PRODUCT CHARACTERIZATION OF SELECTED DEHYDRATED VEGETABLES (CARROTS, TURKEY BERRIES, AMARANTH LEAVES AND EGGPLANT LEAVES)

This thesis is submitted to the University of Ghana, Legon, in partial fulfilment of the requirement for the award of PHD in FOOD SCIENCE Degree

by

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DECLARATION

I affirm that apart from the references to studies, which I have cited, this study, "**PRODUCT CHARACTERIZATION OF SELECTED DEHYDRATED VEGETABLES (CARROTS, TURKEY BERRIES, AMARANTH LEAVES AND EGGPLANT LEAVES)**" was carried out by me in the Department of Nutrition and Food Science, School of Biological Sciences, University of Ghana, Legon. No part of the study has been submitted for the award of a degree elsewhere.

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ABSTRACT

Sub-Saharan Africa grapples with cyclical abundance and scarcity in agricultural produce due to seasonal weather patterns, leading to substantial post-harvest losses. In Ghana, approximately 40-50% of harvested crops go to waste, emphasizing the urgent need to enhance post-harvest processes, particularly for fruits and vegetables, aligning with the UN's strategic development goal 2 (SDG 2) for improved nutrition and food security. This study investigated the product characterics of dehydrated vegetables (amaranth leaves, eggplant leaves, carrots, and turkey berries). The research studied the impact of pre-treatments such as blanching and various drying methods (convection oven drying, solar drying, and freeze-drying) on different aspects of these vegetables. Steam blanching of carrots, amaranth leaves and egg plants for 5 minutes before drying stabilized the green colour (a*-values) of the dehydrated samples. On the other hand, hot water blanching of turkey berries for 1 or 3 minutes showed the least colour change from the control after drying. Drying was generally faster in blanched vegetables compared to unblanched vegetables. Drying kinetics varied and established thin-layer drying models, specifically, Page, Wang and Singh, and Lewis were identified as suitable for describing the drying characteristics. The study determined the phytochemical and nutraceutical composition of the dehydrated vegetables, to understand the influence of blanching and drying methods. This involved total phenolic content (Folin-Ciocalteu), total flavonoid content (aluminium chloride colorimetric assay), antioxidant activity (DPPH radical scavenging activity) using the UV Spectrophotometer. Lutein, β-carotene, catechins, chlorogenic acids and quercetin concentrations were measured using HPLC. Drying methods significantly ($p<0.05$) decreased the phytochemical content of the vegetables in this study. Blanching caused a reduction in the phytochemical content compared with the unblanched samples. Freeze-drying retained the highest amount of originally contained total flavonoids, DPPH inhibition, and total phenolics. The nutritional and anti-nutritional compositions were examined, emphasizing the impact of drying methods on proximate analysis, mineral content, and anti-nutrient levels. The dehydrated vegetables exhibited low moisture content and water activity, as well as low fat and crude fibre. The dehydrated vegetables contained essential minerals such as iron, zinc, potassium, calcium, magnesium, and manganese. Blanching was shown to reduce anti-nutrient levels, enhancing overall nutritional quality. Furthermore, the study assessed the sensory characterization and nutritional contribution of a composite vegetable powder from the selected vegetables. This highlighted an optimum formulation of approximately 33% amaranth leaves, 23% carrots, 27% turkey berries, and 17% eggplant leaves, through sensory evaluation. The optimum formulation (composite powder) was described as olive green, dry, gritty and herby. Lastly, the physico-chemical properties, microstructure, and storage stability of the composite vegetable powder were determined. The powder had a slight greenish-yellow colour with low water activity (a_w) which ensures stability during storage. The composite powder showed favourable characteristics for convenient use in food preparations. Overall, these findings provide comprehensive insights into pre-treatment methods, preserving nutritional and sensory qualities, and developing composite vegetable powders to address nutritional deficiencies and enhance food preservation techniques.

DEDICATION

To my husband, Dr. James Freeman Duah-Bisiw, and kids, Felix, James, Julia and Manuel. I love you very much and thank you for the support throughout my PhD studies. I also dedicate it to my Supervisory Committee, the Ofori-Appiah and Duah-Bisiw families, and friends who cared and supported my education. The Almighty God bless and keep you. A special dedication goes to my parents who have been an inspiration for me.

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LIST OF ACRONYMS

AOAC	Association of Official Analytical Chemists International
CVP	Composite Vegetable Powder
NCD	Non-Communicable Disease
RDA	Recommended Dietary Allowance
SDG	Sustainable Development Goal
SEM	Scanning Electron Microscope
UNICEF	United Nations Children's Fund
USA	United States of America
USDA	United States Department of Agriculture
WHO	World Health Organization

CHAPTER ONE

1.0 INTRODUCTION

In sub-Saharan Africa seasonal cycles of heavy rains, followed by droughts result in cycles of gluts and then scarcity of agricultural produce leading to high post-harvest losses. This is exacerbated by poor post-harvest management practices. It is estimated that nearly 40-50% of the crops harvested in Ghana never reach the consumer due to spoilage and waste. Efforts should be directed towards enhancing the effectiveness of post-harvest handling, preservation, and/or value addition of agricultural produce, especially fruits and vegetables. This is essential for maximizing their nutritional benefits and contributing to food security, aligning with the United Nations' strategic development goal 2 (SDG 2) (Sugri *et al.,* 2021). Fruits and vegetables are very important sources of vitamins and minerals, and therefore their scarcity will have impacts on micronutrient availability in the diet. The World Health Organization (WHO) has classified Vitamin A deficiency as a significant public health problem, affecting about one-third of children aged 6-59 months, with the highest rates in Sub-Saharan Africa (48%) and South Asia (44%). It is the leading cause of preventable childhood blindness (Song *et al.,* 2023; UNICEF, 2023). It is therefore recommended that eating at least five portions of fruits and vegetables (a recommended minimum of 400 g) per day will help reduce the risk of non-communicable diseases (NCDs) such diabetes, cancers, cardiovascular diseases and chronic respiratory diseases as well as ensure an adequate daily intake of dietary fibre (Keller & Tukuitonga, 2005; Gebremedhin & Bekele, 2021). However, studies showed that current consumption of fruits and vegetables are below the recommended amounts in many Sub-Saharan countries (Micha *et al.,* 2015; Mensah *et al.*, 2021). For example, in Ghana, a typical diet is predominantly starch-based, consisting mostly of roots and cereals but usually low in fruits and vegetables, and therefore deficient in important micronutrients, particularly iron and vitamin A (Atuna *et al.,* 2022).

Vegetables can be categorised according to the parts eaten and are noted for the maintenance of health and prevention of diseases (Adeniyi *et al.*, 2012). They are rich sources of macro and micro-nutrients but also possess bioactive compounds with antioxidant potential (Dhandevi and Rajesh, 2015; Javid *et al.*, 2019). Carrots and other vegetables such as leaves from amaranth, jute, cowpea, pumpkin, cocoyam, cassava, and eggplant are not only rich in macro- and micronutrients, but they are also inexpensive and affordable to many low-income consumers. The cultivation of these vegetables not only acts as a means of income for farmers but also proves advantageous due to their typically brief growth cycle, minimal investment needs, and substantial yield (Kamga *et al.*, 2013).

Carrots *(Daucus carota)*, amaranth leaves *(Amaranthus cruentus*), locally known as *"aleefu'* and eggplant leaves (*Solanum macrocarpon*), also known as '*gboma*' are all easily cultivated and fast-growing. They have high yield potential and are excellent sources of carotene, vitamin C, iron, folate, calcium, and other micronutrients (Uusiku *et al.*, 2010; Kumar *et al.,* 2020). Carrots are one of the most preferred vegetables due to their versatility in culinary uses. They are a good source of β- carotene, fibre, vitamins, and antioxidants (Krivokapić *et al.,* 2020; Singh *et al.,* 2021). In addition, they contain two essential carotenoids- lutein and zeaxanthin that play crucial roles in colour vision development in children and help prevent age-related macular degeneration in adults (Eggersdorfer & Wyss, 2018; Mrowicka *et al.,* 2022). Turkey berry (*Solanum torvum*) is another popular vegetable in the dietary habits of Ghanaians. The fruits have been reported to contain phyto-constituents such as steroid glycosides; non-volatile oils; vitamin B group; vitamin C; iron salts: saponins, and steroidal alkaloids (Akoto *et al.,* 2015).

1.1 Problem Statement and Justification

Green leafy vegetables, despite their abundance and immense dietary and health potential, remain highly underutilized in many regions (Abbey & Timpo, 1999; Atuna et al., 2022). A significant barrier to their utilization is their high perishability, which leads to postharvest losses ranging from 40–75% of harvests (Affognon et al., 2015; Kitinoja & Kader, 2015). These losses are exacerbated by limited knowledge among value chain actors regarding appropriate postharvest treatments and preservation technologies that could extend shelf life and maintain quality (Kitinoja et al., 2011; El-Ramady et al., 2015; Gogo et al., 2018; Etefa et al., 2022). The consequences of such losses are multifaceted: they threaten food security, limit the availability of nutrient-dense foods, and contribute to the persistent issue of micronutrient deficiencies or "hidden hunger," particularly in vulnerable populations. The absence of effective preservation strategies for vegetables further undermines their potential to be a reliable year-round source of nutrition and culinary versatility. Drying, an age-old and cost-effective preservation technology, offers a promising solution to this challenge. By reducing water activity, drying minimizes biochemical and microbiological deterioration, thereby extending the shelf life of perishable crops. Dehydrated vegetables also meet consumer demands for convenience and versatility in culinary applications, as demonstrated by sensory studies on dehydrated tomato (Owureku-Asare et al., 2017), onion (Aparna et al., 2021), and okra (Kwadzo et al., 2022). However, research on applying dehydration technology to extend the shelf life of popularly consumed green leafy vegetables remains limited. Addressing this gap is critical to reducing postharvest losses, enhancing food availability throughout the year, and combating malnutrition. This study, therefore, seeks to explore dehydration as a preservation method for selected widely consumed vegetables, aiming to produce shelf-stable, high-quality ingredients that cater to both consumer preferences and nutritional needs.

1.2 Main Objective

The main objective was to formulate a composite dehydrated vegetable powder consisting of carrots, turkey berries, amaranth leaves and eggplant leaves with an adequate vitamin and mineral profile to deliver the minimum nutritional requirements of children (2-3years) and adults.

1.3 Specific Objectives

The specific objectives were to:

1. Identify appropriate pre-treatments that maintain the colour of selected vegetables during dehydration and determine the associated drying characteristics.
2. Assess the effect of varied drying technologies on the functional, physicochemical, and nutraceutical properties of selected vegetables.
3. Develop a composite product of the dehydrated vegetables with a defined vitamin and mineral profile and assess its characteristics.
4. Determine the storage stability of the composite product.

CHAPTER TWO

LITERATURE REVIEW

2.1 Vegetables

Vegetables, often tender and edible parts of plants, form an integral component of global diets, either as main meals or as supplements (Jia et al., 2022). With over ten thousand plant species consumed as vegetables, only slightly more than 50 are recognized commercially, highlighting a vast untapped potential for dietary diversity (Tubb & Seba, 2021). The inclusion of vegetables in daily diets not only enriches meals but also contributes to culinary diversity, as noted by Sarkar et al. (2020). Beyond their culinary value, vegetables are a rich source of secondary metabolites that confer therapeutic benefits, offering significant health protection against chronic and degenerative diseases (Rana et al., 2022). Malnutrition remains a critical public health concern in many developing countries, particularly in Sub-Saharan Africa, where diets are predominantly starch-based and lack sufficient nutrient diversity (Singh & Mayanglambam, 2015; Olusanya et al., 2023). Increasing vegetable consumption in this region represents a strategic approach to combating malnutrition by enhancing dietary quality. Leafy vegetables, in particular, are exceptional sources of essential vitamins, minerals, and bioactive compounds that enhance antioxidant activity, improve dietary flavour profiles, and address nutritional deficiencies (Uusiku et al., 2010). Vegetables can be categorized through various approaches, including botany, life cycle, edible parts, family classification, and sensitivity to temperature (Tsao et al., 2005). Among these, classification based on edible portions—such as roots, leaves, and fruits—is the most widely used.

For example, carrots and potatoes are classified as roots due to their similarity to tree roots and their role in nutrient storage (Radovich, 2011). Furthermore, Maina and Mwangi (2008) highlighted the distinction between indigenous and introduced vegetables in Africa. Indigenous vegetables, native to tropical Africa, have evolved within local ecosystems and are often well-adapted to the region's climate and growing conditions. In contrast, introduced vegetables, adopted over generations, have become integral to local diets but require more external inputs for successful cultivation (Grubben et al., 2014). The therapeutic and nutritional potential of vegetables underscores their pivotal role in addressing global health and nutrition challenges. However, their underutilization—particularly among indigenous species—signals an opportunity to explore and promote these vegetables further. Such efforts could contribute to enhanced food security, sustainable agricultural practices, and improved public health outcomes, especially in regions vulnerable to malnutrition and dietary monotony.

2.1.1 Solanum macrocarpon

The African eggplant, also known as *gboma* in the local language, is a vegetable from the *Solanaceae* family, scientifically referred to as *Solanum macrocarpon*. Originating in West Africa, *Solanum macrocarpon* is a tropical plant with over 1000 global species, around 100 of which are indigenous to Africa, particularly widespread in Central and East Africa. Every part of the plant is utilized for food, with the fruits being edible raw or cooked, and the leaves commonly incorporated into stews and vegetable soups.

Figure 0.1: Eggplant leaves (Solanum macrocarpon)

Source: Mahbou *et al.* (2022)

In Ghana, *Solanum macrocarpon* roots are employed to treat bronchitis, asthma, alleviate itches, body aches, and wounds (Bonsu *et al.*, 2002). Rich in vitamins such as pro-vitamin A carotenoids, niacin, thiamine, riboflavin, ascorbic acid, calciferol, and tocopherol, *Solanum macrocarpon* boasts significant nutritional value. Specifically, it is abundant in retinol (42 mg/100 g), ascorbic acid (2.5 mg/100 g), thiamin (0.032 mg/100 g), iron (31.41 mg/100 g), and riboflavin (0.033 mg/100 g) (Usunobun & Igwe, 2016). These findings align with Dougnon *et al.*'s (2012) earlier report, which indicated high levels of vitamin A (3530 mg/kg), iron (251 mg/kg), zinc (220 mg/kg), and 92.58% ash in *Solanum macrocarpon*.

2.1.2 Amaranthus cruentus

Amaranthus, a well-known leafy green vegetable found in tropical and subtropical regions, especially in Africa, is not only recognized for its vegetative qualities but also for producing nutritious grains. *Amaranthus cruentus*, one of three cultivated Amaranthus species alongside *Amaranthus hypochondriacus* and *Amaranthus caudatus*, is notable for its clusters of pink flowers. Referred to by various names in different languages, it is known as 'Aleefu' among the Ewe people in Ghana and blood amaranth, red amaranth, and purple amaranth in English. This versatile plant is traditionally used to address health concerns, treating constipation, anaemia, and kidney complaints, and serving as a laxative for infants when boiled with honey. *Amaranthus cruentus* is a rich source of carotene (5716 µg/100 g), iron (8.9 mg/100 g), and ascorbic acid (64 mg/100 g) (Alegbejo, 2013). It also exhibits substantial content of carbohydrates (27.7%), fiber (22.9%), and ash (18.8%) (Khanam & Oba, 2020). This vegetable is a valuable reservoir of vitamins and amino acids, including A, B6, C, and B12, along with essential amino acids like lysine, phenylalanine, leucine, and arginine (Khanam & Oba, 2020). With carotenoids, flavonoids, and phenolic acids contributing to its high antioxidant activity, Amaranthus is known for more than just its nutritional value (Venskutonis & Kraujalis, 2013). *Amaranthus cruentus* can be prepared by cooking the delicate stems and leaves in oil or frying, mixed with meat, fish, groundnuts, and palm oil. This dish is commonly paired with cereals or tubers. Additionally, the leaves can be ground into a powder, providing a seasoning option, particularly useful for preservation during the dry season (Grubbens & Denton, 2004). Recognizing the perishable nature of the leaves, their conversion into powder adds value and facilitates preservation or processing (Singh *et al.*, 2014). Numerous studies have explored the composition, processing techniques, and applications of both amaranth seeds and leaves (Venskutonis & Kraujalis, 2013).

Figure 0.2: An image of Amaranthus cruentus on the farm.

Source: Field pictures

2.1.3 *Daucus carota*

Carrots (*Daucus carota)* are root vegetables of immense nutritional and medical importance. It belongs to the family *Apiaceae* and is reported to have originally been cultivated in the lands of South-Eastern Asia. Carrots are excellent sources of vitamins and proteins. Yellow and orange carrots contain lutein, which helps in the development of macular pigments that are essential for optimal eye function (Prasad, 2015). According to Steinmetz and Potter (1996) orange vegetables like carrots are rich in beta-carotene. Furthermore, lycopene found in carrots has a powerful singlet oxygen-scavenging activity. Additionally, carrots contain 0.2 to 0.7% fat, 9.58 to 10.6% carbohydrates, 0.6 to 2.9% fibre, and 5.4 to 7.5% sugars (Prasad, 2015). Carrots are associated with a lowered risk of cancer and heart disease, as well as enhanced vision, owing to their abundant content of vitamin A, carotenoids, and fibre (Harling, 2017). They are beneficial to the teeth and help to maintain the skin (Singh *et al.*, 2021). Carrots can be eaten in their raw form, cooked, or juiced, and are used in diverse recipes like salads, pastries, soups, and stews. Carrots serve as a foundational ingredient for various culinary creations, including carrot juice, carrot puree, and sauces (Harling, 2017).

Figure 0.3: A field picture of a carrot farm

2.1.4 Turkey berry (*Solanum torvum*)

Turkey berry, also known as pea eggplant or devil's fig, is a bushy perennial plant. In Ghana, it grows naturally in the wild and has long been used for food. It is typically included in soups made with palm fruits (Ogah, 2015). Turkey berries can be used in cooking many dishes such as soups, curries, dals, and also consumed as the dried berry seasoned with salt and spices (Adonu *et al.*, 2018). They have a piquant, bitter taste and are often used as eggplant substitutes.

Regarding nutrients, phytochemicals, and medicinal properties, turkey berries are vegetables with a wide range of advantages (Hernández-Rodríguez *et al.,* 2018). In addition to various uses, the chemical components of this plant have been employed as antioxidants, anti-platelet aggression agents and anti-microbial agents (Weremfo *et al.,* 2022). They are also recognized as being rich sources of phenolic acids, catechins, anthocyanins and proanthocyanins, with the primary phenolic components being phenolic acids, flavonoids, stilbenes, hydrolysable and condensed tannins.

Figure 0.4: Turkey berry (Solanum torvum)

2.2 Minimizing Post-harvest losses

Postharvest losses of vegetables in Ghana pose significant challenges to food security, economic sustainability, and livelihoods (Agbenorhevi & Oduro, 2016). These losses occur at various stages of the supply chain, from harvesting and handling to transportation and storage (Asibuo & Yiridoe, 2019). High moisture contents in fruits and vegetables, inadequate infrastructure, and poor handling practices contribute to losses (Maisnam *et al.*, 2017). To address this issue, several strategies such as value addition and processing, improved harvesting and handling processes, packaging and postharvest treatments among others, have been proposed to minimize postharvest losses and improve the overall efficiency of vegetable production and distribution in the country (Sakyi & Amoah, 2017; FAO, 2019).

2.3 Drying

One effective approach to controlling post-harvest losses in vegetables is transforming fresh produce into low-moisture products, such as vegetable powders, through drying (Tiwari & O'Donnell, 2013; Sidhu et al., 2018). This process significantly enhances the convenience, storage stability, and versatility of vegetables, making them more accessible for consumption and use in diverse food applications (Sun et al., 2019; Salehi et al., 2019). Vegetable powders retain essential nutrients, natural flavours, and bioactive compounds, offering a sustainable solution to reducing food waste, extending shelf life, and improving nutritional availability (Gupta & Prakash, 2011; Egbi et al., 2018; Owade et al., 2020).

Drying remains the most widely used and economical method of food preservation, particularly in regions where cold storage facilities are limited or unavailable. Its affordability and effectiveness make it an ideal solution for reducing post-harvest losses in developing countries. By lowering the water activity of vegetables, drying inhibits microbial growth and enzymatic activity, thereby extending the product’s shelf life and preserving its quality. The dried form also allows for easier transportation and integration into processed food products, addressing consumer demands for convenience and functionality.

The drying process involves the transfer of moisture from the interior of the material to its surface, where it evaporates into the surrounding air. This mass transfer is facilitated through three primary mechanisms: diffusion, capillarity, and advection (Mujumdar, 2006; Mujumdar & Law, 2010). Diffusion plays a key role in moving water molecules from regions of high moisture concentration to lower concentration within the vegetable. Capillarity, influenced by surface tension, moves water through narrow pores and spaces within the material. Advection, driven by airflow and temperature gradients, aids in the removal of surface moisture. Together, these mechanisms ensure effective moisture reduction, making the drying process a cornerstone of post-harvest preservation technologies.

The use of drying to produce vegetable powders not only enhances the shelf life of these highly perishable products but also contributes to addressing global challenges related to food security and waste management. This preservation method has gained attention for its ability to maintain nutritional integrity while ensuring the year-round availability of vegetables, even in resource-constrained environments.

2.3.1 Diffusion

Diffusion is the movement of molecules from an area of higher concentration to an area of lower concentration. In the context of drying, it refers to the movement of water molecules within a solid material towards the surface (Perre, 2014). During the drying process, as the surface of the material becomes drier, moisture from the interior migrates towards the surface (Roger *et al.*, 2018). Studies by Akonor & Amankwah, (2012), Onwude *et al.* (2016) and Inyang *et al.* (2018) described the movement of water during drying of vegetables as being by diffusion. The rate of diffusion depends on the material's properties, such as porosity, permeability, and diffusion coefficient (Iqbal *et al.,* 2019; González-Pérez *et al.*, 2021).

2.3.2 Capillarity

Capillarity involves the movement of liquid in porous materials due to the capillary action, which is the ability of a liquid to flow in narrow spaces without the assistance of, or against, external forces like gravity (Lade Jr, 2018). In porous materials, capillary forces aid in the movement of moisture through small channels or pores towards the surface for evaporation (Iranshahi, *et al.,* 2022). Rojas *et al.* (2019) demonstrated that water can be transported by capillarity in pumpkin xylem vessels during drying. This capillary action facilitates the movement of moisture towards the material's surface, promoting faster drying.

2.3.3 Advection

Advection refers to the bulk movement of moist air across the material's surface. It plays a crucial role in removing evaporated water from the material surface. Convective drying processes rely on advection to carry away the moisture evaporated from the material (Iranshahi, *et al.,* 2022). Studies by Srikiatden & Roberts, (2007); Onwude *et al.* (2016) and Inyang *et al.* (2018) emphasize the role of advection in removing evaporated water from the surface of fruits and vegetables during the drying process to extend the shelf life of the products.

2.4 Drying techniques

The drying process is pivotal in preserving a variety of agricultural products and foods. Drying methods can be categorized into natural and artificial drying methods depending on the source of energy employed. These various methods of drying have associated advantages and disadvantages. According to Maisnam *et al.* (2017), Calín-Sánchez *et al.* (2020) and Petikirige *et al.* (2020), artificial methods exemplified by techniques like spray drying, vacuum drying, hot air or freeze drying, boast efficiency and speed. They emphasized their capability to remove substantial moisture while allowing meticulous management of variables such as temperature, drying air flux, and drying time. This precise control facilitates a standardized and controlled drying process, suitable for a broader range of products. Nevertheless, artificial methods come with drawbacks, including high energy consumption, potential for quality loss due to rapid drying, and significant initial investment costs.

Natural drying methods harness solar or ambient air energy, offering low energy costs and minimal environmental impact (Gallali *et al.,* 2000). Particularly suitable for products like fruits and vegetables, these methods, however, hinge on unpredictable weather conditions, leading to extended drying times and limited control over variables such as temperature and humidity (Gallali, *et al.,* 2000; Owureku-Asare *et al.*, 2018).

The effects of these methods are discernible in the final products. Natural drying imparts distinct flavours and characteristics (Calín-Sánchez *et al.*, 2020; Petikirige *et al.,* 2020), due to its unhurried process, while artificial drying, with its controlled environment, ensures consistency but may sacrifice some nuanced qualities found in naturally dried products (Berk, 2018).

2.4.1 Solar drying

The use of solar energy for drying agricultural produce is an ancient preservation technique that remains relevant today. Solar drying can be categorized into two methods: open sun drying, where produce is exposed directly to sunlight, and solar drying, which involves trapping solar energy in an enclosed chamber to dry produce indirectly (Owureku-Asare et al., 2018). While open sun drying is simple and widely practiced, it is prone to contamination from dust, rain, and animals, as well as uneven or excessive drying, which can compromise product quality. In contrast, solar drying offers significant improvements by providing an enclosed environment that protects food materials from contaminants, making it especially suitable for drying vegetables in tropical regions (Rwubatse et al., 2014; Singh et al., 2014; Romuli et al., 2019; Skåra et al., 2022).

Numerous studies have highlighted the advantages of solar drying over traditional open sun drying. Rwubatse et al. (2014) evaluated a solar dryer designed for fruits and vegetables in Rwanda, demonstrating its potential for improved drying efficiency and product quality. Similarly, Singh et al. (2014) reviewed various solar drying methods, including conventional solar dryers and cloth-shade techniques, and emphasized their sustainability and cost-effectiveness due to reliance on abundant, renewable solar energy. However, traditional solar drying methods still face limitations, such as vulnerability to environmental conditions and inconsistent drying rates, which can impact the sensory and nutritional attributes of dried products, particularly fruits and vegetables.

Advancements in solar drying technology, such as dryers incorporating natural or forced convection, have shown promise in addressing these challenges. Romuli et al. (2019) analyzed and compared the performance of natural and forced convection solar dryers for fruits and vegetables, demonstrating effective moisture removal and improved drying rates. These improved systems offer consistent drying processes, better control over product quality, and reduced environmental impact, making them viable solutions for preserving perishable produce in resource-limited settings.

Despite these benefits, solar drying remains dependent on weather conditions, which can affect drying speed and consistency. Additionally, optimal results require careful monitoring and management of drying parameters, such as temperature and airflow. As a result, while solar drying is a sustainable and efficient preservation method, its implementation must account for specific regional and operational challenges to maximize its potential for reducing post-harvest losses and ensuring product quality.

