, rosmarinic acid, p-coumaric acid, dihydroxy benzoic acid, myricetin, elachic acid, and trans-cinnamic acid were received from Sigma-Aldrich. All chemical suppliers come from Mumbai in India.

3B.2.3. Preparation of Nuggets

The initial moisture content of collected cotyledon, whole black gram, and husk was around 12%. They were soaked in tap water at 23 ± 2 °C for 4 h. The soaked product moisture content was 54% (wet basis, wb). All sample moisture content was analyzed by a moisture analyzer (PGB1MB, Wensar Weighing Scales Limited, India). Prepared the batter using a wet-grinder (MK-SW200BLK, Panasonic, India) with the addition of drinking water. Then the batter was filtrated through the 60-mesh size sieve where 90% of the batter passed through the sieve. The moisture content of the prepared batter was 68.11±0.83% (wb). The prepared batter was whipped or beated for 90 seconds and operated at 1350 min^{-1} (approximately) to achieve air incorporation. Air incorporation level was 22.07±1.44 % (v/v) for cotyledon and whole gram but 5.16 % (v/v) for tush samples. The reduced air intake in bran was the presence of dietary fibers in large quantities and carbohydrates and protein in small amounts. Nuggets were prepared by placing approximately 5±1 mL of batter on fine cotton cloths and then in a different dryer. The nuggets were ready in cylindrical shape of 28 mm in diameter (D) and 23 mm in width (L). After preparing the nuggets, the cotyledon nuggets or cotyledon bori or dal *bori* were marked as CB, whole black gram or kolai nuggets or kolai *bori* mark was marked as KB, and tush or husk nuggets or tush *bori* or khosa *bori* was marked as TB. After drying, the final moisture content of nugget samples was 2.877±1.387 % (dry basis, db).

3B.2.4. The Drying of nuggets

3B.2.4.1. Hot-air drying

Hot-air drying was performed in a tray dryer (SS-24, Mac Pharma Tech, India), and the dimensions of each tray were 0.75×0.35 m. The relative humidity of the drying air was not regulated, and it varied from 15 to 40%. During the drying process, the dryer was operated at 60 ºC for 6 h of CB, 6.5 h of KB, and 5.5 h of TB, and the air velocity was maintained at 1.5 m/s. Before placing the sample on the stainless-steel tray, the dryer was left on for at least 20 min to reach steady-state conditions. Then 200 g samples of nuggets were placed onto the perforated stainless-steel tray coated with a muslin cloth in a single layer. Three samples (approximately 15 to 20 g) were withdrawn at 40-, 45-, and 50-min intervals of TB, CB, and KB, respectively, to determine the moisture content at different drying times.

3B.2.4.2. Freeze-drying

Here 25 g of nuggets prepared from batter was frozen at −40 ºC for 4 h in a freezer with a very low-temperature C340-86, New Brunswick Scientific, England). Then freeze-drying was performed in a freeze dryer (FDU1200, Eyela, Japan) at the pressure of 14 Pa and the condenser temperature of −45 ºC for 8 h.

3B.2.4.3. Microwave drying

A microwave oven (CE1041DFB/XTL, Samsung, India) was used to perform the microwave drying, and the working frequency was maintained at 2450 MHz and adjustable irradiation time and power levels. Microwave drying was operated at four different power levels 600, 450, 300, and 180 W. Approximately 25 g of batter was placed on each glass plate of each sample in a thin layer and dried. The moisture loss throughout the drying process was recorded at 50 s, 60 s, 90 s, and 140 s of CB, 40 s, 60 s, 80 s, and 280 s of KB, and 80 s, 90 s, 150 s, and 180 s of TB at the 600 W, 450 W, 300 W, and 180 W microwave power respectively.

3B.2.4.4. Drying Kinetics

The drying kinetics of nuggets were tested using six selected models listed below. The experiential framework is applied to build new or improved drying methods and was acquired straight from the standard design of Fick's law (Nadi & Tzempelikos, 2018). The WPS Workbench Ink. (WPS Analytics, World Programming, UK) was used to perform the regression analysis.

$$MR = \frac{M_t}{M_0} \quad (3B.1.)$$

Where M_t is the moisture content at time t, and M_o is the initial moisture content. All moisture contents were expressed in g water / g dm; a, b, c, g – dimensionless drying constant, k – constant of drying velocity (h^{-1}), n – dimensionless drying constant, and t – time (h).

Additionally, using the following equation, moisture diffusivity (D_{eff}) on cylindrical nuggets was calculated:

$$ln\,(MR) = ln\left(\frac{M_t}{M_o}\right) = ln\left(\frac{8}{\pi^2}\right) - \left(\frac{\pi^2 D_{eff}}{4L^2}t\right) \quad (3B.2.)$$

L was the Sample half-thickness (L=11.5 mm). Temperature and moisture diffusivity were constant, and shrinkage was negligible throughout the drying process.

The better suitable fitted model was ascertained by the equivalence of the less sum of square error (SS_{error}), the root means square error (RMSE), and more correlation coefficient R (R^2) value.

$$SS_{error}=\sum(y_i-\hat{y})^2 \quad (3B.3.)$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}(MR_{pre,i} - MR_{exp,i})^2\right]^{\frac{1}{2}} \quad (3B.4.)$$

$$R^2 = 1 - \frac{\sum_{i=1}^{N}(MR_{pre,i} - MR_{exp,i})^2}{\sqrt{[\sum_{i}^{n}(MR_{exp,i} - MR_{exp,mean})^2]}} \quad (3B.5.)$$

Where $\hat{y}$ is the mean response and y_i is the i^{th} observed response value. $MR_{exp,\,i}$ is the experimental moisture ratio, $MR_{pre,\,i}$ is the predicted moisture ratio, N is the number of observations, and n is the number of constants in the drying model.

Table 3B.1. Selected drying mathematical models.

Model name	Model	
Lewis	$MR = exp(-kt)$	(3B.6.)
Midilli et al	$MR = a\ exp(-kt^n) + bt$	(3B.7.)
Page	$MR = exp(-kt^n)$	(3B.8.)
Two-term	$MR = aexp(-kt) + bexp(-gt)$	(3B.9.)
Henderson-Pabis	$MR = a\ exp(-kt)$	(3B.10.)
Logarithmic	$MR = a\ exp(-kt) + c$	(3B.11.)

3B.2.5. Physiochemical analysis and Antioxidant of nuggets

3B.2.5.1. Measurement of bulk density and porosity

The black gram nuggets' bulk density and porosity were measured as per section 3A.2.5.6.

3B.2.5.2. Texture Profile Analysis (TPA)

TPA tests were carried out according to section 2.2.5.

3B.2.5.3. Color measurement

The color profile is determined following section 3A.2.5.5.

3B.2.5.4. Antioxidant properties

The antioxidant extraction process, antioxidant profiles, and HPLC study of polyphenolic compounds were measured according to section 2.2.3. and 3A.2.5.3. respectively.

3B.2.6. Statistical analysis

All mathematical model was conducted on WPS Workbench Ink. (WPS Analytics, World Programming, UK) and data analysis was carried out by MINITAB 19.0 (Minitab, Inc., Pennsylvania, PA).

3B.3. Result and Discussion

3B.3.1. Drying of black gram nuggets

Moisture ratio (MR) was plotted against dehydration time (Figure 3B.2.). The figure showed that the MR value asymptotically decreased with time. The probable cause might be that due to the removal of free water, the moisture loss rate was rapid initially; however, it slowed down as the vapor diffusion increased. The effective moisture diffusivity was calculated using equation 3B.2. and the values for dried CB, KB, and TB varied from 84.6717×10^{-8} to 0.7925×10^{-8} m^2/s, 118.9607×10^{-8} to 7.605×10^{-7} m^2/s, and 4.8676×10^{-9} to 0.07305×10^{-9} m^2/s, respectively (Table 3B.3.). The highest value of moisture diffusivity was obtained in microwave drying at 600 W. The most negligible value was obtained in the freeze-drying of nuggets. Similar variations were reported for spinach and corn cob (Bualuang et al., 2017; Saha et al., 2019). For dried black gram nuggets, six mathematical models (Table 3B.1., model

3B.6. - 3B.11.) were applied to MR data, resulting in a better deal of instruction for all models except the logarithmic model (Table 3B.2.) between predicted and experimental values. The complexity of the model depends on the number of constants present. Because of more constants, the Logarithmic, Midilli, and Two-Term models are more complex than Henderson-Pabis, Lewis, and Page models. Instead, the statistical parameter was used to choose the model rather than the number of constants (Onwude et al., 2016). The Page model had the lowest SS_{error}, RMSE value, and highest R^2 value, which indicated the best model fit for all drying procedures of black gram nuggets (Table 3B.2.). Figure 3B.2.(a, b, c) shows the relationship between moisture ratio and drying time fitted to Page Model. For the same model, the plot of observed and predicted values is illustrated in Figure 3B.2.(d).

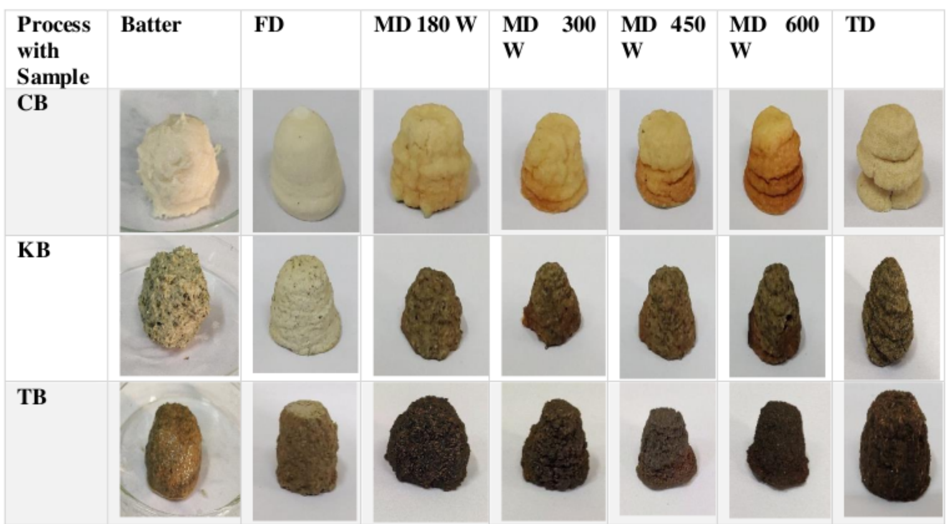

Figure 3B.1. Picture of different nuggets at different drying processes.

In prior investigations, the Page model outperformed other drying kinetics models in its ability to simulate the electromagnetic evaporation of lentil seeds (Heydari et al., 2020). Photographs of batter and dried nuggets are shown in Figure 3B.1.

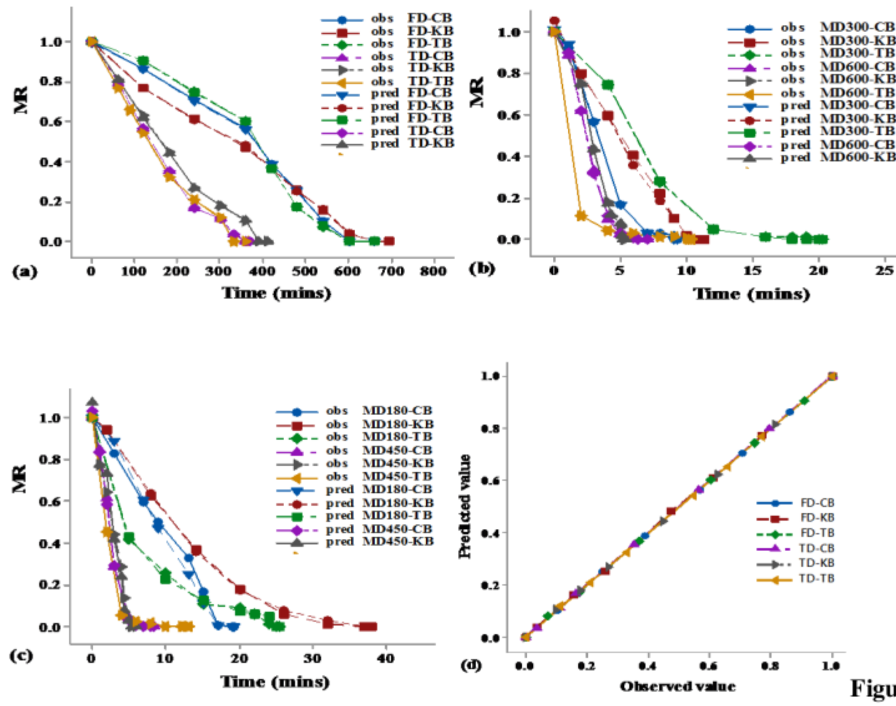

Figure 3B.2. Drying kinetics of different black gram nuggets, dehydrated by (a) freeze and hot air drying and (b) (c) microwave drying at different powers. Solid lines represent observed and predicted values determined using the Page model. (d) Plot between observed and predicted values showing a linear relationship.

Table 3B.2. Result of selected mathematical modeling with regression parameters of all nuggets.

Process	***Mathematical Equation of Lewis model: MR = exp(-kt)***						
	k				SS_{Error}	RMSE	R^2
A-CB	0.002				0.085	0.116	0.971
B-CB	0.095				0.062	0.099	0.976
C-CB	0.283				0.075	0.104	0.971
D-CB	0.393				0.090	0.107	0.963
E-CB	0.372				0.104	0.124	0.959
F-CB	0.006				0.034	0.071	0.986
A-KB	0.003				0.050	0.089	0.979
B-KB	0.077				0.027	0.062	0.991
C-KB	0.179				0.059	0.096	0.975
D-KB	0.328				0.059	0.097	0.976
E-KB	0.360				0.122	0.140	0.935

F-KB	0.005				0.020	0.055	0.992
A-TB	0.002				0.151	0.153	0.952
B-TB	0.151				0.006	0.032	0.995
C-TB	0.154				0.064	0.099	0.963
D-TB	0.492				0.014	0.048	0.988
E-TB	1.066				0.002	0.016	0.998
F-TB	0.006				0.017	0.050	0.994
Mathematical Equation of Midilli et al., model: MR = aexp(-ktn) + bt							
	k	n	a	b	SS_{Error}	RMSE	R^2
A-CB	0.0147	0.155	1.001	-0.002	0.067	0.065	0.991
B-CB	0.001	0.88	1.21	-0.069	0.051	0.034	0.997
C-CB	0.107	12.146	1	0.027	0.029	0.232	0.988
D-CB	0.116	2.157	0.985	0.001	0.019	0.017	0.999
E-CB	0.101	2.199	0.993	-0.001	0.001	0.012	0.999
F-CB	0.0006	1.417	0.998	-0.0002	0.003	0.019	0.999
A-KB	0.003	0.561	1.000	-0.002	0.099	0.063	0.990
B-KB	0.025	1.388	1.001	-0.001	0.001	0.005	0.999
C-KB	0.007	0.510	1.001	-0.096	0.019	0.008	0.999
D-KB	0.104	2.136	1.094	0.212	0.039	0.028	0.997
E-KB	0.048	2.603	1.001	0.0001	0.0005	0.011	0.999
F-KB	0.0007	1.333	0.996	-0.0001	0.0009	0.014	0.999
A-TB	0.007	0.641	1.087	-0.002	0.095	0.119	0.971
B-TB	0.029	0.655	0.999	-0.003	0.018	0.018	0.999
C-TB	0.015	2.141	0.999	0.001	0.008	0.001	0.999
D-TB	0.061	4.028	1	0.039	0.004	0.013	0.993
E-TB	1.509	0.549	1	0.0005	0.00009	0.001	0.999
F-TB	0.001	1.323	0.998	-0.00005	0.0005	0.009	0.999
Mathematical Equation of Page model: MR = exp(-ktn)							
	k	n			SS_{E}rror	RMSE	R^2
A-CB	0.004	1.276			0.042	0.062	0.992
B-CB	0.019	1.669			0.021	0.064	0.991
C-CB	0.060	2.088			0.001	0.010	0.999
D-CB	0.127	2.070			0.003	0.019	0.998
E-CB	0.105	2.181			0.001	0.012	0.999
F-CB	0.0004	1.523			0.002	0.020	0.998
A-KB	0.013	1.752			0.030	0.063	0.996
B-KB	0.020	1.488			0.001	0.013	0.999
C-KB	0.050	1.692			0.013	0.046	0.993
D-KB	0.151	1.653			0.019	0.053	0.994
E-KB	0.048	2.606			0.001	0.009	0.999

F-KB	0.006	1.401			0.001	0.013	0.999
A-TB	1.761	2.963			0.020	0.055	0.994
B-TB	0.224	0.824			0.003	0.022	0.997
C-TB	0.016	2.114			0.002	0.006	0.999
D-TB	0.222	1.851			0.001	0.012	0.999
E-TB	1.560	0.499			0.00002	0.002	0.999
F-TB	0.001	1.347			0.001	0.009	0.999
Mathematical Equation of Two-term model: MR = aexp(-kt) +bexp(-gt)							
	k	a	b	g	SS_{Error}	RMSE	R^2
A-CB	0.003	1.337	-0.337	8.05	0.050	0.092	0.982
B-CB	0.120	1.257	-0.257	8.05	0.041	0.082	0.983
C-CB	0.381	1.404	-0.404	7.5	0.024	0.063	0.989
D-CB	0.582	1.602	-0.602	9.4	0.024	0.058	0.989
E-CB	0.574	1.653	-0.653	8.3	0.024	0.063	0.989
F-CB	0.008	1.329	-0.329	8.05	0.010	0.040	0.995
A-KB	0.003	1.228	-0.228	8.05	0.035	0.077	0.984
B-KB	0.089	1.158	-0.158	8.05	0.012	0.045	0.995
C-KB	0.236	1.354	-0.354	8.05	0.030	0.070	0.986
D-KB	0.151	1.078	-0.088	8.09	0.006	0.030	0.997
E-KB	0.753	3.482	-2.482	8.05	0.009	0.038	0.995
F-KB	0.006	1.212	-0.212	8.05	0.006	0.033	0.997
A-TB	0.003	1.485	-0.485	8.05	0.083	0.118	0.971
B-TB	0.120	0.773	0.227	8.05	0.002	0.020	0.998
C-TB	0.277	2.273	-1.273	8.05	0.002	0.019	0.998
D-TB	1.024	3.486	-2.486	8.05	0.0008	0.011	0.999
E-TB	0.411	0.248	0.752	8.05	0.0001	0.005	0.999
F-TB	0.007	1.231	-0.231	8.05	0.003	0.022	0.998
Mathematical Equation of Henderson-Pabis model: MR = aexp(-kt)							
	k	a			SS_{Error}	RMSE	R^2
A-CB	0.002	1.081			0.076	0.113	0.973
B-CB	0.101	1.064			0.056	0.097	0.977
C-CB	0.306	1.099			0.062	0.101	0.972
D-CB	0.425	1.1			0.077	0.105	0.965
E-CB	0.408	1.111			0.087	0.121	0.962
F-CB	0.006	1.062			0.029	0.069	0.986
A-KB	0.003	1.051			0.047	0.088	0.979
B-KB	0.081	1.060			0.021	0.060	0.991
C-KB	0.190	1.070			0.053	0.094	0.976
D-KB	0.347	1.058			0.055	0.096	0.976
E-KB	0.379	1.075			0.116	0.139	0.935

F-KB	0.005	1.051			0.017	0.053	0.993
A-TB	0.003	1.112			0.134	0.149	0.954
B-TB	0.149	0.985			0.006	0.032	0.995
C-TB	0.161	1.067			0.059	0.099	0.964
D-TB	0.497	1.015			0.014	0.048	0.988
E-TB	1.066	0.999			0.002	0.016	0.998
F-TB	0.006	1.049			0.013	0.047	0.995
Mathematical Equation of Logarithmic model: MR = aexp(-kt) + c							
	k	a	c		SS_{Error}	RMSE	R^2
A-CB	1.020	0.59	0.41		0.437	0.265	0.848
B-CB	0.015	3.304	4.291		0.004	0.025	0.998
C-CB	0.168	1.417	-0.353		0.030	0.070	0.987
D-CB	0.262	1.348	-0.280		0.042	0.078	0.981
E-CB	0.165	1.801	-0.734		0.034	0.076	0.985
F-CB	0.003	1.613	-0.594		0.005	0.028	0.998
A-KB	1.020	0.59	0.41		0.399	0.257	0.826
B-KB	0.049	1.326	-2.294		0.004	0.026	0.998
C-KB	0.003	1.056	-2.057		0.0004	0.008	0.999
D-KB	0.044	3.832	4.816		0.006	0.031	0.997
E-KB	0.046	3.898	4.928		0.021	0.059	0.988
F-KB	0.003	1.601	-0.586		0.003	0.021	0.999
A-TB	1.020	0.59	0.41		0.572	0.305	0.809
B-TB	0.165	0.962	0.031		0.005	0.028	0.996
C-TB	0.108	1.243	-0.197		0.035	0.076	0.978
D-TB	0.475	1.030	-0.017		0.013	0.047	0.989
E-TB	0.040	0.953	0.047		0.009	0.038	0.992
F-TB	0.003	1.494	-0.480		0.002	0.019	0.999

A, B, C, D, E, and F denote FD, MD 180 W, MD 300 W, MD 450 W, MD 600 W, and TD process.

3B.3.2. Structural analysis

The structural properties of black gram nuggets were assessed using various conditions by comparing the products' hardness, resilience, porosity, and moisture content. Hardness and resilience for different drying procedures were increased in the following order: FD < TD < MD-600W < MD-450W < MD-300W < MD-180W (Table 3B.3.). Porosity for different drying processes had in the order as FD > TD > MD-600W > MD-450W > MD-300W > MD-

180W (Table 3B.3.). During the drying process due to the process of evaporation a pressure gradient was formed within the dried material.

Table 3B.3. Textural profiles of black gram nuggets as influenced by drying.

Process	Time (min)	Moisture Diffusivity (10^{-8} m^2/s)	Porosity (%)	Hardness (N)	Resilience
A-CB	600	0.793	59.524±1.054 [ab]	61.600±0.654 [abcd]	0.111±0.001 [e]
B-CB	19	26.778	40.048±2.005 [defg]	113.930±0.456 [a]	0.441±0.001 [cde]
C-CB	12	44.666	50.733±1.025 [abcd]	76.840±0.789 [abc]	0.177±0.001 [e]
D-CB	8	59.501	52.520±1.648 [abc]	69.270±0.619 [abcd]	0.126±0.001 [de]
E-CB	6.6	84.672	52.580±1.998 [bcde]	68.120±0.945 [a]	0.125±0.001 [e]
F-CB	360	1.176	53.940±1.023 [cdef]	67.080±0.810 [cd]	0.118±0.001 [e]
A-KB	660	0.761	60±0.998 [a]	21.930±0.813 [d]	0.073±0.0009 [e]
B-KB	37	23.967	33.867±2.054 [fgh]	123.330±0.551 [a]	1.538±0.003 [ab]
C-KB	11.2	66.361	39.150±1.589 [defg]	101.300±0.715 [ab]	1.370±0.002 [a]
D-KB	7.6	76.043	53.341±1.365 [abc]	87.360±0.823 [abc]	0.189±0.001 [e]
E-KB	5	118.961	53.822±1.014 [abcd]	86.600±0.885 [ab]	0.171±0.001 [de]
F-KB	390	1.108	54.520±1.985 [cdef]	76.930±0.984 [bcd]	0.126±0.001 [e]
A-TB	600	0.731	58.750±1.087 [ab]	49.650±0.498 [bcd]	0.098±0.001 [e]
B-TB	24	14.538	22.348±2.525 [hi]	99.500±0.832 [abc]	1.502±0.001 [ab]
C-TB	20	24.419	28.884±2.135 [gh]	98.700±0.881 [abc]	0.976±0.001 [abcd]
D-TB	13.3	35.960	35.793±2.004 [efg]	66.900±0.478 [abcd]	0.883±0.002 [bcd]
E-TB	10.6	48.676	36.913±1.723 [gh]	65.870±0.589 [abc]	0.558±0.001 [abc]
F-TB	330	1.034	35.520±2.035 [i]	64.730±0.426 [abc]	0.517±0.001 [e]

A, B, C, D, E, and F denote FD, MD 180 W, MD 300 W, MD 450 W, MD 600 W, and TD process, respectively.