2.4.2 Freeze drying

Freeze drying, also known as lyophilization, is a process in which water in the form of ice under low pressure is removed from the food material by sublimation (Nowak & Jakubczyk, 2020). This method is widely used for the stabilization of high-quality food, biological materials, and pharmaceuticals, such as proteins, vaccines, bacteria, and mammal cells. The quality of the dried product (biological, nutritional, and organoleptic properties) is retained (Ochmian *et al.,* 2020). Freeze-dried vegetables exhibit good rehydration characteristics, minimal shrinkage, and little changes in chemical composition and colour (Oyinloye & Yoon, 2020; Shonte *et al.*, 2020, Liu *et al.,* 2022). The solid state of water during freeze-drying protects the primary structure and the shape of the products with minimal volume reduction, allowing for maximal nutrient and bioactive compound retention (Shonte *et al.,* 2020). The process also results in minimal color deterioration and the highest rehydration ratio compared to air-dried materials (Liu *et al.,* 2022). Therefore, freeze-drying is a suitable method for preserving the quality of vegetables, as it retains their original characteristics and minimizes changes in chemical composition and colour. Application of freeze drying to tomatoes, ginger, garlic, coffee and tea, have been reported to produce high value products due to maximum retention of chemical constituents (Ding *et al.,* 2012; Gümüşay Özlem *et al*, 2015; Fante & Noreña, 2015; Batta *et al.*, 2020). Freeze dried persimmon chips were reported to have the highest rehydration ratios with minimal shrinkage when compared to hot air and combined hot air -microwave dried persimmons (Jia *et al.*, 2019). Freeze-drying, while advantageous for preserving the quality of food, has a significant drawback which is the slow process, with an average cycle of 24+ hours, making it time-consuming and energy-intensive (Waghmare *et al.*, 2022).

2.4.3 Microwave drying

Microwave drying is a process that utilizes microwaves to penetrate moist materials, where the microwaves are converted into heat, causing the moisture to turn into vapour and be removed from the material (Khodifad & Dhamsaniya, 2020). The process is similar to heating food in a microwave oven, with the microwaves ceasing when the drying machine or microwave oven is switched off. Microwave drying is also used in food drying, where the microwaves penetrate the material and are converted to heat, allowing for the removal of moisture (Kumar & Karim, 2019). Microwave drying is quicker and more energy-efficient than traditional methods such as sun drying and convection ovens, making it an ideal solution for evaporating water from various products (Indiarto *et al.*, 2021).

Microwave drying has recently become quite popular, and has been used in the dehydration of various fruits and vegetables at lower temperatures and reduced times (Gamboa-Santos & Campañone, 2019). The end-products are usually of high quality, but the technique is associated with high cost and energy (Guiné, 2018). The usage of microwave-assisted procedures is advantageous for commodities with high sugar concentrations to increase quality of dehydrated products (Hasan *et al.*, 2019).

Changrue *et al.* (2006), Gamboa-Santos & Campañone (2019) and Keser *et al.,* (2020) reported on the use of microwave drying for carrots, potatoes, green beans and strawberries. They highlighted the advantages of the drying process, such as shorter drying times and better retention of nutrients in the dehydrated products.

2.4.4 Convective Drying

Convective drying by hot air is a widely used method for dehydrating food products, including vegetables. In food processing, convective drying by hot-air is still one of the most extensively used methods (Hasan *et al.*, 2019). The drying agent, hot air, provides the energy necessary for water evaporation and removes water vapor from the dryer, making it a cost-effective and extensively used method for drying vegetables (Nurkhoeriyati *et al.*, 2021; Usama *et al.*, 2022;

Calín-Sánchez *et al.*, 2022). Studies have shown that this method offers several advantages. For example, a study by Omolola *et al.* (2019) found that convective drying resulted in reduced weight and volume of food products, leading to a longer shelf life. Similarly, research by Santos *et al.* (2021) highlighted the simple design, easy operation, and low cost of convective drying, making it an attractive option for food dehydration. Nayak *et al.* (2021) also noted the effectiveness of convective drying in removing moisture from vegetables, leading to extended shelf life and preservation of nutritional quality. However, there are also some disadvantages to convective drying. Geng *et al.* (2022) found that convective drying can result in a long drying time, which may not be suitable for all food products. Additionally, the high temperatures used in convective drying can lead to crust formation on the product surface, potentially affecting the overall quality.

Generally, drying practices without considerations for the drying kinetics, can significantly affect the efficiency of dryers, increase the cost of production, and reduce the quality of the dried product (Inyang *et al.*, 2018). Taking into account the drying kinetics before choosing a drying method can help select the best drying techniques and regulate the drying process (Maisnam *et al.*, 2017).

2.5 Physical, Chemical, and Nutritional Changes in Dried Vegetables

Drying is a common preservation method for vegetables, aiming to reduce moisture content and inhibit microbial growth, thereby extending shelf life. However, the drying process can influence various attributes of vegetables, including nutritional content, colour, flavour, texture, and rehydration properties. A study by Mohammadi *et al.* (2020) found that the drying process can result in a reduction of the nutritional value and sensory attributes of dried vegetables. The study highlighted that the drying process can influence various attributes of vegetables, including nutritional content, colour, flavour, texture, and rehydration properties. The findings emphasized the importance of understanding these effects for maintaining product quality and meeting consumer expectations. Understanding these effects is crucial for maintaining product quality and meeting consumer expectations. Drying imparts both observable physical changes, easily discernible through visual assessment by consumers, and chemical modifications that may not be immediately apparent. Studies by Oliveira *et al.* (2016), Kaur *et al.* (2020) and Sarkar *et al.* (2022) noted that the major chemical changes linked with drying are related to the degradation of phytochemicals, such as vitamins, antioxidants, pigments, and other bioactive compounds sensitive to heat, light, and oxygen, which can compromise the overall quality of the final product. Similarly, a study by Oboh and Akindahunsi (2004) found that sun-drying can cause a significant decrease in the Vitamin C content of green leafy vegetables, highlighting the impact of drying on the nutritional value of vegetables. These changes can result in a reduction of the nutritional value and sensory attributes of dried vegetables. Drying can also lead to physical alterations in the vegetables. For example, the structure of the vegetables may change, leading to differences in texture and rehydration properties (Deng *et al.,* 2019). The drying process can also cause a reduction in the volume and weight of the vegetables, as well as changes in their appearance and shape (Santos *et al.*, 2019). Overall, the drying process can have a significant impact on the quality of vegetables, leading to changes in their nutritional content, colour, flavour, texture, and rehydration properties.

2.6 Pre-treatment

Pre-treatment is widely used before drying of agricultural products to inactivate enzymes, enhance drying process and improve quality of dried products (Osae *et al.*, 2020). It involves the application of various methods such as chemical solutions, thermal blanching, and non-thermal processes to reduce the moisture content and minimize drying time while conserving the nutritional and sensory attributes of the products (Oliviera *et al.*, 2016; Kaur *et al.,* 2020; Sarkar *et al.,* 2022). The aim of pre-treatment is to better preserve the fresh food properties, reduce energy needs, and maintain the quality of the final dried products (Osae *et al.*, 2020).

2.6.1 Blanching

Blanching is a widely employed pre-treatment technique in the processing of dried fruits and vegetables (Korus, 2022). The purpose of blanching vegetables before drying is to deactivate enzymes that might otherwise trigger undesirable changes in colour, texture, or flavour (Nighitha & Santhi, 2019; Quaye *et al.*, 2021; Barathiraja *et al.*, 2022). The duration of the blanching process also influences the texture, appearance, colour, flavour, and other sensory attributes of the dried product (Conte *et al.*, 2020; Yildiz, 2022), impacting the rate of dehydration as well (Falade & Shogaolu, 2010). It's worth noting that hot water blanching of vegetables before drying can lead to the loss of certain water-soluble vitamins like vitamin C, B-complex, and minerals (Sarkar *et al.*, 2022).

2.6.2 Chemical Pre-treatments

Pre-treating fruits and vegetables with various chemicals before the drying process is recognized for its significant role in enhancing the overall quality, safety, and nutritional characteristics of the resulting dried products (Ajibola *et al.*, 2023; Satpute *et al.*, 2023). These chemicals include hyperosmotic, alkali, sulphite and acid solutions, as well as gases such as sulphur dioxide, carbon dioxide, and ozone. These treatments contribute to improved colour, flavour, and nutrient retention, while also serving to control enzymatic browning and curb microbial growth throughout the drying process.

Despite the positive impact of sulphite pre-treatment on preserving the colour of fruits and vegetables, it comes with drawbacks such as the loss of certain water-soluble nutritional compounds, the development of undesirable flavour, and a softening of the texture (Garcia-Martinez *et al.*, 2013). Additionally, a significant concern associated with sulphite pre-treatment is the presence of chemical residues in the final product, potentially leading to health issues like asthmatic reactions in sensitive individuals (Kamiloglu *et al.*, 2016). Acid dips, another form of pre-treatment, have been linked to nutrient loss through leaching into the dipping solution and degradation in acidic environments (Zuh *et al.*, 2007). Furthermore, the use of acid solutions may result in the degradation of pigments such as chlorophylls and carotenoids, causing changes in colour (Hiranvarachat *et al.*, 2011; Ngamwonglumlert *et al.*, 2015).

2.7 Composite Vegetable Powders (CVP)

Composite vegetable powders (CVPs) are derived from a combination of various vegetables that undergo dehydration and pulverization processes to form a nutrient-dense powder. These powders have gained significant attention in recent years due to their potential to enhance nutritional intake and provide various health benefits (Oikeh *et al.*, 2016; Chandrasekara & Shahidi, 2018; Kadam *et al.*, 2018; Egbi *et al.*, 2018). Oikeh *et al.* (2016) explored a CVP made from moringa leaves and spinach. The combination offered a rich source of vitamins, minerals, and antioxidants. Moringa is known for its high nutritional value, while spinach adds additional vitamins and a pleasant taste. Such CVPs could be used to fortify various foods and beverages to combat malnutrition. Chandrasekara and Shahidi (2018) also investigated a CVP consisting of carrots and beetroot which could be used to enhance the colour and nutritional value of products like soups and smoothies.Furthermore, Egbi *et al.* (2018) demonstrated that incorporating a CVP of amaranth leaves and eggplant leaves into school meals substantially improved the intake of iron, zinc, and beta-carotene among rural school children.These examples illustrate the versatility of composite vegetable powders in providing diverse nutrients and flavors. CVPs can be used to address nutritional deficiencies, improve the sensory qualities of food products, and support various health-related goals. Their convenience and long shelf life make them a valuable addition to the food industry and dietary practices.

2.8 Water Activity (a_w)

An essential property of water in food processing is the water activity (a_w) of food. The water activity of foods depicts the degree to which the water is accessible to support the biochemical activities of microorganisms (Andrade *et al.*, 2011). Water activity (a_w) is a critical parameter that dictates the shelf-life stability of food and is a food safety concern. It refers to the amount of free water available in food for microbial growth and is a measurement of the water that is not bound to components in the food, and therefore available for microbial growth (Barbosa-Cánovas *et al.*, 2020). Most food falls within a water activity range of 0.2 to 0.99, and the lower the a_w value, the more "dry" a food item is considered (Rahman & Labuza, 2007; Labuza & Altunakar, 2020). Water activity is determined by the ratio of the vapor pressure of the food itself, when in a completely undisturbed balance with the surrounding air media, and the vapor pressure of distilled water under identical condition (Razak *et al.,* 2023). Water activity affects food stability, and it must be brought to a suitable level at the end of drying and maintained within an acceptable range of activity values during storage (Bell, 2020). For example, the water activity of dried fruits is typically in the range of 0.60 to 0.65, while dried meat may have a water activity of 0.80 to 0.92 (Tapia *et al.*, 2020). Controlling water in food by drying, freezing, or adding sugar or salt is able to preserve and control food quality and safety. Free water in food supports the growth of bacteria, yeasts, and moulds (fungi) (Andrade *et al.*, 2011). As water activity increases, water gains enhanced capabilities as a solvent, medium, and participant in reactions. Water activity plays a pivotal role in determining various physical attributes of foods like texture, enzyme activity, and storage stability (Andrade *et al.*, 2011). Consequently, managing water activity is a significant approach to ensuring physical, chemical, and microbiological stability of food. The equilibrium moisture content of biological products is primarily influenced by the temperature and relative humidity specific to the product's characteristics. The equilibrium moisture content denotes the point at which a sample no longer absorbs moisture from or releases moisture into the surrounding air. Aspects such as the product's physiological maturity, historical background, and the method of achieving equilibrium (absorption or desorption) all contribute to its equilibrium moisture content (Andrade *et al.*, 2011).

2.9 Moisture Sorption Isotherm

A moisture sorption isotherm describes the relationship between water activity and the equilibrium moisture content for a food product at constant pressure and temperature (Karataş & Arslan, 2022). It provides vital data on storage stability and extrapolation of shelf-life, indicating the humidity-water activity relationship at a given temperature (Andrade *et al.*, 2011). Several models have been suggested for expressing the relationship between the equilibrium moisture content and the water activity. Among them, the Guggenheim-Anderson-de Boer (GAB) and Brunauer-Emmett-Teller (BET) models have been applied successfully to dried foods, including powders/flours (Andrade *et al.*, 2011; Robertson & Lee, 2021). The principal methods for obtaining sorption isotherms for foods are gravimetric, manometric and hygrometric (Basu *et al.*, 2006). The manometric method involves measuring the vapor pressure of water when it is in equilibrium with a sample at a given moisture content, while the hygrometric method directly measures the vapor pressure above a food to determine water activity (Aviara, 2020). The gravimetric method exposes the samples to atmospheres of saturated salt solutions or sulfuric acid solutions of known relative humidity. This method is a lengthy and laborious process involving a series of repetitive weighing (Andrade *et al.*, 2011; Basu *et al.*, 2006).

Conclusion

Enhancing the global food basket is crucial for safeguarding nutrition and food security, particularly in developing nations, as the climate continues to evolve. This has sparked a desire to explore the use of indigenous and lesser-known vegetables as a means to guarantee food and nutrition security in developing nations. While carrots, turkey berries, amaranth, and eggplant leaves offer substantial nutritional advantages, a significant challenge arises due to their rapid deterioration post-harvest. These vegetables contain valuable nutrients that can contribute to a balanced diet and improved health. However, their short shelf life can limit their availability and potential impact on nutrition. To fully harness the benefits of these vegetables and incorporate them effectively into diets, characterization of their dehydrated products is imperative.

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CHAPTER THREE

INFLUENCE OF PRE-TREATMENTS ON THE PHYSICAL QUALITY AND DRYING CHARACTERISTICS OF SELECTED POPULARLY CONSUMED VEGETABLES IN GHANA

3.1 INTRODUCTION

Vegetables are nutrient powerhouses, rich in vitamins (e.g., β-carotene, ascorbic acid, riboflavin, folic acid) and essential minerals (e.g., calcium, iron, phosphorous) (Sood *et al.,* 2021). They also contain health-boosting phytochemicals like polyphenols known for their potent antioxidant properties (Coman *et al.*, 2020; Putriani *et al.*, 2022). Consequently, the frequent consumption of vegetables is strongly recommended (Amagloh and Nyarko, 2012). However, due to the seasonal availability and perishable nature of fresh vegetables (Devon, 2018), they need to be subjected to some form of preservation in order to make them shelf stable and available when they are out of season. One of the most popular and least expensive means of preserving vegetables is by drying (Calín-Sánchez *et. al.,* 2020). Various pre-treatments such as thermal blanching, chemical dips, and non-thermal processes are employed to improve drying efficiency and product quality (Nayak *et al.*, 2021).

One common pre-treatment is thermal blanching which includes hot water and steam blanching. Hot water blanching is popular due to its requirements for simple equipment and ease of operation (Tang *et al.*, 2019) but it can lead to nutrient loss due to leaching (Garba *et al.,* 2015). Steam blanching is preferable for preserving minerals and water-soluble components (Del *et al.*, 2012; Deng *et al.*, 2019). Chemical solutions, particularly sulphiting, enhance the quality and drying kinetics of fruits and vegetables ((Deng *et al.*, 2019; Yu *et al.*, 2017) However, sulphiting may pose concerns for sulphur-sensitive consumers.

The quality of dried products hinges on pre-treatments, with some vegetables prone to discoloration during drying (Papoutsis & Edelenbos, 2021; Barathiraja *et al.,* 2022; Putriani *et al.,* 2022). Among several drying methods, open sun-drying in the tropics is one of the oldest known technologies of food preservation. However, the quality of open sun-dried products is completely subject to the weather, and is frequently poor due to contamination by dust, birds, rodents and insects (Akpinar, 2010). Solar drying, on the other hand, offers an eco-friendly and hygienic alternative. Convective oven drying is faster but comes with higher costs (Kumar *et al.,* 2013; Ali *et al.,* 2016). Long periods of drying have been associated with poor quality of final products

(Agarry *et al.,* 2013) hence, shortening drying times while retaining nutritional quality is crucial (Agarry and Aworanti, 2012). Studies have revealed that non-chemical pretreatment such as blanching, increases the rate of drying and thereby reduce the period of drying (Agarry and Aworanti, 2012; Ando *et al.,* 2013; Akonor and Tortoe, 2014; Afolabi *et al.*, 2015). It is frequently employed prior to drying to improve the drying efficiency of fruits and vegetables and enhance product quality (Ando *et al.,* 2013; Agarry *et al.,* 2013; Gupta *et al.,* 2014; Doymaz, 2014).

Irrespective of the pre-treatment, drying rates differ widely among vegetables (Awogbemi and Ogunleye, 2009; Deng *et al.,* 2019; Nighitha & Santhi, 2019). The drying characteristic of each vegetable is an intrinsic property and thus vegetables behave uniquely during drying (Guine and Fernandes, 2006).

Mathematical models are employed to predict moisture removal behavior during drying, contributing to energy efficiency and product quality (Fudholi *et al.*, 2011). Various drying models, such as the Midilli model, Page model, and Modified Henderson and Pabis model, have been used to describe drying kinetics for different vegetables (Sobukola *et al.*, 2007; Akonor and Amankwah, 2012; Alara *et al.*, 2018; Omolola *et al.*, 2019). However, there is limited research on the effects of blanching pre-treatment on the drying characteristics of indigenous and underutilized vegetables in Ghana, such as amaranth, eggplant leaves, and turkey berry. This knowledge gap hinders the accurate prediction of drying rates and times for these vegetables during solar and air-oven drying. As such, this study's primary objective was to determine the drying kinetics of turkey berries, amaranth leaves, carrots, and eggplant leaves under convective oven and solar drying. Pre-treatments which minimized colour change during drying were also identified. By understanding the drying dynamics of these commonly consumed Ghanaian vegetables, this research aims to contribute to the development of suitable drying systems and conditions that enhance post-drying product quality.

3.2 Materials and Methods

3.2.1 Sample preparation

Vegetable samples (Carrots, amaranth and eggplant leaves) were obtained from the farm gate, while turkey berries were sourced from the Madina market. They were transported to the laboratory in the Food Science Department of the Radiation Technology Centre, Ghana Atomic Energy Commission. The fresh samples were used the same day without storage. The leaves were de-stalked and washed under clean running water. Carrots were sliced into about 2mm thicknesses. The samples were divided into three batches of approximately 500g each. One batch was used immediately for colour determination (fresh), another batch was subjected to a pre-treatment before drying (blanched) and the other batch was dried without pre-treatment (unblanched). Three (3) replications were done.

3.2.2 Pre-treatment methods

Based on preliminary studies, pre-treatments selected for the samples were thermal and chemical methods. Preliminary studies showed that using chemical methods as pre-treatment for the leafy vegetables resulted in a marked discolouration and were thus not selected for the leaves. Additional pre-treatments were investigated for turkey berries to ascertain the method that best retained the green colour. The thermal methods involved hot water and steam blanching and the chemical methods were citric acid and potassium metabisulphite dipping. Hot water and steam blanching times were 1, 3, and 5 min for all the vegetables (carrot, turkey berries, amaranth leaves, and eggplant leaves). Chemical treatment was carried out for carrots and turkey berries only. Carrots were dipped in citric acid solution (0.2%) for 5 min. Turkey berries were dipped for 5 min in citric acid solution (0.2%), potassium metabisulphite solution (0.2%), and combination treatment methods. The combinations treatment involved an initial thermal treatment (hot or steam blanched) followed by a citric acid dip. A summary of the pre-treatment methods applied is represented in Figure 3.1.

Due to the varied nature of the vegetables, the pre-treated samples were oven-dried at 40ºC for amaranth and eggplant leaves, and 60ºC for carrots and turkey berries (Raja *et al.,*2019; Agiriga *et al.,* 2015; Otu *et al.,* 2017)

3.2.3 Colour Determination

Fresh samples were assessed for tristimulus colour before pre-treatment and drying. After, pre-treatment and dehydration processes, the dried samples were then assessed for colour change. Hunter Lab colour meter ((LABSCAN XE Hunter Lab, Virginia, USA), was used for the analysis. The equipment was calibrated with a standard black and white ceramic tile. Colour measurements were done at three regions on the sample surface for L*- varying from lightness to darkness (100 – 0), a* varying from redness to greenness (+ve to –ve), and b* values (varying from yellowness to blueness (+ve to –ve). Total Colour Difference (TCD or ΔE) was calculated from the values of L*, a* and b* as

$$\Delta E^* = \sqrt{(\Delta L)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \qquad (1)$$

Where ΔL-difference in L*, Δa*-difference in a*, Δb*-difference in b* (Zielinska &Markowski, 2012).

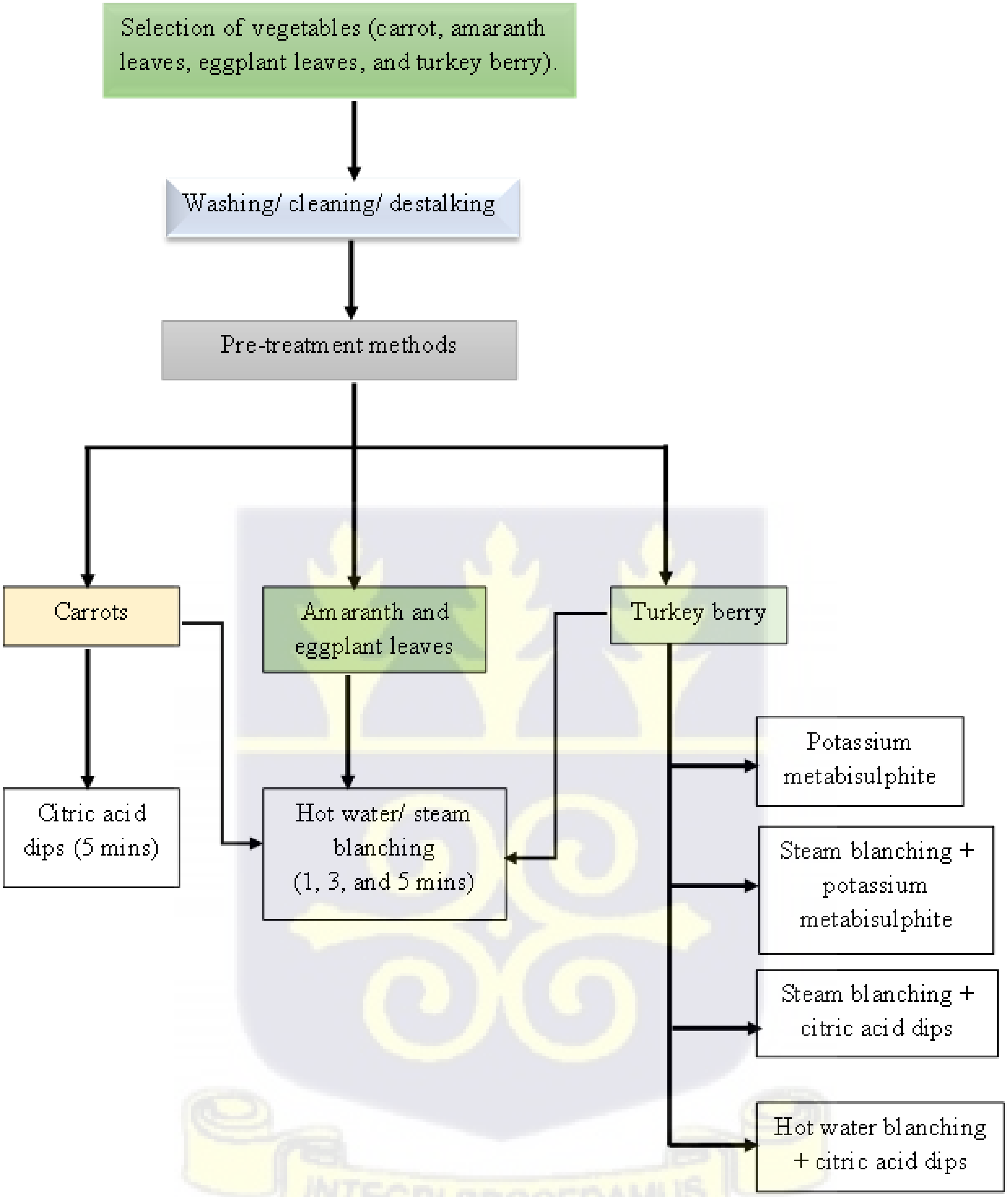

Figure 3.1: Flow chart of the thermal and chemical methods used for the pre-treatment of vegetables before drying.

3.2.4 Drying Studies

Pre-treatments that minimized change in the colour of the vegetables during drying were selected and used in the determination of drying characteristic of the vegetables. These pre-treatments were steam blanching for 5min for carrots, amaranth and eggplant leaves, and 3min hot water blanching for turkey berries.

3.2.4.1 Convection Oven Drying

Drying was carried out in a convection air oven (Memmert UF 110 model; Germany). The blanched and unblanched samples were separately placed in a single layer on 60 cm × 30 cm aluminium trays and dried at 40°C (for amaranth and eggplant leaves) and 60°C (for turkey berries and carrots). At regular time intervals of 30 min, samples were withdrawn and allowed to cool in a desiccator before weighing to determine the moisture loss. The end of drying was determined when constant weights were recorded.

3.2.4.2 Solar Drying

The blanched and unblanched vegetables were distributed uniformly in a single-layer on a tray separately, and then solar dried in portable direct solar driers (Dehytray^{TM}). The samples were dried for 9 h daily in May-June 2022 until constant weights were achieved. During dehydration, the weight loss and the temperature of the ambient air were recorded (Thermo hygrometer, Hanna HI 91610) from 8 am to 5 pm. The moisture loss during drying was determined by measuring the loss in weight of samples at hourly intervals. The drying temperature ranged between 49.8 °C (RH 31.3%) and 50.7°C (RH 32.8) over the period of drying.

3.2.4.3 Moisture content determination

Moisture content in the fresh and dried vegetable samples were determined according to the approved methods of the AOAC (2000), and the % moisture content was calculated based on equation 2:

$$\%\ Moisture\ content = \frac{change\ in\ weight}{sample\ weight} \times 100 \qquad (2)$$

3.2.4.4 Mathematical modelling

Mathematical modelling allows for the prediction of the behaviour of agricultural products during the drying process. Ratio of moisture (*MR*) of the selected vegetables was computed using equation 3:

$$MR = \frac{M_t - M_e}{M_0 - M_e} \qquad (3)$$

Where MR is the moisture ratio (dimensionless), M_t = Moisture content (%) after time t; M_e = Equilibrium moisture content and M_o = Initial moisture content. However, according to Doymaz and Pala (2002), M_e is relatively small compared to M_o and M_t, thus equation (3) was simplified as:

$$MR = \frac{M_t}{M_0} \qquad (4)$$

Experimental data for moisture ratio vs. drying time of oven and solar dried vegetables were fitted to five (5) drying models commonly used to describe the thin layer drying kinetics of perishable fruits and vegetables (Table 3.1). Model fitting was performed using non-linear regression in Origin Pro 8.5 (Origin Lab, Northampton, MA, USA).

Table 3.1: Selected Thin layer Drying Models

Model name	**Equation**	**References**
Lewis	$MR = \exp(-kt)$	Deshmukh *et al.* (2014)
Page	$MR = \exp^{(-kt^{n})}$	Wang *et al.* (2007)
Henderson and Pabis	$MR = a\exp(-kt)$	Motevali *et al.* (2011)
Logarithmic	$MR = a\exp(-kt) + c$	Agarry (2016)
Wang and Singh	$MR = 1+at+bt^2$	Wang and Singh (1978)

In these models, a, b, and c are dimensionless drying coefficients while k and n are drying constants (min^{-1}) and t is time.

The main criteria used in assessing the adequacy of fit and choosing the best model to describe the drying behaviour of the samples were the coefficient of determination (R^2), reduced chi-square (χ^2), and the Root Mean Square Error (RMSE). High R^2 and low χ^2 and RMSE correspond to better goodness of fit (Akpinar *et al.,* 2003). The χ^2 and RMSE were calculated from equations 4 and 5 respectively:

$$\chi^2 = \frac{\sum_{i=1}^{N}(MR_{exp}-MR_{pre})^2}{N-Z} \qquad (4)$$

$$RMSE = \sqrt{\left[\frac{1}{N}\sum_{i=1}^{N}(MR_{exp}-MR_{pre})^2\right]} \qquad (5)$$

Where N= Number of observations; z = Number of constants in the model; MR_{exp} and MR_{pre} are experimental and predicted moisture ratios respectively.

3.3 Data Analysis

Data was obtained in triplicates and processed using Microsoft Excel and Minitab 17 (Minitab Inc., USA). One-way analysis of variance (ANOVA) was used to compare means of the various treatments, and where the means were different, the Tukey's HSD was used to separate them ($p<0.05$).

3.4. Results and Discussion

3.4.1 Amaranth leaves and Eggplant leaves

Pre-treatments that minimized change in the colour of the vegetables during drying were selected and used in the determination of drying characteristic of the vegetables. These pre-treatments were steam blanching for 5min for amaranth leaves and eggplant leaves. The data presented in Table 3.2, shows the impact of steam blanching at 1, 3, and 5 mins, on the colour attributes of dehydrated Amaranth leaves. Steam blanching had a notable impact ($p \leq 0.05$) on the colour parameters L*, a*, and b*. The rise in lightness (L*-value) suggests a lightening of the vegetables' colour. This may indicate that blanching induced carotenoid isomerization, transforming them from all-trans to partially cis and producing lighter and less biologically active derivatives (Mulokozi & Svanberg, 2003; Ngamwonglumlert *et al.*, 2020). From Table 3.2, the unblanched amaranth sample showed the highest colour change ΔE (7.57±0.09) compared to the steam-blanched samples. The greenness (i.e., the a* values) showed there was better green colour retention (-a), in steam blanched samples than unblanched samples. Duangrat & Prasong (2010) and Xiao *et al.* (2016) reported that steam blanching could minimize the green colour degradation of dried lettuce leaves and retain the colour of the final product. Studies by Negi &Roy (2004) and Singh *et al.* (2006) also revealed that steam blanching of green leafy vegetables prior to dehydration retained the bright green colour of the leaves compared to unblanched leaves.

Table 3.2: Colour readings for Amaranth leaves after pre-treatment and drying

Treatment	L*	a*	b*	ΔE
Fresh	27.82 ± 0.07^{d}	-5.86 ± 0.03^{d}	6.94 ± 0.02^{e}	-
Unblanched	34.61 ± 0.08^{a}	-3.22 ± 0.08^{a}	9.14 ± 0.05^{b}	7.57 ± 0.09^{a}
Steam blanched (1min)	30.76 ± 0.11^{b}	-3.48 ± 0.04^{b}	8.23 ± 0.08^{c}	3.94 ± 0.10^{b}
Steam blanched (3 min)	28.72 ± 0.09^{c}	-3.59 ± 0.05^{b}	7.42 ± 0.03^{d}	2.50 ± 0.07^{d}
Steam blanched (5min)	28.63 ± 0.08^{c}	-4.53 ± 0.02^{c}	10.01 ± 0.03^{a}	3.46 ± 0.05^{c}

Means that do not share the same superscript letters in a column are significantly different ($p<0.05$)

The heating of vegetables results in the inactivation of enzymes, hence a reduction in the degradation of colour. However, high nutritional losses are associated with increased blanching time (Patil *et al.*, 2020). In this work, amaranth leaves that were steam blanched for 5 mins showed the greenest colour with an a* value of -4.53. A similar trend in green colour was observed in blanched and unblanched eggplant leaves (Table 3.3). Eggplant leaves that were steam blanched for 5 mins showed the highest a* value of -4.53 with the least green colour observed in unblanched eggplant leaves (-2.68). There was no significant difference in the lightness (L*), yellowness (b*) and total colour change (ΔE) of 1min and 3mins blanched eggplant leaves.

Table 3.3: Colour readings for eggplant leaves after treatment and drying

Treatment	L*	a*	b*	ΔE
Fresh	40.10±0.06^{a}	-6.99±0.02^{e}	7.84±0.03^{c}	-
Unblanched	34.59±0.07^{b}	-2.68±0.01^{a}	11.95±0.13^{a}	8.10±0.09^{b}
Steam blanched (1 min)	32.48±0.44^{c}	-3.04±0.06^{b}	9.75±0.06^{b}	8.78±0.39^{a}
Steam blanched (3 min)	32.15±0.13^{c}	-3.96±0.05^{c}	9.72±0.01^{b}	8.69±0.100^{a}
Steam blanched (5min)	32.63±0.08^{c}	-4.53±0.02^{d}	10.01±0.03^{d}	8.15±0.06^{b}

Means that do not share the same superscript letters in a column are significantly different ($p<0.05$)

3.4.2 Turkey berries

The various pre-treatments significantly influenced colour change of the turkey berry samples (Table 3.4). The L*-values of fresh turkey berries were 69.67, greenness (a*) was -6.69, and yellowness (b*) was 24.40. The total colour difference of dried turkey berry from the various pre-treatments was significantly different ($p < 0.05$) and the values varied from 17.16 - 37.38 (Table 3.4). Turkey berry samples that were hot water blanched for 1 or 3 mins had the least total colour change (ΔE), while samples that were steam blanched for 1 and 3 mins showed the greatest colour difference (ΔE) from the fresh samples. Citric acid or sulphite dipping showed total colour change that were significantly higher than hot water blanching. Although these pre-treatment methods have been shown to be effective in some vegetables such as tomato and chilli (Owureku-Asare *et al.*, 2014; Chaethong & Pongsawatmanit, 2015), it is possible that the levels used in this experiment were not effective in maintaining the fresh turkey berry colour. Pre-treatments that minimized change in the colour of the turkey berries during drying were selected and used in the determination of drying characteristic of the vegetable.

Table 3.4: Colour readings for turkey berries after pre-treatment and drying.

Treatment	L*	a*	b*	ΔE
Fresh	69.67±0.11^{a}	-6.69±0.12^{k}	24.40±0.10^{a}	-
Unblanched	37.57±0.10^{g}	1.75±0.06^{d}	12.79±0.06^{ij}	35.27±0.10^{b}
Steam blanched (1 min)	36.06±0.35^{h}	2.47±0.00^{a}	11.99±0.12^{k}	37.08±0.35^{a}
Steam blanched (3 min)	35.49±0.57^{h}	1.11±0.04^{e}	11.74±0.16^{k}	37.38±0.57^{a}
Steam blanched (5mins)	39.63±0.12^{ef}	0.90±0.03^{f}	13.30±0.02^{h}	33.01±0.10^{cd}
Hot water blanched (1 min)	53.61±0.48^{b}	-0.57±0.05^{h}	19.61±0.10^{b}	17.95±0.47^{g}
Hot water blanched (3 min)	54.33±0.67^{b}	-1.8±0.04^{j}	18.78±0.10^{c}	17.16±0.59^{g}
Hot water blanch (5mins)	48.42±0.52^{c}	-1.26±0.02^{i}	17.87±0.17^{d}	22.98±0.53^{f}
Citric dip	40.38±0.41^{e}	2.40±0.02^{a}	13.05±0.09^{hi}	32.81±0.40^{d}
Bisulphite dip	39.14±0.04^{f}	2.27±0.03^{b}	12.71±0.02^{j}	34.01±0.02^{c}
Steam blanch+ bisulphite	43.36±0.17^{d}	1.03±0.02^{ef}	14.03±0.04^{g}	29.42±0.16^{e}
Steam blanch + citric dip	42.93±0.53^{d}	1.90±0.03^{c}	15.47±0.20^{e}	29.58±0.54^{e}
Hot water blanch + citric dip	42.46±0.44^{d}	0.06±0.02^{g}	14.98±0.14^{f}	29.68±0.44^{e}

Means that do not share the same superscript letters in a column are significantly different ($p<0.05$)

3.4.3 Carrots

The effect of steam blanching, hot water blanching and citric acid dips on the colour of dried carrots are shown in Table 3.5. The pre-treatment significantly influenced the changes in colour, particularly in a* (redness) and b* (yellowness). Treated carrots exhibited elevated values for both a* (redness) and b* (yellowness) compared to untreated or unblanched carrots. Notably, there was a significant ($p \leq 0.05$) decline in redness during the drying process, corresponding to a substantial decrease in the a* parameter compared to the reference sample. The decrease in the b* value indicates a reduction in the yellowness of the sample during drying, potentially attributed to the partial decomposition of carotenoids and the formation of brown pigments. Zielinska &Markowski (2012) and Mercadante & Rodríguez-Amaya (1991) further explain that carotenoids can undergo various chemical reactions during drying, including oxidation and isomerization, which may lead to the generation of brown pigments. These reactions can cause a decrease in yellowness (b* value) and contribute to colour changes in dried products. Carrots that were steam blanched for 5 mins recorded the least colour change (17.78±0.13) with high values for a* (redness) and b* (yellowness). This observation was also reported by Tadeese *et al.* (2015) in their work on pre-treatment effects on carrots. The pre-treatment that minimized change in the colour of the carrots during drying were selected and used in the determination of drying characteristic of the vegetable.

Table 3.5: Colour readings for carrots after pre-treatment and drying.

Treatment	L*	a*	b*	ΔE
Fresh	49.22±1.04^{c}	23.07±0.48^{a}	38.58±0.05^{a}	-
Unblanched	59.14±0.25^{a}	11.10±0.04^{f}	26.23±0.09^{e}	22.50±0.12^{a}
Steam blanch (1 min)	55.67±0.09^{b}	12.81±0.05^{e}	26.65±0.17^{e}	20.54±0.19^{b}
Steam blanch (3 min)	56.07±0.62^{b}	13.42±0.01^{cd}	27.68±0.13^{d}	18.98±0.13^{c}
Steam blanch (5min)	56.03±0.50^{b}	14.06±0.08^{b}	28.34±0.09^{c}	17.78±0.13^{ef}
Hot water blanch (1 min)	59.40±0.09^{a}	13.38±0.02^{d}	29.47±0.08^{b}	17.28±0.07^{f}
Hot water blanch (3 min)	56.20±0.13^{b}	13.61±0.05b^{cd}	28.36±0.02^{c}	18.13±0.05^{e}
Hot water blanch (5min)	56.33±0.27^{b}	13.91±0.06^{bc}	28.10±0.06^{cd}	18.15±0.02^{de}
Citric dip	56.23±0.18^{b}	13.35±0.23^{d}	27.80±0.34^{d}	18.92±0.48^{cd}

Means that do not share the same superscript letters in a column are significantly different ($p<0.05$)

3.4.4 Drying Characteristics

Figures 3.2-3.5 depict the drying curves, obtained by plotting experimental moisture content and drying time for the chosen vegetables. These graphs follow the typical curve observed in food materials, as reported by Pal *et al.* (2008) and Rayaguru and Routray (2012). In the initial phase, moisture evaporation occurred rapidly, gradually decreasing as drying time advanced until a state of constant weight was reached. Generally, longer drying periods were required for solar drying. For instance, the drying time for the leafy vegetables (amaranth and eggplant leaves) under solar drying was about twice the time required for air-oven drying (Figures 3.2 and 3.3). For carrots nearly one and a half the time required for air oven was used in solar drying (Figure 3.4). This observation may be ascribed to the higher temperature, consistent temperature and uniformity of heating in the air oven, compared to solar drying which is associated with fluctuations in drying temperature. From Figures 3.2-3.4, a greater reduction in the moisture content of blanched samples was observed during the first 30 mins (oven) and 60 mins (solar) of drying compared to the unblanched samples. This could be attributed to the fact that blanching of the vegetables increased the rate of drying. After blanching cell walls are softened and water displaces air trapped in tissues, thus improves the thermal conductivity of the food materials. Also, the loss to cell rigidity enhances mass transfer of moisture from the centre to the outer surface of the food material leading to shorter drying periods (Singh *et al.*, 2022).

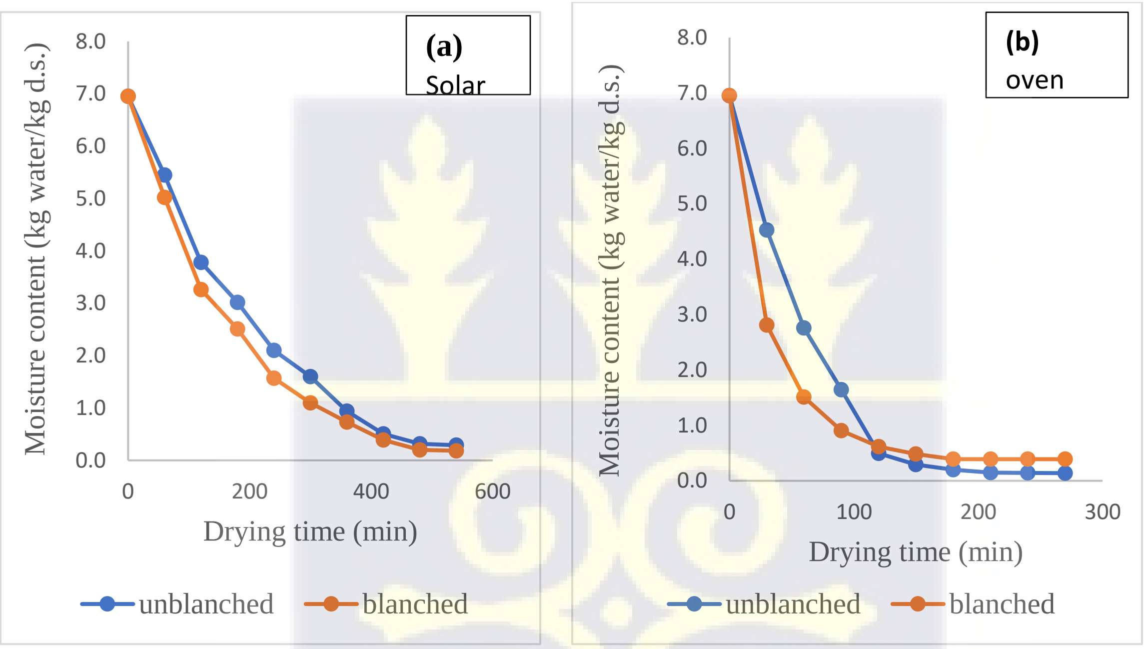

Figure 3.2: Drying curves for unblanched and blanched amaranth leaves dried using solar (a) and convection oven (b) methods

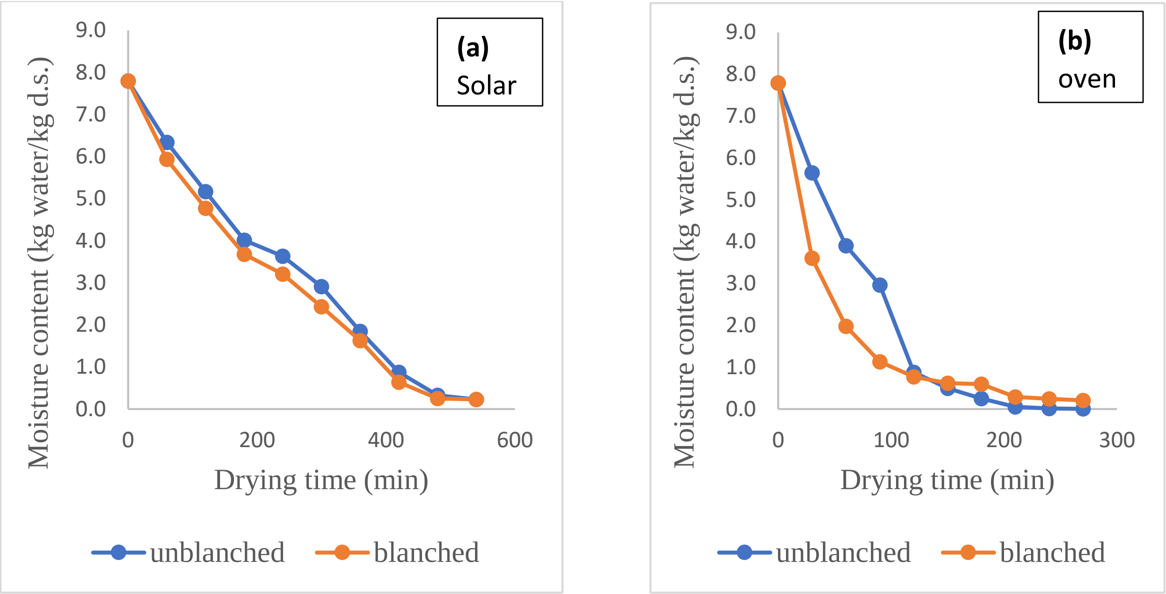

Figure 3.3: Drying curves for unblanched and blanched eggplant leaves dried using solar (a) and convection oven (b) methods

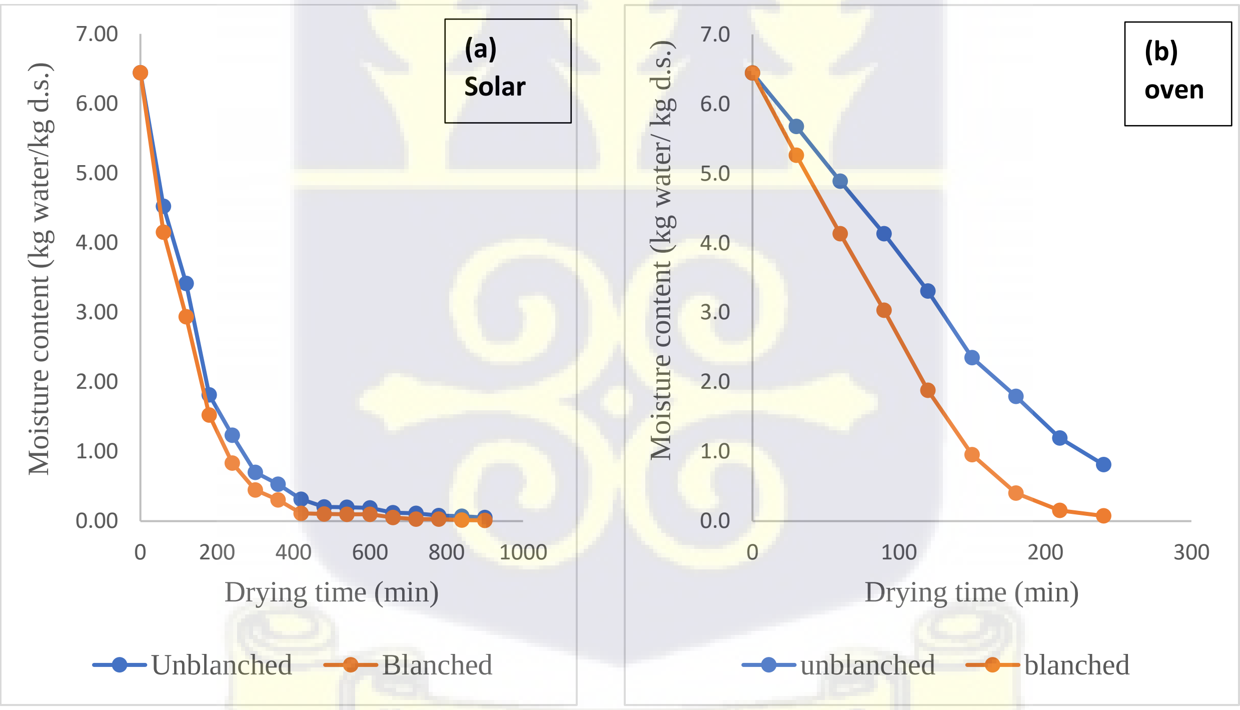

Figure 3.4: Drying curves for unblanched and blanched carrot slices dried using solar (a) and oven (b) methods.

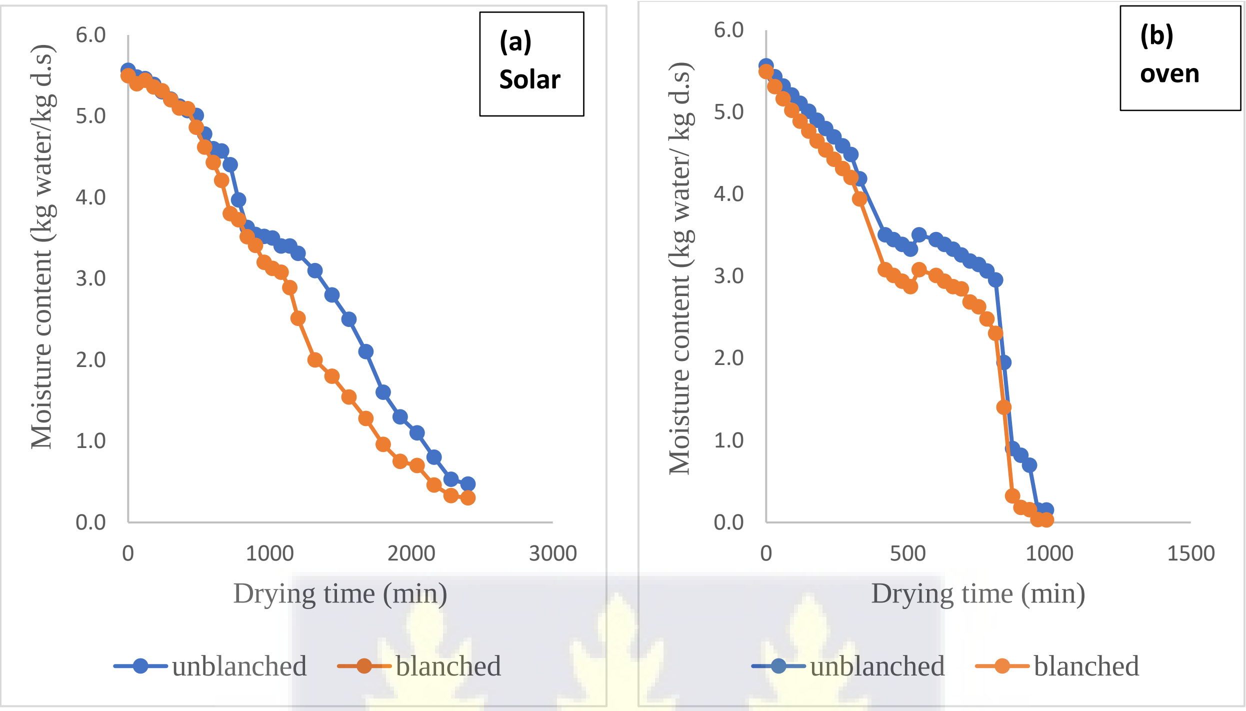

Figure 3.5: Drying curves for unblanched and blanched turkey berries dried using solar (a) and convection oven (b) methods

3.4.5 Mathematical modelling

The parameters for the selected thin layer drying models are presented in Table 3.6. For air oven drying, R^2 values obtained for all five models indicated good fits (Agarry and Aworanti, 2012) between the experimental data and predicted models. However, the Page model showed highest R^2 values (0.9964 - 0.9991) and corresponding least values for RMSE and reduced chi-square, thus, best described the drying characteristics of carrots, amaranth leaves and eggplant leaves. These results are in agreement with Akonor and Amankwah (2012), Roman and Hensel (2011) and Doymaz (2004) who independently determined the Page model as the best to describe the drying kinetics of Xanthosoma leaves, celery and carrots respectively. For turkey berries, the Wang and Singh model showed the best fit with values of 0.9058 and 0.9202 for control and hot water blanched samples respectively (Table 3.6). The high R^2 values (0.9058 and 0.9202) and corresponding least values for RMSE and reduced chi-square suggest that the Wang and Singh model best describes the drying behaviour of turkey berries under both control and hot water blanched conditions. Doymaz (2009), also demonstrated that the Wang and Singh model best described the drying kinetics of unblanched and hot water blanched apple slices.

The drying rate constant "k" reflects how fast the moisture content decreases during the drying process. A higher "k" value indicates a faster drying rate (Alvarez *et al.,* 2021; Raaf *et al.*, 2022). The empirical constant "n" represents the shape of the drying curve, and the value influences the shape of the curve, determining whether the drying process is faster or slower in the initial or later stages. A higher "n" value indicates a slower decline, while a lower 'n' value suggests a more rapid decline in the drying rate (Velaga *et al.*, 2018; Alvarez *et al.*, 2021; Guo *et al.,* 2022).The results (Table 3.6) showed that the drying constant 'k' of treated vegetables described by Page model, was higher (indicating a faster drying process) than the 'k' value for the control samples; while the empirical constant 'n' was lower for treated samples, suggesting a faster drying process in the initial stages. Similar findings have been reported for hot air drying of tomato (Agarry, 2016).