Significantly in the case of freeze-drying, the pressure gradient was reduced by the in-existence of an evaporator and decreased air pressure, resulting in the breakdown of the uncontrolled perforated structure of the dehydrated products (Nadi & Tzempelikos, 2018). According to Paengkanya et al., (2015), microwave drying contributed to the durian chips' improved hardness and resistance. The high power of the microwave made a high percentage of perforation and vacuum fraction of the structure. Thus, higher microwave power was responsible for the lower quality of dried black gram nugget hardness and resilience, more significant deterioration of the structure, and higher porosity. In the absence of electoral heat, structural fragmentation had decreased.

In the sample study of black gram nuggets, the hardness was increased with the decrease of the porosity and moisture value, and a similar correlation study was observed in date flesh (Rahman & Al-Farsi, 2005). In the microwave study, MD 450 W process was best for low hardness, low resilience value, and high porosity value. Concerning the increased value of porosity, decreased value of hardness, and resilience, the KB sample was found best than the other samples.

3B.3.3. Color

The high ΔE and low L*, a*, and b* values indicated that the whole microwave drying method had significantly blackened the nuggets. All FD and only TD-KB nuggets had lightened considerably, as could be supported by the ΔE and lightness value. For the TD nuggets, no significant changes were observed.

Table 3B.4. The color value of dried black gram nuggets and fresh batter.

Process	L*	a*	b*	ΔE
Ba - CB	82.788±1.077^{b}	0.377±1.039^{D}	17.164±1.557^{e}	
A-CB	88.091±2.536^{a}	0.419±0.916^{D}	14.865±3.094^{f}	5.780
B-CB	75.431±0.721^{c}	7.004±1.528^{BC}	28.760±0.783^{c}	15.248
C-CB	76.400±0.866^{c}	5.347±1.591^{C}	32.443±0.749^{b}	17.290
D-CB	72.492±0.414^{d}	8.078±1.618^{AB}	36.362±0.338^{a}	23.106
E-CB	70.290±0.656^{d}	10.244±1.999^{A}	35.934±0.634^{a}	24.614
F-CB	82.017±0.684^{b}	1.151±0.904^{D}	20.527±0.768^{d}	3.536
Ba - KB	53.600±2.953^{g}	2.473±0.864^{H}	17.684±0.384^{j}	
A-KB	67.415±0.380^{e}	2.509±0.856^{H}	17.409±0.553^{j}	13.818
B-KB	49.680±0.285^{h}	6.230±0.839^{F}	20.726±0.217^{i}	6.224
C-KB	48.678±0.443^{hi}	9.192±1.004^{E}	22.968±0.445^{gh}	9.864
D-KB	46.380±0.375^{i}	9.303±0.972^{E}	22.230±0.318^{h}	10.929
E-KB	46.786±0.479^{hi}	10.390±1.042^{E}	23.756±0.527^{g}	12.082
F-KB	56.349±1.691^{f}	3.929±1.142^{G}	17.627±0.331^{j}	3.111
Ba - TB	49.560±1.572^{k}	1.094±0.976^{L}	14.324±0.488^{o}	
A-TB	59.485±0.463^{j}	2.112±0.936^{KL}	17.756±0.296^{m}	10.551
B-TB	44.912±0.323^{l}	8.602±0.980^{J}	22.812±0.315^{k}	12.249
C-TB	36.112±0.361^{m}	10.240±0.683^{I}	19.528±0.301^{l}	17.076
D-TB	35.600±0.273^{mn}	9.482±0.572^{IJ}	18.036±0.354^{m}	16.704
E-TB	33.554±0.337^{n}	8.226±0.574^{J}	15.904±0.394^{n}	17.594
F-TB	50.381±1.640^{k}	2.943±0.851^{K}	16.074±0.562^{n}	2.675

Ba, A, B, C, D, E, and F denote as a batter, FD, MD 180 W, MD 300 W, MD 450 W, MD 600 W, and TD process, respectively.

Three types of batter were used as controls for three samples. Sample drying processes could be found in this order if sorted in the order of blackening (higher ΔE: MD-600W > MD-450W > MD-300W > MD-180W > TD > FD and lower L* value) (Table 3B.4.). Similar experimental results were reported in previous studies by Apinyavisit et al., (2017). When the samples were dried in the microwave at different powers, the cellular structure's nonenzymatic browning and superior degree of degradation at high temperatures were responsible for the color change.

3B.3.4. Antioxidant Properties

The total polyphenol (5.271±0.0881 mg GAE/g dm) and flavonoid (1.7214±0.1702 mg QE / 100 g dm) contents were highest in all TB than KB and CB (Figure 3B.3.(a)) samples. The seed coat of pulses greatly enhanced the antioxidant properties of whole seeds (Dueñas et al., 2006; Luo et al., 2016). The total polyphenol and flavonoid content was observed in higher amounts in chickpeas (Sreerama et al., 2010), mung beans, and faba beans (Boudjou et al., 2013; Luo et al., 2016; Tajoddin et al., 2010). Dark-colored pulses had been reported to have higher levels of polyphenols than pale ones and, at the same time, had higher antioxidant activity (Xu et al., 2007). Microwave drying methods enhanced the accessibility of the phenolic and flavonoid components significantly because of the unblocking of phenolic and flavonoid content in microwave samples (Figure 3B.3.(a)). Similar work was observed in a previous study (Bualuang et al., 2017; Ragaee et al., 2014).

In short, the observed trend for the variety of antioxidant content was: MD-450W > MD-600W > MD-300W > FD > MD-180W > TD (Figure 3B.3.(a)). High temperature inactivated polyphenol oxidase during microwave drying. The primary active nutrient that causes enzymatic oxidation is best perceived as the free antioxidant components. The polyphenol oxidase activity was high at temperatures close to 55 ºC, but at 75 ºC, it was reduced rapidly and was observed in different drying processes (Goula et al., 2016; Mphahlele et al., 2016).

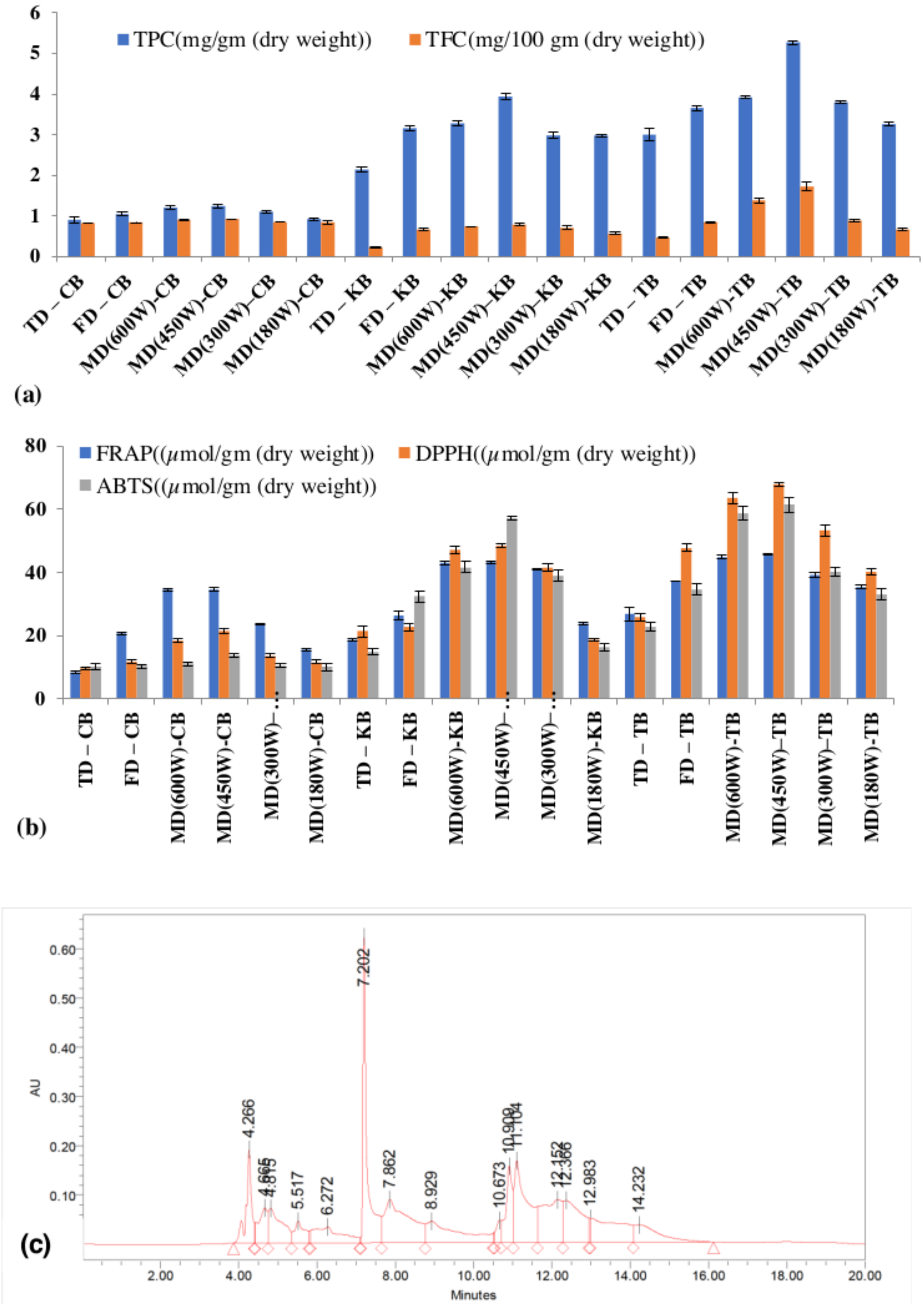

Figure 3B.3. Variation of (a) antioxidant content, (b) antioxidant activity of different black gram nuggets with the drying process, and (c) HPLC study of nuggets (TB): dihydroxy benzoic acid (4.815 min), catechin (5.517 min), caffeic acid (6.272 min), chlorogenic acid (7.202min), gallic acid (4.266 min), vanillic acid (7.862 min), rutin (8.929 min), elachic acid (10.673min), trans-cinnamic acid (10.909min), protocatechuic acid (4.665 min), ferulic acid (11.104min), myricetin (12.152min), quercetin (12.366min), apigenin (12.983min) and kaempferol (14.232min).

According to Bualuang et al., (2017) and Wojdyło et al., (2014), the reduction in the content of polyphenols with the decline in thermal and antioxidant damage by oxidation was confirmed by the results of this study. Microwave drying at 450 W of CB, TB, and KB showed a high amount of antioxidant content, that's why further HPLC studies of phenolic and flavonoid compounds were conducted only microwave 450 W drying technique of dried nuggets. TB contains more numerical and quantitative polyphenols and flavonoids than CB and KB. The major phenolic and flavonoids identified in the black gram nuggets were mentioned in (Figure 3B.3.(c)).

An easy and effective way to rank plants for antioxidant activity is to determine radical scavenging activity. It has been claimed that the existence of hydroxyl, which acts as oxidants, singlet oxygen quenchers, reducing oxidants, or metal ion chelators as phenolic compounds, affects how well different antioxidants work (Vashisth et al., 2011). By using the FRAP, DPPH, and ABTS assays, the activity of antioxidants of each nugget extraction was evaluated in this study. Significantly higher ($p<0.05$) radical scavenging activity and reducing power were shown in microwave nuggets than in TD and FD samples. TB nuggets had 61.42 (ABTS), 67.81 (DPPH), and 45.71 (FRAP) μmol AAE/g dm at 450 W microwave power (Figure 3B.3.(b)). A previous study also supported this outcome (Girish et al., 2012). The summary of the observed trends for a variety of antioxidant activities was as follows: TD < MD-180W < FD < MD-300W < MD-600W < MD-450W (Figure 3B.3.(b)). Similar results were reported for corncob (Saha et al., 2019), germinated corn (Bualuang et al., 2017), strawberry (Wojdyło et al., 2009), sweet corn (Dewanto et al., 2002), and sour cherries (Wojdyło et al., 2014). Thus, microwave drying at 450 W was an excellent process for drying nuggets to achieve the best quality products.

3B.4. Conclusion

An effective processing method for nuggets was found for the microwave drying method, and the potential application of the method has been highlighted in this study. Mathematical modeling, the most important part of the drying system, is important for designing and building a fully operational drying system. It might help to generate a product with high bioactivity and quality. The Page model has been regarded as the most influential mathematical representation of the drying characteristics of nuggets. The freeze-drying method has been defined as the best method for producing bright (lightness) color values. Freeze-drying KB nuggets had high porosity, low hardness, and resilience values. Antioxidant content and activity were found at the maximum level for the microwave drying method at 450 W for three types of nuggets. The highest amounts of TPC, TFC, FRAP, ABTS, and DPPH were found in TB nuggets, and the values were 5.27mg GAE / g dm, 1.72 mg QE / 100 g dm, 45.71, 61.42, and 67.81 μmol AAE/g dm at 450 W microwave drying method. As a result, microwave-dried nuggets were applied to reduce the drying time and increase the antioxidant and antioxidant activity with a high amount of polyphenol and flavonoid content. After oil frying, nuggets are eaten as a snack or ingredient in several Indian meals. There is a high demand for it across the nation. In the future, some micro-enterprise projects can be developed around this product to achieve maximum quality and promote therapeutic use due to the presence of critical phytochemicals.

Chapter 4

Quality evaluation of locally available food materials generally consumed by vulnerable groups using a numerical stool and statistical model

Part -A

4A.1.Introduction

Researchers are becoming interested in developing functional and supplementary foods from inedible, unprocessed waste, low-cost plant ingredients for health enrichment products, and better economic sustainability (Esteban & Ladero, 2018). The scientific name used for biological reference is *Nelumbo nucifera,* a member of the Nelumbonaceae family, majorly grown in Eastern Asia, India, and China (Hu et al., 2012). Later it was introduced in other countries like Japan and continents like Australia and Europe (Guo, 2009; Showkat et al., 2021). It is grown in water bodies like ponds, all lakes, and pools in low and high-altitude regions (Hussain et al., 2016; Rout, 2015). All parts of the lotus have been used in traditional medicine, oriental medicine, and folk medicine for many years, and it possesses significant importance in Ayurveda (Paudel & Panth, 2015). Lotus has been used as Chinese herbal medicine for centuries (Guo, 2009). The length of smooth lotus rhizomes is 60 - 140 cm, and the diameter varies within a range of 0.5 - 2.5 cm. The colors of the rhizome are generally yellowish-white to yellowish-brown. The lotus rhizomes are enriched with phytochemicals like glycosides, saponin, phenolic compounds, and alkaloids. They store many minerals like calcium, copper, iron, magnesium, zinc, potassium, and sodium (Mukherjee et al., 2009). It is also a reliable resource of carbohydrates, protein (Ullah et al., 2018), starch, fatty acid, and procyanidins (Chen et al., 2019). LR (lotus rhizomes) contain ash 1.1%, carbohydrate 9.7%, and protein 1.7% (Sridhar & Bhat, 2007). A high content of flavonoids and phenols has been found in methanolic extracts of lotus (Ullah et al., 2018). LR is effective as an antifungal, antibacterial, and antidiarrheal and has diuretic activities. The nodes of rhizomes are used to cure nasal bleeding, hemoptysis, haematuria, and active uterus bleeding. LR is proven to have memory-improving activity. It is a good immunomodulator (Chen et al., 2019; Mukherjee et al., 2009). Healthy beverages made from lotus rhizomes have an anti-fatigue effect (G. Chen et al., 2019). After conducting a study on the four Korean white lotus cultivars, it was found that they contain a high amount of phenols, proteins, and ascorbic acid and show anti-proliferative activities on human cancer cell lines (Park et al., 2009). The study also developed fiber-rich extruded food from lotus rhizome and broken rice flour blends (Hussain et al., 2017).

One of the earliest preservation methods is drying, which inhibits the growth of bacteria by removing moisture from the food and preventing spoilage, which is needed to conserve the plant for future use. Moisture, antioxidant content, color, and texture vary depending on the drying method (Devahastin & Niamnuy, 2010; Guo et al., 2020). The vacuum drying method helps improve the nutritional value of vegetables and fruits; hence, vacuum drying has been used to dry many fruits and vegetables (Amellal & Benamara, 2008; Rahman et al., 2009). The product is dehydrated in freeze-drying by the process of sublimation. The absence of liquid water and low temperature are the main reasons for the long shelf-life of a product without microbial spoilage, which makes the product better in quality. Still, despite its many reasonable rates, freeze-drying has been identified as the most expensive drying technique. The product type, packaging, plant capacity, etc., are the main factors on which the cost of freeze-drying depends (Ratti, 2001). The cost of each drying process was estimated from the power consumption level. Freeze-dried persimmon chips required 7-9 times more energy than hot air drying and combined hot air microwave drying. The hot air-drying technique is effortless to use and, at the same time, affordable also (Jia et al., 2019). In microwave drying, the product's inside is first heated by electromagnetic radiation. The heat spreads out, and internal vapor pressure is generated that removes the moisture from the product (Dronachari & Yadav, 2015). Drying energy efficiency is closely associated with drying time and energy consumption of dryers, and that can be defined by the moisture extraction rate (MER), specific moisture extraction rate (SMER), and specific energy consumption (SEC). Various researchers inspected the drying of *Ocimum basilicum* using different dryers like a tray, microwave, freeze, vacuum microwave dryer, and sun and shade dryer (Akpinar, 2006; Díaz-Maroto et al., 2004; Ghasemi Pirbalouti et al., 2017; Gurkan & Hayaloglu, 2017; Kadam et al., 2011; Yousif et al., 1999).

Drying changes the color of the product. When a consumer decides to buy a product, they first notice the color of the product. Maillard reaction, pigment dehydration, enzymatic browning, or ascorbic acid oxidation are the main factors for color change (Chong et al., 2013).

Enzymatic and non-enzymatic changes in pectin (a cell wall polysaccharide) are mainly responsible for the texture degradation of the dried product. To understand the textural change in the product hardness (Aamir & Boonsupthip, 2017), cohesiveness, gumminess, springiness, fracturability, adhesiveness, chewiness, and stringiness are measured.

Drying changes the color of the product. When a customer chooses to purchase a product, they first notice the product's color. Maillard reaction, pigment dehydration, enzymatic browning, or ascorbic acid oxidation are the main factors for color change (C. Chen et al., 2015; M. Chen et al., 2015). Due to its low instrumentation requirements and straightforward implementation, UAE is an innovative extraction method with significant promise for obtaining phenolic chemicals from food. During the use of ultrasonic in a fluid medium, cavitation bubbles, also called the cavitation phenomenon, propagate and implode, causing superficial peeling, erosion, the disintegration of the vegetal cell matrix, and better hydration. Target chemicals are more directly and thoroughly solubilized due to increased solvent uptake by cells and dispersion due to the solution's increased surface size, availability, and absorption (Chemat et al., 2017). Ultrasonic extraction improved the performance and efficiency of soybeans (isoflavone), strawberries (phenolics), olives (chlorogenic acids), and Euonymus alatus (Thunb) (rutin and quercetin) when compared to traditional techniques (Al-Dhabi et al., 2017; Herrera & Luque De Castro, 2004; Li et al., 2005; Rostagno et al., 2003; Yang & Zhang, 2008). According to research, heat-sensitive phenolics are convincingly destroyed during sample preparation in some instances, only 20 minutes after extraction—by high temperatures and sustained ultrasonic wave exposure (Mane et al., 2015).

Several studies have been conducted on lotus rhizomes, such as their proximate composition, functional properties, and practical uses, such as their use in breadsticks (Shad et al., 2011; Thanushree et al., 2017). o my best knowledge, there are gaps in the existing research, and this paper has tried to improve these gaps in the following manner: a) Research has been done on the effects of microwave and hot air drying at different temperatures on lotus rhizomes (Sung et al., 2020). This paper further discusses other possible drying techniques like vacuum drying, freeze-drying, and tray drying; b) Research has already been done on the effects of microwave drying at different powers, i.e., 50, 100, and 150 W. This paper studies these effects at powers of 180, 300, 450, 600 and 900 W; c) No study has been conducted on the analysis of the free and bound phenolic compounds present in lotus rhizomes as well as the extraction retention time of lotus rhizomes, so far. This paper discusses these aspects in detail. Due to the extraction of bound phenolic compounds, the total antioxidant content is enhanced. Thus, there is an increase in health benefits; d) This paper discusses the physicochemical properties of lotus rhizomes, i.e., texture properties like hardness, fracturability, and resilience, as well as the color profile, e.g., changes of color, and browning index. There needs to be a current study on these aspects.; e) Research has been done on the effects of vacuum drying on lotus seeds (Zhao et al., 2021), but the same has yet to be done for lotus rhizomes. This paper discusses the process and effects of vacuum drying for lotus rhizomes in detail.

The study aimed to investigate the best drying model, minimum extraction time of UAE for antioxidants, the energy consumption of dryer, energy cost value, drying time, moisture diffusivity value, free and bound phenolic and flavonoid compounds, HPLC study of polyphenolic compounds, antioxidant activity, color and texture profile and significant effects of different drying processes.

4A.2. Material and Method

4A.2.1. Preparation of sample

The four months old fresh lotus rhizomes were collected from the agricultural water land of the lotus by the farmer at Bhogpur village (Lat-Long 22.425640 N, 87.861260 E) in East Medinipur, West Bengal in India. Then, the plan material was washed with clean water and cut into cylindrical slices. Each slice was cut to 10.33±0.866 mm in length (thickness) and 13.722±1.034 mm in diameter. The samples were evenly placed in a circular glass tray with a diameter of 15 cm and dried once the dryers attained steady-state conditions for the specified points (at least 30 min). The sample glass tray was placed along the middle portion of the dryer. The weight of the lotus rhizome was measured with an analytical balance (TW-423, Shimadzu, Japan) with an accuracy of 0.1 mg, and moisture loss throughout the drying process was recorded at 49 min intervals for hot air drying and 47 min interval for tray drying, 69 min intervals of freeze-drying, 7 min intervals of vacuum drying, 90 s, 70 s, and 50 s intervals for microwave drying at 450, 600 and 900 W power level respectively. 5 and 3 min intervals for 180 W and 300 W of microwave drying. When the lotus rhizomes' moisture loss was 76% (approximately), drying was stopped (wet basis). After drying, the samples were kept in glass jars at 18 °C until quality testing. We used the desiccator to maintain the moisture content during the whole drying period. The initial and final moisture content was noted as 3.647±1.345 g moisture/g dry matter (dm) and 0.387±0.169 g moisture/g dm, respectively. The weight of the sample was taken as 4.242±1.564 g. Changes in the moisture content were monitored after each time interval. The sample moisture content was analyzed by a moisture analyzer (PGB1MB, Wensar Weighing Scales Limited, India). Each plate contained 4.242 g of sample for initial drying. Thus a total of 40 g of sample was dried for each type of drying.