Table 3.6: Model parameters of fitted data for oven-dried selected vegetables to Page, Lewis, Henderson and Pabis, Logarithmic and the Wang and Singh models

Model	**Parameter**	**Amaranth**		**Eggplant**		**Carrot**		**Turkey berry**	
		Unblanched	**Blanched**	**Unblanched**	**Blanched**	**Unblanched**	**Blanched**	**Unblanched**	**Blanched**
Page	k	0.0101	0.08868	0.0047	0.0654	0.0004	0.0006	0.0001	0.0002
	n	1.1040	0.6890	1.2114	0.7368	1.5235	1.4632	1.7485	1.6092
	χ^2	0.0001	0.0001	0.0005	0.0002	0.0003	0.0003	0.01259	0.0125
	RMSE	0.0008	0.00050	0.0037	0.0016	0.0026	0.0023	0.36222	0.3650
	R^2	0.9991	0.9991	0.9963	0.9978	0.9964	0.9967	0.8517	0.8686
Lewis	k	0.0157	0.02576	0.0124	0.0223	0.0104	0.0064	0.0011	0.0014
	χ^2	0.0002	0.0018	0.0013	0.0012	0.0062	0.0041	0.01857	0.01802
	RMSE	0.0022	0.0106	0.0117	0.0110	0.0493	0.0331	0.5572	0.5426
	R^2	0.9979	0.9847	0.9898	0.9869	0.9541	0.9576	0.8894	0.8118
Henderson and Pabis	a	1.0124	0.9811	1.0283	0.9795	1.0732	1.0666	1.0926	1.0910
	k	0.0159	0.0253	0.0127	0.0218	0.0111	0.0069	0.00129	0.0015
	χ^2	0.0003	0.0021	0.0013	0.0013	0.0060	0.0037	0.0175	0.0171
	RMSE	0.0020	0.0103	0.0106	0.0105	0.0417	0.0257	0.5083	0.4969
	R^2	0.9978	0.9822	0.9895	0.9858	0.9557	0.9626	0.79181	0.82104
Logarithmic	a	1.0127	0.93052	1.0652	0.9488	1.3855	2.4072	6.0209	5.45432
	k	0.0159	0.03212	0.0111	0.0259	0.0061	0.0020	0.0001	0.0001
	c	-0.0004	-0.0660	-0.0507	-0.0453	-0.3556	-1.3923	-6.0104	-5.4441
	χ^2	0.00028	0.00022	0.00077	0.0003	0.0017	0.0004	0.01127	0.0096
	RMSE	0.0020	0.0009	0.0054	0.0021	0.01021	0.0027	0.3156	0.2689
	R^2	0.9975	0.9981	0.9939	0.9967	0.9873	0.9955	0.8661	0.8997
Wang and Singh	a	-0.0092	-0.0155	-0.0082	-0.0013	-0.0074	-0.0045	-0.0004	-0.0006
	b	0.0001	0.00006	0.0002	0.0001	0.0001	0.0001	-0.0001	-0.0002
	χ^2	0.0071	0.0117	0.0017	0.0172	0.0009	0.0004	0.0079	0.0076
	RMSE	0.0570	0.0584	0.0135	0.1374	0.0064	0.0028	0.2299	0.2216
	R^2	0.9377	0.8987	0.9868	0.8149	0.9932	0.9959	0.9058	0.9202

In solar drying of the selected vegetables, R^2 values obtained for the models (Table 3.7) indicated good fits (Madamba *et al.*, 1996, Agarry and Aworanti, 2012) between the experimental data and predicted models. However, the Page model described the drying curves of carrots, blanched turkey berries and amaranth leaves (highest R^2 values and corresponding least values for RMSE and reduced chi-square) thereby, exhibiting a high agreement between experimental and predicted (estimated) moisture ratio. Similar observation was made by Akonor and Amankwah (2012) and Djebli *et al.* (2020). Their findings further support the applicability of this model in the context of vegetable drying kinetics. The reliability of the developed models was assessed by comparing the computed moisture ratio of both blanched and unblanched vegetables with the values derived from the experimental data for the vegetables under investigation. The consistency of the models during oven drying of amaranth and egg-plant leaves are illustrated in Figures 3.6 and 3.7 while solar drying of carrots and turkey berries are illustrated in Figures 3.8 and 3.9. The model predictions and the drying data are seen generally to be banded around the curves, which shows that the assumed models are well suited to describing the drying behaviour of the selected vegetables.

Table 3.7: Model parameters of fitted data for solar-dried selected vegetables to Page, Lewis, Henderson and Pabis, Logarithmic and the Wang and Singh models

Model	**Parameter**	**Amaranth**		**Egg plant**		**Carrot**		**Turkey berry**	
		Unblanched	**Blanched**	**Unblanched**	**Blanched**	**Unblanched**	**Blanched**	**Unblanched**	**Blanched**
Page	k	0.5693	0.0041	0.7242	0.6181	0.00296	0.00372	0.00308	0.00292
	n	1.9860	1.0773	2.1745	2.0286	1.15018	1.14263	1.7594	1.87142
	χ^2	0.0031	0.0002	0.0224	0.0186	0.00037	0.00022	0.00134	0.00033
	RMSE	0.0127	0.0017	0.0179	0.0149	0.00519	0.00313	0.0389	0.0096
	R^2	0.9971	0.9981	0.9502	0.9632	0.9958	0.9973	0.9839	0.9969
Lewis	k	0.00509	0.0061	0.0039	0.0043	0.00649	0.0077	0.03203	0.03939
	χ^2	0.0009	0.0003	0.0044	0.0027	0.00059	0.00042	0.00934	0.01165
	RMSE	0.0085	0.0029	0.0392	0.0246	0.0089	0.0063	0.28028	0.3495
	R^2	0.9913	0.9969	0.9602	0.9743	0.9932	0.9950	0.8893	0.8876
Henderson and Pabis	a	0.100	0.1000	0.2001	0.1900	0.0124	0.0268	1.1283	1.1656
	k	0.5321	0.4321	0.5541	0.5182	0.7511	0.6883	0.03856	0.04825
	χ^2	0.0158	0.0128	0.0224	0.0187	0.00653	0.0050	0.00629	0.00698
	RMSE	0.1223	0.6235	0.1732	0.01451	0.0863	0.0715	0.1824	0.20236
	R^2	0.8543	0.8628	0.8041	0.8320	0.8253	0.8401	0.9337	0.9243
Logarithmic	a	0.0717	0.0813	0.6958	0.7305	0.8996	0.9265	2.3955	3.3703
	k	0.9815	0.9643	0.6367	0.4208	4.0914	3.8841	0.0001	0.00984
	c	0.2255	0.6958	0.3042	0.2695	0.1005	0.0734	-2.3850	-2.2891
	χ^2	0.0182	0.0192	0.0056	0.0433	0.00703	0.0054	0.00105	0.00167
	RMSE	0.1271	0.1964	0.0793	0.4652	0.0914	0.0704	0.02931	0.0467
	R^2	0.6687	0.6312	0.7741	0.7115	0.8195	0.8546	0.9874	0.9841
Wang and Singh	a	0.0038	0.0044	0.0028	0.0032	0.0035	0.0037	0.0177	0.02455
	b	0.00004	0.0004	0.0001	0.00002	0.00003	0.00003	0.0001	0.0003
	χ^2	0.0005	0.0015	0.0011	0.0014	0.00983	0.01435	0.00105	0.00271
	RMSE	0.0041	0.0123	0.0087	0.0108	0.1376	0.2009	0.0304	0.07871
	R^2	0.9952	0.9857	0.9899	0.9873	0.8876	0.8290	0.9874	0.9742

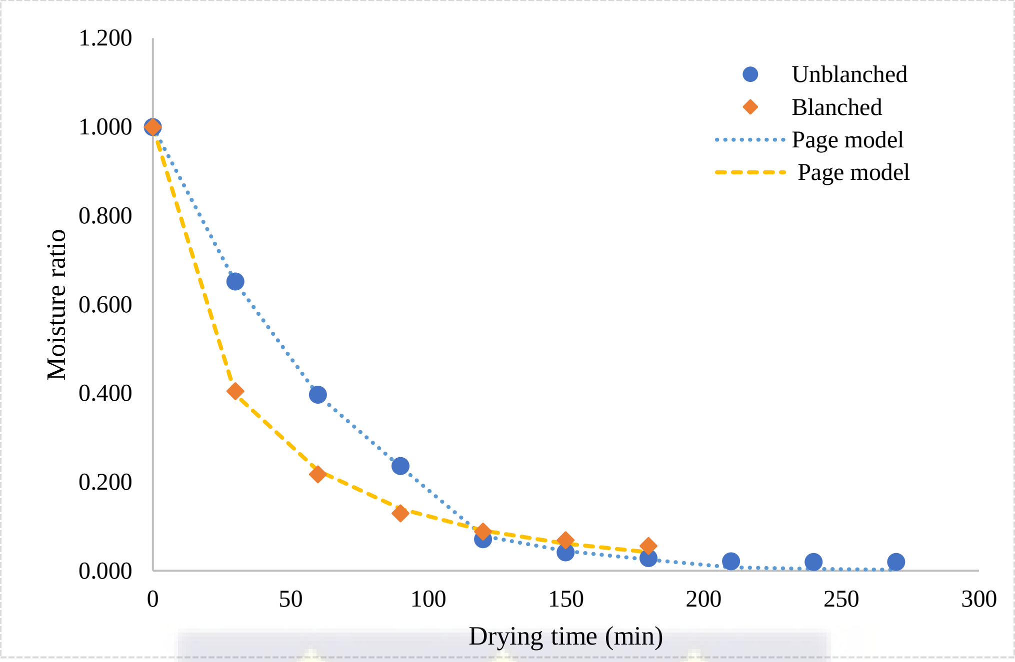

Figure 3.6: Comparison of experimental and predicted (Page model) moisture ratio for oven-dried amaranth leaves

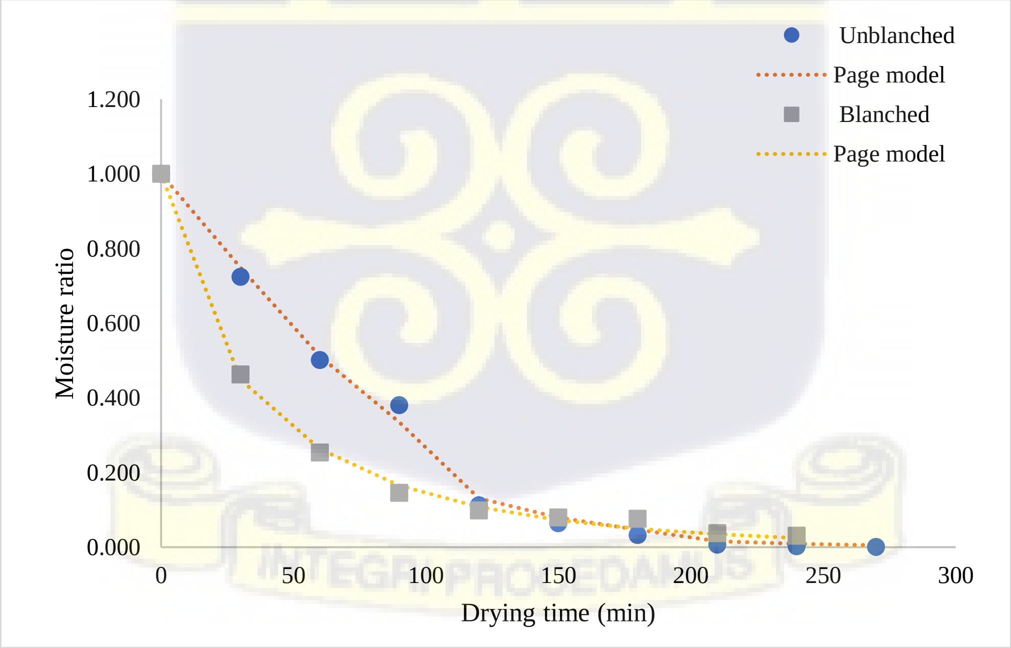

Figure 3.7: Comparison of experimental and predicted (Page model) moisture ratio for oven-dried eggplant leaves

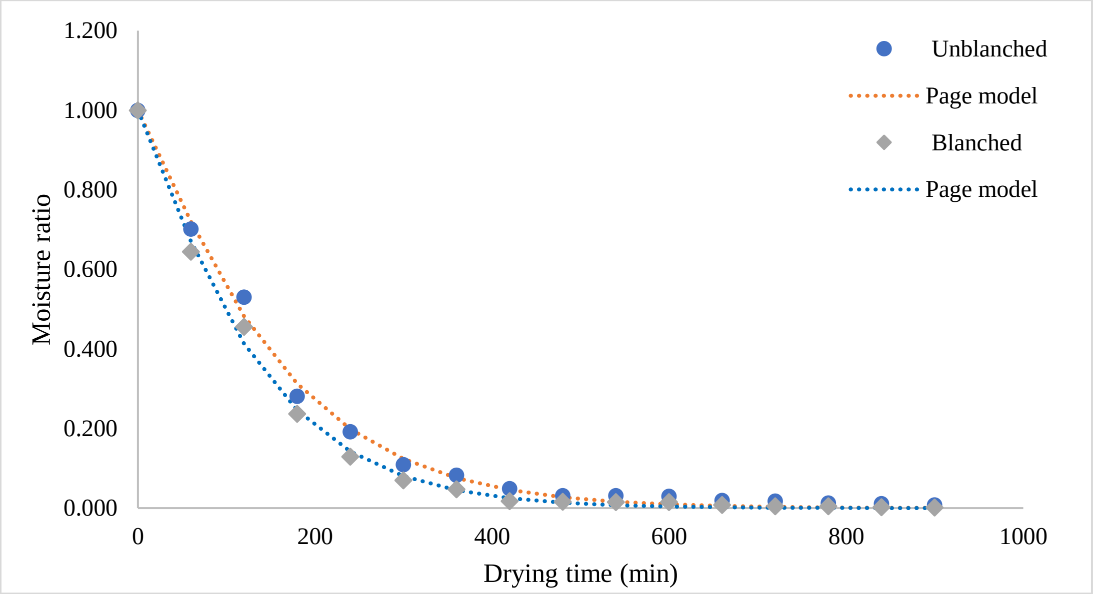

Figure 3.8: Comparison of experimental and predicted (Page model) moisture ratio for solar-dried carrot slices

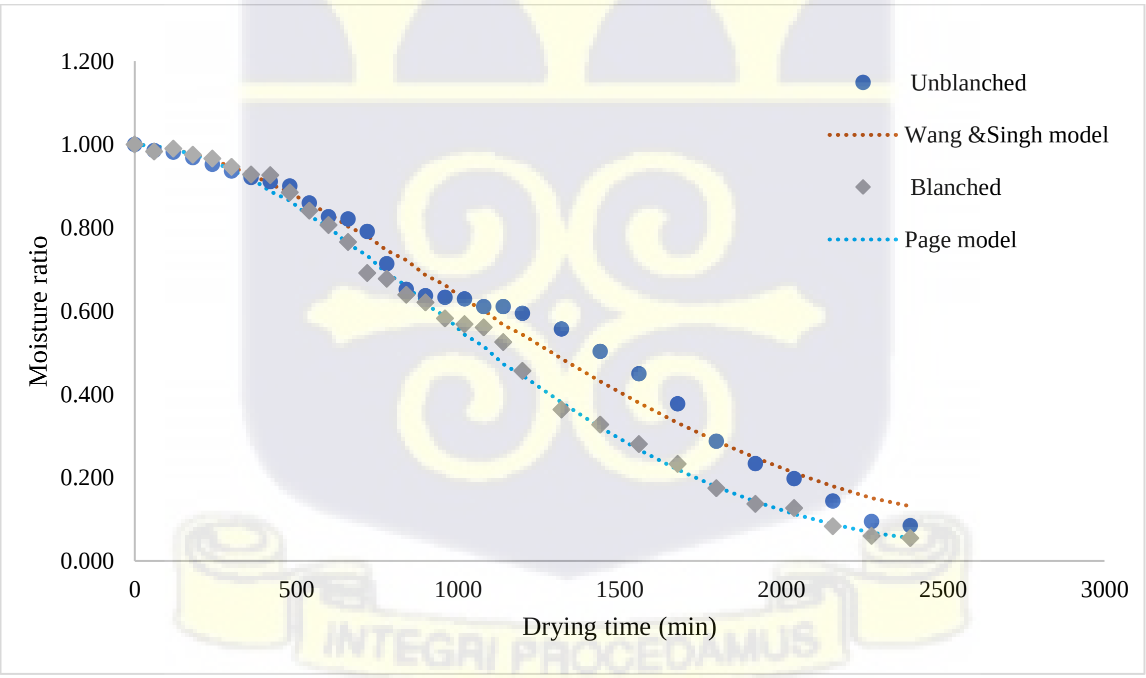

Figure 3.9: Comparison of experimental and predicted (Page and Wang & Singh models) moisture ratio for solar-dried turkey berries.

3.5 Conclusions

The vegetables largely behaved differently in their requirements for blanching pre-treatments before drying. Steam blanching of carrots, amaranth leaves and egg plants for 5 minutes before drying stabilized the green colour (-a*values) of the dehydrated samples. On the other hand, hot water blanching of turkey berries for 1 or 3 minutes showed the least colour change from the control after drying. Drying was generally faster in blanched vegetables compared to unblanched vegetables. The Page model proved to be the most suitable for characterizing the drying behaviour of carrots, amaranth leaves, and eggplant leaves in oven drying. For turkey berries under oven drying, the Wang and Singh model adequately described the drying characteristics. In solar drying, the Page model best describing the drying behaviour of amaranth leaves, carrots, and blanched turkey berries. Meanwhile, the Lewis model and Wang and Singh model were found to be the most appropriate for depicting the drying characteristics of eggplant leaves and unblanched turkey berries, respectively.

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CHAPTER FOUR

EFFECT OF BLANCHING AND DRYING ON PHYTOCHEMICALS AND ANTIOXIDANT ACTIVITY OF SELECTED DEHYDRATED VEGETABLES

4.1 Introduction

Vegetables are an important part of a healthy diet and provide several nutraceutical benefits. They contain a variety of phytochemicals (polyphenols, flavonoids, carotenoids, and so on), macronutrients (protein, fibre, carbs, fats), and micronutrients (minerals, vitamins such as vitamin C) (Li *et al.,* 2021; Sultanbawa & Sivakumar, 2022; Osafo, 2021). These phytochemicals, notably phenolic compounds and carotenoids, function as antioxidants, neutralizing free radicals that cause oxidative damage to cells and tissues (Arias *et al.*, 2022). Indeed, epidemiological, and clinical studies have linked diets high in fruits and vegetables to a lower risk of heart disease, cardiovascular, neurological, and chronic diseases, and cancer (Boeing *et al.*, 2012; Connolly *et al.*, 2021). Vegetables are perishable products with high moisture content ranging between 60.0-90% (Sharma *et al.,* 2019; Xu *et al.,* 2022). Due to their seasonal and perishable nature, raw vegetables are subjected to some form of preservation to make them available for later consumption (Kumar *et al.,* 2022; Deng *et al.,* 2022). Therefore, appropriate preservation and storage methods are required to preserve them and improve shelf-life for future consumption (Reis *et al.,* 2022; Kumar *et al.,* 2022; Natarajan *et al.,* 2022). Blanching is an important step in the processing of vegetables before dehydration, as it helps in the inactivation of enzymes and enhances the quality of the end product (Wang *et al.,* 2022). The drying process involves the removal of moisture through the simultaneous heat and mass transfer. Dried vegetables can be converted into fresh-like form by rehydration, and this ensures availability throughout the year.

Drying can be achieved by different methods and including hot-air-, freeze, microwave, solar, and sun-drying. The drying process influences the antioxidant potential of fruits and vegetables (Catorze *et al.,* 2022; Kapoor & Feng, 2022) and it is necessary to understand the effects of such post-harvest processes on their nutritional properties, phytochemical content and consequently their antioxidant activity. Thus, the aim of this study was to evaluate the effects of blanching and different drying methods on the phytochemicals and antioxidant activity of selected dehydrated vegetables.

4.2 Materials and Methods

4.2.1 Sample preparation

The vegetable samples were steam-blanched for 5 mins (amaranth leaves, eggplant leaves, carrots) or hot water blanched (turkey berries) prior to freeze drying, solar drying and oven drying. The unblanched but dried samples served as controls. Solar dried turkey berries turned mouldy and blackened due to the extended drying time (about nine days) and were therefore not included in the study. Amaranth and eggplant leaves were oven dried (Memmert UF 110 model; Germany) at 40˚C whilst carrots and turkey berries were dried at 60˚C until constant weight was achieved. Solar drying was performed using a direct solar dryer (Dehytray^{TM}). Samples were freeze-dried using a standard unheated chamber of dimensions 215 × 300 mm height (Telstar LyoQuest-55, Milan, Italy) at a vacuum pressure of 100 Pa and a final condenser temperature of −55˚C. The dried samples were milled into powder using a Kenwood dry mill blender (BL335, Manchester, United Kingdom) for further analysis.

4.2.2 Sample extraction

Each sample, (1g) was extracted in 10 ml of 50% ethanol. The mixture was placed in a conical flask, covered with aluminium foil, and subjected to agitation at 200 rpm using an orbital shaker for one hour at 25°C and filtered. An additional 10 ml of ethanol was added for re-extracting the residue, and the resulting supernatants were combined. The same procedure was repeated, replacing ethanol with distilled water as the solvent (Donkor *et al.*, 2022).

4.2.3 Determination of Total Phenolic Content

The determination of the total phenolic content utilized the Folin-Ciocalteu (FC) method with Gallic acid as the standard, incorporating modifications from Singleton *et al.* (1999). Fifty microliters of each ethanol and aqueous extract were combined with 3 ml of distilled water (dH2O) and 250 µl of FC reagent. After allowing the mixture to stand for 5 minutes, 750 µl of 20% Na_2CO_3 was added, and the resulting mixture was vigorously vortexed for two minutes. Following a 30-minute incubation at room temperature, absorbance values were measured at 760 nm using a UV-VIS Spectrophotometer (Shimadzu, 1201, Japan). All determinations were conducted in triplicate. A calibration curve was established using freshly prepared 1 mg/mL Gallic acid dissolved in water, serially diluted to concentrations of 0.2 mg/mL, 0.4 mg/mL, 0.6 mg/mL, 0.8 mg/mL, and 1 mg/mL. A regression equation of $y = 1159x + 0.0112$ with $R^2 = 0.998$ was derived. The polyphenolic content in each extract was calculated from the calibration curve, and the results were recalculated and expressed as gallic acid equivalents per gram of dry vegetable sample (mg GAE/gdwb).

4.2.4 Determination of Total Flavonoid Content

The evaluation of total flavonoid content (TFC) in the samples utilized the aluminium chloride colorimetric assay method (Zhishen *et al.*, 1999), employing quercetin as the standard. In this process, 500 µl of extracts was combined with 1500 µl of 99.9% ethanol (EtOH), 100 µl of 1 M potassium acetate, 100 µl of 10% aluminium chloride, and 3000 µl of distilled water. After vigorous shaking, the mixture was allowed to stand in the dark at room temperature for 15 minutes, followed by a 30-minute incubation period at room temperature. The absorbance was measured at 415 nm, and all determinations were conducted in triplicate. A standard calibration curve was developed using quercetin standard solutions ranging from 12.5 µg/ml to 100 µg/ml. Each standard (500 µl) underwent the same treatment as the samples, resulting in a linear regression equation for the calibration curve: $y = 0.0105x + 0.0054$. The flavonoid content in each extract was determined from the curve, and the results were recalculated and expressed as micrograms of quercetin equivalent per gram of dry sample (µg QE/gdwb).

4.2.5 Determination of Antioxidant Activity

The assessment of the extracts' free radical scavenging ability against DPPH free radicals followed the procedure outlined by Oliveira *et al.* (2008). In brief, 200 µl of each extract was introduced to 3800 µl of 0.004% DPPH methanolic solution. Following a 60-minute incubation period at room temperature in the dark, absorbance was measured at 517 nm. A blank sample comprising only methanol was employed to calibrate the spectrophotometer. Ascorbic acid served as a reference for comparison. Each experiment was conducted in triplicate.

The calculation for antioxidant activity (I%) is as follows:

$$I\,\% = \left[\frac{Abs_0 - Abs_1}{Abs_0}\right] * 100 \qquad (1)$$

Where Abs_0 = absorbance of 0.004% DPPH without analyte.

Abs_1 = absorbance of 0.004% DPPH plus the test compound

4.2.6 Determination of carotenoids using high-performance liquid chromatography (HPLC)

4.2.6.1 Determination of Lutein and β-carotene

The method was based on a procedure established by Kimura and Rodriguez-Amaya (2002). Three (3) grams of sample (dry matter) were extracted with 50 mL of cold acetone and filtered through a Buchner funnel until loss of pigmentation. The extract was taken in a separating funnel (500ml) and partitioned to petroleum ether (40ml). Distilled water was gently introduced along the walls of the funnel and the two phases were allowed to separate. Washing was repeated about three times and the lower phase was carefully discarded. The upper phase was collected through a small funnel containing anhydrous sodium sulphate (15 g) and the filtrate was dried under nitrogen, redissolved immediately in HPLC grade acetone(1mL), filtered through a 0.45μm syringe filter (Millipore) directly into sample vials and injected into the chromatograph.

4.2.6.2 Standard Solutions

Precise quantities of lutein and β-carotene were accurately measured and dissolved in methanol to create stock standard solutions at concentrations ranging from 1.0 to 5.0 mg/mL. Subsequently, these stock solutions were further diluted to generate a range of concentrations from 0.1 to 5.0 mg/L, forming standard working solutions. The calibration curves for each carotenoid were constructed by plotting the peak area against the respective concentration.

4.2.6.3 HPLC Conditions

The HPLC analyses were conducted using an Agilent 1100 system (Santa Clara, CA, USA), which consisted of a quaternary pump, autosampler, diode array detector (DAD), and HP ChemStation Software. Carotenoids were separated on an ODS C18 column (250 x 4.6 mm i.d., 5µm particle size) maintained at 30^{o}C. The mobile phase for carotenoid separation was a mixture of methanol and hexane (90:10, v/v). HPLC analysis involved injecting 15 µL of samples under isocratic conditions at a flow rate of 0.7 mL/min, with monitoring at 450 nm using a UV-Vis detector (Shimadzu, Tokyo, Japan).

The peak identities of carotenoids were verified by comparing HPLC retention times with corresponding standards and co-chromatography with added standards. Additional confirmation was achieved by comparing spectral data obtained with a photodiode array detector (Azevedo-Meleiro & Rodriguez-Amaya, 2004). Quantification was performed based on peak areas relative to respective reference standards. The limits of detection (LOD) were defined as the carotenoid amount resulting in a peak height three times the baseline noise, and limits of quantification (LOQ) were set at 2.5 times the LOD (Taylor *et al*., 2006). The detection limit for β-carotene and lutein was 0.50 µg/100g and 0.45 µg/100g, respectively, while the LOQ was determined to be 1.5 µg/100g and 1.35 µg/100g, respectively.

4.2.6.4 Determination of Catechins, Quercetin and Chlorogenic acids using HPLC

The method of Gottumukkala *et al.* (2014) was used with slight modification. The use of three grams (3) of sample and formic acid in HPLC water was the modification to 50mg of sample and orthophosphoric acid in HPLC water.

4.2.6.1 Standard Solutions

Standard solutions of catechins, quercetin, and chlorogenic acids (4 mg/mL) were created by dissolving the respective standards in methanol. As required, less concentrated solutions were prepared by diluting with methanol. Calibration standards ranging from 100 to 600 μg/mL were formulated by diluting each stock solution with methanol. Standard curves were generated by plotting the peak areas against the various concentrations.

4.2.6.2 Preparation of samples

Three grams of the sample were placed in a 100 mL volumetric flask with 75 mL of methanol, left to stand for 20 minutes, and sonicated for an additional 10 minutes. The solution was then diluted to 100 mL with methanol and filtered through a 0.45 μm membrane syringe filter (Millipore) directly into sample vials, ready to be injected into the chromatograph.

4.2.6.3 HPLC Condition

The HPLC analysis was conducted using an Agilent 1100 system (Santa Clara, CA, USA), consisting of a quaternary pump, autosampler, diode array detector (DAD), and HP ChemStation Software. Chromatographic separation took place on an ODS C18 analytical column (250 x 4.6 mm i.d., 5µm particle size) maintained at 30ºC. The mobile phase, composed of water with 0.1% formic acid (A) and acetonitrile (B), flowed at a rate of 0.7 mL/min. The gradient program was set as follows: 0–10 min, 10–20 %B; 10–15 min, 20–30 %B; 15–20 min, 30–60 %B; 20–25 min, 60–80 %B; 25–30 min, 80–80 %B; 30–35 min, 80–10 %B, 35–40 min, 10–10 %B. An injection volume of 20 µL was used, and the wavelength was monitored at 280 nm. Specificity was ensured by analyzing both standards and samples, confirming peaks for catechin, quercetin, and chlorogenic acid by comparing their retention times with those of standards. The limits of quantitation (LOQ) and detection (LOD) were set at concentrations with signal-to-noise ratios of 3 and 10, respectively, resulting in detection limits of 0.012 µg/100g for catechin, 0.015 µg/100g for quercetin, and 0.036 µg/100g for chlorogenic acid.

4.3 Results and Discussion

4.3.1 Antioxidant activity of the selected vegetables

The DPPH radical scavenging activity was used to investigate the antioxidant potential of extracts of selected vegetables. Results of the effect of blanching and drying on the antioxidant activity are shown in Table 4.1. Blanching and drying contributed to the reduction of antioxidant activity in the selected vegetables when compared to the fresh produce.

Blanching had significant effects ($p \leq 0.05$) on the antioxidant activity of the dried vegetables with higher values recorded in the unblanched samples compared with the blanched samples. This reduction might be due to the degradation of phenolic compounds by heat or leaching from the vegetable tissues. During blanching, disruption of the cell wall of the plant may occur leading to leaching of the soluble phenolic compounds (Bamidele *et al.,* 2017; Irondi *et al.,* 2016). Findings of this study are consistent with those of Chan *et al.* (2014), who reported that blanching of vegetables generally caused declines in antioxidant activity in vegetables. Ethanol extracts of the samples recorded higher antioxidant activity than aqueous extracts. This may be due to the interaction and higher solubility of antioxidant compounds in ethanol (Mohammed *et al.*, 2022).

The drying process is known to affect the antioxidant potential of fruits and vegetables (Kamiloglu *et al.*, 2016). Among the drying methods employed, it was observed that freeze drying better retained the antioxidants in the samples compared to oven and solar drying. Freeze-drying is known to preserve the antioxidant activity of foods better than the other drying methods (Devi *et al.,* 2019) which may explain the higher antioxidant activity observed in the freeze-dried samples.

Table 4.1: Antioxidant activity of the selected vegetables (DPPH % scavenging activity)

Drying method	Amaranth leaves				Eggplant leaves			
	Aqueous extraction		Ethanol extraction		Aqueous extraction		Ethanol extraction	
	Unblanched	Blanched	Unblanched	Blanched	Unblanched	Blanched	Unblanched	Blanched
Freeze	52.60±0.16^{bA}	49.66±0.16^{aA}	72.97±0.65^{aB}	47.29±1.45^{bB}	35.65±0.39^{bB}	26.10±0.17^{aA}	69.80±0.61^{aA}	40.11±1.21^{bA}
Oven	23.79±0.16^{bB}	20.26±0.26^{aB}	47.76±0.80^{aC}	42.98±1.84^{bA}	26.81±0.26^{aC}	21.65±0.04^{cC}	59.88±0.65^{aB}	37.48±0.98^{bB}
Solar	21.12±0.10^{aC}	16.09±0.33^{bC}	41.03±0.92^{aA}	41.63±1.84^{aC}	24.83±0.24^{bA}	17.55±0.26^{aB}	43.42±0.62^{aC}	32.81±0.01^{bC}
Fresh	76.55±1.09		82.76±0.16		59.63±1.18		72.11±1.22	
	Carrots				Turkey berries			
Drying method	Aqueous extraction		Ethanol extraction		Aqueous extraction		Ethanol extraction	
	Unblanched	Blanched	Unblanched	Blanched	Unblanched	Blanched	Unblanched	Blanched
Freeze	40.23±1.06^{aA}	32.90±0.75^{bB}	40.23±1.06^{aA}	32.92±0.01^{bB}	69.37±0.42^{aA}	43.81±0.53^{bA}	79.29±0.20^{aA}	78.62±0.14^{aA}
Oven	28.24±0.13^{aB}	17.65±0.27^{bC}	32.89±0.75^{aB}	30.32±0.20^{bB}	44.47±0.88^{aB}	39.84±1.34^{bB}	46.58±0.20^{aB}	45.28±0.13^{aB}
Solar	17.17±0.77^{aC}	14.44±0.26^{bA}	27.17±0.77^{aC}	18.15±0.10^{bA}	-	-	-	-
Fresh	44.44±1.67		59.54±0.97		102.39±0.86		113.80±0.13	

Means with different lowercase alphabets within rows are significantly different ($p \leq 0.05$). Means with different uppercase alphabets within columns are significantly different ($p \leq 0.05$). Fresh = non dehydrated

This could be because, in freeze drying, products are dried under low temperatures and vacuum; hence, there is minimum disruption of cell walls, which may result in the preservation of phytochemicals. On the other hand, oven and solar drying require relatively higher temperatures and prolonged exposure time, which may cause degradation of the phytochemicals.

4.3.2 Total Phenolic Content (TPC) of the selected vegetables

Phenolic compounds are phytochemicals found in all plants. The results of the effect of blanching and drying methods on the total phenolic content of the selected vegetables are shown in Table 4.2. There are many factors that govern the content of total phenolics of vegetables, including genetics, variety, and agrochemical characteristics of the soil. Results of this study showed varied phenolic contents in the selected vegetables with highest values observed in turkey berries contributing to the high antioxidant activity observed in Table 4.1. The vegetable samples generally demonstrated highest TPC in ethanolic extracts of unblanched samples. The observation of the effects of blanching and drying methods on the phenolic contents are similar to those made by Wang *et al* (2021) who observed that blanching reduced the phenolic contents in samples when compared to unblanched samples. Irondi *et al.* (2017) reported a decrease in the phenolic content of blanched *Adansonia digitata* leaves. They attributed the decrease in phenolic content to oxidation and leaching out of phenolic compounds during blanching. From the current study, freeze dried samples demonstrated a better preservation of phenolic content in the vegetables compared to the other methods.

Table 4.2: Total Phenolic Content (mg GAE/gdwb) of the selected vegetables

Drying method	Amaranth leaves				Eggplant leaves			
	Aqueous extraction		Ethanol extraction		Aqueous extraction		Ethanol extraction	
	Unblanched	Blanched	Unblanched	Blanched	Unblanched	Blanched	Unblanched	Blanched
Freeze	14.56±0.19^{aA}	12.35±0.25^{bB}	15.35±0.14^{aA}	12.64±0.97^{bB}	10.78±0.26^{aB}	10.78±0.38^{aB}	13.72±0.07^{aB}	10.56±0.07^{bB}
Oven	12.44±0.14^{aB}	10.53±0.19^{bA}	11.26±0.03^{aC}	10.89±0.25^{aA}	5.55±0.19^{aA}	5.55±0.31^{bA}	13.68±0.06^{aB}	6.82±0.14^{bA}
Solar	7.79±0.26^{aC}	5.01±0.12^{bC}	8.32±0.31^{aB}	10.13±0.15^{aA}	4.85±0.31^{aA}	6.09±0.31^{bA}	9.64±0.74^{aA}	7.65±0.12^{bA}
Fresh	19.03±1.32		24.05±1.53		15.53±0.26		23.70±0.36	
	Carrots				Turkey berries			
Drying method	Aqueous extraction		Ethanol extraction		Aqueous extraction		Ethanol extraction	
	Unblanched	Blanched	Unblanched	Blanched	Unblanched	Blanched	Unblanched	Blanched
Freeze	2.11±0.23^{aA}	2.53±0.12^{aA}	10.75±0.74^{aA}	3.74±0.14^{bA}	32.01±0.84^{bA}	18.90±0.14^{aA}	69.01±0.97^{bA}	43.98±0.19^{aA}
Oven	1.57±0.19^{bB}	0.45±0.19^{aC}	9.69±0.33^{aB}	5.24±0.19^{bB}	13.93±0.40^{bB}	10.61±0.25^{bB}	14.29±0.47^{aB}	13.84±0.19^{aB}
Solar	1.36±0.07^{bB}	0.95±0.19^{aB}	4.70±0.19^{aC}	4.61±0.26^{aC}	-	-	-	-
Fresh	2.99±0.12		11.90±0.19		37.87±1.52		79.01±1.23	

Means with different lowercase alphabets within rows are significantly different ($p \leq 0.05$). Means with different uppercase alphabets within columns are significantly different ($p \leq 0.05$). Fresh = non dehydrated; GAE/gdwb - Gallic acid equivalent per gram dry weight basis

4.3.3 Total flavonoid content (TFC) of the selected vegetables

Flavonoids are one of the most common phenolic compounds and groups in plant tissues (Somdee *et al.,* 2016). The amount of TFC estimated varied among the selected vegetables and results are shown in Table 3. Total flavonoid content of the fresh samples ranged from 371.89 µg QE/gdwb to 93.75 µg QE/gdwb. The highest levels were observed in turkey berries with lowest concentrations in carrots. In reference to the fresh samples, a general reduction in TFC was observed in the dehydrated samples. Drying influenced flavonoid concentrations with significant differences observed among the drying methods. The superior performance of freeze drying over oven and solar methods could be due to its low-temperature process.

Blanching is reported to induce significant changes in the phytochemicals, such as phenolic content and flavonoid content, which could be due to thermal degradation, diffusion, and/or leaching (Somdee *et al.,* 2016). Thus, this could have contributed to the observed reduction (Table 4.3) on the flavonoid concentrations of blanched samples compared to unblanched samples.

Table 4.3: Total Flavonoid Content (μg QE/gdwb) of the selected vegetables

Drying method	Amaranth leaves				Eggplant leaves			
	Aqueous extraction		Ethanol extraction		Aqueous extraction		Ethanol extraction	
	Control	Blanched	Control	Blanched	Control	Blanched	Control	Blanched
Freeze	328.88±5.68^{aA}	217.63±1.86^{bA}	547.10±3.65^{aA}	513.88±2.42^{bA}	307.68±2.46^{aA}	193.80±2.46^{bB}	343.79±11.54^{aA}	341.45±11.91^{aA}
Oven	216.02±2.46^{aB}	98.63±2.46^{bC}	393.30±23.10^{aB}	377.24±3.50^{aB}	227.81±2.46^{aB}	132.40±4.05^{bA}	341.98±11.25^{aA}	182.07±18.76^{bB}
Solar	181.18±2.46^{aC}	168.85±4.25^{bB}	361.70±1.43^{aC}	282.39±2.61^{bC}	186.84±1.61^{aC}	178.50±2.79^{bC}	179.03±14.50^{bB}	182.78±13.68^{aB}
Fresh	333.10±1.49		551.80±1.07		322.01±1.32		510.72±1.09	
Drying method	Carrots				Turkey berries			
	Aqueous extraction		Ethanol extraction		Aqueous extraction		Ethanol extraction	
	Control	Blanched	Control	Blanched	Control	Blanched	Control	Blanched
Freeze	90.05±3.22^{bA}	74.65±2.47^{aB}	118.96±3.27^{aA}	82.55±2.46^{bB}	170.10±19.56^{aA}	158.31±29.18^{bA}	376.83±4.05^{aA}	254.08±3.22^{bA}
Oven	56.28±3.22^{aB}	52.53±6.09^{aC}	80.72±2.46^{aB}	76.43±1.61^{bB}	169.75±33.94^{aA}	154.86±20.72^{bA}	256.76±2.46^{aB}	214.41±2.46^{bB}
Solar	25.19±1.86^{bC}	20.05±3.02^{aA}	40.20±1.61^{bC}	29.11±0.93^{aA}	-	-	-	-
Fresh	93.75±1.81		129.01±1.43		292.67±1.45		371.89±1.92	

Means with different lowercase alphabets within rows are significantly different ($p \leq 0.05$). Means with different uppercase alphabets within columns are significantly different ($p \leq 0.05$). Fresh = non dehydrated; QE/gdwb - Quercetin equivalent per gram dry weight basis

Table 4.4 shows a Pearson's correlation analysis between antioxidant components using aqueous and ethanolic extracts. The correlation between the DPPH scavenging activity and flavonoids is moderate in both extracts, with a slightly higher correlation in the ethanol extract ($r = 0.562$, $p < 0.01$) than in the aqueous extract ($r = 0.357$, $p < 0.05$). The correlation between the DPPH scavenging activity and phenolics is also moderate in both extracts, with a slightly higher correlation in the ethanol extract ($r = 0.737$, $p < 0.01$) than in the aqueous extract ($r = 0.560$, $p < 0.01$).

The observed correlations can be explained by the fact that flavonoids and phenolics are the major antioxidant components in the vegetables, and they exhibit strong antioxidant properties. The correlation between the DPPH scavenging activity and flavonoids/phenolics could be attributed to the fact that these compounds possess strong radical scavenging activity (Sreelatha & Padma, 2009).

In summary, the correlation analysis provides evidence that the dehydrated vegetable extracts have strong antioxidant activity, and the correlation between the antioxidant components varies depending on the extraction method. The strong positive correlation between the flavonoids and phenolics suggests that these compounds are the major contributors to the antioxidant activity of the vegetable extracts.

Table 4.4: Correlation between antioxidant components using aqueous and ethanolic extracts

Main effect	Total Flavonoids (Aqueous extract)	Total Flavonoids (Ethanol extract)	DPPH (Aqueous extract)	DPPH (Ethanol extract)	Total Phenolics (Aqueous extract)	Total Phenolics (Ethanol extract)
Total Flavonoids (Aqueous extract)	1					
Total Flavonoids (Ethanol extract)	.828**(0.00)	1				
DPPH (Aqueous extract)	.357**(0.00)	.288*(0.19)	1			
DPPH (Ethanol extract)	.606**(0.00)	.562**(0.00)	.685**(0.00)	1		
Total Phenolics (Aqueous extract	.789**(0.00)	.864**(0.00)	.560**(0.00)	.755**(0.00)	1	
Total Phenolics (Ethanol extract	.706**(0.00)	.692**(0.00)	.728**(0.00)	.737**(0.00)	.756**(0.00)	1

****. Correlation is significant at the 0.01 level.**

***. Correlation is significant at the 0.05 level.**

4.3.4 Phytochemicals in dehydrated vegetables

Phytochemicals in vegetables contribute to their nutritional and potential health benefits. Table 4.5 shows the effect of different drying methods and blanching on some of the polyphenols (chlorogenic acid, catechin, quercetin), lutein, and beta-carotene in selected dehydrated vegetables. Generally, blanching and drying resulted in a reduction in the content of phytochemicals in the selected vegetables compared to the fresh samples. Freeze-drying better preserved these compounds compared to the other drying methods. From the table, turkey berries were observed to be rich sources of polyphenols with high concentrations of chlorogenic acids whereas beta carotene was abundant in all the selected vegetables, particularly carrots and amaranth leaves. Unblanched freeze dried turkey berries preserved the polyphenol content however, blanching significantly reduced the concentrations. Blanching could cause leaching of some compounds, leading to a reduction in their content. Ahmed and Eun (2018) reported that blanching could result in the disruption of cells and degradation of polyphenols due to polymerization or oxidative degradation. Oven drying and solar drying often resulted in significant reductions in phytochemical content. However, the impact of blanching and drying varied among the different phytochemicals and the specific vegetable samples. The variability in the data observed in the current study can be attributed to several factors, including the drying method, treatment, and extraction solvent used. For example, the freeze-drying process involves removing moisture from the sample at low temperatures, which may result in the preservation of phytochemicals. On the other hand, oven-drying may result in higher temperatures, which may cause degradation of the phytochemicals. The use of different solvents for extraction may also affect the yield of phytochemicals, as some solvents may be more effective than others. The drying methods and treatment could affect the phytochemical content by altering the structure and composition of the plant tissues, thereby affecting the extraction and release of phytochemicals (Bamidele *et al.*, 2017). The extraction solvent used also affected the yield of phytochemicals extracted. The differences in phytochemical content and antioxidant activity between the drying methods may be due to differences in the drying temperature, duration, and the rate of water removal, which can affect the retention of phytochemicals in the dried samples.

4.3.5 **Conclusion**

Drying methods and extraction solvent had significant ($p<0.05$) effect on the phytochemical content of the vegetables in this study. Freeze-drying better preserved the phytochemicals compared with the other drying methods. Ethanol extraction was generally more effective in extracting flavonoids and phenolics from the vegetables. Blanching caused a reduction in the phytochemical content compared with the unblanched samples. Freeze-drying resulted in the highest levels of total flavonoids, DPPH inhibition, and total phenolics for both aqueous and ethanol extractions. Solar drying resulted in the lowest levels of these parameters. These drying methods must be optimized to harness the full nutritional and nutraceutical potential of these vegetables for the health of the consumer.

Table 4.5: Concentration of selected phytochemicals in dehydrated vegetables

Phytochemicals	**Drying methods**	**Amaranth leaves**		**Eggplant leaves**		**Carrot**		**Turkey berries**	
		Control	**Blanched**	**Control**	**Blanched**	**Control**	**Blanched**	**Control**	**Blanched**
Chlorogenic acid (µg/100g)	Fresh	63.45±0.01^{dA}	56.45±0.01^{eA}	520.63±0.01^{cA}	511.74±0.01^{cA}	832.24±0.01^{bA}	805.16±0.01^{bA}	1381.54±0.01^{aA}	1291.05±0.01^{aA}
	Freeze	56.49±0.01^{eB}	45.16±0.01^{fB}	514.36±0.01^{cA}	317.99±0.01^{dB}	789.29±0.01^{bB}	24.18±0.01^{gB}	1374.00±0.01^{aA}	45.88±0.01^{fB}
	Oven	34.13±0.01^{dC}	40.15±0.01^{cC}	208.10±0.01^{aB}	22.32±0.01^{eC}	47.52±0.01^{cB}	21.89±0.01^{eB}	68.61±0.01^{bB}	4.02±0.01^{fC}
	Solar	1.63±0.01^{dD}	1.89±0.01^{dD}	36.34±0.01^{aC}	14.57±0.01^{cD}	19.49±0.01^{bC}	1.95±0.01^{dC}	-	-
Catechin (µg/100g)	Fresh	6.72±0. 01^{fA}	5.28±0. 01^{gA}	50.12±0. 01^{cA}	31.07±0. 01^{dA}	38.73±0. 01^{dA}	26.45±0. 01^{eA}	93.11±0. 01^{aA}	61.11±0. 01^{bA}
	Freeze	6.20±0.10^{aA}	2.39±0.01^{bB}	46.72±0.01^{aA}	1.86±0.01^{bB}	35.77±0.01^{aA}	18.64±0.01^{bB}	90.02±0.01^{aA}	18.16±0.01^{bB}
	Oven	2.45±0.01^{dB}	2.36±0.01^{dB}	18.37±0.01^{aB}	1.93±0.01^{dB}	8.22±0.01^{bB}	1.54±0.01^{cC}	7.52±0.01^{cB}	0.68±0.01^{fC}
	Solar	2.71±0.01^{bB}	0.93±0.01^{cC}	2.33±0.01^{bC}	0.84±0.01^{cC}	3.13±0.01^{aC}	0.48±0.01^{dD}	-	-
Quercetin(µg/100g)	Fresh	12.68±0.01^{cA}	9.71±0.01^{dA}	13.37±0.01^{cA}	10.12±0.01^{dB}	5.84±0.01^{eA}	3.13±0.01^{fA}	42.35±0.01^{aB}	38.97±0.01^{bB}
	Freeze	10.98±0.01^{aB}	1.98±0.01^{bD}	5.51±0.01^{aC}	4.31±0.01^{bD}	4.15±0.01^{aB}	0.81±0.01^{bC}	35.55±0.01^{aC}	10.55±0.01^{bC}
	Oven	4.22±0.01^{dC}	3.17±0.01^{eB}	6.96±0.01^{cB}	31.30±0.01^{bA}	1.79±0.01^{fC}	1.64±0.01^{fB}	89.41±0.01^{aA}	90.72±0.01^{aA}
	Solar	2.94±0.01^{cD}	2.08±0.01^{cC}	12.57±0.01^{aA}	6.08±0.01^{bC}	6.82±0.01^{bA}	1.17±0.01^{dB}	-	-
Lutein(µg/100g)	Fresh	13.37±0.01^{fA}	10.48±0.01^{gA}	90.45±0.01^{aA}	78.97±0.01^{bA}	95.23±0.01^{aA}	65.88±0.01^{cA}	43.18±0.01^{dA}	29.83±0.01^{eA}
	Freeze	9.37±0.01^{eB}	3.42±0.01^{fC}	86.42±0.01^{aA}	74.65±0.01^{bA}	87.23±0.01^{aA}	28.92±0.01^{dB}	37.19±0.01^{cB}	3.02±0.01^{fC}
	Oven	8.73±0.01^{cC}	7.70±0.01^{fB}	56.14±0.01^{aB}	29.39±0.01^{cB}	49.66±0.01^{bB}	22.62±0.01^{cC}	17.28±0.01^{dC}	8.76±0.01^{eB}
	Solar	3.59±0.01^{cD}	1.57±0.01^{bD}	5.64±0.01^{bC}	3.08±0.01^{cC}	7.52±0.01^{aC}	5.71±0.01^{bD}	-	-

Beta carotene(µg/100g)	Fresh	7921.06±0.01^{aA}	5101.23±0.01^{bA}	3501.12±0.01^{cA}	1587.33±0.01^{eA}	25256.60±0.01^{dA}	1986.10±0.01^{eA}	246.98±0.01^{fB}	198.13±0.01^{gB}
	Freeze	7631.88±0.01^{aA}	4023.21±0.01^{bB}	3472.75±0.01^{cA}	501.77±0.01^{fB}	23356.30±0.00^{dA}	1965.50±0.00^{eA}	198.11±0.01^{gC}	521.78±0.01^{fA}
	Oven	5309.47±0.01^{aB}	1271.36±0.01^{eD}	2478.70±0.01^{bB}	1188.44±0.01^{eA}	16285.80±0.00^{cB}	1408.10±0.01^{dB}	571.82±0.01^{fA}	579.04±0.01^{fA}
	Solar	3309.94±0.01^{aC}	2988.33±0.01^{bC}	368.03±0.01^{cC}	270.45±0.01^{dC}	2293.33±0.01^{bA}	2059.79±0.01^{bA}	-	-

Means with different lowercase alphabets within rows are significantly different ($p \leq 0.05$). Means with different uppercase alphabets within columns are significantly different ($p \leq 0.05$). Fresh = non dehydrated vegetable.

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CHAPTER FIVE

CHANGES IN NUTRITIONAL AND ANTI-NUTRITIONAL COMPOSITIONS OF DEHYDRATED VEGETABLES AS A RESULT OF PRE-PROCESS TREATMENTS

5.1 Introduction

Humans need a wide range of nutrients for growth and development to achieve active and healthy lives. Vegetables, apart from adding variety to the menu, are valuable sources of nutrients, including protein, carbohydrates (including fibre), micronutrients (minerals, vitamins), and other nutrients in daily diets (Asaolu *et al.,* 2012; Ozel, 2017). Micronutrients such as vitamins and minerals are essential dietary compounds obtained from different edible parts of plants (Arhin *et al.*, 2017). Minerals are inorganic nutrients required by the body in small amounts. They are necessary for the maintenance of specific physicochemical processes that are essential to life. Malnutrition leads to the possibility of chronic diseases such as stunted growth and some other nutritional disorders. Calcium, zinc, iron, and vitamin A deficiency are of global health concern. The consumption of vegetables is necessary in the prevention of several diseases however, these plant sources also possess a group of substances known as antinutrients, which can either hinder nutrient absorption or have health benefits (López-Moreno *et al.*, 2022). Antinutrients, such as tannins, oxalates, and phytates, are naturally occurring compounds found in various plant foods. For these, different processing methods have been found to reduce their quantity in foods (López-Moreno *et al.*, 2022). The high perishability of vegetables due to their high moisture content and seasonality affects their availability all year round. To ensure stability on the shelf, vegetables are dried, ground and used in the form of powder (Ying *et al.*, 2021). Blanching is a common preliminary step prior to drying under different conditions. It is, therefore, necessary to understand the effects of blanching and drying on the nutritional and antinutritional properties of vegetables.

The main aim of this study was to evaluate the effect of blanching and drying (solar drying, oven drying and freeze drying) on the nutritional and antinutritional composition of selected vegetables.