4A.2.2.1. Drying process of lotus rhizomes

Freeze, hot air, and microwave drying of all samples were conducted as per section 3B.2.4. Hot air oven drying (HD) was carried out in the laboratory by using Hot Air Oven (BST/HAO-1122, Bionics, India) with three trays each with a dimension of 0.445×0.445 m. The temperature was set at 60 °C with an air velocity of 1 m/s throughout the process (Saha et al., 2019). Vacuum drying (VD) was carried out in a vacuum dryer (VS-1202V5, ICT, India) at a temperature of 60 °C and pressure of −760 mmHg (Monteiro et al., 2016).

4A.2.2.2. Drying kinetics

The moisture ratio (MR) and moisture diffusivity of the samples, SS_{error}, *RMSE, and* R^2 were determined by section 3B.2.4.4.

All moisture contents were expressed in g moisture/g dm. The final moisture content was used for each run's equilibrium moisture content. The drying rate (DR) was determined by the following equation (Altay et al., 2019):

$$DR = \frac{M_{(t+dt)} - M_t}{dt} \qquad (4A.1.)$$

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Where $M_{(t+dt)}$ Is the moisture content at t+dt (g moisture/g dm), M_t is the moisture content at time t, and t is the drying time in sec.

The equilibrium moisture content was ignored because of its very negligible value. L (L=11.5 mm) is the sample's half thickness. Throughout the drying process, temperature and, moisture, diffusivity was kept constant, and shrinkage was negligible.

4A.2.3. Determination of energy efficiencies of drying systems and cost analysis

The energy meter determined all dryers' energy consumption (B07WYJB314, Power India, India). The system effectiveness determined by this order, 3 the specific moisture extraction rate (SMER), the moisture extraction rate (MER), the specific energy consumption (SEC), and the energy value (EV) were evaluated by the following formula (Caliskan & Dirim, 2017).

$$SMER = \frac{Amount\ of\ water\ removed\ during\ drying\ (kg)}{Total\ energy\ supplied\ in\ the\ drying\ process\ (kWh)} \qquad (4A.2.)$$

$$MER = \frac{Amount\ of\ water\ removed\ during\ drying\ (kg)}{Drying\ time\ (h)} \qquad (4A.3.)$$

$$SEC = \frac{Total\ energy\ supplied\ in\ the\ drying\ process\ (kWh)}{Amount\ of\ water\ removed\ during\ drying\ (kg)} \qquad (4A.4.)$$

EV=SEC × Price of kWh in industrial tariff scale in WBSEDCL.

(4A.5.)

4A.2.4. Extraction and assay of antioxidants of lotus rhizomes

UAE was performed in an ultrasonic bath (D-150/IH, Shanti Industrial Estate, India).

1g of dried lotus rhizomes powder was mixed with 25 ml of acetone water in a 1:1 v/v ratio in a 100 ml reflux condenser-equipped Conical flask. The full extraction process maintained the ratio of sample and solvent at 1:25. The extraction for every sample was subsequently finished by placing the Conical flask in an ultrasonic bath at 70 °C for an ideal pre-set period during the whole process to maintain the distance of the flask and transducer. In this extraction process, no movement was applied. Then centrifuged (C-24BL, REMI, India) the extract at 8900 rpm at 4 ºC for 5 min, and the supernatant was stored for future analysis. After that, the residue was used for repeated extraction, followed by a sample solvent ratio to isolate the bound phenolic compounds using ethyl acetate described by Lopez-Martinez et al., (2009). Then the total collected supernatant was mixed and stored in a tarson tube for further study.

Phenolic content (PC), DPPH free radical scavenging activity, flavonoid content (FC), and Ferric ion reducing antioxidant power (FRAP) were all determined according to section 2.2.3. The UAE method's kinetic properties were determined using the second-order rate equation 4A.9., which was analyzed with the variable yield data during the extraction of phenolic and flavonoids from the lotus rhizomes (Michail et al., 2016).

$$\frac{t}{Y_t} = \frac{1}{K{Y_e}^2} + \frac{t}{Y_e} \qquad (4A.6.)$$

Here, concentration (mg/g) denotes the Y_t, Y_e, rate of extraction denotes the K, time is t, and retention time (T_R) was calculated by this formula (Saha et al., 2019):

$$T_R = \frac{1}{Y_e \times K} \qquad (4A.7.)$$

4A.2.5. HPLC assay

The phenolic compounds analysis by the following procedure is described in section 3A.2.5.3.

4A.2.6. Texture Profile Analysis (TPA)

Tests for TPA were conducted following section 2.2.5.

4A.2.7. Analysis of color

According to section 3A.2.5.5, color profile studies were conducted.

The browning index (BI) of the food sample is calculated by this equation (Ding & Ling, 2014).

$$BI = [100 (X - 0.31)] / 0.17 \quad (4A.8.)$$

Where $x = (a^* + 1.75L^*) / (5.645L^* + a^* - 0.3012b^*)$.

4A.2.8. Statistical analysis

The statistical analyses of the obtained results were performed by MINITAB 17.0 (Minitab, Inc., Pennsylvania, PA) software and WPS Workbench Ink (WPS Analytics, World Programming, UK). ANOVA and Tukey's test was used to determine the significant differences where $p<0.05$. All mean values of triplicate observations were presented in the experimental design (n=3).

4A.3. Results and Discussion

4A.3.1. Drying kinetics

Moisture was removed in the falling rate period during each drying operation through an initial to an equilibrium moisture content of 3.647 g and 0.387 g moisture /g dm. Photographs of fresh and dried lotus rhizomes are shown in Figure 4A.1. According to exhausting literature, the drying of biological products occurs almost entirely in the falling rate period. In our study, the drying of lotus rhizomes occurred in the falling rate period, similar to a previous study (Qiu & Chin, 2022; Sung et al., 2020).

The effective moisture diffusivity (D_{eff}) was determined by analyzing the falling rate period (Khawas et al., 2014). The moisture diffusivity (D_{eff}) was expressed as the rate of moisture movement. D_{eff} values given in Table 4A.5. were calculated from equation 4A.3.

Figure 4A.1. Image of lotus rhizomes (10 mm thickness and 13 mm diameter).

The rate was quick initially because of rapid liquid water diffusion. Nonetheless, the drying process was prolonged because vapor dispersion predominated at a later phase (Figure 4A.2.). The highest (900 W) and lowest (FD) value for D_{eff} was 36.008×10^{-10} m^2/s and 0.366×10^{-10} m^2/s respectively. The variation of the energy transport mechanism across various methods might explain the variety of diffusivities. Other researchers found similar changes in spinach, germinating maize, kiwifruit, and corn cob (Bualuang et al., 2017; Maskan, 2001; Ozkan et al., 2007; Saha et al., 2019). During microwave drying, water evaporation from the plant matrix is considerably accelerated by the radiative transmission of electromagnetic energy and immediate and exclusive absorption of a radiant wave by polar substances, especially water. Electromagnetic radiation is mainly responsible for microwave drying. The inside of the product is heated; first, rapid energy binds with the product's moisture and creates the internal vapor pressure that helps remove water vapor from food products quickly (Dronachari & Yadav, 2015). Studies support that microwave drying is the best drying technique to dehydrate the product (Hernández-Ortega et al., 2013; Pallavi & Shikha, 2016).

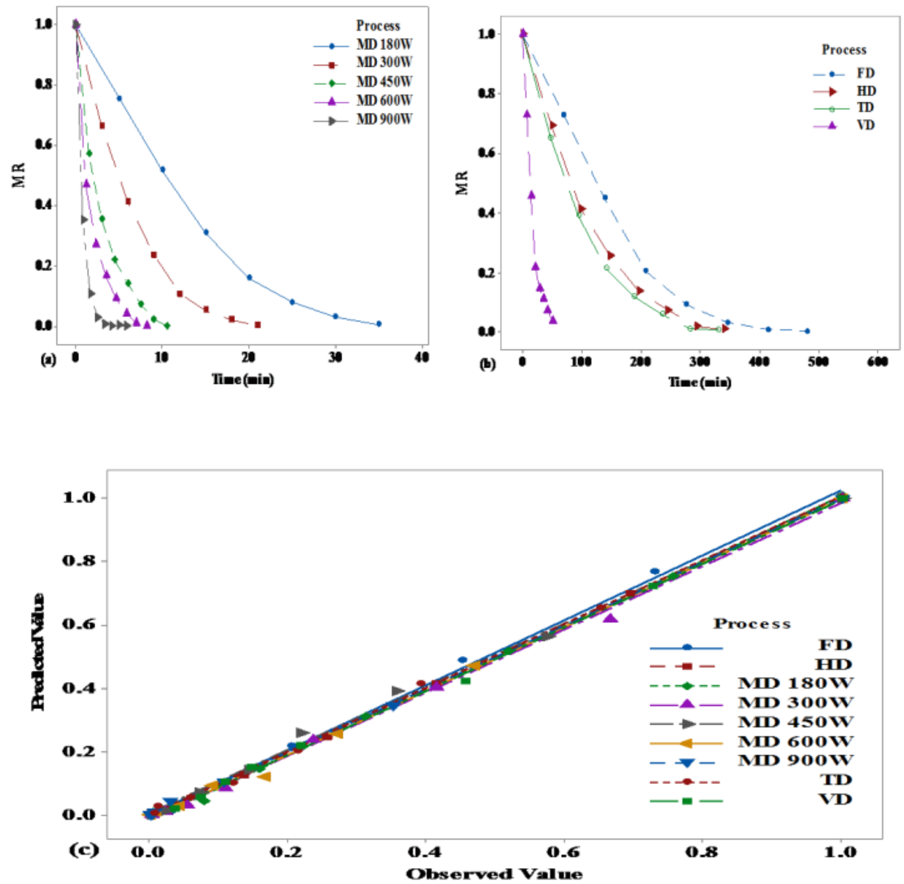


Figure 4A.2. Kinetics of drying of lotus rhizomes, dehydrated by (a) microwave and (b) freeze, hot air, tray, and vacuum driers. (c) plot between observed and predicted values showing a linear relationship.

Polyphenol oxidase activity was high at the temperature ranges between 55 to 75 °C, but it was observed to be reduced rapidly at different drying processes (Mphahlele et al., 2016). In this study, a 60 °C temperature was selected to dry the sample in a tray dryer. Contrarily, FD, HD, and TD depend less on power and much more costly slower heat transfer by convection and sublimation under or external pressure, respectively (Mandal et al., 2008). With a drying period of 480 min FD was the slowest method, whereas MWD was the fastest process, take to 32 min to complete (Table 4A.5.). HD is an effortless and common drying technique with comparatively low cost, but as the temperature rises so that products quality will be decreased (Vu et al., 2017). The total time duration recorded in the case of HD, TD, FD, VD, and MD at (180 W, 300 W, 450 W, 600 W, and 900 W) was 340 min, 330 min, 480 min, 50 min, 22 min, 18 min, 10 min, 8.5 min, and 6 min respectively. In this study, since the temperature is low, it took a long time to dry in the HD, that is 340 min, whereas MD at 900 W takes only 6 min to dry. Microwave drying at 600 W shows four times more moisture diffusivity than MD at 180 W. After HD, the lowest moisture diffusivity was seen in FD, with the highest time. Even variations in microwave power have a significant ($p < 0.05$) influence on moisture diffusion. The vapor pressure gradient and surroundings are enhanced when the pressure is reduced by vacuum, accelerating the mass transfer rate. As a result, vacuum drying took less time than hot-air drying, tray drying, and freeze drying (Kayacan et al., 2018). Microwave-vacuum combination or only vacuum drying was applied to the following foods in different studies - guava, strawberry, mushroom, anola, and garlic (Maisnam et al., 2017). As a result, using microwaves and vacuum dryers produced a drying process that was substantially quicker and required less energy.

The values of six thin-layer drying models are given in Table 4A.1., describing the best-suited model for drying. An increase in the number of constants makes the model more complex. Lewis and Page's model consist of one and two constants. For that reason, these two models are considered simple models. The values calculated from equation 4A.4 showed the lowest SS_{error} (0.0145 to 0.002), RMSE (0.02 to 0.005), and highest R^2 (0.999 to 0.992), making this Midilli et al., model best fitted for drying of lotus rhizomes. According to (Nema et al., 2013), the best-suited model for explaining the drying behavior of ginger is the Midilli model in pulse microwave drying. Another study explained the best drying model for dry eggplant was the Midilli model (Ertekin & Yaldiz, 2004). Midilli et al. established a new model in 2002 by including extra t with a coefficient to the Henderson-Pabis model developed using Fick's second law of diffusion (Midilli & Kucuk, 2003).

Table 4A.1. Result of Statistical value of different mathematical drying models of lotus rhizomes

			Lewis: MR = exp(-kt)				
Process	**K**				**SS_{error}**	**RMSE**	**R^2**
FD	0.0068				0.0323	0.066	0.983
TD	0.0145				0.0184	0.051	0.986
HD	0.0128				0.0183	0.050	0.987
MD 180W	0.1573				0.0142	0.044	0.989
MD 300W	0.3306				0.0018	0.016	0.998
MD 450W	0.3640				0.0131	0.042	0.991
MD 600W	0.5380				0.0026	0.019	0.998
MD 900W	0.8751				0.0039	0.025	0.997
VD	0.0483				0.0276	0.060	0.986
			Midilli et al: MR = aexp(-kt^n) + bt				
	k	n	a	b	SS_{error}	RMSE	R^2
FD	0.0007	1.4226	0.9873	-0.00001	0.0145	0.045	0.992
TD	0.0003	1.8710	1.0001	0.000069	0.0005	0.008	0.999
HD	0.0005	1.7475	1.0015	0.000093	0.00342	0.022	0.997
MD 180W	0.0666	1.0212	0.6829	0.0275	0.0003	0.005	0.999
MD 300W	0.3773	1.2512	0.0736	-0.00389	0.001	0.010	0.999
MD 450W	0.2319	1.2969	0.9985	-0.00182	0.0002	0.011	0.999
MD 600W	0.4378	1.1763	0.9999	0.00108	0.0002	0.005	0.999
MD 900W	0.7828	1.2401	0.9995	-0.00072	0.0003	0.012	0.999
VD	0.0224	1.0031	1.4549	-0.00082	0.0088	0.012	0.999
			Page: MR = exp(-kt^n)				
	k	n			SS_{error}	RMSE	R^2
FD	0.1970	7.0090			0.7794	0.334	0.862
TD	0.1970	7.0090			0.0108	0.040	0.992
HD	0.1970	7.0090			0.3420	0.221	0.745
MD 180W	0.1970	7.0090			0.3507	0.224	0.740
MD 300W	0.1970	7.0090			0.1557	0.014	0.999
MD 450W	0.1970	7.0090			0.3777	0.133	0.923
MD 600W	0.1970	7.0090			0.1475	0.007	0.999
MD 900W	0.7935	7.0090			0.0009	0.013	0.999
VD	0.1970	7.0090			0.6032	0.017	0.999
			Two-term: MR = aexp(-kt) +bexp(-gt)				
	k	a	b	g	SS_{error}	RMSE	R^2
FD	0.0082	1.2397	-0.2397	8.0500	0.0212	0.055	0.988
TD	0.0274	2.6601	-1.6601	8.0500	0.0016	0.015	0.999
HD	0.0211	1.9791	-0.9791	8.0500	0.0034	0.023	0.997
MD 180W	0.2206	1.6614	-0.6614	8.0500	0.0002	0.0053	0.999
MD 300W	0.3003	0.8876	0.1124	8.0500	0.0015	0.015	0.999
MD 450W	0.4748	1.4539	-0.4539	8.0500	0.0032	0.021	0.998
MD 600W	0.6815	1.4470	-0.4470	8.0500	0.0006	0.009	0.999
MD 900W	0.8037	1.3733	-0.3733	8.6969	0.0009	0.056	0.986
VD	0.0632	1.4040	-0.4040	8.0500	0.0052	0.027	0.997
			Henderson-Pabis: MR = a exp(-kt)				
	k	a			SS_{error}	RMSE	R^2
FD	0.0070	1.0403			0.0303	0.066	0.983
TD	0.0147	1.0204			0.0179	0.051	0.986
HD	0.0131	1.0232			0.0177	0.050	0.987
MD 180W	0.1600	1.0261			0.0134	0.044	0.990
MD 300W	0.3301	0.9980			0.0018	0.016	0.998

MD 450W	0.3701	1.0246			0.0124	0.042	0.991
MD 600W	0.5401	1.0060			0.0026	0.019	0.998
MD 900W	0.8812	1.0095			0.0038	0.025	0.997
VD	0.0503	1.0523			0.0243	0.059	0.987
Logarithmic: MR = a exp(-kt) + c							
	k	a	c		SS_{error}	RMSE	R^2
FD	1.2859	0.6178	0.3822		0.7184	0.054	0.989
TD	3.8497	0.9891	0.0109		0.2610	0.206	0.766
HD	2.0243	1.0107	-0.0107		0.3612	0.049	0.988
MD 180W	2.7129	0.9372	0.0628		0.2618	0.029	0.996
MD 300W	2.4680	0.9518	0.0482		0.1103	0.009	0.999
MD 450W	2.2137	0.9385	0.0615		0.2907	0.022	0.998
MD 600W	2.8127	0.9806	0.0194		0.1310	0.009	0.999
MD 900W	2.5983	0.9764	0.0236		0.2061	0.185	0.834
VD	1.6027	0.3946	0.6054		1.2786	0.036	0.995

According to the Henderson Pabis model, the moisture ratio is determined by the following formula. $MR = a\ exp(-kt)$. Here, a and k are denoted as a model and drying constant, respectively. In the Midilli et al., model, extra t with a coefficient was introduced with the previously established model. $MR = a\ exp(-kt^n) + bt$. *Here,* a and b are denoted as model constant, and k is expressed as the drying constant (h^{-1}). The accuracy improved with an increase in the number of constants of the model. Since Midilli et.al., contain three constants, they can be used to describe the best drying characteristics of foods and vegetables. It has been found from different literature reviews that over 24 % of studies proved Midilli et al., model as the best model for drying kinetics (Alara et al., 2018; Charmongkolpradit & Luampon, 2017; Erbay & Icier, 2010; Onwude et al., 2016).

A graphical representation (Figure 4A.2.) is plotted using the Midilli model. Figures 4A.2. (a) and 4A.2. (b)) show the rate of decreasing moisture over time at different drying conditions. It can be observed from the study that in the first phase of the falling rate period D_{eff} with moisture content declined sharply, but in the next period of declining rates, D_{eff} with moisture content decreased slowly. Linearity between the predicted value and observed value is shown in graph (c) (Figure 4A.2.). We can conclude that the predicted model fits the observed drying data well depending on the linear nature of the curve at a 45° slope from the origin.

4A.3.2. Energy efficiencies and drying cost of a dryer

The evaporation of the moisture of an object depends on the heat supply source; this is known as a highly energy-intensive drying process. Product quality and energy efficiency depend on the various drying methods that have been proven in research (Altay et al., 2019; Surendhar et al., 2019). The results of this study on the cost of energy obtained for different dryers and their value are given in Table 4A.2. SMER is usually used to enhance the energy efficiency of a dryer based on the amount of latent energy stored when removing a certain amount of water. In this process, the movement of a large amount of water expresses the high energy efficiency of a system (Chua et al., 2002). In this study, the lowest SMER value was obtained in the tray dryer (0.0040 kg/kWh), and the highest value was present in all microwave drying processes (Table 4A.2.). The vacuum oven dryer has a high SMER value (0.5011 kg/kWh). SMER value directly depends on the energy consumption of the machine. Electrical energy consumption or power is defined as BOT unit (Board of trade unit), Unit, or kWh. It has been found that for those with a higher BOT unit value, their SMER value is lower (Altay et al., 2019).

Table 4A.2. The results of energy efficiency with cost of different drying methods.

Process	BOT (kWh)	SMER (kg/kWh)	MER (kg/h)	SEC (kWh/kg)	Energy cost (Rs)	Capacity
FD	6.4732^{b}	0.0227^{f}	0.0034^{g}	212.5916^{b}	1255.56^{b}	1.6892 L
TD	7.634^{a}	0.004^{g}	0.0051^{g}	250.2916^{a}	1518.33^{a}	150 L
HD	0.2375^{c}	0.128^{e}	0.0051^{g}	7.8108^{c}	56.94^{c}	40 L
MD 180 W	0.096^{c}	0.3181^{d}	0.0573^{e}	3.144^{d}	31.88^{d}	28 L
MD 300 W	0.09^{c}	0.3414^{c}	0.1024^{d}	2.9288^{d}	30.73^{d}	28 L
MD 450 W	0.09^{c}	0.342^{c}	0.1539^{c}	2.9242^{d}	30.7^{d}	28 L
MD 600 W	0.08^{c}	0.3924^{b}	0.2354^{b}	2.5484^{d}	28.68^{d}	28 L
MD 900 W	0.09^{c}	0.3445^{c}	0.3101^{a}	2.9024^{d}	30.59^{d}	28 L
VD	0.0627^{c}	0.5011^{a}	0.0304^{f}	1.9956^{d}	25.72^{d}	9.0514 L

MER means how much amount of water is removed during drying per hr. The lowest and highest MER values, 0.0034 kg/h and 0.3101 kg/h, were obtained from FD and MD 900 W, respectively. The MER value is negatively correlated with drying time, which was reported by scientists (Doymaz, 2004; Kadam et al., 2011; Simal et al., 2000).

The energy required to extract one unit of water from a sample during drying is called SEC (Altay et al., 2019). The SEC value varied between 1.9956 kWh/kg to 250.2916 kWh/kg. The lowest value (1.9956 kWh/kg) and the highest value (250.2916 kWh/kg) were observed in the vacuum dryer and tray dryer, respectively. The SMER and SEC value depends on the energy consumption of the dryer. Energy consumption again depends on the dryer's loading capacity and other efficiencies (Altay et al., 2019).

The energy cost of the various drying methods is calculated by the SEC value multiplied by WBSEDCL industrial tariff slab price stand (Table 4A.2.). The SEC value is positively correlated with energy cost (Rs). Vacuum and all microwave drying energy costs are lower than other drying processes. The highest energy cost (Rs.1518.33) is calculated in the tray dryer because its loading capacity and energy consumption rate are increased. In an in-tray and hot air oven dryer, it is possible to dry a considerable amount of sample at a time because of its high capacity. Still, for a freeze and vacuum dryer, it is impossible. After tray drying, freeze drying occupies the second position regarding low power and high operating cost. The cost of drying is low (Rs. 25.72) for a vacuum dryer. Still, the cost of microwave drying is nearly 30 Rs. Comparing all drying processes, microwave drying is best for low cost with short time duration for drying of the sample.

4A.3.3. Analysis of the antioxidant content of lotus rhizomes

Total phenolic content (TPC) and total flavonoid content (TFC), both in free and bound forms, are collectively called total antioxidants, containing a vast number of phenolics and flavonoids that have been measured using six different drying methods. To evaluate the effect of drying conditions on UAE performance, the experimental time yield of different dried lotus rhizomes was determined using equation 16, and the kinetic parameters results were given in Table 4A.4. The antioxidant of all lotus rhizomes was presented in Table 4A.3.

The major phenolic and flavonoid compounds identified in dried lotus rhizomes include myricetin, quercetin, gallic acid, catechin, rutin, etc. (Figure 4A.4.). From the study, it was found that amount of myricetin is high on (7.969 mg/g) MD 600 W. All other majorly found TPC and TFC including quercetin, gallic acid, catechin, and rutin were found at the highest quantity in VD lotus rhizomes. Quercetin was most stable in high-temperature drying, especially in VD. Polyphenols and flavonoids present in bound forms could not come in free form due to low temperature in case of freeze-drying. The extractability and stability of the antioxidant both depend on the drying conditions.