5.2 Materials and Methods

5.2.1 Sample preparation and dehydration

Selected vegetables (carrots, turkey berries, amaranth and eggplant leaves) were destalked and washed thoroughly with distilled water. Samples of carrot slices (2mm), amaranth leaves and eggplant leaves were each portioned into blanched (steam blanched) and unblanched groups and further subjected to oven, solar and freeze drying. Turkey berry samples were divided into blanched (hot water blanched) and unblanched groups and each group was dried using oven and freeze-drying methods. Solar dried turkey berries were mouldy and blackened due to the extended drying time (about nine days) and were therefore not included in the study. Oven drying (Memmert UF 110 model; Germany) was conducted at 40˚C (amaranth and eggplant leaves) and 60˚C (turkey berries and carrots). Solar drying was performed using a direct solar dryer (Dehytray^{TM}). Samples were freeze-dried using a standard unheated chamber of dimensions 215 × 300 mm height (Telstar LyoQuest-55, Milan, Italy) at a vacuum pressure of 100 Pa and a final condenser temperature of −55˚C.

5.2.2 Proximate Composition of Samples

5.2.2.1 Crude Fat

The crude fat content of each sample was determined following the procedure outlined in AOAC (2005) using a Soxhlet extractor. 2 g of each sample were weighed and placed in filter paper, which was then inserted into an extraction thimble. The thimble was positioned in the extractor, and extraction was conducted using petroleum ether (boiling-point 40–60ºC) for a duration of 5 hours.

Subsequently, the filter papers were meticulously extracted, dried in an air-oven at 106°C for 30 minutes, allowed to cool in a desiccator, and then weighed. The percentage of crude fat was calculated using the formula:

$$\%\,Crude\ fat = \frac{Loss\ in\ weight}{weight\ of\ sample} * 100 \qquad (1)$$

5.2.2.2 Fiber Content

The determination of crude fiber in each sample was conducted in accordance with the method outlined in AOAC (2005). Initially, 1.25% freshly prepared sulfuric acid (200 mL) was added to 2 g of the sample (W1) in a 500 mL conical flask. The mixture was gently boiled for 30 minutes, with a cooling finger employed to maintain a consistent volume. Following this, the mixture was filtered through muslin cloth, and the residue was washed until free of acid. Subsequently, 1.25% NaOH (200 mL) was added, and the mixture was boiled for an additional 30 minutes. After another filtration using muslin cloth, the residue underwent thorough washing with hot distilled water (four times) and one rinse each with 10% HCl and hot distilled water (four times). The residue was further rinsed with ethanol and three times with petroleum ether (boiling range 40–60°C). The rinsed residue was then transferred to a previously ignited silica dish at 600°C, cooled, and dried to a constant weight (W2) at 105°C. The organic matter of the residue was ignited in a muffle furnace at 600°C for 30 minutes, cooled in a desiccator, and weighed (W3). The loss in ignition was reported as crude fibre and calculated as follows:

$$\%\,Crude\ fiber = \frac{w2-w3}{w1} * 100 \qquad (2)$$

5.2.2.3 Moisture content

The moisture content of the chosen dehydrated vegetables was assessed using the air-oven method. Two grams of the samples were weighed, subjected to drying at 105°C for 4 hours, and then cooled in a desiccator. The samples underwent further drying until a consistent weight was achieved, and the percentage moisture content was subsequently calculated as follows:

$$\%\ Moisture\ content = \frac{weight\ lost}{sample\ weight} * 100 \quad (3)$$

5.2.2.4 Ash Content

The ash content percentage was assessed using a hot muffle furnace. Two grams of each sample were measured into a dish, and the organic matter was incinerated through ignition in a muffle furnace at 550°C for 5 hours. Ashing persisted until a consistent weight was achieved. The dish with the residue was then cooled in a desiccator, and the ash content percentage was calculated using the following equation:

$$\%\ Ash = \frac{weight\ of\ the\ ash}{weight\ of\ the\ sample} * 100 \quad (4)$$

5.2.2.5 Crude Protein

The crude protein content was determined using the standard micro Kjeldahl method. Approximately 0.2 grams of each sample were weighed into a micro-Kjeldahl flask. A mixed catalyst, consisting of copper (II) tetraoxosulphate (VI) and sodium tetraoxosulphate, was added along with 3.5 mL of concentrated tetraoxosulphate (VI) acid. Each sample and its content were heated on an electrical heater for 2 hours (digestion). The digested material was then cooled and placed in the distillation apparatus. To this, 20 mL of 40% NaOH was added, and the mixture was heated and distilled until 50 mL was collected in a 100 mL conical flask. The evolved ammonia was received in 10 mL of 2% boric acid. The trapped ammonia was titrated against 0.02 N hydrochloric acid (HCL) using universal indicator (Bromo cresol green and methyl red in alcohol). The protein content percentage was calculated as follows:

$$\%\,Crude\ Protein = \frac{Molarity\ of\ HCl * 0.014 * titre\ value * dilution\ factor}{weight\ of\ sample} * 100 \qquad (5)$$

5.2.2.6 Total Carbohydrates

The carbohydrate contents of the dehydrated vegetable samples were calculated as the difference in dry sample weight. This involved subtracting the sum of the percentages of protein, crude fat, total ash content, crude fibre, and moisture content from 100%. The results were subsequently expressed on a dry weight basis.

$$\%\,\text{Carbohydrate} = 100\% - (\text{Sum of the \%moisture, ash, fat, crude fiber and crude protein})$$

(6)

5.2.2.7 Estimation of Energy

The sample calorific value was estimated (in kcal/g) by multiplying the percentage crude protein, crude fat, and carbohydrate by the recommended Atwater factors of 4, 9, and 4 respectively (FAO, 2006).

5.2.2.8 Mineral Composition

The procedure involved weighing 1.0g of the samples and placing them in a clean porcelain crucible, which was then heated to 550°C in a muffle furnace. The resulting ash was dissolved in 5.0ml of HNO3/ HCl/ H2O (1:2:3) and gently heated until brown fumes disappeared. Subsequently, 5.0ml of distilled water was added to each sample in the crucible and heated until a colourless solution was achieved. The mineral solution underwent filtration into a 100.0ml volumetric flask through filter paper, and the volume was adjusted to the mark with distilled water. The solution was analyzed in triplicate for its elemental composition using the Perkin Elmer 403 model of atomic absorption spectrophotometer, with sodium and potassium contents determined by flame photometry. The concentration of each element in the sample was calculated as a percentage (%) of dry matter.

5.2.3 pH and water activity

Ten (10) g of the sample was homogenized in a blender with 10 ml of distilled water and topped up to 100 ml with distilled water. The pH was determined using a Jenway Research pH meter (model 3330, Gransmore Green, England) (Ogori *et al.*, 2020). Water activity was determined using Hydrolab Multi-channel Humidity and Water Activity Analyzer (Huntington, USA)

5.2.4 Determination of Antinutrients

5.2.4.1 Tannin

Tannin content in the samples was measured following the method outlined by Bainbridge *et al.* (1996). Approximately 1 mL of the methanolic extract was combined with 5 mL of vanillin reagent, and the mixture was left to incubate at room temperature for 30 minutes. Subsequently, the absorbance was recorded at 500 nm using a spectrophotometer (PG Instruments, England). The tannin content of the samples was determined using a calibration curve prepared with tannic acid (2 mg/mL) as the standard.

5.2.4.2 Oxalate

The titration method outlined by Day and Underwood (1986) was employed. About 1 g of the sample was weighed into a 100 ml conical flask, and then 75 ml of 3 M H_2SO_4 was added, stirring for 1 hour with a magnetic stirrer. After filtration using Whatman No. 1 filter paper, 25 ml of the filtrate was extracted and titrated while hot against a 0.05M $KMnO_4$ solution until a persistent pink colour remained for at least 30 seconds. The oxalate content was subsequently calculated, considering 1 ml of 0.05M $KMnO_4$ as equivalent to 2.2 mg of oxalate.

5.2.4.3 Phytates

The method reported by Lubem, *et al.* (2019) was adopted for phytate quantification. About 4g of finely ground sample was soaked in 100 ml of 2% HCl v/v for 3 h and filtered into a 250 ml conical flask. To the filtrate, 5 ml of 0.3% ammonium thiocyanate solution and 50ml distilled water were added, thoroughly mixed, and titrated against standard $FeCl_3$ (containing 0.00195g Iron (III) Chloride) until a wine colour persisted for 5 min. Blank was titrated similarly and 1 ml which equals 1.19 mg phytin phosphorus was determined and the phytate content was calculated by multiplying by a factor of 3.55.

5.3 Results and Discussion

5.3.1 Proximate analysis, pH and water activity of selected dehydrated vegetables

The results of the proximate analysis of the dehydrated vegetables are shown in Table 5.1. There were significant effects ($p \leq 0.05$) of the drying methods on the various proximate composition of the four selected vegetables. The moisture content of blanched and unblanched vegetables for the different drying methods was within the range of (3.14±0.0 1- 13.10±0.01) % and (4.25 – 11.11) %, respectively. Freeze-dried, blanched eggplant leaves recorded the least moisture content, and solar-dried blanched carrots recorded the highest moisture content of 13.10%. Pre-treatment (blanching) of the selected vegetables did not have significant effects ($p \geq 0.05$) on the water activity. However, the drying methods had significant effects ($p \leq 0.05$) on the water activity of the vegetables. The water activity (a_w) values ranged from 0.43 to 0.68, with the lowest value observed in the unblanched freeze dried carrot and the highest value observed in the blanched oven dried carrot. Blanched vegetables generally had higher a_w values than unblanched vegetables. Water activity lower than 0.6 is considered microbiologically safe for storage (Gichau *et al.*, 2020) as it enhances the product's stable shelf life. The pH values of freeze-dried amaranth ranged from 5.25 to 5.32 and were not statistically significant ($p \geq 0.05$). This trend was observed in the other unblanched and the blanched samples. However, significant differences ($p \leq 0.05$) were recorded in the pH values with respect to the different drying methods. The blanching process generally resulted in lowering the acidity of the vegetables, and this could be due to the leaching of water-soluble organic acids into the blanching water (Table 5.1). However, the lower pH values observed in the dried turkey berry samples could be due to the nature of their tough cell walls, which may have reduced the rate of leaching (Barreiro *et al.,* 2008; Lin *et al.*, 2010).

The fibre content of the vegetables ranged from 0.14% to 3.32%, with blanched vegetables generally having higher fibre content than the control vegetables. This could be due to the breakdown of cell walls during blanching, which may have made the fibre more accessible and easier to extract (Zhang *et al.*, 2014; Wali *et al.*, 2018). Most vegetables are low in acid and sugar, making them prone to spoilage and a shorter shelf-life. Blanching of vegetables is done to slow down the enzymatic activities, soften the cell structures and allows a faster rehydration process. However, blanching could reduce the nutritional composition (Odedeji *et al.*, 2014).

Table 5.2 shows the mineral composition of blanched and unblanched vegetables dehydrated under three drying methods. The iron content of all the samples was high compared with recommended daily allowance (RDA) (mg/day). Iron is an important trace element in the body, and its deficiency has been described as the most common nutritional deficiency in the world, especially in Africa (WHO, 2008). Oven dried amaranth leaves recorded the highest amount of iron (14.99mg/100g) with solar dried carrots, recording the least (8.34mg/100g). The level of zinc in the dehydrated leafy vegetable samples were moderately high.

Table 5.1: pH, water activity and proximate analysis of selected dehydrated vegetables.

Parameter	Drying method	Amaranth		Eggplant		Turkey berries		Carrot	
		Control	Blanched	Control	Blanched	Control	Blanched	Control	Blanched
pH	Freeze	5.32 ± 0.01^{bA}	5.25 ± 0.01^{bB}	6.88 ± 0.01^{aA}	6.47 ± 0.02^{bC}	5.48 ± 0.01^{aA}	4.91 ± 0.01^{bA}	5.57 ± 0.01^{aA}	5.06 ± 0.01^{bC}
	Oven	5.18 ± 0.00^{bC}	5.55 ± 0.01^{bA}	5.20 ± 0.00^{bC}	6.64 ± 0.01^{aA}	5.22 ± 0.01^{aB}	4.89 ± 0.01^{bB}	5.54 ± 0.01^{aB}	5.22 ± 0.01^{bB}
	Solar	5.30 ± 0.00^{bB}	5.56 ± 0.01^{bA}	6.58 ± 0.01^{aB}	6.51 ± 0.01^{bB}	-	-	4.91 ± 0.01^{bC}	5.41 ± 0.01^{aA}
a_w	Freeze	0.49 ± 0.00^{bC}	0.51 ± 0.00^{bC}	0.48 ± 0.00^{bC}	0.50 ± 0.00^{aC}	0.46 ± 0.00^{aA}	0.43 ± 0.00^{bA}	0.52 ± 0.00^{bC}	0.54 ± 0.00^{aC}
	Oven	0.53 ± 0.00^{bB}	0.55 ± 0.00^{bB}	0.54 ± 0.00^{aB}	0.53 ± 0.00^{bB}	0.45 ± 0.00^{aB}	0.43 ± 0.00^{bA}	0.65 ± 0.00^{bA}	0.68 ± 0.00^{aA}
	Solar	0.56 ± 0.00^{bA}	0.58 ± 0.00^{bA}	0.55 ± 0.00^{bA}	0.56 ± 0.00^{aA}	-	-	0.63 ± 0.00^{aB}	0.58 ± 0.00^{bB}
Fat (%)	Freeze	1.86 ± 0.01^{bA}	2.44 ± 0.01^{bA}	2.67 ± 0.01^{bA}	2.95 ± 0.01^{aB}	2.24 ± 0.01^{bB}	4.26 ± 0.01^{aA}	0.39 ± 0.01^{aC}	0.52 ± 0.01^{bC}
	Oven	1.17 ± 0.01^{bC}	2.34 ± 0.01^{bB}	2.65 ± 0.01^{aA}	2.39 ± 0.01^{bC}	3.14 ± 0.01^{bA}	3.21 ± 0.01^{aB}	1.36 ± 0.01^{aA}	0.95 ± 0.01^{bA}
	Solar	1.41 ± 0.01^{bB}	2.04 ± 0.01^{bC}	1.99 ± 0.01^{bB}	3.05 ± 0.01^{aA}	-	-	0.83 ± 0.01^{aB}	0.78 ± 0.01^{bB}
Fiber (%)	Freeze	1.44 ± 0.01^{bA}	2.06 ± 0.01^{bA}	1.68 ± 0.01^{aA}	1.64 ± 0.01^{bC}	2.01 ± 0.01^{bB}	3.32 ± 0.01^{aB}	0.14 ± 0.01^{bC}	0.23 ± 0.01^{aC}
	Oven	1.07 ± 0.01^{bB}	1.98 ± 0.01^{bB}	1.63 ± 0.01^{bA}	1.98 ± 0.01^{aB}	2.97 ± 0.01^{aA}	2.98 ± 0.01^{aA}	1.06 ± 0.01^{aA}	0.63 ± 0.01^{bB}
	Solar	0.96 ± 0.01^{bC}	0.88 ± 0.01^{bC}	1.20 ± 0.10^{bB}	2.31 ± 0.01^{aA}			0.71 ± 0.01^{aB}	0.66 ± 0.01^{bA}
Ash (%)	Freeze	13.33 ± 0.01^{bC}	18.52 ± 0.01^{bB}	13.25 ± 0.01^{aB}	10.00 ± 0.01^{bC}	7.06 ± 0.01^{aB}	6.65 ± 0.01^{bB}	5.56 ± 0.01^{bC}	5.88 ± 0.01^{aC}
	Oven	16.44 ± 0.01^{bB}	16.42 ± 0.01^{bC}	12.33 ± 0.01^{bC}	12.50 ± 0.01^{aB}	9.09 ± 0.01^{aA}	6.81 ± 0.01^{bA}	6.49 ± 0.01^{bB}	8.11 ± 0.01^{aA}
	Solar	18.29 ± 0.01^{bA}	19.35 ± 0.01^{bA}	14.95 ± 0.01^{bA}	16.04 ± 0.01^{aA}			8.65 ± 0.01^{aA}	7.58 ± 0.01^{bB}
Moisture (%)	Freeze	4.25 ± 0.01^{bC}	3.86 ± 0.01^{bC}	4.76 ± 0.01^{bC}	3.14 ± 0.01^{aC}	5.12 ± 0.01^{aB}	4.33 ± 0.01^{bB}	5.09 ± 0.01^{aC}	4.50 ± 0.01^{bC}
	Oven	10.96 ± 0.01^{bA}	8.47 ± 0.01^{bA}	7.50 ± 0.01^{aB}	5.88 ± 0.01^{bA}	6.33 ± 0.01^{aA}	5.62 ± 0.01^{bA}	10.28 ± 0.01^{aB}	7.41 ± 0.01^{bB}
	Solar	5.41 ± 0.01^{bB}	7.41 ± 0.01^{bB}	8.45 ± 0.01^{aA}	5.26 ± 0.01^{bB}	-	-	11.11 ± 0.01^{bA}	13.10 ± 0.01^{aA}
Crude Protein (%)	Freeze	12.19 ± 0.01^{bA}	11.02 ± 0.01^{bA}	7.69 ± 0.01^{aA}	7.37 ± 0.01^{bA}	7.64 ± 0.01^{aA}	7.10 ± 0.01^{bA}	8.66 ± 0.01^{aA}	6.11 ± 0.01^{aC}
	Oven	10.81 ± 0.01^{bB}	10.41 ± 0.01^{bB}	6.72 ± 0.01^{aB}	6.69 ± 0.01^{bB}	6.28 ± 0.01^{aB}	6.25 ± 0.01^{bB}	7.39 ± 0.01^{aB}	6.76 ± 0.01^{bB}
	Solar	10.30 ± 0.01^{bC}	9.92 ± 0.01^{bC}	6.22 ± 0.01^{aC}	6.20 ± 0.00^{bC}	-	-	7.24 ± 0.01^{bC}	7.82 ± 0.01^{aA}
	Freeze	63.93 ± 0.01^{bA}	56.10 ± 0.01^{bB}	69.95 ± 0.01^{bA}	70.90 ± 0.00^{aA}	68.93 ± 0.01^{bB}	70.34 ± 0.01^{aB}	70.16 ± 0.01^{bC}	74.75 ± 0.01^{aB}

Carbohydrate (%)	Oven	59.55±0.01^{bC}	60.38±0.01^{bA}	69.17±0.01^{bB}	70.56±0.01^{aB}	72.19±0.01^{bA}	75.13±0.01^{aA}	73.41±0.01^{bA}	76.15±0.01^{aA}
	Solar	63.63±0.01^{bB}	60.39±0.01^{bA}	67.17±0.01^{aC}	67.14±0.01^{bC}	-	-	71.46±0.01^{aB}	70.07±0.01^{bC}
Energy (%)	Freeze	278.22±0.01^{bA}	254.61±0.01^{bB}	310.53±0.01^{bA}	316.71±0.01^{aA}	303.93±0.01^{bB}	332.96±0.01^{aB}	284.70±0.01^{bC}	304.62±0.01^{aB}
	Oven	253.01±0.01^{bC}	270.49±0.01^{bA}	307.06±0.01^{bB}	311.68±0.01^{aB}	328.90±0.00^{bA}	241.34±0.01^{aA}	310.13±0.01^{bA}	315.66±0.01^{bA}
	Solar	271.04±0.01^{bB}	245.45±15.59^{bB}	291.40±0.01^{bC}	305.26±0.01^{aC}	-	-	296.14±0.01^{aB}	289.95±0.01^{bC}

‘Means with different lowercase alphabets within rows are significantly different ($p \leq 0.05$). Means with different uppercase alphabets within columns are significantly different ($p \leq 0.05$).’

Table 5.2: Mineral composition of selected dehydrated vegetables

Mineral	Drying method	Amaranthus		Eggplant		Turkey berry		Carrot	
		Control	Blanched	Control	Blanched	Control	Blanched	Control	Blanched
Calcium	Freeze	335.63 ± 0.31^{bC}	379.30 ± 0.10^{aA}	324.90 ± 0.30^{bB}	378.23 ± 0.31^{aA}	122.29 ± 0.04^{aA}	121.93 ± 0.04^{bA}	77.96 ± 0.30^{bC}	95.29 ± 0.04^{aB}
	Oven	377.47 ± 0.40^{aA}	349.93 ± 0.13^{bB}	141.87 ± 0.31^{aA}	134.37 ± 0.03^{bB}	123.40 ± 1.54^{aA}	99.33 ± 0.03^{bA}	109.63 ± 0.45^{bB}	118.10 ± 1.54^{aA}
	Solar	340.22 ± 0.07^{aB}	297.17 ± 0.03^{bC}	157.48 ± 0.05^{bC}	103.47 ± 0.45^{aC}	-	-	122.33 ± 0.45^{aA}	97.43 ± 0.04^{bB}
Magnesium	Freeze	216.21 ± 0.03^{bC}	264.94 ± 1.54^{aC}	224.27 ± 0.31^{aA}	168.76 ± 0.03^{bA}	50.30 ± 0.13^{aA}	40.62 ± 0.03^{bA}	41.08 ± 0.04^{aA}	16.26 ± 0.05^{bA}
	Oven	395.86 ± 0.07^{aA}	370.22 ± 0.06^{bA}	141.87 ± 0.31^{aC}	134.37 ± 0.03^{bB}	35.68 ± 0.11^{bB}	44.04 ± 0.03^{aB}	12.05 ± 0.31^{bC}	15.30 ± 1.54^{aA}
	Solar	335.23 ± 0.04^{aB}	275.67 ± 0.31^{bB}	157.48 ± 0.04^{aB}	103.47 ± 0.45^{bC}	-	-	15.34 ± 0.05^{aB}	14.63 ± 0.04^{bA}
Manganese	Freeze	3.43 ± 0.68^{aB}	2.43 ± 1.03^{aA}	1.83 ± 0.35^{aC}	0.90 ± 0.26^{bC}	1.23 ± 0.35^{bB}	4.13 ± 0.57^{aA}	10.20 ± 3.00^{aA}	18.80 ± 15.40^{aA}
	Oven	27.50 ± 0.95^{aA}	4.33 ± 0.57^{bA}	7.50 ± 0.36^{bB}	14.20 ± 0.26^{aA}	2.40 ± 0.36^{aA}	1.97 ± 0.47^{aB}	5.20 ± 1.30^{aA}	5.80 ± 0.36^{aA}
	Solar	30.50 ± 3.00^{aA}	2.80 ± 0.87^{bA}	24.20 ± 1.30^{aA}	10.17 ± 0.47^{bB}	-	-	19.00 ± 15.40^{aA}	6.60 ± 2.00^{aA}
Iron	Freeze	12.47 ± 0.31^{aC}	11.22 ± 0.03^{bB}	10.91 ± 0.31^{bA}	13.54 ± 0.31^{aA}	8.91 ± 0.13^{bB}	10.10 ± 0.60^{aA}	11.84 ± 0.06^{aA}	9.00 ± 0.03^{bA}
	Oven	14.99 ± 0.11^{bA}	19.75 ± 0.04^{aA}	10.14 ± 0.45^{bA}	11.18 ± 0.07^{aB}	10.89 ± 0.09^{aA}	10.91 ± 0.30^{aA}	9.64 ± 0.03^{aB}	10.56 ± 1.54^{aA}
	Solar	11.62 ± 0.35^{aB}	11.28 ± 0.03^{aC}	11.00 ± 0.45^{aA}	10.71 ± 0.30^{aB}	-	-	9.48 ± 0.45^{aB}	8.34 ± 0.04^{bA}
Zinc	Freeze	18.77 ± 0.47^{aB}	17.83 ± 0.68^{aB}	4.73 ± 3.06^{aB}	3.20 ± 0.36^{aB}	1.60 ± 0.17^{aA}	0.93 ± 0.35^{bA}	2.10 ± 0.36^{aB}	2.20 ± 1.08^{aA}
	Oven	9.35 ± 0.01^{aA}	6.50 ± 0.10^{bA}	3.82 ± 0.01^{aA}	3.81 ± 0.01^{aA}	1.42 ± 0.01^{aA}	1.30 ± 0.36^{aA}	1.63 ± 0.01^{bC}	0.90 ± 0.30^{aA}
	Solar	12.50 ± 0.10^{aB}	9.72 ± 0.01^{bC}	3.80 ± 0.10^{bB}	3.65 ± 0.01^{aA}	-	-	3.57 ± 0.47^{aA}	3.03 ± 0.35^{aA}
Potassium	Freeze	485.93 ± 0.45^{aA}	440.52 ± 0.07^{bC}	711.93 ± 0.31^{aA}	395.93 ± 0.45^{bC}	249.78 ± 0.06^{aB}	246.32 ± 0.07^{bA}	246.37 ± 0.03^{aC}	265.80 ± 0.03^{aC}
	Oven	546.92 ± 0.07^{aB}	332.70 ± 0.30^{bB}	480.63 ± 0.04^{bC}	783.93 ± 0.31^{aA}	255.79 ± 0.04^{aA}	228.93 ± 0.45^{bB}	388.17 ± 0.03^{aB}	369.70 ± 1.54^{bA}
	Solar	609.62 ± 0.03^{bB}	628.99 ± 0.04^{aA}	703.13 ± 0.45^{aB}	670.13 ± 0.31^{bB}	-	-	394.93 ± 0.45^{aA}	281.50 ± 0.30^{bB}

‘Means with different lowercase alphabets within rows are significantly different ($p \leq 0.05$). Means with different uppercase alphabets within columns are significantly different ($p \leq 0.05$).’

The values obtained ranged between 3.20 and 18.77mg. The values are similar to those reported by Asaolu and Asaolu (2010) and Ayoola *et al.* (2010), Asalou *et al.,* (2012). Adepoju & Adefila, (2015) recorded varied amounts of iron, zinc, calcium, potassium, and phosphorus in dry okro (*Abelmoschus esculentus*). Blanching and drying methods had a significant effect on the mineral composition of the vegetables.

5.3.2 Anti-nutritional factors

The effect of blanching and drying on the antinutrient content of dehydrated amaranth leaves, eggplant leaves, carrots, and turkey berries are quantified in Table 5.3. The utilization of numerous plants for food is often constrained by the presence of antinutrients in them, which can have adverse effects on both humans and animals (Kubmarawa *et al.*, 2008). The levels of phytates, tannins, and oxalates in all the examined vegetables were considerably lower than the recommended tolerable limits of 1500-2500mg/day (tannins), 200-500mg/day (phytates), and 200-300mg/day (oxalates) (Kunatsa *et al.*, 2020). The antinutrient potential of phytates arises from its strong binding affinity for essential minerals like zinc, iron, and calcium, thereby reducing their bioavailability (Dendougui and Schwedt, 2004). Similarly, the toxicity of oxalate results from its reaction with divalent metallic cations such as calcium ($Ca^{2+)}$ and iron (II) (Fe^{2+}), forming crystals of corresponding oxalates that are excreted in urine as minute crystals (Resnick, 1990). Tannins, being astringent plant polyphenolic compounds, bind to and precipitate proteins, subsequently reducing the bioavailability of dietary proteins (Katie and Thorington, 2006).