All MD and VD lotus rhizomes had higher free PC and FC (Y_{FP}: 24.851 to 46.751 mg/g and Y_{FF}: 3.662 to 5.8411 mg/g) than other drying processes. Thus, they significantly improved the availability of phenolic compounds. TPC and TFC can be present in free and bound forms in the food product. In this study, Figure 4A.3.(a) clearly showed that (VD and MD) released high-free phenolic and flavonoid compounds other than FD.

Table 4A.3. The antioxidant content and antioxidant activity of different dried lotus rhizomes, the result shows the value of Mean ± SD.

Process	TPC (mg/gm)	TFC (mg/gm)	FRAP (μmol/gm)	DPPH (μmol/gm)	ABTS (μmol/gm)
FD	44.563±0.719^{cd}	9.609±0.969^{a}	46.524±0.798^{f}	40.2±0.619^{cd}	75.064±0.391^{d}
TD	42.648±0.642^{d}	7.373±0.946^{bc}	44.292±0.748^{g}	38.611±0.521^{e}	69.96±0.769^{e}
HD	37.79±0.178^{e}	7.209±0.184^{bc}	39.708±0.156^{h}	38.14±0.139^{e}	67.936±0.146^{e}
MD 180W	39.234±0.422^{e}	6.231±0.795^{c}	45.684±0.547^{g}	35.981±0.189^{f}	66.712±0.175^{e}
MD 300W	42.22±0.323^{d}	7.509±0.632^{bc}	57.756±0.168^{e}	43.911±0.348^{d}	79.008±0.638^{c}
MD 450W	45.533±0.738^{c}	8.764±0.174^{b}	71.748±0.812^{d}	43.961±0.317^{d}	81.688±0.489^{c}
MD 600W	77.179±0.465^{a}	9.906±0.609^{a}	97.908±0.654^{b}	61.765±0.316^{b}	90.312±0.598^{b}
MD 900W	60.824±0.486^{b}	9.664±0.337^{a}	94.788±0.294^{c}	58.85±0.316^{c}	87.896±0.628^{b}
VD	78.364±0.453^{a}	10.819±0.867^{a}	108.312±0.778^{a}	74.621±0.389^{a}	104.36±0.169^{a}
Fresh	80.522±0.397^{a}	10.973±0.207^{a}	45.624±0.387^{g}	39.199±0.591^{cd}	72.18±0.638^{d}

Polyphenol accessibility is higher in all microwave drying processes than in the other method. Compared to the T_R value, where MD required 7 to 15 min to reach equilibrium, the different processes take nearly 45 min; the results are presented in Table 4A.4.

The ultrasonic extraction procedure was compared with the conventional extraction procedure. It was found that yield of polyphenols and the capacity of antioxidants were higher in UAE procedures than in traditional methods. Twenty min is the maximum reaching time for antioxidant ultrasonication of flax, hemp, and canola seed cake (Teh & Birch, 2014).

As mentioned in Table 4A.4. the free phenolic and flavonoid content was high in VD. Long-time exposure to hot air generally causes oxidation, and as a result, the antioxidant capacity of the product is reduced. In another study, sour cherry was treated with vacuum microwave drying (VMD), and it was found that low temperature reduced the oxidation at lower air pressure. Another reason was mentioned in the study that the moderate oxidation condition of polyphenols can cause a tremendous amount of antioxidants in the non-oxidized state (Kayacan et al., 2018; Wojdyło et al., 2014). VD showed higher TPC, TFC, and antioxidant activity in dried bee pollen compared with the hot air-drying method. Total phenolic and flavonoid compounds exhibited no significant difference between VD and MD at 600W in this study, as they belonged to the same group.

Table 4A.4. The kinetic profiles of free antioxidants of lotus rhizomes.

Process	Phenolic content (Free PC)			Flavonoid content (Free FC)		
	K	Y_{FPC}	T_R	K	Y_{FFC}	T_R
FD	0.00167[e]	22.6454[fg]	47.2433[a]	0.0068[f]	3.4602[cd]	42.7682[b]
TD	0.00122[f]	18.1290[hi]	45.3226[ab]	0.0075[f]	2.8843[e]	46.0340[a]
HD	0.00124[f]	17.3883[i]	46.3049[ab]	0.0075[f]	2.8225[e]	47.0505[a]
MD 180W	0.00252[d]	24.8509[ef]	15.9419[c]	0.0178[e]	3.6617[c]	15.3387[d]
MD 300W	0.00423[b]	25.9067[e]	9.1244[d]	0.0277[b]	3.6697[c]	9.8312[e]
MD 450W	0.00349[c]	29.9312[d]	9.5630[d]	0.0240[c]	4.4444[b]	9.3733[e]
MD 600W	0.00354[c]	39.5726[b]	7.1309[d]	0.0216[d]	5.6465[a]	8.2044[e]
MD 900W	0.00354[c]	33.0033[c]	8.5611[d]	0.0186[e]	5.5006[a]	9.7745[e]
VD	0.00048[g]	46.7508[a]	44.8855[ab]	0.0044[g]	5.8411[a]	39.1179[c]
Fresh	0.00664[a]	20.131[gh]	44.0493[b]	0.0508[a]	3.142[de]	45.5921[a]

Y_{FPC} and Y_{FFC} were free phenolics of GAE (mg / g db.) and flavonoids of QE (mg / g db.) at equilibrium. K is the extraction rate per minute. T_R is equilibrium reach time per minute.

In this study, the antioxidant of the fresh sample was measured on a wet basis, but when comparing the dried sample with the new one, it was converted to a dry basis. The result indicated that the drying technique increased the quality of LR by enhancing TPC, TFC, and antioxidant activities compared to the fresh sample. The possible explanation for this might be the high amount of bioactive compound in the dried product due to the removal of moisture during drying that facilitates the preservation of polyphenols. In the fresh sample, high moisture is the reason for low antioxidants (Mediani et al., 2014; Najafabad & Jamei, 2014). Therefore, according to the study, it can be considered that dried LR is enriched with bioactive compounds and preserved for a more significant period due to low water content.

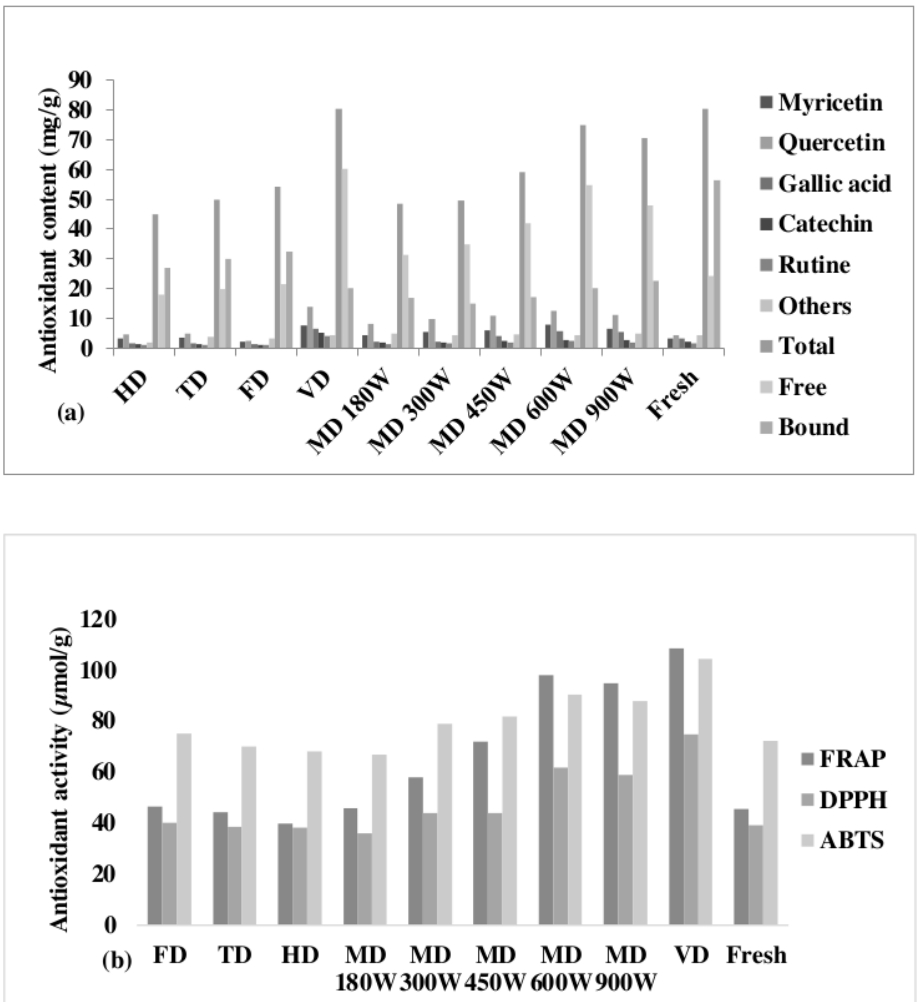


Figure 4A.3. The difference between (a) antioxidant content and (b) antioxidant activity of lotus rhizomes at different drying processes.

4A.3.4 Analysis of the antioxidant activity of lotus rhizomes

The radical scavenging activity of plants can be measured, a quick and efficient technique to gauge their antioxidant capacity. Here antioxidant activity is measured by FRAP, DPPH, and ABTS assay of all lotus rhizomes. Higher FRAP, DPPH, and ABTS values were (108.312 μmol, 74.621312 μmol, and 104.36 312 μmol of ascorbic acid equivalent /g of extract) observed at VD. The antioxidant activity value of all lotus rhizomes was presented in Table 4A.3. and figure 4A.3.(b). It was observed that after drying, there was a significant increase in FRAP, ABTS, and DPPH values. The lowest antioxidant activities were observed in all high-temperature drying processes. Differences in antioxidant activity in this sequence have been observed in different drying methods of dried lotus rhizomes.

FRAP: HD < TD <Fresh < MD 180 W < FD < MD 300 W < MD 450 W < MD 900 W < MD 600 W < VD

DPPH: MD 180 W < HD < TD < Fresh < FD < MD 300 W < MD 450 W < MD 900 W < MD 600 W < VD

ABTS: MD 180 W < HD < TD < Fresh < FD < MD 300 W < MD 450 W < MD 900 W < MD 600 W < VD

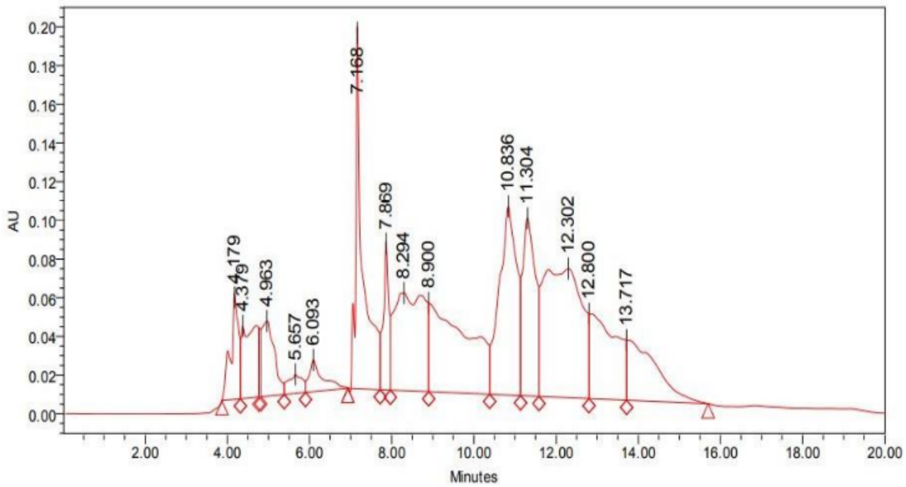


Figure 4A.4. HPLC study of lotus rhizomes: catechin (4.963 min), chlorogenic acid (5.657 min), gallic acid (4.179 min), vanillic acid (6.093 min), syringic acid (7.168 min), protocatechuic acid (4.379 min), rutin (7.869 min), elachic acid (8.294 min), sinapic acid (8.900 min), ferulic acid (10.836 min), myricetin (11.304 min), quercetin (12.302 min), apigenin (12.800 min) and kaempferol (13.717 min).

The radical scavenging activity has a positive correlation with free phenolic compounds.

Their efficiency could explain the possible explanation for imparting high hydrogen atoms. Prolonged heat treatment and the presence of bound phenolic compounds exhibited lower antioxidant activity in the case of HD, TD, and MD 180 W. The less free phenolic compound in the fresh sample caused lower antioxidant activity. Since the free phenolic compounds are higher in VD and all microwave drying except MD 180 W, they showed higher antioxidant activity. Similar results were found in fruits and vegetables (Bualuang et al., 2017; Chang et al., 2006; Dewanto et al., 2002; Saha et al., 2019; Wojdyło et al., 2009, 2014). It was evident from the result that VD was the most acceptable in terms of more excellent antioxidant activity and retained the highest number of bioactive compounds.

4A.3.5. Analysis of textural characteristics

Hardness, resilience, and fracturability are the indicators used to explain the textural change of a product. Heat results in moisture evaporation that leads to the development of a pressure gradient within the product during drying. In FD, the absence of heat caused a decreased pressure. In MD or other heating, the method caused the formation of fragile structures because of the increased pressure gradient. In the case of MD, when equilibrium cell pressure increases from yield stress, the cell structure is destroyed, and the product's hardness decreases (Saha et al., 2019). From this study, as we can see in Table 4A.5., the hardness of the product was most in MD at 180 W because of a long time of exposure to heat as compared with other MD methods. In the case of HD, the hardness and fracturability were high because of the higher energy that dried the product. Due to long-time exposure to heat, they both have no significant difference (Sahoo et al., 2017). Due to no and low temperatures, the hardness, fracturability, and resilience values were very low in fresh and FD lotus rhizomes. Hardness is negatively correlated with moisture content. In the case of resilience, VD, HD, MD 300W, MD 600W, and MD 900W were all in the same group according to Tukey's test; hence no significant variation ($p<0.05$) was observed. Therefore, it was observed from the result that the hardness and the resilience both are high in MD 180W. In the case of VD, the value was almost average of all the drying methods and the most acceptable. The value of hardness, fracturability, and resilience in the following sequence improved for different drying procedures.

Hardness: Fresh < FD < MD 900W < VD < MD 600W < MD 450W < TD < MD 300W < HD < MD180W.

Fracturability: Fresh < FD < MD 900W < MD 600W < VD < MD 450W <TD < MD 300W < MD 180W < HD.

Resilience: Fresh < FD < TD < MD 450W < MD 600W < VD < MD 300W < HD < MD 900W < MD 180W.

In the case of VD, the value was almost average among all drying methods and the most accepted. Hardness, resilience, and fracturability are interrelated with each other. Therefore, long-time exposure to high temperatures in HD, MD 180W, and MD 300 W compared to other drying processes was the reason for higher hardness, fracturability, and more significant shrinkage. From the study, we can conclude that prolonged heat treatment caused greater hardness, fracturability, and resilience.

Table 4A.5. The value of drying and textural properties of different dried lotus rhizomes, the result shows the value of Mean ± SD

Process	Hardness (N)	Fracturability (N)	Resilience	Moisture Diffusivity (10^{-10} m^2/s)	Time (min)
FD	12.642±0.748^{f}	12.272±0.914^{e}	0.468±0.394^{b}	0.366^{g}	483^{a}
TD	42.730±0.77^{bc}	42.550±0.100^{b}	0.631±0.97^{b}	0.481^{fg}	329^{b}
HD	49.514±0.845^{a}	47.921±0.456^{a}	1.031±0.247^{ab}	0.411^{g}	343^{b}
MD 180W	57.713±0.992^{a}	47.571±0.969^{a}	2.730±0.90^{a}	5.534^{e}	35^{d}
MD 300W	44.660±0.600^{b}	42.903±0.390^{b}	0.828±0.690^{ab}	7.559^{d}	21^{e}
MD 450W	41.928±0.649^{bcd}	40.337±0.720^{bc}	0.637±0.195^{b}	18.395^{c}	10.5^{ef}
MD 600W	39.267±0.594^{cd}	36.120±0.880^{cd}	0.776±0.326^{ab}	22.627^{b}	8.167^{ef}
MD 900W	32.630±0.840^{e}	31.920±0.850^{d}	1.036±0.688^{ab}	36.008^{a}	5.833^{f}
VD	38.150±0.944^{d}	36.279±0.327^{cd}	0.787±0.381^{ab}	1.199^{f}	49^{c}
Fresh	12.036±0.334^{f}	10.031±0.70^{e}	0.203±0.57^{b}	-	-

4A.3.6. Assessment of color

The color changes of a food product are measured by three chromatic coordinates L, a, and b indicating brightness/darkness, redness-greenness, and yellowness-blueness, respectively. This depends on the types and quantities of some components. The color changes after thermal treatment are mainly due to the browning reaction and destruction of pigments (Youssef & Mokhtar, 2014). The intensity of drying temperature is proportional to the browning response. On the other side, when the temperature intensity was high, less time was required for drying, and that caused lesser exposure to oxidizing effect of high temperature (Nadi & Tzempelikos, 2018). ΔE values (equation 4A.17.) are the human eyes' ability to differentiate between samples' colors (Wojdyło et al., 2014). According to Karasu et al., (2015), when the ΔE value was greater than 12 U, it indicated a more significant color change. In this study, except for FD, all the ΔE values were lesser than 12 U. The lowest color change was observed in TD. The mean values of fresh lotus rhizomes were measured as L^* = 46.63, a^* = 7.404, and b^* = 20.028. In this study, the value of ΔE ranges between 6.378 and 14.569 depending on the time and temperature of the thermal treatment shown in Table 4A.6. This sequence of color differences has been observed in different patterns of dried lotus rhizomes, which are FD > Fresh > TD > MD 180 W > VD > HD > MD 300 W > MD 450 W > MD 600 W > MD 900 W (high L*, a*, b* value, and low ΔE value). The ΔE value of purslane leaves was highest and lowest in FD and hot air oven drying at 50 ºC, respectively, compared with another high-temperature drying method. As the temperature rises, the greenish color turned into a reddish hue because of the non-enzymatic browning reaction. In the case of low-temperature drying like FD, more L* indicated more lightness, resulting from the destruction of pigment in food (Youssef & Mokhtar, 2014). FD lotus rhizomes showed brighter color with higher L*, a*, b*, and ΔE values as compared with fresh and other dried lotus rhizomes because the absence of heat does not cause any non-enzymatic browning reaction. The lowest value of L^* (36.078) was observed in the MD at a 900 W power level, which means a more darkened color. The dried sample became reddish with a higher a* value as the temperature decreased. High temperature and cellular degradation may be due to the non-enzymatic browning reaction responsible for color variation. After TD, the lowest value of ΔE was observed in VD with the highest b^* value, which means there is not much difference in the color of the vacuum-dried product and with fresh product.

Table 4A.6. The difference in the color parameter of different dried lotus rhizomes, the result shows the value of Mean ± SD.

Process	L*	a*	b*	ΔE	BI
FD	61.158±0.211^{a}	8.438±0.866^{a}	20.362±0.599^{a}	14.569^{a}	7.671±0.944^{e}
TD	41.3±0.331^{c}	7.146±0.743^{b}	16.534±0.398^{bcd}	6.378^{e}	12.602±1.250^{d}
HD	38.266±0.325^{de}	6.06±0.493^{abc}	15.314±0.344^{cd}	9.695^{cd}	15.188±0.922^{bc}
MD 180W	39.35±0.319^{d}	6.76±0.624^{ab}	16.712±0.347^{bcd}	8.026^{d}	13.031±1.131^{cd}
MD 300W	37.63±0.289^{e}	5.354±0.612^{cd}	14.968±0.970^{cd}	10.526^{c}	13.126±1.020^{cd}
MD 450W	37.232±0.298^{ef}	4.978±0.519^{cd}	13.62±0.80^{ef}	11.631^{bc}	14.722±1.339^{bcd}
MD 600W	37.19±0.341^{ef}	5.27±0.707^{abcd}	14.472±0.318^{de}	11.689^{bc}	16.366±1.118^{ab}
MD 900W	36.078±0.331^{f}	4.796±0.578^{cd}	13.048±0.245^{f}	12.918^{b}	14.066±1.165^{bcd}
VD	39.012±0.473^{d}	6.088±0.705^{abc}	16.42±0.400^{bcd}	8.531^{d}	17.820±1.321^{a}
Fresh	46.63±0.293^{b}	7.404±0.682^{b}	20.028±0.61^{a}	--------	14.622±0.947^{bcd}

During the preparation of many fruits, a browning reaction occurs. Phenolics are used as substrates in this process. The Browning index value of all samples is presented in Table 4A.6. Different patterns of dried lotus rhizomes that are VD > MD 600W > HD > MD 450W > Fresh > MD 900W > MD 300W > MD 180W > TD > FD have shown this progression of BI. Phenolic compounds and BI positively correlate in all drying processes except FD. VD and MD 600W show high BI, antioxidant content, and phenolic compounds. Browning reactions in fruit are caused by both enzymatic and non-enzymatic browning. Metal ion interaction with phenolics, ascorbic acid breakdown, and the Maillard process are all examples of non-enzymatic browning. In the first enzymatic browning phase, phenolics are oxidized to create unstable quinine products, which combine with other chemicals to form browning pigment in the second nonenzymatic browning phase (Robards et al., 1999). On the other hand, Quinones generated during the initial step of oxidation might revert to phenol by reacting with ascorbic acid or other reducing chemicals. Browning is therefore prevented until ascorbic acid is exhausted, following which brown pigments are formed. Not all phenolics found in fruits, such as flavonol glycosides, are polyphenol oxidase (PPO) substrates. However, they can degrade when browning occurs (Cheynier et al., 1997). The total phenolic content of the Indian gooseberry browning index, which was determined from color space, has a strong positive connection with total phenolic content (Ruangchakpet & Sajjaanantakul, 2007).

4A.4. Conclusion

Lotus rhizome is a low-cost, versatile vegetable rich in phytochemicals. From the study, it can be concluded that high temperatures and long-time exposure to heat destroyed the quality of the product. So, optimization of the power level at MD is essential to restore the quality of lotus rhizomes. By investigating the drying kinetics, it was found that Midilli Model was the best for explaining the drying characteristics of lotus rhizomes which had the lowest value of SS_{error} ranges between 0.0145 and 0.0088. MD at 600 W gave the accepted value of Moisture diffusivity, but the quality, including antioxidant content and activity, was high in the case of VD. High moisture diffusivity was seen (36.008×10^{-10} m^2/s) for MD at a 900 W power level. The freeze dryer takes 8 hrs to complete the drying process, whereas, in a microwave, the drying gets completed in nearly 30 min, and the vacuum oven takes 50 min. The highest SMER and MER and lowest energy consumption values were observed in vacuum drying and microwave drying, which indicates they are the most appropriate methods with a high potential for saving energy, cost, and time. The retention time of all microwave-dried sample ultrasound-assisted extraction is deficient compared to the other process-dried samples. Free-dried samples present low hardness, fracturability, resilience, and high whiteness. A high amount of antioxidant content, antioxidant activity, and polyphenolic compounds were present in vacuum-dried samples. So overall, by considering all the factors, VD is the most acceptable method to dry lotus rhizomes. Vacuum drying removes moisture at low temperatures, minimizes the risk of oxidation because of its oxygen-efficient processing environment, and helps restore the quality and nutritional value of the dried product. Further studies can be conducted on clinical trials to expose its role in treating diseases. In the future, there is a vast scope of utilization of dried lotus rhizomes in the food and medicinal industry as it is a significant storehouse of phenolic and flavonoid compounds.

Part -B

4B.1. Introduction

The *Borassus flabellifer* is mainly known as a tropical plant in Southeast Asia, Africa, and South America. It belongs to the kingdom: Plantae, order: Arecales, family: Arecaceae, genus: Borassus, species: *b. Flabellifer*. It is commonly known by several names such as doub palm, Palmyra palm, tala palm, toddy palm, wine palm, and ice apple. The fruit part is a soft fleshy portion containing watery fluid inside. The ripped and unripe fruit is used as a traditional food source or to make various dishes in many parts of the Indian subcontinent, such as jaggery, sugar, toddy, chocolate, fresh juice, and many more. The palm tree is also known as the Miracle Tree because of its beneficial role in health (Khatri et al., 2020). It is a rich source of vitamins A, B, and C and antioxidants. *B. Flabillifer* contains carbohydrates like sucrose. Palm fruit is effective against inflammation. The anti-inflammatory activity may be due to crude flavonoids, saponins, and phenolic compounds (Krishnaveni et al., 2020). Several phytochemicals like tannins, flavonoids, saponins, glycosides, and terpenoids were found in the aqueous, methanolic, and ethanolic extract of the seed coat of *B. Flabillifer*. The study concluded that the phytochemicals present in the ethanolic and methanolic extract could prevent the growth of some harmful pathogens (Alamelumangai et al., 2014). Leaf stalks are used in gastritis and hiccough; roots are beneficial as ant gonorrhoeal, anthelmintic and restorative. Fresh juice from toddy also has diuretic and laxative effects (Mohanty et al., 2018). The plant roots are used as a diuretic. The spadix portions are applicable against hurt burns and enlargement of the spleen and liver (Krishnaveni et al., 2020).

When the fruit is ripe, palm seed is collected. The endosperm of germinated Palmyra is soft and gelatinous in its immature period; it becomes hard and hollow when it starts to ripen (Srivastava et al., 2017). The soft and spongy endosperm is nutritionally enriched with many bioactive compounds (Krishnaveni et al., 2020). Many parts of the country satisfy their hunger by eating soft and gelatinous endosperm of Palmyra (Aman et al., 2018). Ted, planted in soil, ash, and sand, undergoes germination. The following factors should be considered while germinating palm seed temperature (27 °C to 32 °C), adequate light and moisture, cleanliness, and hygiene (Robinson, 2009). Germination occurs in palm seeds in two ways – one is remote germination, and the other is adjacent germination. It takes a month to begin germination, and the process takes about a year to complete (Meerow, 1969). During germination, palm seed faced several changes and enhanced its nutritional value Phytochemicals are chemical compounds primarily found in plants like whole grains, fruits, and vegetables with protective and disease-preventing properties. To develop the product as a food source, phytochemical screening is essential. A study proved that thermal processing caused no change in the phytochemical components of raw palmyra palm fruit pulp (RPFP) and thermally processed palmyra palm fruit pulp (PPFP) (Saranya & Vijayakumar, 2016). Palmyra starch can be used in the food processing industry because of its thermal stability, and it also has the property of a thickener agent in frozen food (Naguleswaran et al., 2010). To add value, every part of the Palmyra palm can be processed as edible and non-edible products (Srivastava et al., 2017). Products such as palm spread, cream, and toffee can be prepared from ripe Palmyra palm pulp (Golly et al., 2017). Another study developed a famous baked confectionary muffin from Palmyra sprout flour. After incorporation, nutritional improvement happened in formulated food (Khatri et al., 2020).

The ideal drying procedure is visually described using kinetics (Chen et al., 2015). Drying must be performed to preserve the food materials for further analysis without spoilage. Drying causes changes in the products in terms of quality, color, and texture. So selecting appropriate drying techniques is necessary to enhance the quality (Aamir & Boonsupthip, 2017; Devahastin & Niamnuy, 2010). First-class polyphenol compounds like procyanidins, caffeoylquinic acid, and epicatechin are susceptible to high-temperature thermal processing and are treated with low-temperature rapid drying. S-class polyphenolic compounds like 4-methyl catechol, catechol, dopamine, caffeic acid, gallic acid, and chlorogenic acid are treated with high/ medium temperatures to prevent their losses (Chong et al., 2013).

Ultrasound-assisted extraction (UAE) technique is a technique that is cheap and easy to operate as compared with other extraction techniques. UAE, by applying mechanical effort, increases the penetration of the solvent into the sample matrix. The solute can be dissolved in the solvent very quickly by expanding the area where the liquid and solid phases come into touch (Pan et al., 2012). A high rate of extraction was observed at a low cost in the UAE technique (Al-Dhabi et al., 2017). This technique can extract many bioactive pigments from the sample using minimal solvent and low energy loss, which is also considered environmentally friendly (Chemat et al., 2017). In short, UAE exhibits advantages like less energy and time consumption, eco-friendly, high yields with better quality, and safe and easy to operate (Chemat et al., 2017; Guo et al., 2017). The importance of the UAE was mentioned in a study to prepare natural antioxidants in extracts of sugar beet molasses (Chen et al., 2015).

The Color of the product significantly changed by drying. When buyers decide to buy a product first, they notice the product's color. The color of the dehydrated product changes for the following reason- Maillard reaction, pigment dehydration, enzymatic browning, or ascorbic acid oxidation (Chong et al., 2013). Enzymatic and non-enzymatic changes in pectin (a cell wall polysaccharide) are mainly responsible for the texture degradation of the dried product. To understand the textural change in the product hardness (Aamir & Boonsupthip, 2017), Cohesiveness, gumminess, springiness, fracturability, adhesiveness, chewiness, and stringiness are measured. Despite its improved nutritional value, it is not as popular as food. It has been chosen as a subject so that a lot of work, like incorporation or fortification, can be carried out in the future using the best drying method described in this study.

4B.2. Materials and Methods

4B.2.1. Raw materials

B. Flabellifer species of Palmyra can be primarily seen in the east and west Medinipur of

West Bengal (Mondal et al., 2017). Palmyra endosperm was collected in household farming at Arit village (Lat-Long 22.553101 N, 87.770508 E respectively) in West Medinipur, West Bengal, India. The geographical locations were identified by using google earth pro software.

4B.2.2. Chemical compounds

SRL, Lab chem, and Merck supplied all of the materials used in the study.

4B.2.3. Preparation of sample

After collecting the fresh GPS from the land of East Medinipur, West Bengal, India, they were washed with clean water and then cut to collect the spongy endosperm of palmyra. Each slice was cut to 4 mm in length and 12 mm in diameter. According to Saha et al., (2019), 5 mm diameter and 10 mm length were taken in the case of a corncob. In this study, the diameter was taken as much as the maximum could be taken. They were dried under different drying conditions, such as microwave drying (MD-at 900W, 600W, 450W, 300W, 180W power levels), hot air oven drying, freeze-drying, and tray drying. The initial and final moisture contents were noted as 82.212±1.884 g water/g fresh and 1.560±0.536 g water/g dm, respectively. Changes in the moisture content were monitored at each interval of time.

4B.2.4. Drying process of SE-GPS

The tray, freeze, hot-air oven, and microwave drying techniques are measured in section 4A.2.2.1.

4B.2.5. Drying kinetics

The drying kinetics moisture ratio, moisture diffusivity, and model fitting factors were calculated according to section 4A.2.2.2.

4B.2.6. Antioxidant analysis of SE-GPS

Section 4A.2.4 was used to determine antioxidant profiles.

4B.2.7. Analysis of HPLC assay

According to section 3A.2.5.3, polyphenolic substances were identified.

4B.2.8. Texture profile analysis (TPA)

Section 2.2.5 was followed when conducting the TPA tests.

4B.2.9. Measurement of bulk density and porosity

In line with section 3A.2.5.6, the method was used to evaluate bulk density and porosity.

4B.2.10. Scanning Electron Microscopy

SEM has done a morphological study of all dried SE-GPS in different drying methods. 1.5 mm length and 12 mm diameter cylindrical size SE-GPS was added to the surface area of the double-sided tape attached to stubs followed by a thin gold coated layer under vacuum by Quoram coater (Q150RS, Quoram, Germany). All samples were viewed at 140x, 381x, 570x, 1366x, 10000x, and 20000x magnification by Field Emission Scanning Electron Microscope (INSPECT F50, FEI, Netherland).

4B.2.11. Color Assessment

According to section 3A.2.5.5, color studies were done.

4B.2.12. Statistical analysis

Minitab 19.0 (Minitab, Inc., Pennsylvania, PA) and WPS workbench. Ink (WPS Analytics, World Programming, UK) software was used to statistically analyze all the data at a 0.05 significance level (n=3).

4B.3. Results and discussion

4B.3.1. Drying kinetics of GPS

In this study, 4 mm width SE-GPS was taken for drying in a Freeze, Microwave (180, 300,450,600 & 900 W power level), Hot air oven, and tray dryer. In a moisture analyzer, the sample's moisture content was 82.212±1.884 gm (db.). After drying, that was reduced to

1.560±0.536. It was seen from the values obtained from the equation (Table 4B.1.) that the highest and lowest value of moisture D_{eff} was observed in the case of MD at 900 W (27.19010^{-10} m^2/s) and FD (0.073 10^{-10} m^2/s) respectively.

The best-fitted drying model was the selection on the lowest value of $ss_{error.}$ The drying model constants and coefficients calculated from the statistical analysis are mentioned in Table 4B.2. Values obtained from the six thin-layer drying models (Table 4B.2.) revealed that the lowest value of ss_{error} (0.09 to 0.0004) was observed in the two-term model, making the model well suited for drying SE-GPS. The logarithm of MR values versus drying time was plotted graphically (Figure 4B.1.). The declination of moisture content was very sharp in the first phase of the falling rate period, and the rate of reduction in removal of moisture decreased slowly in the later phase. In graphs A and B (Figure 4B.1.), the linearity between predicted & observed values showed that the expected value is a good fit for actual data.

Being the primary controlling agent of the drying process, moisture diffusion at constant relative humidity is the main reason for the mass transfer of moisture, which explains the drying behavior that occurred during the declining rates (Khawas et al., 2014). The highest moisture diffusivity was recorded at MD at 900 W power levels. In Microwave drying, the heat generated from the inside then spreads to the outside of the product. It results in the development of internal vapor pressure that helps remove moisture from the product in a comparatively short time and has high drying rates (Dronachari & Yadav, 2015). All microwave-dried samples are lower in moisture content and water activity, according to (Vu et al., 2017). In this study, MD takes a short time to dry the sample compared to other drying types. As a result of low moisture content and less water activity, microbial and enzymatic deterioration is also reduced (Leistner, 1992). The highest polyphenol oxidase activity was observed between 55 and 75 ^{0}C, but at different drying temperatures, its activity decreases (Mphahlele et al., 2016). In this study, 60 ^{0}C temperature was chosen to dry the sample in a tray dryer. HD is an effortless and common drying technique with comparatively low cost, but product quality decreases as the temperature rises (Vu et al., 2017).

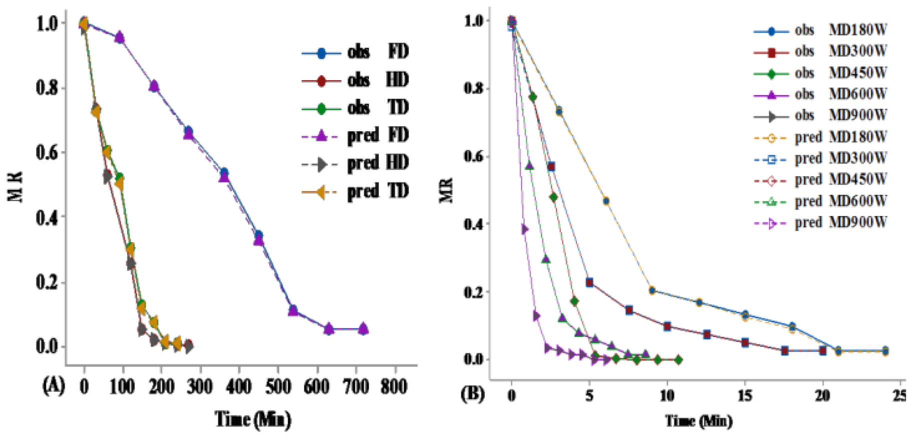


Figure 4B.1. Drying kinetics of SE-GPS, dehydrated via (A) freeze, hot-air oven, and tray drying and (B) microwave drying at different powers. Solid lines represent observed and predicted values determined using the Two-term model. Experimental methods are FD, HD, MD 180 W, MD 300 W, MD 450 W, MD 600 W, MD 900 W, and TD.

The sample was weighted after several time intervals. The drying temperature is closely related to the drying time. When the drying temperature is increased, the drying time is reduced. The two-term model with the lowest value of ss_{error} was considered the best model for explaining the drying kinetics of SE-GPS in this study. The model of Two-term was best fitted for explanations of parboiled rice drying characteristics (Chandra & Singh, 1984). Other studies supported the Two-term model best for their experiments (Chen et al., 2015; Pu & Sun, 2015). The plotted graph (Figure 4B.1.) showed a sharp reduction of the falling rate period at the very first phase compared with the later stage, indicating that the moisture removal rate from the sample was very rapid in the first few min. Figure 4B.2. Depicts images of both fresh and dried SE-GPS.

Table 4B.1. The value of drying and Structural properties of different dried SE-GPS. Presented experimental data are FD, fresh, HD, MD 180 W, MD 300 W, MD 450 W, MD 600 W, MD 900 W, and TD.

Process Name	Time (min)	Moisture Diffusivity (10^{-10} m^2/s)	Porosity (%)	BD
FD	720	0.012	73.793	0.1345
Fresh			-------	0.6724
HD	270	0.052	60.00	0.1857
MD 180W	24	0.481	55.789	0.2053
MD 300W	20	0.759	58.065	0.2097
MD 450W	10.5	1.12	59.551	0.2191
MD 600W	9	1.71	50.465	0.2267
MD 900W	6	4.32	51.446	0.2349
TD	240	0.077	61.574	0.1806

Table 4B.2. Result of Statistical value of different mathematical drying model's in-tray, freeze, Hot Air Oven, and microwave dryers of SE-GPS.

Process	Mathematical Equation of Lewis model: MR = exp(-kt)						
	K				**Ss_{error}**	**RMSE**	**R^2**
FD	0.00209				0.11670	0.154029	0.975374
HD	0.00916				0.03540	0.095110	0.959185
MD 180	0.09690				0.03540	0.044237	0.991905
MD 300	0.20940				0.00686	0.319995	0.985559
MD 450	0.25490				0.08310	0.592953	0.977834
MD 600	0.33260				0.00890	0.039642	0.988128
MD 900	0.98500				0.000663	0.008851	0.989639
TD	0.00788				0.08650	0.078711	0.972839
Mathematical Equation of Midilli et al model: MR = aexp($-kt^n$) + bt							
	K	N	A	B	Ss_{error}	RMSE	R^2
FD	0.50550	1.66266	1.0000	-0.00197	0.64110	0.135000	0.97800
HD	0.08805	2.36820	0.9549	-0.00011	0.02220	0.056329	0.988220
MD 180	0.04990	0.34300	1.6827	0.02080	1.19860	0.281477	0.970164
MD 300	0.16800	1.18700	1.0031	0.02430	0.00379	0.023282	0.997323
MD 450	0.05320	0.91560	0.9883	-0.00224	0.00283	0.020090	0.998486
MD 600	0.25430	1.07530	1.0000	-0.00774	0.00013	0.004030	0.999910
MD 900	1.54300	3.24700	0.0846	-0.01130	0.00569	0.030711	0.966102
TD	1.61900	1.59600	0.3796	-0.00135	0.41220	0.111100	0.941980

Mathematical Equation of Page model: MR = exp(-kt^n)							
	K	N			Ss_{error}	RMSE	R^2
FD	0.9700	1.0763			2.41810	0.1120280	0.974378
HD	0.9700	1.0763			0.88550	0.0922090	0.965385
MD 180	3.3330	1.4422			0.74260	0.0448390	0.993904
MD 300	0.2059	1.0097			0.00685	0.0305980	0.997559
MD 450	0.0526	1.9636			0.00408	0.0579550	0.985838
MD 600	0.2270	1.2552			0.00136	0.0206440	0.991127
MD 900	0.9618	1.0684			0.000475	0.0079851	0.991634
TD	0.9700	1.0763			1.27640	0.0768050	0.981838
Mathematical Equation of Two-term model: MR = aexp(-kt)+bexp(-gt)							
	K	A	B	G	Ss_{error}	RMSE	R^2
FD	0.00251	1.1734	-0.1734	8.05000	0.0910	0.114020	0.97336
HD	0.01360	1.7661	-0.7661	8.05000	0.0581	0.091109	0.969183
MD 180	0.12960	1.4359	-0.4359	8.05000	0.0113	0.040238	0.993903
MD 300	0.22720	1.0930	-0.0934	8.05000	0.0063	0.029996	0.995557
MD 450	0.38250	1.7424	-0.7424	8.05000	0.0227	0.056951	0.987830
MD 600	0.39890	1.2869	-0.2869	8.05000	0.0027	0.019641	0.998120
MD 900	1.07240	1.1205	-0.1205	16079.8	0.000432	0.007854	0.999630
TD	0.01170	1.5933	-0.5933	8.05000	0.0391	0.074709	0.982837
Mathematical Equation of Henderson-Pabis model: MR = aexp(-kt)							
	K	A			Ss_{error}	RMSE	R^2
FD	0.00228	1.0794			0.10460	0.124028	0.971378
HD	0.00965	1.0773			0.10790	0.092107	0.965184
MD 180	0.10110	1.0530			0.03200	0.041239	0.991905
MD 300	0.21060	1.0059			0.00682	0.030998	0.993554
MD 450	0.26970	1.0839			0.07450	0.057953	0.984833
MD 600	0.33770	1.0219			0.00837	0.020643	0.996121
MD 900	0.98650	1.0021			0.000659	0.008856	0.991631
TD	0.00842	1.0779			0.07900	0.075708	0.981838
Mathematical Equation of Logarithmic model: MR = aexp(-kt) + c							
	K	A	C		Ss_{error}	RMSE	R^2
FD	1.32108	0.581300	0.4187		0.7402	0.09145	0.967000
HD	1.01590	0.000108	-0.0173		1.9750	0.091109	0.969183
MD 180	1.20830	0.448900	0.5511		0.9628	0.040238	0.993903
MD 300	1.99800	0.897700	0.1023		0.2480	0.029996	0.995557

MD 450	1.60798	0.888000	0.1112		0.6310	0.056951	0.987830
MD 600	1.68000	0.900900	0.0991		0.2729	0.019641	0.998120
MD 900	1.81709	0.974300	0.0257		0.1404	0.007854	0.999630
TD	0.60010	0.560200	0.4398		0.5488	0.52100	0.987000

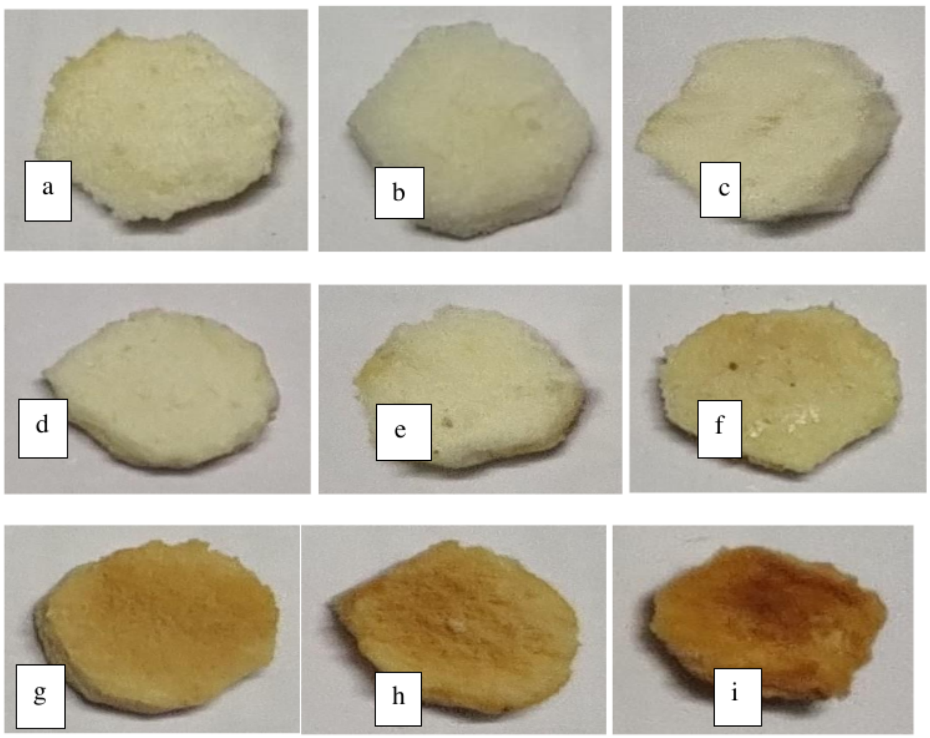


Figure 4B.2. Picture of SE-GPS (whole slices of 4 mm thickness and 12 mm diameter). Experimental method: (a)Freeze, (b) Fresh, (c) HD, (d) MD 180 W, (e) MD 300 W, (f) MD 450 W, (g) MD 600 W, (h) MD 900 W, and (i) TD.

4B.3.2. Antioxidant content and activity

The effect of drying methods on the ultrasound-assisted extraction procedure was evaluated using equation 4A.6. The outcomes were provided in Table 4B.3. The highest concentration of phenolic (12.857 mg/g) was observed in the case of fresh. The FPC and FFC (6.854 mg/g and 1.358 mg/g, respectively) were high in the MD case at a 450-W power level. Polyphenol compounds identified (Figure 4B.3.) in SE-GPS after drying were mentioned in Figure

4B.3.(B). The main phenolic compound in GPS found high is CGA (1.3707 mg/g) at MD 450W, among all other antioxidants. GA was observed as the equal amount in the all-power level of MD. Other phenolic compounds, such as syringic acid, protocatechuic acid, sinapic acid, quercetin, and ferulic acid, were seen in the highest amount at MD 450W compared with other types of drying. All microwave dried SE-GPS free PC and FC were higher (Y_{FP}: 4.465 to 6.854 mg/g and Y_{FF}: 0.972 to 1.358 mg/g) than other drying processes that significantly improved the availability of phenolic compounds. TPC and TFC can be present in free and bound forms in the food product. Compared to the T_R value, where MD required 7 to 17 min to reach equilibrium, another process takes nearly 48 min, and the results are presented in Table 4B.3.

Table 4B.3. The kinetic factors of antioxidant extraction of SE-GPS. Presented experimental data are FD, fresh, HD, MD 180 W, MD 300 W, MD 450 W, MD 600 W, MD 900 W, and TD.