Tannin content in dehydrated amaranth leaves ranged from (20.36±0.18) mg/100g to (25.11±0.67) mg/100g. The oxalate and phytate contents in unblanched amaranth leaves were significantly reduced when compared to blanched samples.

In dehydrated carrots, the levels of antinutrients were affected by the drying method and treatment applied. Higher levels of tannins were observed in solar-dried carrots, followed by oven-dried carrots, and then freeze-dried carrots. However, blanching significantly reduced the tannin levels in the products. Oven-dried carrots had higher levels of oxalates, followed by solar-dried carrots, and then freeze-dried carrots. However, blanching did not significantly affect oxalate levels. For phytates, the highest levels were observed in solar-dried carrots, followed by oven-dried carrots, and then freeze-dried carrots. Blanching also resulted in a significant reduction in phytate levels. Results of dehydrated eggplant leaves showed that blanching significantly reduced the levels of tannins in eggplant leaves compared to the control group, while the levels of oxalates and phytates were not significantly affected. The results of dehydrated turkey berries indicate significant differences in antinutrient levels based on the drying method and treatment applied. For tannins, the oven-dried unblanched samples had the highest levels, while the freeze-dried unblanched samples had the lowest levels.

Table 5.3: Antinutrient contents in dehydrated amaranth leaves, eggplant leaves, carrots, and turkey berries

Antinutrients	**Drying methods**	**Amaranth leaves**		**Eggplant leaves**		**Carrot**		**Turkey berries**	
		Unblanched	**Blanched**	**Unblanched**	**Blanched**	**Unblanched**	**Blanched**	**Unblanched**	**Blanched**
Tannins (mg/100g)	Freeze	24.16±0.42^{aA}	20.36±0.18^{bA}	23.08±0.31^{aB}	15.03±0.71^{bB}	21.41±0.24^{aC}	18.97±0.25^{bA}	23.86±0.03^{aA}	23.91±0.47^{aB}
	Oven	24.91±0.74^{aA}	22.56±0.33^{aA}	25.25±1.59^{aB}	20.19±0.24^{bA}	24.01±0.25^{aB}	17.28±0.17^{bB}	17.67±0.19^{bB}	29.32±0.21^{aA}
	Solar	25.11±0.67^{aA}	25.10±0.34^{aA}	30.76±0.05^{aA}	20.00±0.32^{bA}	29.38±0.86^{aA}	14.12±0.40^{aC}	-	-
Oxalates (mg/100g)	Freeze	0.15±0.00^{aA}	0.11±0.00^{bB}	0.07±0.01^{aC}	0.08±0.00^{aC}	0.14±0.00^{aC}	0.13±0.00^{bC}	0.12±0.00^{aB}	0.10±0.00^{b}
	Oven	0.11±0.00^{aC}	0.09±0.00^{bC}	0.10±0.00^{aB}	0.09±0.00^{bB}	0.27±0.00^{aA}	0.15±0.01^{bB}	0.15±0.01^{aA}	0.11±0.00^{b}
	Solar	0.12±0.00^{aB}	0.13±0.00^{aA}	0.12±0.00^{aA}	0.12± 0.00^{aA}	0.22±0.00^{bB}	0.23±0.00^{aA}	-	-
Phytates (mg/100g)	Freeze	24.03±0.23^{aB}	20.34±0.15^{bB}	23.42±0.18^{aC}	15.56±0.05^{bB}	21.59±0.02^{aC}	18.83±0.05^{bA}	23.99±0.21^{aB}	24.44±0.28^{aA}
	Oven	25.20±0.31^{aA}	21.88±0.63^{bB}	26.31±0.09^{aB}	19.92±0.63^{bA}	23.53±0.42^{aB}	17.04±0.17^{bB}	17.82±0.41^{bA}	29.70±0.33^{aB}
	Solar	25.38±0.28^{aA}	25.34±0.00^{aA}	30.86±0.19^{aA}	19.67±0.79^{bA}	30.08±0.13^{aA}	13.92±0.12^{bC}	-	-

Means with different lowercase alphabets within rows are significantly different ($p \leq 0.05$). Means with different uppercase alphabets within columns are significantly different ($p \leq 0.05$).

From Table 5.3, phytates and tannin concentrations were generally higher than oxalates in the samples. Generally, blanching led to a reduction in antinutrient levels compared to the unblanched samples. This is because blanching is known to reduce antinutrient levels by leaching them into the water used for blanching (Udoetok & Uffia, 2012).

The variability in antinutrient levels observed could be attributed to the drying methods and treatment applied. The differences in temperature and time of exposure during drying could affect the stability of antinutrients in the samples. Also, the reduction in these antinutritional factors could also result from rupture of the superficial layer of the vegetables where the concentration of the antinutritional factors is highest due to blanching (Udoetok & Uffia, 2012).

5.4 Conclusion

The study highlights the importance of drying method for different types of vegetables to minimize the loss of proximate matter and minerals during processing. The selected dehydrated vegetables exhibited low moisture content and water activity, as well as low fat and crude fibre. The dehydrated vegetables contained essential minerals such as iron, zinc, potassium, calcium, magnesium, and manganese. The results suggest that blanching and oven drying may be more effective than freeze drying or solar drying in preserving the mineral content of certain vegetables. Additionally, blanching resulted in a reduction of antinutrient concentrations (tannins, phytates and oxalates) of the vegetable samples.

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CHAPTER SIX

SENSORY CHARACTERIZATION AND NUTRITIONAL EVALUATION OF A COMPOSITE VEGETABLE POWDER

6.1 Introduction

In recent times, researchers in the food industry have been prioritizing the development of sustainable new food formulations with health enhancing properties (Proserpio *et al.,* 2019). Dietary deficiencies have a significant impact on public health, especially in the reduction of risk factors that are associated with diseases and chronic conditions due to poor diets (Jimoh *et al.,* 2018). For instance, the incidence of Iron, vitamin A and zinc deficiencies have increased globally posing serious health risks (Ahmed *et al.,* 2012; Okwuonu, *et al.,* 2021) and morbidities. Vegetables are good sources of micronutrients and critical for good health, as they form an important portion of a healthy diet. In many developing countries, the problem of nutrient deficiencies is partly due to the untapped potential of traditional vegetables (Dinnasa *et al* 2015). Advances in technology and research are now exploring overlooked substances in vegetables to recover lost nutrients and address nutrient gaps in vulnerable populations worldwide (Rai *et al.*, 2012; Jimoh *et al.,* 2018). Green leafy vegetables such as amaranth and eggplant leaves have been reported to be excellent sources of potassium, iron, zinc, magnesium, calcium, carotenes, vitamin C and other bioactive compounds (Oboh *et al.*, 2005; Jimoh *et al.,* 2018; Bouhajeb *et al.,* 2020). The consumption of fresh and dried amaranth leaves has been reported to effectively combat malnutrition and vitamin A deficiency in children, recommending it as a sustainable dietary supplement to address nutrient deficiencies (Mulokosi *et al.*,1999; Nawiri *et al.,* 2013). Egbi *et al.* (2018) also reported that the consumption of amaranth leaves and eggplant leaves powder increased the mean haemoglobin and retinol concentrations of Ghanaian school children. They therefore suggested that leaf powders had the potential to minimize the prevalence of anaemia and improve the vitamin A status of the study participants. Carrot (*Daucus carota*) is a root vegetable that has worldwide distribution and is an excellent source of fibre, carotenoids and anthocyanins (Yi *et al.*, 2018). Currently, there is an accelerated increase in the utilization of dried carrots as snack foods (Krivokapić *et al.,* 2020). *Solanum torvum*, commonly known as Turkey berry has been reported to possess essential amino acids, fatty acids, vitamins and minerals and can serve as an excellent source of nutrients for malnourished people when consumed in both fresh and dried forms (Otu *et al.*, 2017; Adonu *et al.,* 2018). In Ghana, most vegetables are readily available, accessible and affordable to households during the rainy season and scarce during the dry seasons. Due to the seasonal availability of these vegetables, adequate dietary intakes of micronutrients such as iron, zinc and pro-vitamin-A (beta-carotene from carrots, and green leafy vegetables among others) in most rural households are affected. As such, consumers are unable to meet their Recommended Dietary Allowances (RDA's) for micronutrients such as iron, vitamin-A and zinc (Egbi *et al,* 2018). A key strategy would, therefore, be to process the vegetables into dry powders that would be shelf-stable, available, accessible, and affordable for easy in-corporation into foods during lean seasons. However, processing these vegetables into a market viable product that can meet consumer expectations and demands can be a daunting task. Sensory evaluation plays a pivotal role in the development of new food products, and its significance extends to the emerging domain of vegetable composite powders (Prasoona *et al.*, 2020). Several manufacturers and researchers have successfully used sensory evaluation methods at different stages of a product life cycle to assess the quality of products and the expectations and reactions of consumers to the products (Akonor *et al.,* 2017; Prasoona *et al.,* 2020; Ying *et al.*, 2021; Thuy *et al.*, 2023). Furthermore, studies by Cai *et al.* (2021), Moss *et al.* (2023) and Akasapu & Uppaluri (2023) demonstrated the use of sensory evaluation in the development of dried vegetable-based products to assess the sensory properties, acceptability, and quality of the products. There is a growing interest in the utilization of vegetable powders as versatile ingredients in food applications (Onwuamaeze *et al.*, 2017; Ying *et al.*, 2021; Thuy *et al.,* 2023). Therefore, the aim of this study was to develop a composite vegetable powder from carrots, turkey berries, amaranth leaves and eggplant leaves, assess its sensory characteristics and estimate the contribution of the composite powder to the RDA of children (2-3years) as well as for adults.

6.2 Materials and Methods

The experimental design used to obtain the composite powder is shown below in Figure 6.1.

6.2.1 Experimental Design

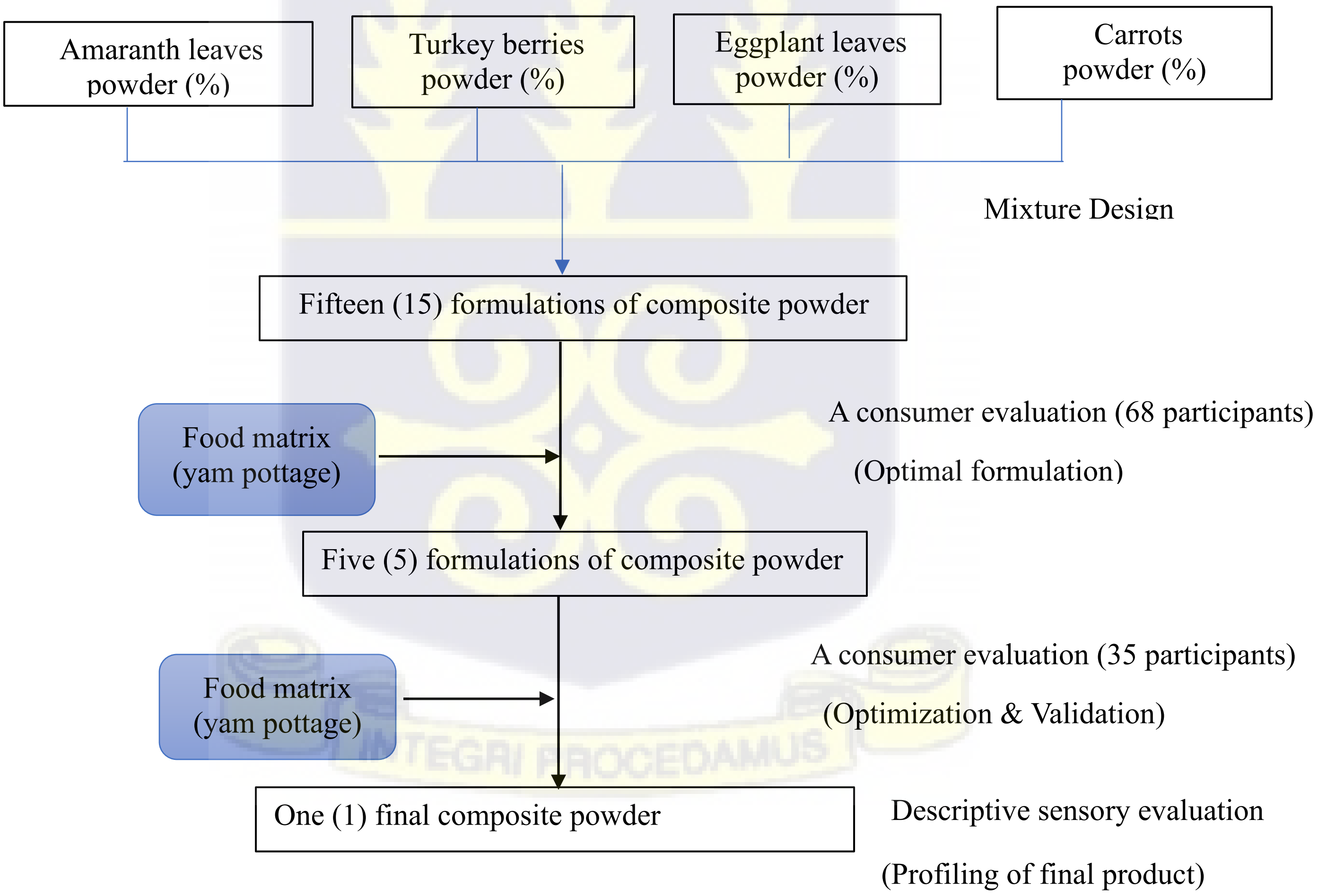

Figure 6.1: Experimental design flow chart

6.2.2 Sample preparation and formulation

Amaranth leaves, eggplant leaves and carrots were steam-blanched for 5 mins, whiles turkey berries were hot-water blanched for 5 mins prior to drying. Amaranth and eggplant leaves were oven dried (Memmert UF 110 model; Germany) at 40ºC for 4 hrs whilst carrots and turkey berries were oven dried at 60ºC for 5 and 9 hrs respectively. The dehydrated vegetables were milled separately into powders using a Kenwood dry mill blender (BL335, Manchester, United Kingdom) operating at a speed of 450W for a duration of three (3) minutes. The resulting powders were then packed into high-density polyethylene bags. Mixed vegetable powders were formulated using a constrained mixture design (Cornel, 1990) for four components, specifically, dried carrots, turkey berries, amaranth and eggplant leaves (Table 6.1). Samples were stored in air-tight polyethylene bags at 4˚C ±2˚C throughout the testing period.

6.2.3 Mixture design

The proportions of the vegetables in the composite were obtained using a four-component constrained centroid mixture design (Kpodo *et al.*, 2013; Cornell, 1990) using Minitab (version 21 Minitab, LLC, State College, Pa, USA) statistical software. Fifteen design points were generated for the four components (Table 6.1). The lower and upper bound constraints for each component; amaranth (30-40%), turkey berry (25-30%), eggplant (15-30%), carrot (15-30%) were decided from preliminary experimentations. The design was used to determine the optimum ratios of dehydrated amaranth leaves, eggplant leaves, turkey berries and carrots that will yield the most acceptable product using sensory analysis. Data generated from the evaluation were analyzed using mixture regression analysis procedures in the Minitab (V. 21 Minitab, LLC, State College, Pa, USA) statistical software.

6.2.4 Preparation of yam pottage

The food matrix used in this study was yam pottage. Pottage can be prepared in various ways, allowing for customization that appeals to both adult and child preferences. The ability of pottage to accommodate different ingredient choices, textures, and flavours makes it practical for assessing and optimizing sensory experiences (Mbah *et al.*, 2015). The pottage was prepared using fresh tomatoes (275g), onions (13.8g) and pepper (12g). The ingredients were boiled (15min) in 500ml water and blended. About 400g of chopped yam, 6g of salt, and 4 litres of water were added to the blended ingredients and cooked for 30 minutes.

Table 6.1: Proportions of components in dried vegetable mixed powders.

Formulation	Component			
	Amaranth leaves (%)	Turkey berries (%)	Eggplant leaves (%)	Carrots (%)
1	32.20	28.60	22.10	17.10
2	34.30	27.10	19.30	19.30
3	40.00	30.00	15.00	15.00
4	30.00	30.00	15.00	25.00
5	37.20	26.10	17.10	19.60
6	30.00	30.00	25.00	15.00
7	32.20	28.60	17.10	22.10
8	40.00	25.00	20.00	15.00
9	32.20	26.10	17.10	24.60
10	30.00	25.00	15.00	30.00
11	40.00	25.00	15.00	20.00
12	30.00	25.00	30.00	15.00
13	37.20	26.10	19.60	17.10
14	37.20	28.60	17.10	17.10
15	37.20	26.10	24.60	17.10

Based on preliminary studies, an amount of 5g of each vegetable formulation (Table 6.1) was added to 200ml of the prepared pottage, allowed to simmer for 3min and then transferred to storage bowls. For each formulation, 20ml of the pottage was served into 40ml clear disposable cups and labelled with 3-digit codes to be served to participants.

6.2.5 Consumer evaluation

Consumer analysis was carried out on the fifteen formulations in a food matrix (pottage) to obtain an optimal formulation.

The assessment of the pottage involved participants who were regular consumers of such dishes and was conducted in a sensory laboratory equipped with individual sensory booths at the Department of Nutrition and Food Science, University of Ghana. The participants used a nine-point hedonic scale to evaluate the appearance, aroma, flavour, mouthfeel, taste, and overall acceptability of the 15 pottage samples (where 1 = extremely dislike, 2 = dislike very much, 3 = dislike moderately, 4 = dislike slightly, 5 = neither like nor dislike, 6 = like slightly, 7 = like moderately, 8 = like very much, and 9 = extremely like). Samples were presented to sixty-eight (68) participants (blocks) based on a Balanced Incomplete Block Design (BIBD) (Rasch *et al.,* 2011) for the 15 treatments generated using Minitab (V. 21 Minitab, LLC, State College, Pa, USA) statistical software. This was to ensure that each participant assessed four (4) pottage samples and each pottage would be assessed sixteen (16) times by the end of the study. Participants were instructed to rinse their mouths with noncarbonated water before tasting subsequent samples.

6.2.6 Optimization and validation of formulations

Contour plots for the test attributes (appearance, aroma, flavour, mouth feel, taste, overall acceptability) were superimposed on the same axis to obtain an optimum region of formulations that satisfied all the sensory attributes. To confirm the effectiveness of the optimal formulation, pottage was cooked using three formulations chosen from the optimal range and two additional formulations from outside this range. These five (5) variations were then served to thirty-five (35) participants who were part of the initial study. The participants evaluated the samples for appearance, aroma, flavour, mouth feel, aftertaste, and overall acceptability. Formulations used for the validation experiment are presented in Table 6.2.

Table 6.2: Formulations used for validation experiment

Formulation	Amaranth Leaves (%)	Turkey berries (%)	Eggplant Leaves (%)	Carrots (%)
1	33.46	27.42	16.62	22.5
2	33.11	27.5	16.89	22.5
3	32.62	27.84	17.04	22.5
4*	30.52	31.3	15.68	22.5
5*	34.46	25.62	17.42	22.5

*Formulations outside optimum region

6.2.7 Quantitative Descriptive Analysis

6.2.7.1 Sample preparation

Two packs of the dehydrated composite formulations (220 g per pack) were retrieved from storage (4˚C ±2˚C). The samples were reconstituted by adding 20 g to 100 ml of hot water and stirring constantly until a uniform mixture was obtained.

6.2.7.2 Descriptive sensory analysis

Eight (8) evaluators with prior experience in the descriptive sensory analysis of various foods, affiliated with the Department of Nutrition and Food Science at the University of Ghana, were chosen, and screened based on the guidelines outlined in ISO Standard 8586 (ISO, 2012) for the research. They comprised of four (4) females and four (4) males.

Discussions were conducted for 3 hours each day, twice a week for three weeks to generate descriptors for the composite powder. A total of 18 hours of training was therefore given to the panel. Six (6) sessions (signifying the number of days used) were attended by the panellists for the entire study. The panel was also trained to quantify the intensity of sensory attributes using line scales. Scale training involved each panellist allocating intensity scores of each attribute per sample on a 10cm line. They then collectively agreed on the ranges of each attribute per product. This helped them use the scale in a similar way as well as establish the rank order of the products. All panellists were aged 18 and above, had no reported food allergies, and had willingly volunteered to take part in the study. The training sessions occurred at the Sensory Evaluation laboratory within the Department of Nutrition and Food Science at the University of Ghana.

The test comprised 4 main activities namely: term generation, consensus building, scale training/attribute rating, and evaluation. Term generation involved each panellist assessing the products and developing attributes or terms that described each product, defining those attributes, and allocating anchors. Panellists also listed references where necessary to provide clarity on ambiguous terms. Consensus building involved all the panellists coming together to agree on a final collated list of descriptors that accurately described the product set.

Reference products were provided to the panel where needed to clarify ambiguous descriptors and align panel agreement. Approximately 5 g and 7 g of dried and reconstituted composite formulations respectively were served to the panellists in 80 cc cups labelled with three-digit codes. The panel was instructed to assess the samples under the following modalities: Appearance, aroma, flavour, mouthfeel, and aftertaste. Each panellist assessed each sample and allocated a score to each attribute on a 10 cm line scale (0 being not intense/not present and 10 being very intense/very present). Panellists evaluated the samples monadically in a balanced randomized order. Randomization was achieved using the Williams Latin Square design (Williams, 1949). Panellists rinsed their palates with water between tastings and a forced break of 30 seconds was allowed after each tasting and a five minutes break between sessions. Each sample was assessed in triplicate. Assessment of all samples was done using Compusensecloud (Guelph, Ontario, Canada).

The panellists evaluated the samples in separate booths equipped with white LED lighting for natural illumination. The sensory assessment took place in a well-ventilated room, maintaining a temperature of 25˚C ± 2˚C through air-conditioning. Additionally, an extractor fan was installed to eliminate odours in the environment.

6.2.8 Nutritional Composition of the Composite Powder

The nutritional composition of the composite powder was estimated on a 100g basis, based on the contribution of the individual dried vegetable sample to the product. The nutrients focused on within the scope of the study were calcium, iron, zinc and vitamin A.

6.3 Statistical Analysis

Data analyses were carried out using XLSTAT 2018 (Addinsoft, New York, USA) for Windows pc. Panel analysis was conducted to determine panel performance based on their repeatability, discrimination, and interactions.

6.4 Results and Discussion

6.4.1 Consumer evaluation

Sensory evaluation is important in product development and product optimization studies because it reveals the interplay of sensory factors, providing a comprehensive score that can be useful for decisions in the processing of products. Mean consumer scores for appearance, flavour, aroma, mouthfeel, aftertaste and overall acceptability were determined and presented graphically as a spider web diagram (Figure 6.2). Some of the compositions yielded quite similar scores and may indicate that the likeness for these formulations is similar. Mean scores for the sensory attributes generally ranged from 3.53 (dislike moderately) to 4.82 (dislike slightly) for appearance; 3.53(dislike moderately) to 4.94 (dislike slightly) for aroma; 4.12 (dislike slightly) to 5.18 (neither like nor dislike) for aftertaste; 3.41 (dislike moderately) to 4.47 (dislike slightly) for flavour; 3.29 (dislike moderately) to 4.82 (dislike slightly) for mouthfeel and 3.29 (dislike moderately) to 4.59 (dislike slightly) for overall acceptability. Generally, low scores for all attributes were observed. This could be attributed to the impact of the powder on the sensory attributes of the pottage as well as consumer perceptions of new products. According to Karam *et al.* (2016), although the incorporation of dried fruits and vegetables into cakes significantly increased the nutritional value, it produced darker colour in the cakes and reduced sensory scores. Gupta and Prakash (2011) also reported that the incorporation of dehydrated greens into various snacks reduced the scores of the samples with respect to appearance, colour, texture, taste and overall acceptance, despite its increased nutritional content.

Panellists were also asked in the questionnaire to briefly comment and recommend other food matrices for the formulated product. They recommended other food matrixes into which they would prefer the formulations to be incorporated. 'Kontomire' (cocoyam leaves) stew / Spinach stew, Palm-nut soup, okro stew and 'Green' soup were the main recommendations. The recommended dishes are popular Ghanaian dishes with a notably green or darker appearance. Mixture contour plots for the sensory attributes evaluated for the pottage showed that consumer preference for acceptability laid within the constraint region, which is highlighted in the darker outline regions in Figures 6.3 – 6.5.