Sample	Free Phenolic content (FPC)			Free Flavonoid content (FFC)		
	K	Y_{FPC}	T_R	K	Y_{FFC}	T_R
FD	0.0078	5.088	46.482	0.0388	0.979	48.255
Fresh	0.0266	4.366	52.177	0.1192	0.649	46.236
HD	0.0069	3.056	47.341	0.0292	0.728	47.016
MD 180	0.0129	4.407	17.585	0.0682	0.913	16.064
MD 300	0.0166	6.345	9.511	0.0793	1.209	10.428
MD 450	0.0200	6.689	7.472	0.0848	1.304	9.042
MD 600	0.0216	6.184	7.502	0.0933	1.139	9.405
MD 900	0.0249	5.214	7.706	0.0925	1.066	10.150
TD	0.0065	3.143	48.712	0.0289	0.745	46.461

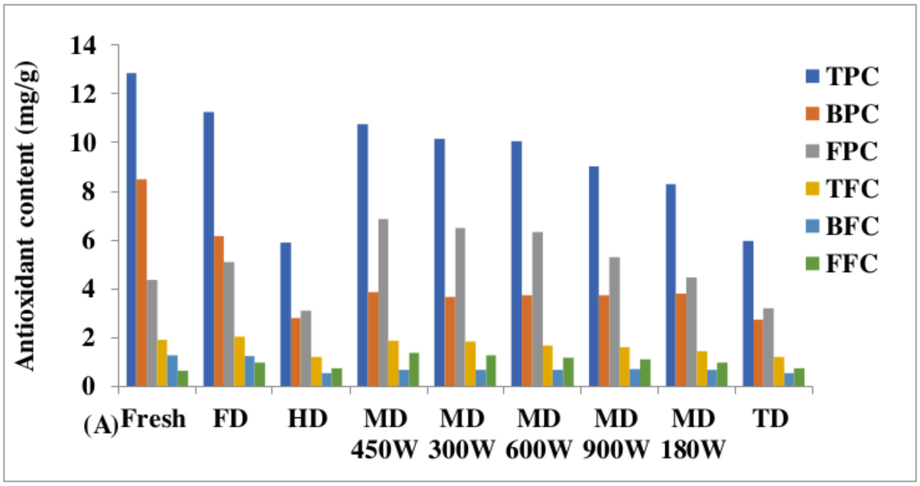
This study observed that after drying, antioxidants' free radical scavenging activity is enhanced, and FRAP, DPPH & ABTS measured that. The antioxidant activity of dried SE-GPS was mentioned in Table 4B.4. A higher value of FRAP, ABTS, and DPPH (47.841 μmol,54.287 μmol, and 56.071 μmol of AAE/g) was observed in the case of MD 450W.

Table 4B.4. Antioxidant activity of SE-GPS in the different drying processes, the result shows the value of Mean ± SD. Presented experimental data are FD, fresh, HD, MD 180 W, MD 300 W, MD 450 W, MD 600 W, MD 900 W, and TD.

Sample Name	FD	Fresh	HD	MD 180	MD 300	MD 450	MD 600	MD 900	TD
DPPH ((μmol / g (dry weight))	26.760±0.012^{f}	7.181 ±0.045^{i}	17.089 ±0.022^{h}	47.642 ±0.045^{d}	48.025 ±0.031^{c}	56.071 ±0.024^{a}	48.416 ±0.032^{b}	47.18 ±0.014^{e}	19.251 ±0.034^{g}
FRAP ((μmol / g (dry weight))	26.251±0.032^{f}	6.89 ±0.012i	16.258 ±0.012^{h}	37.589 ±0.061^{e}	40.991 ±0.053^{d}	47.841 ±0.045^{a}	43.251 ±0.014^{b}	42.993 ±0.013^{c}	18.997 ±0.022^{g}
ABTS ((μmol / g (dry weight))	22.390±0.025^{g}	6.861 ±0.055^{i}	19.564 ±0.013^{h}	40.012 ±0.014^{d}	40.997 ±0.056^{c}	54.287 ±0.018^{a}	41.610 ±0.045^{b}	39.03 ±0.001^{e}	22.984 ±0.045^{f}

Antioxidants include total phenolic (TPC) and total flavonoid (TFC). They are present in free and bound forms and measured using drying kinetics. MD at 450 W was high in FPC and FFC. Many polyphenolic compounds were also observed in MD at 450 W power levels. It was reduced in all other drying methods. The reason may be that elevated temperature in the case of HD, TD, and the entire MD except 450 W destroyed some phenolic compounds. There is a clear relation between extreme heat with long-time exposure and loss of polyphenols.

The extractability and stability of the antioxidant both depend on the drying condition. In this study, Figure 4B.3.(A) clearly showed that MD released high free phenolic and flavonoid compounds than the other drying process. Polyphenol's accessibility is higher in all microwave drying processes than in the other. MD takes less time to reach equilibrium than another process of drying. Twenty min is the maximum reaching time for antioxidant ultrasonication of flax, hemp, and canola seed cake (Teh & Birch, 2014).



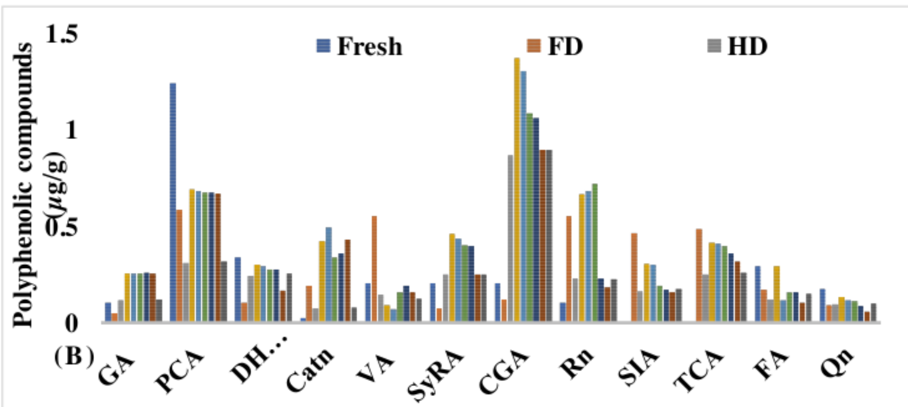


Figure 4B.3. Variation of (A) antioxidant content and (B) polyphenolic compounds (phenolics and flavonoids) of fresh SE-GPS with the different drying processes like FD, HD, MD 180 W, MD 300 W, MD 450 W, MD 600 W, MD 900 W, and TD.

As mentioned in Table 4B.4. the free phenolic and flavonoid content was high in MD. Long-time exposure to hot air generally causes oxidation, and as a result, the antioxidant capacity of the product is reduced. FRAP, ABTS measured the antioxidant activity of the dried sample, and DPPH demonstrated that the microwave-dried product retained good quality in terms of antioxidant activity compared to other drying methods, but optimization of the power level is essential to prevent the losses of quality (Choudhary, 2013; Saha et al., 2019). Therefore, it was found that SE-GPS dried using microwave drying technique at 450W power level was considered best for restoring the highest antioxidant activity.

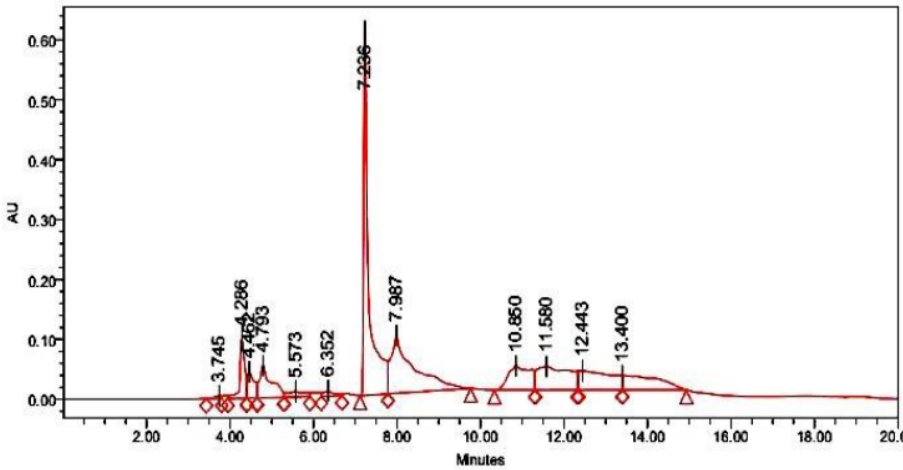


Figure 4B.4. Study of HPLC of SE-GPS: protocatechuic acid (4.286 min), valinic acid (5.573 min), syringic acid (6.352 min), chlorogenic acid (7.236 min), rutin (7.987 min), sinapic acid (10.850 min), dihydroxy benzoic acid (4.492 min), catechin (4.793 min), trans-cinamic acid (11.580 min), gallic acid (3.745 min), ferulic acid (12.443 min) quercetin and (13.400 min).

4B.3.3. Texture Profile

The textural characteristics of SE-GPS will be evaluated mainly based on hardness, fracturability, chewiness, springiness, adhesiveness, cohesiveness, gumminess, and resilience values in Table 4B.5. Hardness, gumminess, and fracturability are observed in higher in MD than in fresh. The hardness of the fresh sample was measured as (7.741±0.873), which quickly increased after microwave drying. The springiness and cohesiveness slightly decrease in all drying than fresh. Freeze-dried products have no measurable change in adhesiveness. It can be observed that the hardness increases after heat treatment, and chewiness decreases as compared with fresh. The chewiness is increased after FD but not as strongly as hardness. After FD closest value of hardness, fracturability, adhesiveness, springiness, and cohesiveness to fresh are TD. The highest value of hardness, fracturability, gumminess, and resilience was observed in MD at 900 W. FD showed the highest value in springiness, cohesiveness, and chewiness.

Table 4B.5. The value of texture profile of SE-GPS with the different drying processes, the result shows the value of Mean ± SD. Presented experimental data are FD, fresh, HD, MD 180 W, MD 300 W, MD 450 W, MD 600 W, MD 900 W, and TD.

Process	Hardness (N)	Fracturability (N)	Adhesiveness (N)	Springiness	Cohesiveness	Gumminess (N)	Chewiness (N)	Resilience
FD	13.362±3.746e	12.362±0.768d	-0.171±0.059bc	1.268±0.134a	0.257±0.013ab	3.434±0.428b	4.354±1.608a	0.055±0.008e
Fresh	7.741±0.873f	7.239±0.904e	-0.137±0.037bc	1.308±0.091a	0.354±0.040a	2.740±0.638b	3.584±0.383ab	0.137±0.007c
HD	18.044±1.736cde	17.142±2.442c	-0.44±0.141a	0.862±0.012b	0.198±0.039b	3.573±0.914b	2.365±0.261ab	0.041±0.023e
MD 180	25.926±0.651b	24.252±0.942b	-0.292±0.083ab	0.623±0.037c	0.169±0.014b	4.381±0.199ab	2.729±0.205ab	0.283±0.021b
MD 300	18.648±0.055cd	17.590±0.331c	-0.278±0.080ab	0.637±0.034c	0.194±0.076b	3.618±0.963b	2.304±0.505b	0.073±0.010de
MD 450	16.152±0.198de	16.930±0.760c	-0.282±0.101ab	0.707±0.027c	0.22±0.018b	3.553±0.178b	2.513±0.097ab	0.067±0.011de
MD 600	20.998±0.275c	21.608±0.583b	-0.245±0.075abc	0.632±0.077c	0.178±0.042b	3.738±0.600b	2.363±0.365ab	0.335±0.023a
MD 900	38.114±2.592a	33.326±0.692a	-0.029±0.023c	0.612±0.064c	0.149±0.047b	5.679±0.665a	3.476±0.973ab	0.365±0.020a
TD	15.109±0.799de	13.572±1.216d	-0.178±0.083bc	0.969±0.016b	0.227±0.030b	3.429±0.587b	3.323±0.553ab	0.109±0.016cd

Heat treatment influenced all textural parameters of the product. Evaporation of moisture leads to the generation of a pressure gradient responsible for the dried product's porous structure. The porous structure's size depends on the power intensity (Marzec et al., 2010). In Microwave drying, the product's hardness was increased due to the rapid reduction of water content in SE-GPS. At 900 W, Microwave dried GPS had a hard texture than other powers because an increase in temperature increased hardness. This textural characteristic is related to the internal bonds of the sample that helps to make the body (Guiné & Barroca, 2011). Springiness values are very similar in drying treatment compared with fresh, meaning that drying treatment did not cause a huge change in the return of the product to its original structure during mastication by teeth. So, it can be observed that all the textural parameters are greatly influenced by drying, and FD is mainly accepted for low hardness, fracturability, gumminess, and high chewiness, cohesiveness, and springiness among all other drying methods applied to dehydrate SE-GPS.

4B.3.4. Morphology

Images recorded through a Scanning electron microscope of a tray, freeze, hot air oven, and microwave oven-dried SE-GPS with different scales of 500, 300, 200, 50, 10, and 5 μm were presented in Figure 4B.5. SE-GPS drying is a moisture contraction process. During drying, many large pores were formed. As the moisture evaporates through drying, most SE-GPS cells shrink and cause minor deformed fractures. Figure 4B.5. Shows a greater degree of curling and distortion of SE-GPS cells dried in different drying methods. Several holes were found due to the drying of SE-GPS in various dryers.

Scanning Electron Microscope analyzed the morphology. The major compounds present in plant material are polymer and water. Protein and polysaccharides are the main components of polymers that give structure to the product. Plant water mainly acts as a plasticizer (Seerangurayar et al., 2019). The dehydration or absorption actively brunt the cell wall structure (Joardder et al., 2017). SE-GPS drying is a moisture contraction process. During drying, the structure in the cell wall of the dried product is destroyed, and many large holes are formed. There is the possibility of shrinkage in the dried product's microstructure. The cell wall's structure tightens; as an outcome, the microstructure of the products becomes minor and sometimes even worse.

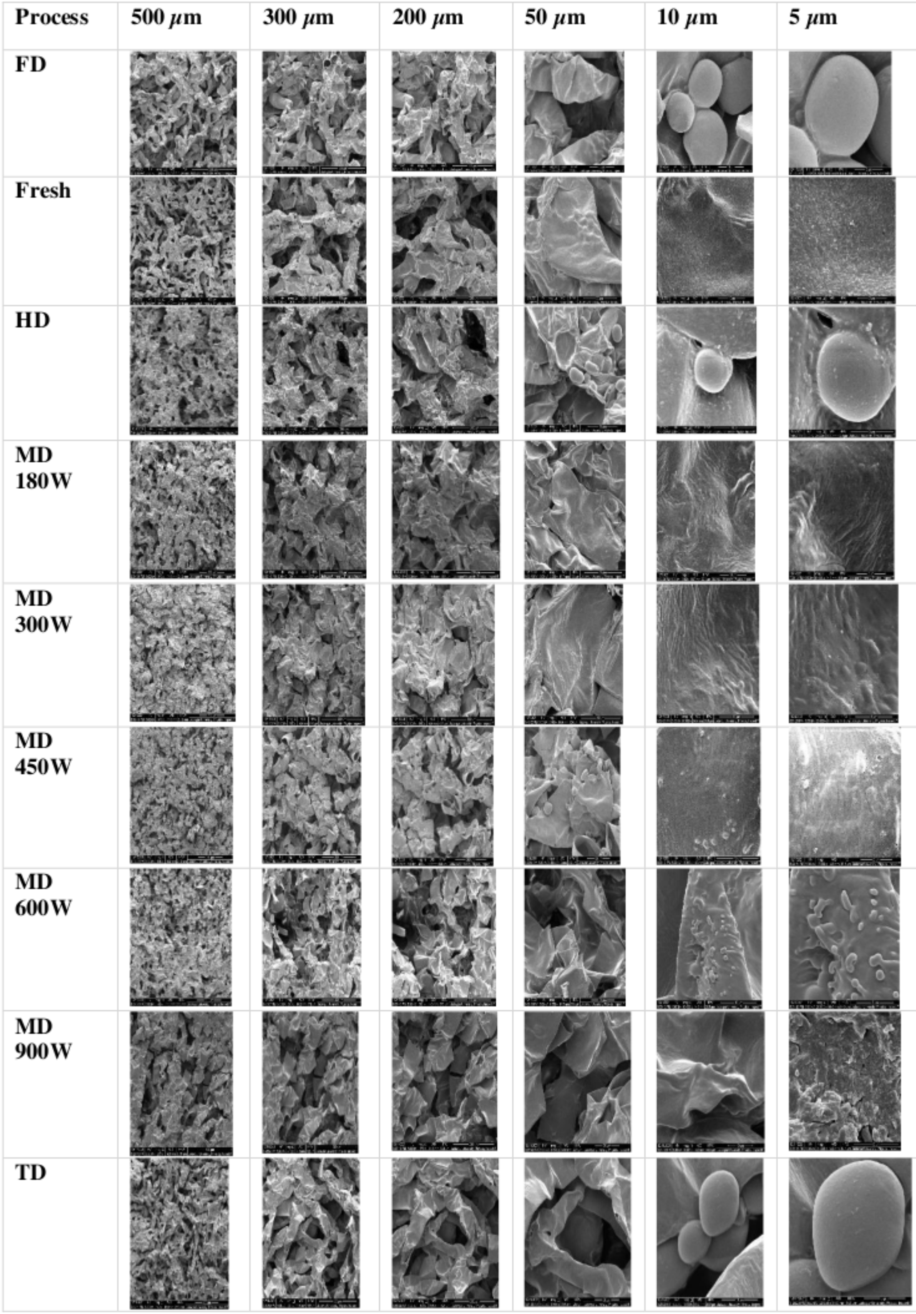


Figure 4B.5. SEM images of the SE-GPS with different scales of 500, 300, 200, 50, 10, and 5 μm at other dried products. Presented experimental data are FD, fresh, HD, MD 180 W, MD 300 W, MD 450 W, MD 600 W, MD 900 W, and TD.

It has been observed that the cell moisture of SE-GPS is rapidly evaporated and expanded. Moisture evaporation leads to shrinkage of cells and minor deformed fractures. It has been observed that high temperatures rapidly dehydrated and deformed turner structures of SE-GPS. The plant cells and network formation are then destroyed in the interstitial and pulp tissue, and the course is separated. It has been observed that FD, Fresh, TD, and HD have less compressed cells of dried SE-GPS, and hence the distance from one cell to another, i.e., the circumference, is quite large. As a result, large holes have been created. In the case of microwave drying, the higher the microwave power and the shorter time causes faster evaporation of the cell water. The more cell shrink, the more brittleness is created. The more porosity comparison will be in this order: FD > TD > HD > MD900W > MD600W > MD450W > MD300W > MD180W (Table 4B.1).

The porosity of an object depends on the bulk and particle density of that object, the bulk density depends on the total volume, and particle density depends on the compact volume. More shrinkage is responsible for the low bulk density of the materials.

More porous structures and greater distances from one cell to another have lower particle density and higher porosity in FD, HD, TD, and MD 900W. Structurally, the distance between the cells of a fresh sample is more significant because it is a spongy food, as seen in Figure 4B.5. All the drying methods were compared according to their structure and morphology. The products were found to have less compact volume, are higher in size, and have more or less large holes with high microstructure circumference.

4B.3.5. Colour

During drying, the color of the product is required to be maintained. The three chromatic

Coordinates L*, a*, and b* describe the product's color. The mean color values of fresh and dried SE-GPS are shown in Table 4B.6. The chromatic parameters of fresh SE-GPS were observed as 81.37±1.14, 0.703±0.391, and 24.725±0.741. All drying resulted in positive a*and b* values which means more red and yellow hue. The highest a* value was observed in MD at 600W, indicating more red chroma because of the browning reaction. The lowest value was noted in MD at 450 W, which means that MD at this power could inhibit the Millard reaction. This situation was mentioned by (Kayacan et al., 2018).

Table 4B.6. Results related to color parameters and color difference of fresh and dried SE-GPS, the result shows the value of Mean ± SD. Presented experimental data are FD, fresh, HD, MD 180 W, MD 300 W, MD 450 W, MD 600 W, MD 900 W, and TD.

Sample Name	L*	a*	b*	ΔE
FD	88.522±0.489[a]	3.777±0.105[c]	26.059±0.435[ab]	7.999±0.369[d]
Fresh	81.37±1.140[b]	0.703±0.391[d]	24.725±0.741[bc]	0
HD	74.068±0.182[de]	7.998±0.155[a]	24.4±0.229[bc]	10.333±0.169[bc]
MD 180	75.268±0.281[cd]	8.424±0.12[a]	23.698±0.478[cd]	9.926±0.321[c]
MD 300	73.41±0.716[e]	8.414±0.334[a]	23.138±0.418[cd]	11.205±0.887[bc]
MD 450	73.21±0.18[e]	5.362±0.464[bc]	18.412±0.19[f]	11.354±0.377[b]
MD 600	68.334±0.143[f]	6.678±0.286[ab]	21.596±0.192[de]	14.703±0.089[a]
MD 900	67.058±0.247[f]	6.68±0.55[ab]	27.386±0.2[a]	15.758±0.077[a]
TD	76.38±0.74[c]	5.228±0.159[bc]	20.428±0.333[ef]	8.025±0.458[d]

ΔE values of the dried sample varied from 9.3445 to 48.0286. In this study, values of ΔE values were maxed higher for another drying process than FD, indicating the darker color of the sample and making the FD acceptable to dry the product based on color profile assessment.

The change in the color after drying was indicated as ΔE value (Kayacan et al., 2018). The red chroma of Microwave dried product at 600W was because of the browning reaction caused by heat treatment. The differences in the color change sequentially placed in the following order from high to low L* value – FD>Fresh>MD 180W>MD300W>MD 450W >TD>MD 600 W>MD 900W> HD. When a consumer goes to buy something, they choose it by looking at its color, so ΔE values are essential, which helps to determine the difference in the color of the sample in the human eye after drying (Wojdyło et al., 2014). In this study ΔE values of all dried samples are more remarkable than FD, indicating the darker color of the sample. This is due to the change in the heat-sensitive compound such as protein and carbohydrates by the high-temperature drying. The heat treatment not only caused color change by non-enzymatic browning reaction but also by the destruction of pigments responsible for the color of the food (Youssef & Mokhtar, 2014). The color of the dehydrated product significantly changed after drying (P>0.05). It can be said that an acceptable change in color was observed in the case of FD.

4B.4. Conclusions

Germinated Palmyra seed's SE is enriched with many bioactive compounds that help human health. The conclusion that can be drawn from the study is that high temperatures with a long time of exposure can harm the product's quality to prevent losses and restore the quality; optimization of power level in case of microwave drying and temperature is essential. By investigating the drying kinetics, the two-term model with the lowest ss_{error} ranges between 0.0910 and 0.0391 has been proven to be the best in this study. By analyzing the sensory profile, including color and texture, it was found that MD 450W was best. The antioxidant content (free phenolic content and free flavonoid content 6.689 and 1.304, respectively) and antioxidant activity (DPPH-56.071±0.024 μmol/g dry weight, FRAP-47.841±0.045 μmol/g dry weight, ABTS-54.287± 0.018 μmol/g dry weight) were observed high in MD at 450W. MD 450W is accepted among all the drying techniques applied to dehydrate GPS. Morphology studies help to determine the structural properties of drying process products. The study's novelty is to dry nutritious and readily available SE-GPS with the best drying technique that produces a high number of phytochemicals and antioxidants. It can be used in the future in the food and pharmaceutical industry.

Chapter 5

To search the nutritional value of the product supplemented to the vulnerable group through supplementary feeding programs (ICDS, Mid-day-meal) and up-gradation of the nutritional quality through technology and market survey basis

5.1. Introduction

According to WHO, Malnutrition is the deficiencies, excess, or imbalances in a person's energy and nutrient intake. WHO mentioned reasons for malnutrition in India include high fertility rate, illness, poverty, mother's nutritional status, women's sanitation, unhealthy eating habit, lack of nutrients, education, and hygiene (Narayan et al., 2019). The rate of stunted children in 2020 was 149 million worldwide (*World Bank Report on Malnutrition in India*., 2020). According to Global Hunger Index 2020, India was positioned 94th out of 107 countries with a score of 27.2, which falls in the severe region of hunger (*Global Hunger Index*, 2018). In India, 48% of total children are suffered from stunting, and due to the COVID-19 pandemic, it is estimated that the number of malnourished and stunted children may increase further (Aayog, 2017). The government initiated many programs to combat malnutrition in India, like the Public Distribution System (PDS), Integrated Child Development Services (ICDS), the Scheme of Mid-Day Meal (MDM), and many more (Birdi et al., 2014). Presently, the numbers of mortality and morbidity in developing countries are increasing, so the emphasis is on making low-cost supplementary food at different levels of the country (Cohuet et al., 2012).

Deficiencies of nutrients, both micro, and macronutrients, can cause growth retardation. ICDS and FAO developed supplementary foods based on locally available cereals and legumes that are a rich source of macro and micronutrients (Khanam et al., 2013). One of the significant steps to reduce the occurrence of malnutrition is to develop supplementary food with locally available ingredients so that they can afford to buy it and meet their nutritional needs as per the RDA. Several studies have been conducted throughout the world on the preparation of low-cost supplements. A pumpkin cream soup was formulated with the addition of tempeh, used as a geriatric supplementary food for older people to improve their nutritional status hampered by age-related disease (Maseta et al., 2017; Setiawan et al., 2021). Prepared supplemental food from quality protein maize to evaluate the potential quality, growth, and rehabilitating potential. Another study concluded that corn-soy blend (CSB) nutritionally was no less than the already available peanut paste-based ready-to-use supplementary food (RUSF$_s$), and CSB was capable of speedy recovery from malnutrition (LaGrone et al., 2012). Apart from that, many other kinds of research were done on the formulation of ready-to-use, low-cost supplementary foods (Bhavani & Kamini, 1998; Hendrixson et al., 2018; Sumathi et al., 2007). A study was conducted to determine the cost and effectiveness of selected child health interventions with the World Health Organization choosing cost-effective Interventions (WHO-CHOICE) (Edejer et al., 2005). In this study, poushtic powder is formulated from locally available ingredients. In addition, lotus rhizomes and endosperm of germinated palmyra seed were used to add extra benefits because of their enriching source of bioactive compounds.

The addition of soybean chunks improves the phytochemicals, proteins, and oil content of the prepared supplements. Acceptance of soybean products 41 has increased nowadays because of their low cost and high nutritional quality with good amino acid balance (Mukherjee et al., 2016). Jaggery was used as an alternative to sugar. More than 70% of the jaggery of the world production is manufactured in India at farmer's units at low capital. At the same time, it is also nutritious and readily available (Rao et al., 2007). Ingredients in the supplements have several micronutrients, including iron, zinc, calcium, and vitamin A. They are also beneficial for immune function and lower the risk of morbidity. Insufficient iron intake in the daily diet causes iron-deficiency anemia (Khanam et al., 2013). Calcium is essential in maintaining the proper function of muscles and nerves. Consumption of insufficient calcium reduces the strength of bones and teeth, so enough calcium must be taken to fulfill the requirement of calcium for individuals in different age groups (Pravina et al., 2013). Free radicals formed in the body cause damage to the cells by oxidation. Antioxidants remove these free radicals by binding with them and helping to prevent damage ("Phytochemicals," 2009); to our knowledge, this poushtic powder preparation and its nutritional and physicochemical characterization have not been evaluated in any previous study.

The RUSF is developed to provide a balanced intake of essential micro and macronutrients for maintaining the proper growth and development of young children and malnourished individuals of low socio-economic groups. Cost and storage studies must be analyzed so people of a low socioeconomic group can easily afford them. Drying needs to be performed to store the supplements for a longer duration. Drying causes changes in the product parameters like quality, texture, and color (Devahastin & Niamnuy, 2010).

To prevent malnutrition and keep children healthy, the ICDS center provides several foods: poushtic laddu, made with rice, wheat, groundnut, gram flour, and sugar. The women of the self-help group mainly make these nutritious laddu ingredients and provide the ICDS center. Currently, several ICDS centers offer poushtic powders made by CINI known as Nutrimix, which is advised to feed the children as laddu at home. This laddu powder lags far behind in nutrition and phytochemicals, and this is the reason for submitting the report to improve the quality of this laddu in terms of nutrition. The objectives of this study were to develop ready-to-eat supplementary food with high-quality protein, iron, and calcium from natural ingredients. Analysis of parameters like macro-micro nutrient, antioxidant content and antioxidant activity, HPLC study of present phenolic and flavonoid compounds, texture profile, color profile, cost, storage study of formulated supplementary food at different containers with different time duration, Sensory evaluation by hedonic scale, calculation the percentage of RDA fulfillment of different age group will also be done.

5.2. Material and methods:

5.2.1. Ingredients

Bengal gram, black gram, groundnut, wheat, sunned rice, soya bean chunk, garden cress seed, poppy seed, coconut, pumpkin, carrot, beetroot, sweet potato, jaggery, zip lock bag, polythene bag, plastic container, steel container, and glass container was purchased from the open-air local market at Jadavpur (Lat-Long 22.494249 N, 87.370399 E), Kolkata in West Bengal. The food materials will be selected for the formulation of poushtic powder based on availability in the local market at low cost and consumed commonly by the vulnerable group in the Midnapore district in West Bengal, India. Lotus rhizome collected from agricultural water land of the lotus by the farmer at Bhogpur village (Lat-Long 22.425640 N, 87.861260 E) in East Midnapore district in West Bengal of India. Palmyrah endosperm was collected in household farming at Arit village (Lat-Long 22.553101 N, 87.770508 E) in West Midnapore, West Bengal, India. The geographical locations were identified by using the Google Earth Pro software.

5.2.2. Chemicals

All chemicals are analytical grade and purchased from SRL, and Mark, chemical suppliers, registered suppliers in Jadavpur University, Kolkata in India.

5.2.3. Flour preparation

Extraneous matter of the purchased cereals, seeds, and legumes was removed at first. After cleaning with tap water, washed materials were dried in a tray drier (Mac Pharma Technology, India) at 60 °C for 5 hrs. All fresh vegetables were washed and cut into one-centimeter size, then dried in a tray drier at 60 °C for 5 hrs. The polyphenol oxidase activity was high at temperatures close to 55 °C. Still, at 75 °C temperature, it was reduced rapidly and was observed at different drying processes (Mphahlele et al., 2016), so 60 °C temperature was used in this study to dry all samples. After that, all dried food materials were taken for grinding in the home mixer grinder (PHILIPS, HL7720/00, Mixer Grinder, 230V-50HZ/750W, YC1A2042008165), and finally, the powder was prepared and passed through the 0.6 mm sieve in our laboratory to get fine structure.

5.2.4. Development of Poushtic Powder

Three supplementary products were prepared from powder using different food multi-mixing processes. The ratio of the food ingredients like cereals, pulses, vegetables, seeds, nuts, and others are given below: For P (13:52:10:7:10:13), PC (10:45:2:18:10:20), and PI (13:45:15:12:5:15). Cini Nutrimix is marked as 'N' used as a control in this study which is collected from the ICDS center at kaminachak (Lat-Long 22.021110 N, 87.771330 E) village in East Midnapore, West Bengal, India. High protein, protein-iron, and protein-calcium poushtic powder marked as 'P,' 'PI,' and 'PC' are used as a sample in this study.

5.2.5. Nutritional Analysis

The total amount of ash, moisture, fat, protein, and carbohydrates is determined by section 2.2.4. Energy content was measured by multiplying Atwater's conversion factors of carbohydrate, protein, and fat and their contents. Calcium, iron, and phosphorus content were determined using an atomic absorption spectrophotometer (VARIAN SPECTRA AA 220FS, AUSTRALIA).

5.2.6. Antioxidant Content and Antioxidant Activity

The entire antioxidant profile was calculated following section 2.2.3.

5.2.7. Analysis of HPLC assay

According to clause 3A.2.5.3, phenolic and flavonoid chemicals were measured.

5.2.8. Texture Profile Analysis (TPA)

The TPA tests were carried out in Section 2.2.5.

5.2.9. Analysis of color

Section 3A.2.5.5 states that color studies were carried out.

5.2.10. Morphology by Scanning Electron Microscopy

Particle size and Morphological study of different poushtic powders have been done by SEM. 0.1 to 0.3 g of all powder samples were added to the surface area of the double-sided tape attached to stubs, followed by a thin gold-coated layer under vacuum by Quoram Coater (Model Q150RS, Germany). All samples were viewed at 1512x, 6000x, 12650x, 24827x, and 46771x magnification by Field Emission Scanning Electron Microscope (INSPECT F50, FEI, Netherland).

5.2.11. Sensory Analysis

Prepared poushtic powders were used to analyze sensory parameters based on appearance, smell, taste, mouthfeel, color, and overall opinion. 9 (Nine) - point hedonic scale was used, and a panel of 30 people was chosen to score the sensory input. All panelists were faculty members and research assistants from the Jadavpur University Department of Food Technology and Biochemical Engineering in Kolkata, West Bengal, India. All panel members used water for mouth rinse after and before testing each sample. Glass container was used for storing all samples at room temperature. All samples were scored for evaluating sensory parameters according to the numerical scoring system, where 1 (one) point is denoted as extremely dislike, and 9 (nine) points are represented as extremely like. Environmental conditions and testing were both made properly for this testing.

5.2.12. Storage studies

The additional food self-life studies were carried out in a zip-lock bag, polythene bag, plastic container, steel container, and glass container for three months at an ambient temperature. 100 gm of the sample was packed for each supplementary group. All samples' moisture content, acid index, and peroxide index were measured as an indicator of staleness and noted periodically after 0,15,30,45,60,75 and 90 days (Kunyanga et al., 2012).

5.2.13. The selling price of the product

The novel supplementary food products cost was estimated based on food ingredients, laboring, energy consumption, processing utensils, and transportation. 20% production cost added of all products allows for vendor and producer margin profit.

5.2.14. Statistical analysis

All statistical analyses were performed by Minitab 19 (MINITAB, INC., PA) software. Tukey's test and ANOVA were used to identify statistically significant differences when $p \leq$

0.05. Except for sensory analysis (n=30), all measurements are done in triplicate (n=3). The mean and standard deviation of all data are displayed.

5.3. Result and Discussion:

5.3.1. Supplement Formulation

The locally available ingredients are combined to produce low-cost supplements without necessarily fortifying the products or supplementing them with synthetic nutrients. The result of color, texture, and sensory profile are mentioned in Table 5.1. The methods of preparation are easy to apply also. On the other hand, a small-scale business opportunity at the village level can be developed. This is not a comparative study of test supplements. This study compared P, PC, and PI test supplements with the control supplement Cini Nutrimix N.

These supplements were evaluated based on appearance, smell or aroma, taste, color, and overall opinion. The sensory acceptance level is measured at ≥6.0 on a nine-point hedonic scale. Supplement P and PC scored higher values for color and taste than PI. The appearance was almost similar in all three supplements. The panelists mostly accepted supplement PC. The sweet aroma came from supplement PC due to the presence of jaggery. Three supplements showed not so much difference with N in the case of sensory acceptance. Supplement P, PC, and PI showed light color compared to the CINI product. PC developed a reddish color than others because of jaggery and roasted seeds. P and PC showed no significant difference in the case of yellowness and redness because they are present in a similar group determined by Tukey's test. Lightness is significantly different in all samples. High lightness, low redness, and yellowness were present in N, but low lightness, increased redness, and yellowness were present in PC.

The difference in the color of the three supplements with Cini Nutrimix is because of the multi-mixing process of the ingredients. The complete texture profile is mentioned in Table 5.1. Compared with N, the other three supplements were less hard. Hardness of the product was favorable relationship with gumminess, chewiness, and resilience but was inversely associated with cohesiveness. Adhesiveness was recorded at a negative value. It was found that the harder the supplement, the less adhesive it feels.

Table 5.1. The values of Physiochemical parameters of different Poushtic Powder, the result shows the value of Mean ± SD and significant effect (Tukey's test).

Sample Name	N	P	PC	PI
Colour Parameters				
L*	$79.004^{a} \pm 0.256$	$62.130^{b} \pm 0.327$	$54.760^{d} \pm 0.595$	$59.768^{c} \pm 0.534$
a*	$4.194^{b} \pm 0.971$	$5.637^{ab} \pm 1.651$	$7.895^{a} \pm 1.498$	$5.623^{ab} \pm 1.350$
b*	$21.710^{c} \pm 0.442$	$29.310^{a} \pm 0.225$	$29.745^{a} \pm 0.604$	$26.883^{b} \pm 0.550$
Texture Profile				
Hardness(N)	$37.302^{a} \pm 5.4$	$34.802^{a} \pm 4.4$	$15.332^{a} \pm 1.024$	$20.720^{a} \pm 3.310$
Adhesiveness(N)	$-0.126^{b} \pm 0.038$	$-0.012^{a} \pm 0.001$	$-0.007^{a} \pm 0.001$	$-0.007^{a} \pm 0.003$
Springiness	$0.902^{a} \pm 0.025$	$0.677^{b} \pm 0.013$	$0.866^{a} \pm 0.129$	$0.770^{ab} \pm 0.029$
Cohesiveness	$0.106^{a} \pm 0.038$	$0.111^{a} \pm 0.039$	$0.159^{a} \pm 0.001$	$0.147^{a} \pm 0.006$
Gumminess(N)	$3.954^{a} \pm 5.24$	$3.863^{a} \pm 2.15$	$2.438^{b} \pm 0.077$	$3.046^{ab} \pm 0.402$
Chewiness (N)	$3.566^{a} \pm 4.91$	$2.615^{a} \pm 3.820$	$2.111^{a} \pm 0.111$	$2.345^{a} \pm 0.268$
Resilience	$0.159^{a} \pm 0.039$	$0.116^{a} \pm 0.039$	$0.094^{a} \pm 0.002$	$0.106^{a} \pm 0.007$
Sensory characteristics				
Appearance	$8.125^{a} \pm 0.619$	$7.063^{b} \pm 0.998$	$7.063^{b} \pm 0.772$	$7.500^{ab} \pm 0.516$
Smell/Aroma	$8.438^{a} \pm 0.512$	$6.813^{b} \pm 0.834$	$7.125^{b} \pm 0.957$	$7.563^{b} \pm 0.814$
Taste	$8.625^{a} \pm 0.500$	$7.500^{b} \pm 0.516$	$6.000^{c} \pm 1.265$	$7.500^{b} \pm 0.516$
Texture/Mouth Feel	$7.625^{a} \pm 0.500$	$7.188^{a} \pm 0.750$	$6.250^{b} \pm 1.183$	$7.875^{a} \pm 0.885$
Colour	$8.500^{a} \pm 0.516$	$8.375^{a} \pm 0.500$	$7.938^{ab} \pm 0.680$	$8.250^{ab} \pm 0.447$
Overall Opinion	$8.313^{a} \pm 0.479$	$7.313^{a} \pm 0.479$	$6.688^{b} \pm 0.873$	$8.000^{a} \pm 0.816$

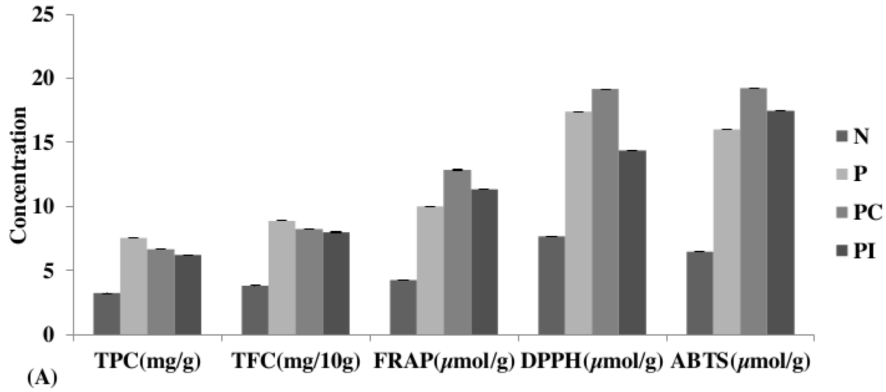
5.3.2. Nutritional Composition, Photochemical, and to meet daily demand

The result of macro and micronutrients was mentioned in Table 5.2. and showed that the intake of 110 gm of supplements provides more protein, iron, calcium fat, and fiber than the market-available product. The result showed statistically significant differences between the three samples ($p<0.05$). The grouping of Tukey's test indicates whether there is any significant effect in the samples, as shown in Table 5.2. If the samples are in the same group, they will have no significant impact; if they are in a separate grouping, they will have a significant effect. The all-sample grouping is marked by an alphabetically small letter. Supplement P is higher in protein content than the other three samples. Supplement PC was prepared with soybean and poppy seed in additional quantities, making them enriched sources of protein and calcium. Supplement PC gives more energy (449.228 Kcal) and is considered a good source of fiber (3.843 gm). This supplement maintained a proper balance of calcium and phosphorus ratio (65:87). Protein content was observed less in PI but high than in N. The presence of garden cress seed and lotus rhizomes of iron content increased the iron content (23.77 mg) at high amounts in PI.

The presence of seasonal locally available vegetables in all three samples is the reason for antioxidant enrichment. The amount of Vitamin C (23.065 mg), chlorogenic acid (7.525 μg/gm), and kaempferol (3.073 μg/gm) were high in supplement PI.

The amount of rutin (1038.104 μg/gm) and gallic acid (1.455 μg/gm) were higher in PC than in others. Ferulic acid and apigenin were absent in PC and PI. The increased amount of ferulic acid (40.345 μg/gm), apigenin (123.113 μg/gm), trans-cinnamic acid (92.181 μg/gm), and quercetin (787.749 μg/gm) present in P. Supplement P contains the highest amount of TPC (7.535 mg/gm) and TFC (8.881 mg/10gm). Antioxidant content and antioxidant activity were presented through the bar diagram in Figure 5.1. (A).

The highest antioxidant activity, like ABTS (19.217μmol/g), FRAP (12.854 μmol/g), and DPPH (19.167 μmol/g), were observed in supplement PC. The antioxidant activity score was lower in N (control) than in test supplements (P, PC, and PI). The major phenolic and flavonoid compound identified in poushtic powder was mentioned in Figure 5.1. (B) and it was determined through the HPLC chromatogram method. In an analysis of food, the HPLC technique has been used extensively and is considered a feasible analytical technique (Hussain et al., 2020).



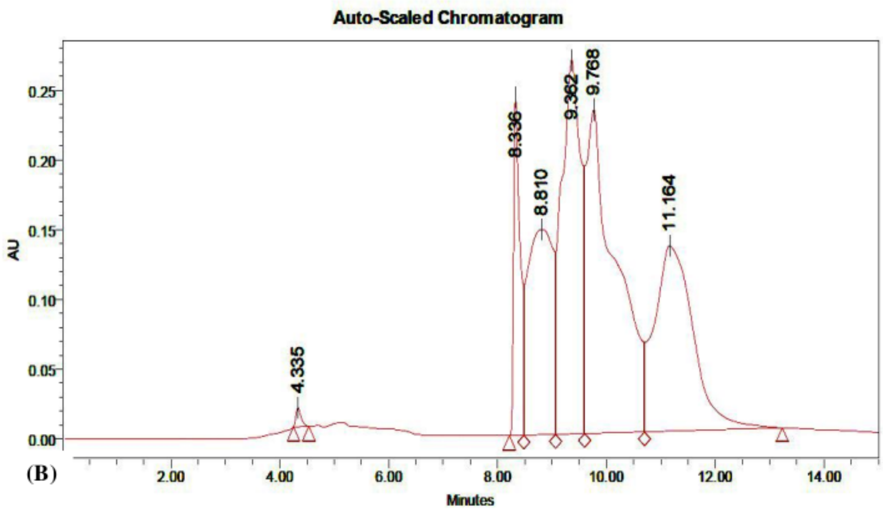


Figure 5.1. (A) Antioxidant content and Antioxidant activity of different Poushtic Powder, the result shows the value of Mean ± SE. (B) HPLC chromatogram of Poushtic Powder: gallic acid (4.335 min), rutin (8.336 min), trans-cinnamic acid (8.810 min), ferulic acid (9.362 min), quercetin (9.768 min), apigenin (11.164 min).

All three supplements- fulfilled the requirements of nutrients and were mentioned briefly in Table 5.3. The per-day protein requirement of 10-12 years old boys and girls are 31.8 gm and 32.8 gm, respectively, as per RDA. The protein of supplement P was estimated as 28.315gm. Supplement P fulfilled 89.04% and 86.33% of the total requirements. The percentage of calcium was not as high as supplement N but satisfactorily met most of the demand. 38.29 %

of calcium requirements are fulfilled by 100 gm PC powder consumption of 10 to 12 years boys.

P, PC, and PI meet the need for phosphorus, fat, dietary fiber, and energy at a more significant percentage than N. 91.4% of iron fulfilled by PI of 16 to 18 years boys' groups.

Table 5.2. The results of macro and micronutrient, polyphenolic compounds by HPLC of different Poushtic Powder show the value of Mean ± SD.

Sample Name	N	P	PC	PI
Amounts (g)	**110**	**110**	**110**	**110**
Macro Nutrient				
Protein (Pro)	16.5^{d}±1.013	28.315^{a}±1.678	26.32^{b}±1.987	25.459^{c}±2.021
Fat (Ft)	1.419^{d}±0.143	8.67^{c}±1.104	15.403^{a}±2.001	9.263^{b}±1.045
Crude fiber (CF)	1.123^{d}±0.356	2.935^{c}±0.056	3.843^{a}±0.245	3.246^{b}±0.156
Carbohydrate (CHO)	88.33^{a}±2.989	52.966^{c}±3.152	51.283^{d}±2.689	53.878^{b}±3.261
Energy (Kcal) (Enrg)	441.54^{b}±5.457	403.318^{c}±5.612	449.228^{a}±6.325	400.853^{d}±5.012
Ash (%)	0.939	0.849	0.864	0.839
Micro Nutrient				
Calcium (mg)	300^{b}±4.125	233.026^{d}±3.985	325.502^{a}±5.612	250.841^{c}±3.025
Phosphorus (mg)	247.5^{d}±3.289	428.103^{b}±4.789	435.415^{a}±6.125	422.453^{c}±5.102
Iron (mg)	5.5^{d}±0.112	16.806^{c}±1.156	18.564^{b}±0.925	23.77^{a}±1.019
polyphenolic compounds				
Vitamin-C (mg/100gm)	22.025^{b}±0.562	ND	ND	23.065^{a}±0.568
Gallic acid (μg/gm)	0.4880^{d}±0.012	0.955^{b}±0.035	1.455^{a}±0.0231	0.926^{c}±0.014
Chlorogenic acid (μg/gm)	7.191^{b}±0.236	ND	4.582^{c}±0.045	7.525^{a}±0.563
Valinic acid (μg/gm)	11.713^{c}±0.452	ND	310.662^{a}±1.023	251.693^{b}±1.025
Rutine (μg/gm)	102.551^{d}±1.253	370.139^{c}±3.025	1038.104^{a}±5.361	546.381^{b}±2.365
Trans-cinamic acid (μg/gm)	14.894^{d}±0.456	92.181^{a}±1.025	44.427^{b}±1.001	34.31^{c}±0.785
Ferulic acid (μg/gm)	2.79^{b}±0.012	40.345^{a}±0.569	ND	ND
Quercetin (μg/gm)	49.607^{d}±1.012	787.749^{a}±2.156	88.803^{c}±1.451	144.316^{b}±2.562
Apigenin (μg/gm)	ND	123.43^{a}±0.987	ND	ND
Kaempferol (μg/gm)	ND	ND	1.972^{b}±0.021	3.073^{a}±0.021

Table 5.3. Fulfill the percentage (%) of Recommended Dietary Allowances for Indians per day at different age groups with different Poushtic Powder.

Sample Name / Nutrients		Boys			Girls					
		10-12 yrs.	**13-15 yrs.**	**16-18 yrs.**	**10-12 yrs.**	**13-15 yrs.**	**16-18 yrs.**	**Women (SW)**	**Man (SW)**	**Child (1-3 yrs.)**
N	**Pro (g)**	51.89	36.75	29.78	50.31	38.19	35.71	36.11	30.44	146.02
	Ft (g)	4.05	2.84	3.55	3.15	4.05	4.05	7.10	5.68	5.68
	CF (g)	2.81	2.81	2.81	2.81	2.81	2.81	3.51	2.81	5.62
	CHO (g)	67.95	67.95	67.95	67.95	67.95	67.95	67.95	67.95	67.95
	Enrg (Kcal)	20.07	15.44	13.30	21.43	18.40	17.66	26.60	20.93	43.72
	Calcium (mg)	38.82	33	31.43	38.82	33	31.43	33	33	66
	Phosphorus (mg)	24.75	24.75	24.75	24.75	24.75	24.75	24.75	24.75	24.75
	Iron (mg)	34.38	25	21.15	19.64	18.33	17.19	18.97	28.95	68.75
P	**Pro (g)**	89.04	63.06	51.11	86.33	65.54	61.29	61.96	52.24	250.58
	Ft (g)	24.77	17.34	21.68	19.27	24.77	24.77	43.35	34.68	34.68
	CF (g)	7.34	7.34	7.34	7.34	7.34	7.34	9.17	7.34	14.68
	CHO (g)	40.74	40.74	40.74	40.74	40.74	40.74	40.74	40.74	40.74
	Enrg (Kcal)	18.33	14.10	12.15	19.58	16.81	16.13	24.30	19.11	39.93
	Calcium (mg)	27.42	23.30	22.19	27.42	23.30	22.19	23.30	23.30	46.61
	Phosphorus (mg)	42.81	42.81	42.81	42.81	42.81	42.81	42.81	42.81	42.81
	Iron (mg)	105.04	76.39	64.64	60.02	56.02	52.52	57.95	88.45	210.08
PC	**Pro (g)**	82.77	58.62	47.51	80.24	60.93	56.97	57.59	48.56	232.92
	Ft (g)	44.01	30.81	38.51	34.23	44.01	44.01	77.02	61.61	61.61
	CF (g)	9.61	9.61	9.61	9.61	9.61	9.61	12.01	9.61	19.22
	CHO (g)	39.45	39.45	39.45	39.45	39.45	39.45	39.45	39.45	39.45
	Enrg (Kcal)	20.42	15.71	13.53	21.81	18.72	17.97	27.06	21.29	44.48
	Calcium (mg)	38.29	32.55	31	38.29	32.55	31	32.55	32.55	65.1
	Phosphorus (mg)	43.54	43.54	43.54	43.54	43.54	43.54	43.54	43.54	43.54
	Iron (mg)	116.03	84.38	71.4	66.3	61.88	58.01	64.01	97.71	232.05
PI	**Pro (g)**	80.06	56.70	45.96	77.62	58.93	55.11	55.71	46.97	225.3
	Ft (g)	26.47	18.53	23.16	20.58	26.47	26.47	46.32	37.05	37.05
	CF (g)	8.12	8.12	8.12	8.12	8.12	8.12	10.14	8.12	16.23
	CHO (g)	41.45	41.45	41.45	41.45	41.45	41.45	41.45	41.45	41.45
	Enrg (Kcal)	18.22	14.02	12.07	19.46	16.70	16.03	24.15	19.00	39.69
	Calcium (mg)	29.51	25.08	23.89	29.51	25.08	23.89	25.08	25.08	50.17
	Phosphorus (mg)	42.25	42.25	42.25	42.25	42.25	42.25	42.25	42.25	42.25
	Iron (mg)	148.56	108.1	91.42	84.89	79.23	74.28	81.97	125.1	297.13

5.3.3. Morphology of Poushtic Powder particles

The morphology of poushtic powders was studied under a scanning electron microscope, and the micrographs were presented in figure 5.2. Obovoidal and spheroidal structured particles have been observed in all powders. In terms of shape, particle size was the largest in the case of N samples and the smallest in PC and PI. In the case of the N sample, several places have large spike-shaped particles. N sample contains a massive number of large particles. The size of the larger spheroidal particle is $31.429 \times 27.143 \mu m$, and the smaller ones are $5.455 \times 4.182 \mu m$. The number of particles is more in P than in PI. The size of large and small particles of P in $15.333 \times 13.333 \mu m$ and $5.385 \times 4.808 \mu m$ respectively, while the size of large and small particles in PI is $25 \times 19.167 \mu m$ and $6.462 \times 6.231 \mu m$ respectively (Figure 5.2.). The size of small and large particles in PC is $5.714 \times 5 \mu m$ and $10.714 \times 7.143 \mu m$ (Figure 5.2.), respectively. The high amount of oil content in sample PC caused adherence of the many small particles with each other.

The hardness of a substance depends on the particle size and numbers of that material. Since the particle size of PC is small and therefore the hardness of this substance is less than that of other samples, and the fineness is much higher, i.e., the solubility of this substance is higher. The large size particle of the sample is present in N, so its hardness is high, and solubility is low. Although the particle size of PI is larger between P and PI, PI has less hardness and more fineness than P due to a smaller number of particles present (Figure 5.2). The size and quantity of the particles are sorted more to less according to N>P>PI>PC, and the hardness (N) of these samples is 37.302>34.802>20.720>15.332, respectively, which TA has analyzed. XT analyzer.

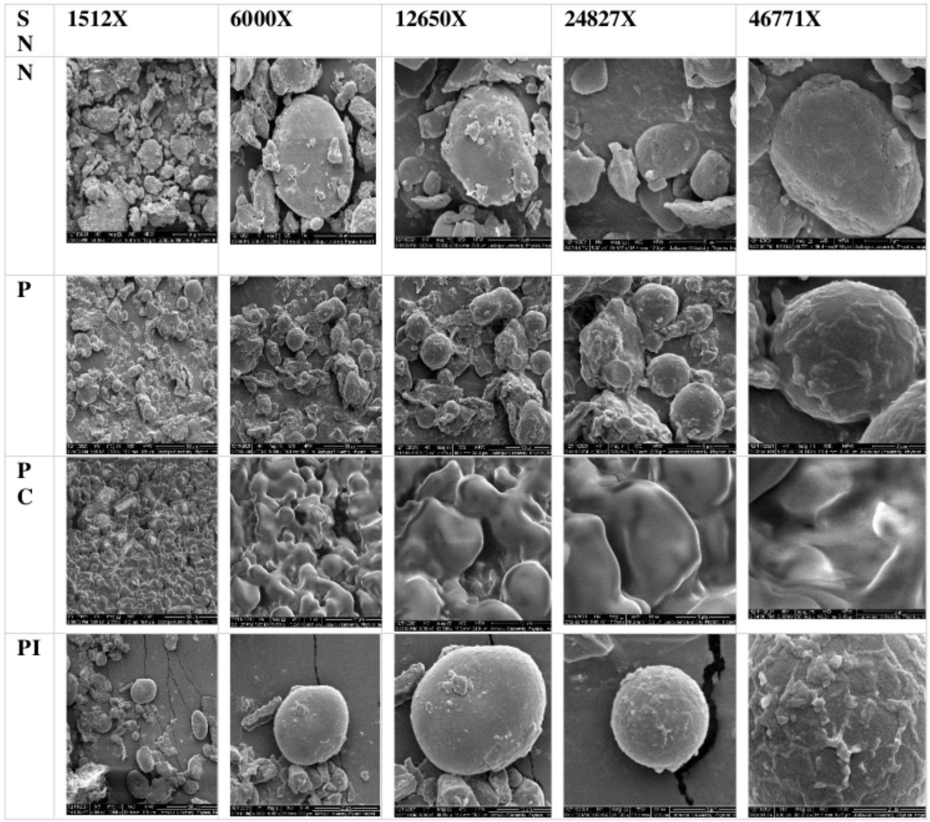


Figure 5.2. Micrographs of Poushtic Powders particles; scale bar as shown at 50 μm, 20 μm, 10 μm, 5 μm, and 2 μm.

5.3.4. Cost Analysis

The cost analysis is shown in Table 5.4. The total production cost was approximately Rs. 144 for P, Rs. 274 for PC, and Rs. 156 for PI per 1 kg powder. The estimated production prices for supplements were lower than the supplementary food Cini Nutri mix (Rs.200/kg) provided by the ICDS center in India, except for PC. The cost of the PC was a little high because of the high price of poppy seed ingredients. The additional benefits of these supplements are that they do not require an additional cost of cooking due to their ready-to-use property.

Table 5.4. Analysis of production cost in rupees (Indian money) of different Poushtic Powder.

Worth (100 gm dry powder)	N	P	PC	PI
Ingredient	20 rupees (market product, price already present)	12.086	25.07	13.259
Grinding or milling		0.5	0.5	0.5
Packaging		0.4	0.4	0.4
Energy		0.3	0.3	0.3
Processing room		0.4	0.4	0.4
Transport cost		0.5	0.5	0.5
Labor to production		0.5	0.5	0.5
Total (In Rupees)	20	14.386	27.37	15.559

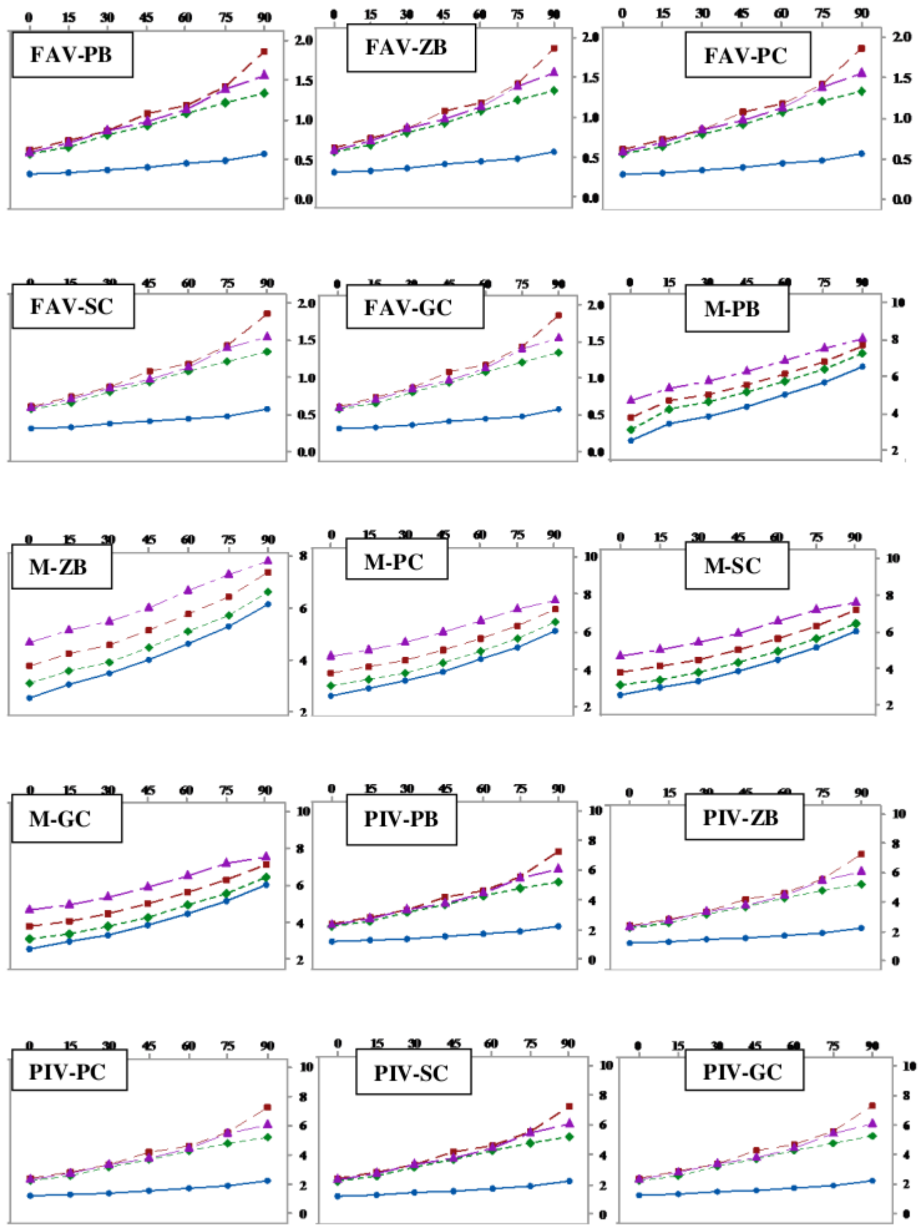
5.3.5. Shelf life

Supplementary foods are very susceptible to spoilage due to chemical reactions such as fat oxidation in the presence of air and mineral pro-oxidants like iron. A large amount of exposed surface induces the process. Microbial damage is also enhanced in water and temperature, causing a cakey-like structure (Sumathi et al., 2007). Figure 5.3. showed the fat acidity value, Moisture content, and peroxide index value of different supplements in a plastic bag, Zip-lock bag, plastic container, steel container, or glass container to varying intervals like 0, 30, 45, 60, 75, and 90 days. Peroxide value is expressed in milliequivalent per peroxide per kilogram of fat (meq/kg) (Erickson, 2007). The peroxide index value of all supplements, including control at every container, was below seven except P. No rancidity was observed according to PIV in N, PC, and PI. On the day of 90, the P supplement was very close to complete rancidity. The fatty acid index value was also an indicator of rancidity. The rancidity developed in P, PC, and PI after 30, 45, and 45 days of storage. Thus, it can be concluded that overall, all supplements can be stored up to 30 days in all types of packaging, in the case of PC and PI storing can be extended up to 45 days without any traits of spoilage. Glass and steel containers are more suitable for sample storage than the other container because FAV, PIV and moisture content less of glass and steel container than another container which is presented in Figure 5.3.

By evaluating the result of the present study, it can be said that the nutritional quality of the three products increased only by combining nutritionally enriched seasonal ingredients without any need for fortification with synthetic nutrients. They were categorized into three types depending on the ratio of addition of elements. P, PC, and PI fulfilled the nutrients recommendation from ICMR of different age groups and also enriched with phytochemicals like gallic acid (1.455 μg/gm), chlorogenic acid (7.525 μg/gm), vitamin-C (23.065 mg/100gm), valinic acid (310.662 μg/gm), routine (1038.104 μg/gm), trans-cinnamic acid (92.181 μg/gm), ferulic acid (40.345 μg/gm), quercetin (787.749 μg/gm), apigenin (123.113 μg/gm) and kaempferol (3.073 μg/gm). Around the world, various types of supplemental food have been developed (Bhavani & Kamini, 1998; Hendrixson et al., 2018; LaGrone et al., 2012; Sumathi et al., 2007). Supplementary food made with locally available and affordable ingredients replenishes nutrient deficiencies of low socio-economic individuals. Supplement PC was rated as the best in terms of sensory evaluation.

From a nutritional point of view supplement, PC was the most favorable among all. Supplementary food prepared in Kenya contained 453.2 kcal energy, 12.2 gm crude protein, 20.8 gm crude fat, 93 mg calcium, and 5.7 mg iron per 100 gm (Kunyanga et al., 2012). Rice-lentil-based RUSF comprised 264 kcal energy, 5.1 gm protein, 14.8 gm fat, 286.0 gm calcium, and 5.905 gm iron per 50 gm (Ahmed et al., 2014).

The supplementary food developed in the present study was higher in protein and iron. Still, it produced less energy than rice lentil-based RUSF and low-cost supplemental foods of Kenya. The cost analysis showed that the price was much lower because of the natural ingredients. After the evaluation of sensory parameters, the three test supplements were accepted by the panelists. Shelf-life studies indicated that they could be stored for up to 30 days in case of P and 45 days in case of PC and PI without showing any positive change in spoilage in all types of packaging (plastic bag, zip-lock, plastic container, steel container, and gas container) at ambient condition. The estimated selling price was also lower than the already available product in the market and did not need extra cooking charges. Many polyphenolic compounds, macro, and micronutrients prevent malnutrition, anemia, calcium deficiency disorder like osteoporosis, and several diseases.



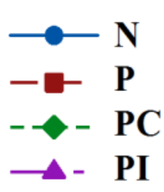


Figure 5.3. Fat acidity value (FAV), moisture content (M), and peroxide index value (PIV) of different storage materials i.e., plastic bag (PB), zip-lock bag (ZB), plastic container (PC), steel container (SC) and glass container (GC) of different Poushtic Powder (N, P, PC, and PI) at 0, 15, 30, 45, 60, 75 and 90 days. All graph "X-axis = Days and Y-axis = Parameter's value".

5.4. Conclusion

The supplementary foods were formulated for vulnerable different age groups from local food ingredients consisting of cereals, pulses, vegetables, seeds, and nuts. Those who cannot afford to buy some expensive supplementary products available in the market can eat this supplemental food due to its advanced quality of nutrition. Poushtic powders prepared in this study can be quickly developed at the village level at a low cost, and that also can be a business opportunity for small-scale entrepreneurs. It is easily consumed in several ways, like diluted in water as a drink, prepared as laddu, semi-solid food dish, etc. Further research is required for clinical trials on different age groups individuals.

Chapter 6

Summary

Currently, traditional food products are in great demand in the market because they are easy to prepare, have high nutritional value, have low processing costs, and do not require any skilled expertise. They can be made quickly, and their concept is easy to know from the elderly at home. As a result, several small industries and entrepreneurship have developed in our society and our country, and there is a possibility of developing these traditional food products in the future. As a result, we will regain the loss of traditional food products in our diet. At the same time, our society and our country are becoming more economically vital through the development of these small industries. Through this study, how to develop traditional food products, what nutrients are there, and how to analyze the nutritional quality has been discussed in detail. The findings of this study are:

I Seasonal vegetable incorporation increases the antioxidants in a traditional food product. This study has shown that the antioxidant profile will increase if the vegetable is added while keeping the number of vegetables fixed during incorporation. Adding different types of vegetable changes their nutritional profile, antioxidant profile, texture profile, and storage profile and shows how these profiles interact.

II What factors are needed while making traditional food products like nuggets, and how those factors are involved in making nuggets. Optimum values of production factors have been investigated. The main factors needed while making the nuggets are the amount of water incorporated in the batter, the amount of air trapped in the batter, and the drying process with drying temperature. Nuggets' nutritional and physical characteristics have been analyzed in this study.

III Nutritional profile, antioxidant profile, polyphenolic compounds, texture, structure, color, and other organoleptic properties also change a lot while making traditional food products using different drying techniques.

IV Advanced computational chemistry and machine learning algorithm tools have been applied to improve our understanding of drying and extraction processes.

V Formulating supplementary food products for a vulnerable group with easily available foods using multi-mixing processes. The nutritional quality, organoleptic properties, storage profile, and market value of the supplementary food have been analyzed.

It is important to note that the study deals with only three traditional food products, out of which one is an entirely traditional food product, and the other two are traditional along with waste material in our agricultural land and vulnerable people's food in society. Three supplementary food products are made from readily available and wasted food. More than fifty traditional foods are available in our country. Many supplementary foods are marketed at high prices, which can only be purchased and consumed by middle, upper-middle, and upper-class people.

Additionally, problems associated with scaling up the ultrasound-assisted extraction process should be resolved for border acceptance of the process in industrial applications. Furthermore, opportunities exist to increase process efficiency by combining novel technologies such as microwaves, vacuum, and ultrasound. Future research should address these limitations to achieve large-scale industrial adaptation of this technology.

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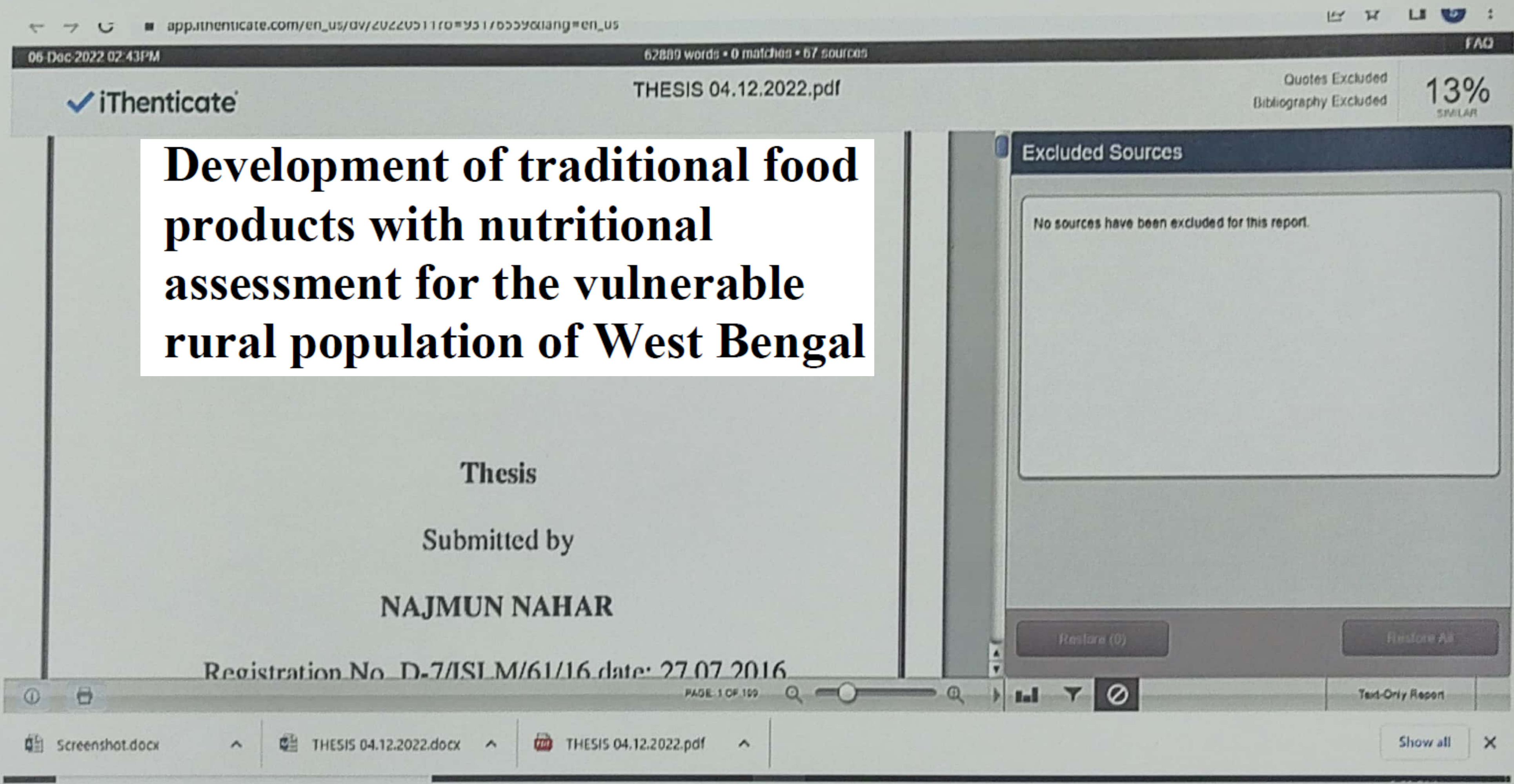

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