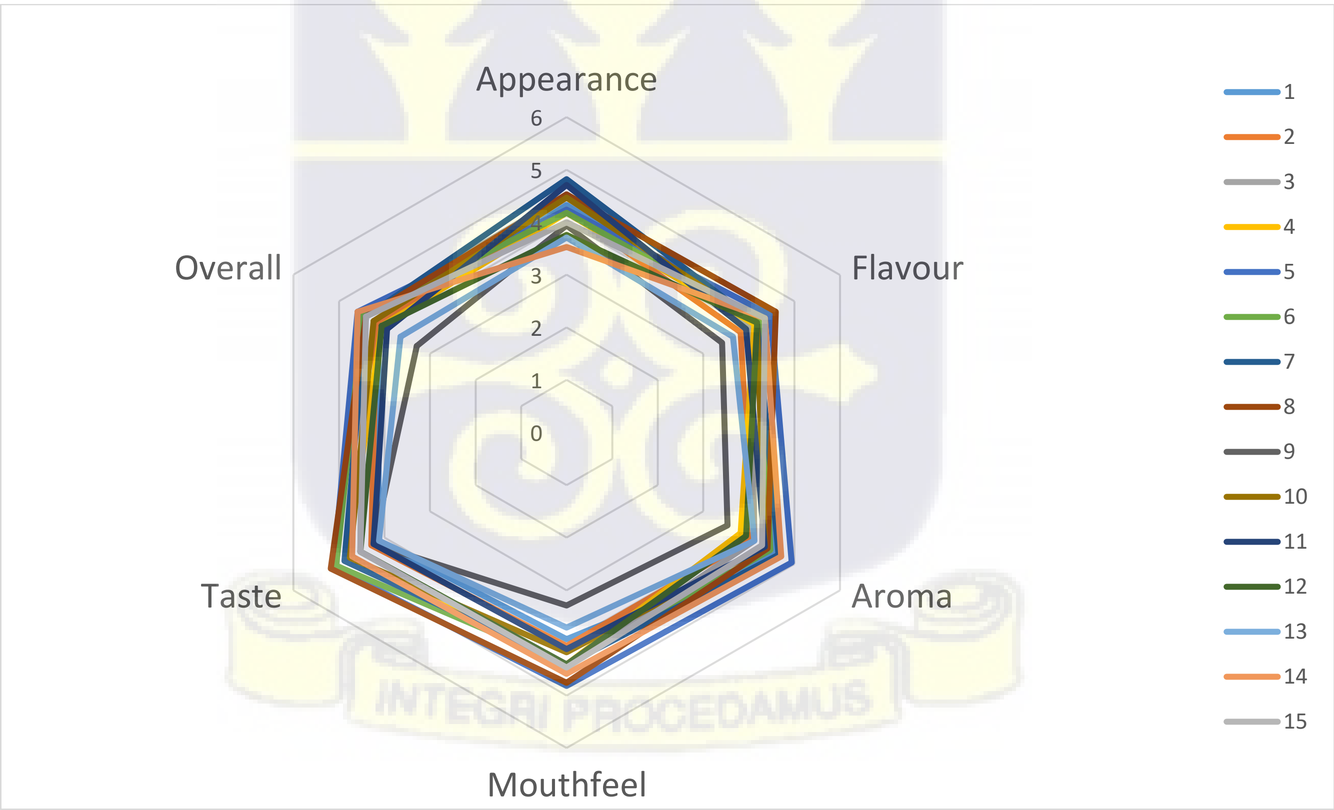

Figure 6.2: Average sensory rating for the fifteen formulations

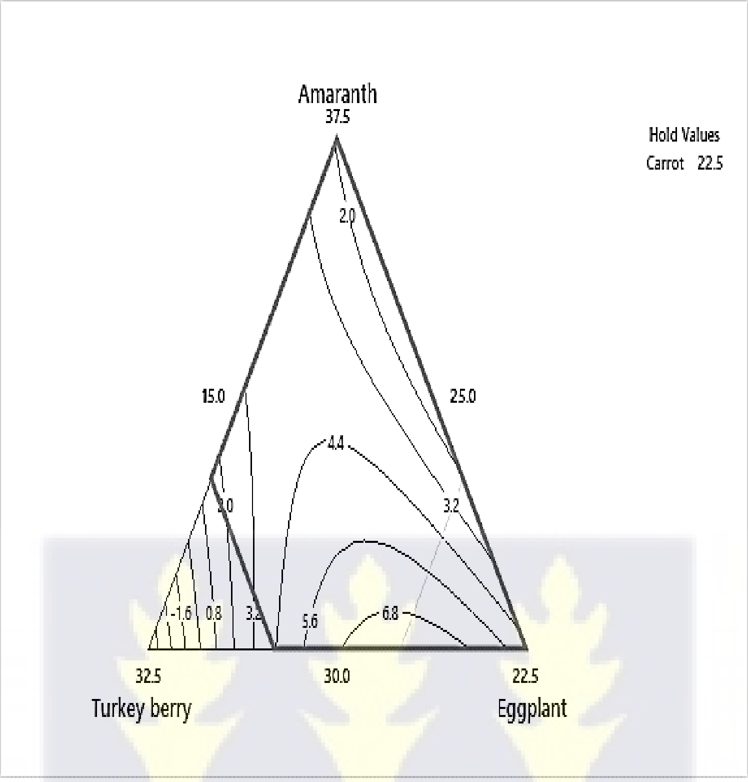

Figure 6.3: Contour plot of appearance

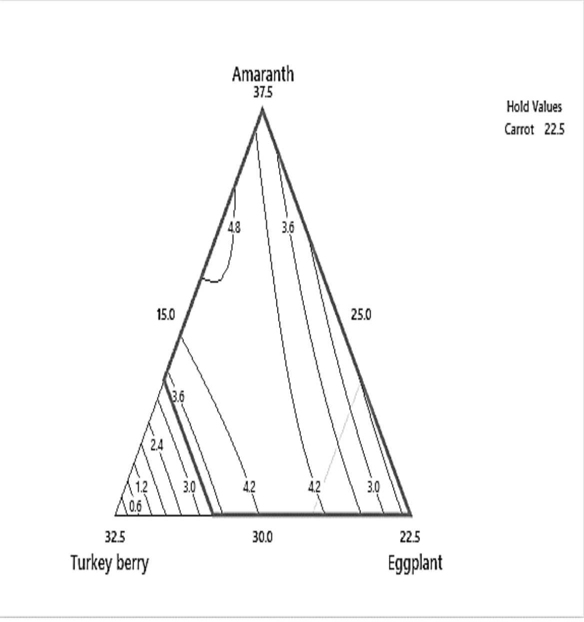

Figure 6.4: Contour plot of aroma

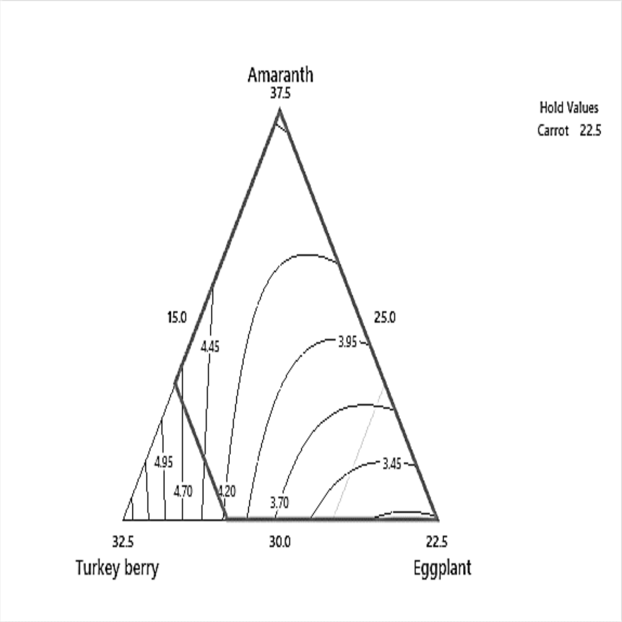

Figure 6.5: Contour plot of mouthfeel

6.4.2 Optimized and Validated Formulation

Optimization is a process of deriving the best from several potential formulations (Prinyawiwatkul *et al.,* 1997). Contour plots of the individual attributes were superimposed to obtain an optimum region (unshaded area in Figure 6.6) where specified conditions of the sensory attributes were satisfied. The optimum region on the contour plot indicates the combination of variables or parameters that leads to the best possible outcome. Results obtained from the overlaid contour plots show that the optimum formulation was composed of about 33% amaranth leaves, 23% carrots, 27% turkey berries, and 17% eggplant leaves.

Validation of formulations in product optimization studies is done to confirm products from the optimum region as the best formulations that appeal to most consumers compared to points outside the optimum region. Formulations within the optimum region (Table 6.3) recorded scores between 4 (dislike slightly) to 6 (like slightly) for appearance, aroma, and flavour respectively. In addition, attribute scores for aftertaste, mouthfeel, and overall acceptability ranged from 4 (dislike slightly) to 5 (neither like nor dislike). The results indicate that the ratings for the formulations from the optimum region fell within the predicted scores. The optimum formulation (composite product) was made up of approximately 33% amaranth leaves, 23% carrots, 27% turkey berries, and 17% eggplant leaves as shown in Figures 6.7 and 6.8.

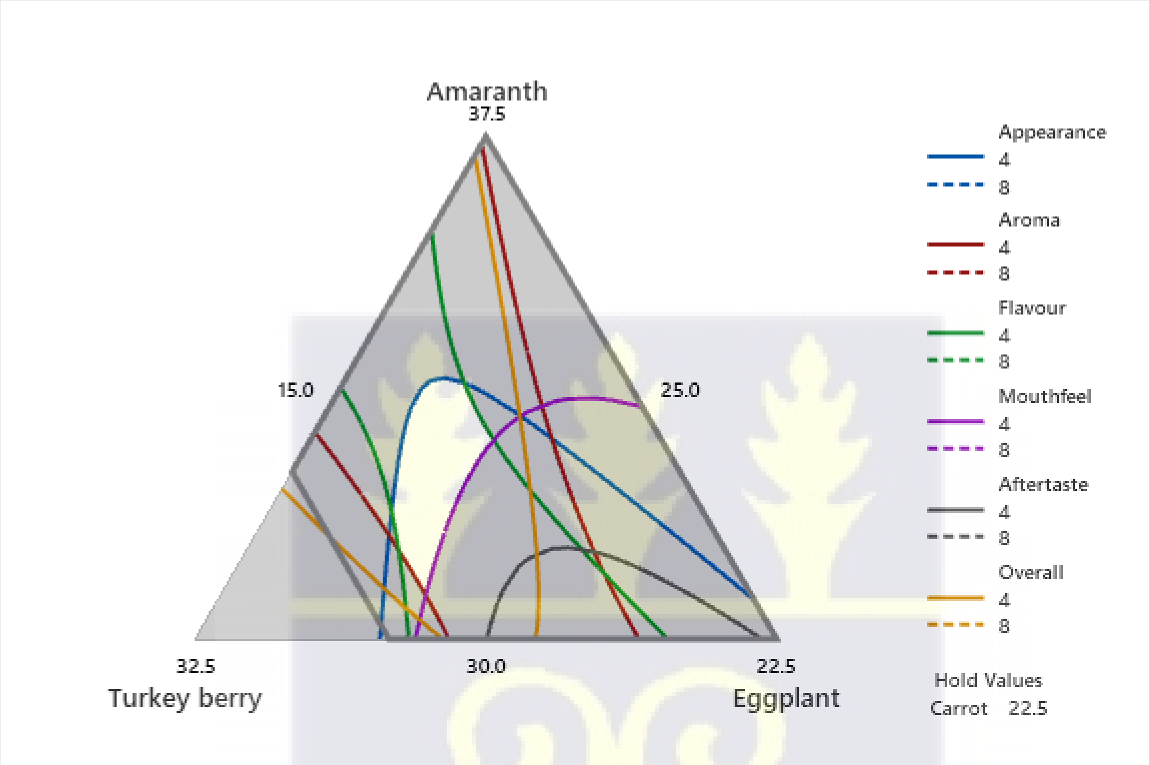

Figure 6.6: Overlaid contour plots of sensory attributes, showing optimal region (unshaded area)

Table 6.3: Mean scores of sensory attributes of validated formulations

Formulation	Appearance	Aroma	Aftertaste	Flavour	Mouthfeel	Overall acceptability
1	6.00±0.17^a	5.97±0.17^a	4.97±0.17^a	5.94±0.34^a	4.97±0.17^a	5.00±0.10^a
2	5.00±0.01^b	4.00±0.10^c	4.00±0.01^b	5.00±0.10^b	4.00±0.10^b	4.03±0.17^b

3	5.94±0.14^{a}	5.00±0.02^{b}	5.00±0.08^{a}	5.00±0.10^{b}	4.03±0.17^{b}	5.00±0.20^{a}
4*	4.00±0.10^{c}	4.00±0.13^{c}	1.00±0.01^{c}	3.00±0.01^{c}	2.00±0.01^{c}	1.00±0.17^{c}
5*	4.00±0.10^{c}	4.00±0.10^{c}	2.00±0.01^{d}	2.00±0.02^{d}	1.00±0.01^{d}	2.00±0.20^{d}

Means with different superscripts within columns are significantly different ($p \leq 0.05$).

*Formulations outside optimum region.

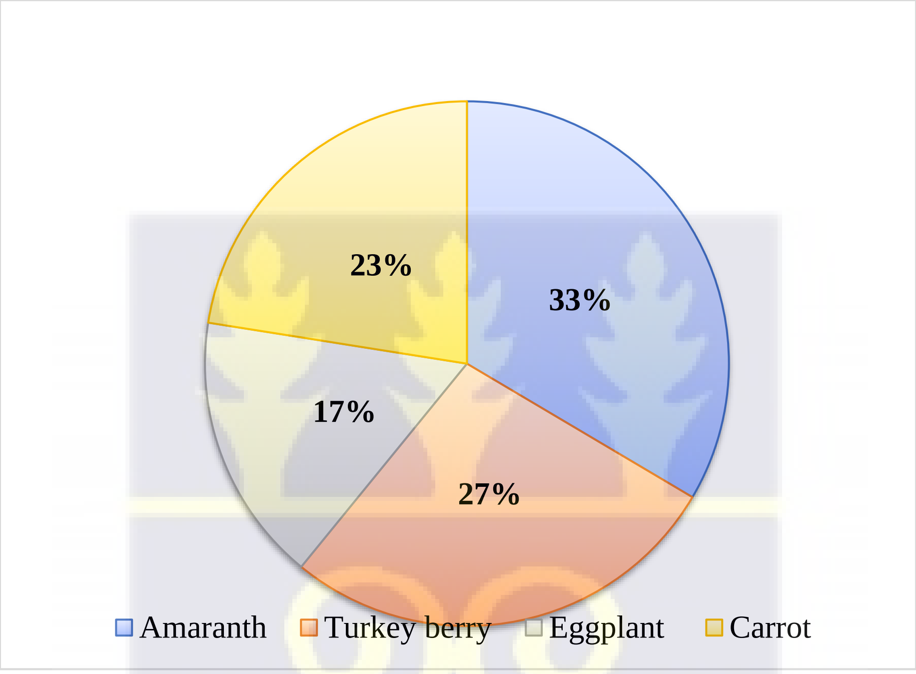

Figure 6.7: Percent contribution of vegetables to the optimum formulation

Figure 6.8: Optimized Composite Powder

6.4.3 Nutritional contribution of the optimum formulation

The consumption of diets rich in vegetables is strongly recommended to prevent micronutrient deficiencies (vitamin A, iron and zinc) which are widespread in the Sub-region (Van Jaarsveld *et al.*, 2014). The composition of the selected micronutrients in the optimum formulation of the composite product were estimated to be 199.74mg/100g calcium, 11mg/100g iron, 4.24 mg/100g zinc and 334.66 µg RAE for vitamin A. The optimum formulation per 100g, contributed over 100% of the recommended dietary allowance for iron, and more than half the RDAs of zinc and vitamin A for children and adults. The recommended dietary allowances for zinc and vitamin A for children 2 – 3 years are 3mg/d and 300µg/d, respectively and that of adults are 8mg/d and 900 µg/d, respectively (Institute of Medicine, 2001; Food and Nutrition Board, 2011). Also, the recommended dietary allowances for calcium and iron for adults are 1200mg/d and 8mg/d, respectively and that of children (2-3yrs) are 700mg/d and 7mg/d respectively (Institute of

Medicine, 2001; Food and Nutrition Board, 2011). This shows that, the composite powder is high in iron, zinc, vitamin A and a source of calcium (Codex Alimentarius, 2013). Diets should be composed of variety of foods that are derived from diverse food groups to meet the recommended dietary allowance (Van Jaarsveld *et al.*, 2014). The contribution of recommended portions of the optimum formulation towards iron, calcium, zinc and vitamin A (RAE) to the RDAs of children (2-3yrs) and adults (Institute of Medicine, 2001; Food and Nutrition Board, 2011) were evaluated and presented in Table 6.4. About one-third of the RDA for iron and one-fourth for zinc and vitamin A, was met and this allows room for the contribution of nutrients from other meals towards the RDAs.

Table 6.4: Estimated contribution (%) of the optimum formulation to recommended dietary allowance (RDA)

Target Group	**Calcium**		**Iron**		**Zinc**		**Vitamin A**	
	RDA (mg/d)	Estimated (%)	RDA (mg/d)	Estimated (%)	RDA (mg/d)	Estimated (%)	RDA (µg/d)	Estimated (%)
Children (2-3yrs) 20g	700	5.70	7	31.42	3	28.33	300	22.31
Adults (30g)	1200	6.00	8	41.25	11	18.74	900	20.08

6.4.4 Quantitative Descriptive Analysis of the optimum formulation

A typical Quantitative Descriptive Analysis (QDA) session typically involves 8-12 trained panellists utilizing a quantitative scale and a reference standard to assign meanings to attributes for describing a product being evaluated (Lawless and Heymann, 2010). Twenty-five (25) descriptive attributes were used to describe the sensory profile of the two samples. They comprised eight (8) appearance attributes, six (6) aroma attributes, five (5) flavour attributes, one (1) mouthfeel attribute, and five (5) aftertaste attributes. Table 6.5 shows the attributes and definitions grouped for each modality.

Table 6.5: List of sensory descriptors generated for the optimum formulation used for Quantitative Descriptive Analysis

Modality	**Descriptor**	**Definition**	**Reference**
Appearance	Olive green	Sample having an olive-green colour	Olive fruit or dried "kuka"
	Dark green	Sample having a dark green colour	Overcooked kontomire or reconstituted "kuka"
	Heterogenous colour	Having a non-uniform colouration of particles	
	Heterogenous particles	Having a non-uniform particle size distribution	
	Coarse	Presence of larger particles that makes the sample appear to be rough	
	Powdery	Having fine particles like that of flour	
	Viscous	Having a thick consistency that makes sample resistant to flow	
	Glossy	Shiny surface	
Aroma	Turkey berry	Having a smell like that of fresh turkey berry	
	Musty	Having a stale smell	Uninfused tea (lipton)
	Dried red chilli pepper	Having a smell like that of dried chilli pepper	
	Herby	Having a smell like that of fresh green vegetables	Cloves basil "nunum", bitter leaf, ayoyo
	Fermented dried banana leaves	Having a smell like that of fermented dried banana leaves	
	Dried vegetables	Having a smell like that of dried green leafy vegetables	
Flavour/Mouthfeel	Bitter	Bitterness associated with caffeine	0.5% caffeine solution

	Salty	The intensity of saltiness	7 % w/v sodium chloride
	Sweet	Taste on the tongue associated with sugars	5% sucrose solution
	Herby	Having a flavour like that of fresh green leafy vegetables	Cloves basil "nunum", bitter leaf, ayoyo
	Dried vegetables	Having a flavour like that of dried leafy green vegetables	
	Gritty	Presence of rough particles in the mouth	
Aftertaste	Sweet	Basic taste	
	Bitter	Basic taste	
	Herby	Lingering taste of fresh green leafy vegetables	
	Dried vegetables	Lingering taste of dried green vegetables	
	Residue	Presence of residue in the mouth after swallowing	

The reconstituted powder was described as dark green in appearance while in its dried powdered form it appeared olive green (Figures 6.9 and 6.10). In its dried powdered form, the composite vegetable product has a low moisture content due to the drying process. Low moisture levels in the dried powdered product could contribute to the colour perception (Balsam *et al.,* 1998) making it appear lighter or more muted, such as olive green. When reconstituted in water, the product absorbs moisture, and the colour intensifies, appearing darker, in this case, dark green (Hutchings & Hutchings, 1999). An implication for food preparation is the impartation of a visually green colour to various dishes, such as soups, sauces and stews.

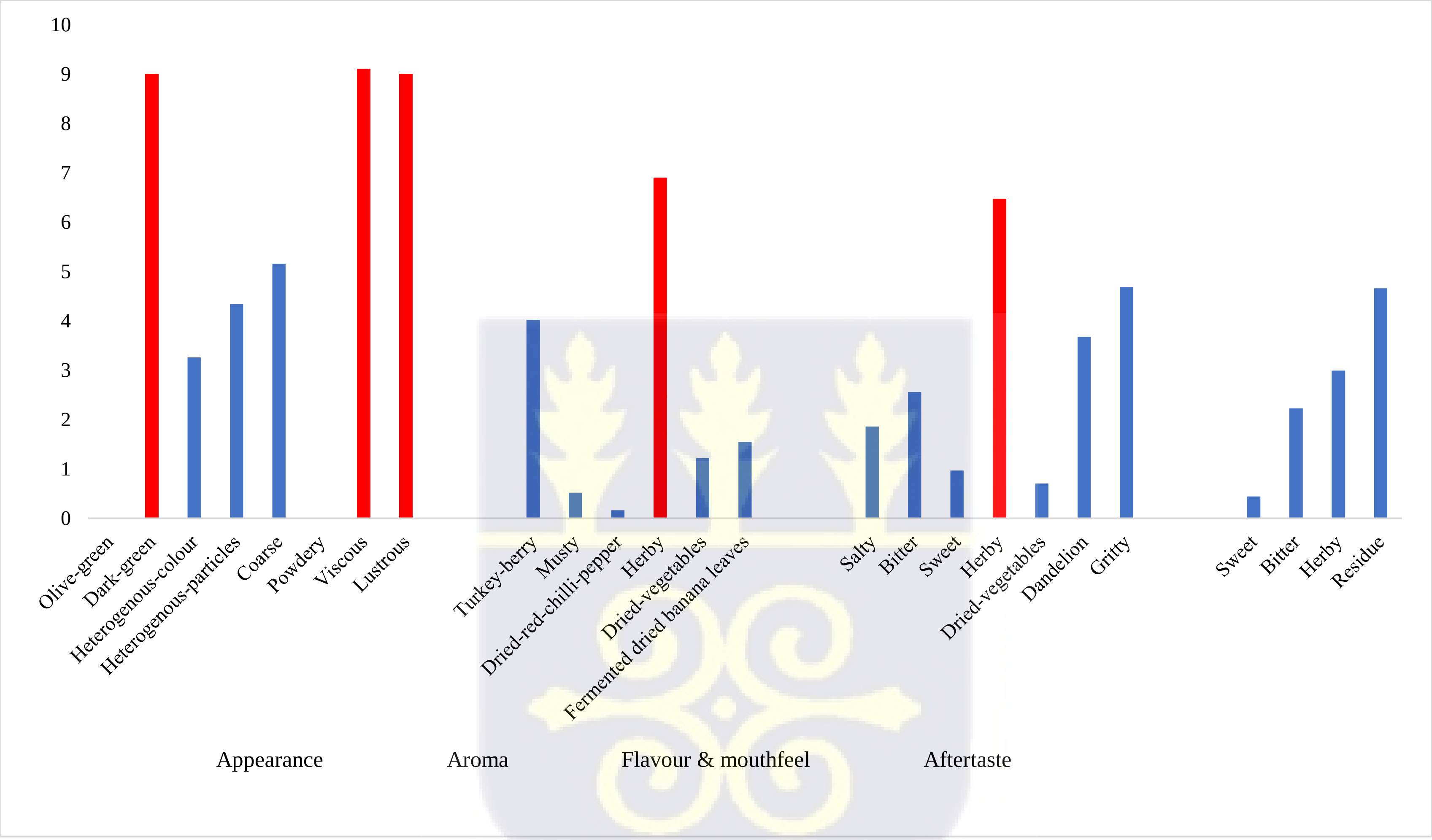

Figure 6.9: Sensory attributes of the optimum formulation reconstituted in water

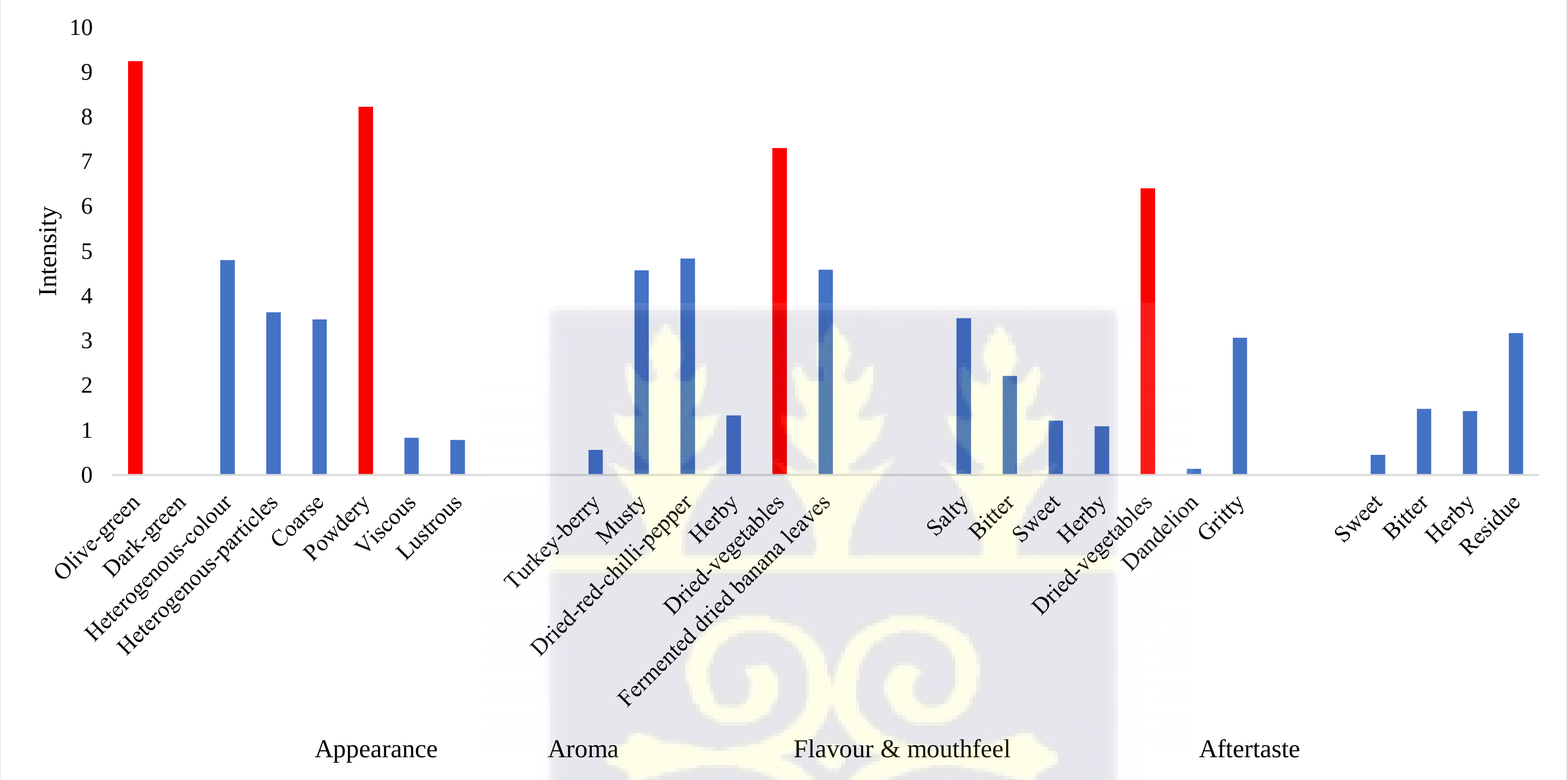

Figure 6.10: Sensory attributes of the optimized composite powder

The herbal aroma was perceived in both powdered and reconstituted forms of the composite product; however, it was more intense in the reconstituted product. A study by Zhang *et al.* (2019), revealed that the aroma of reconstituted dried basil was more intense than that of the dried basil powder. The reconstitution process was suggested to have activated and released more aromatic compounds. Thus, the addition of water during the reconstitution process may have contributed to the more intense herbal aroma in the reconstituted product.

A bitter aftertaste was perceived in the samples however, this bitter aftertaste was very low (about two on a 10cm line scale). Many polyphenolic compounds, such as catechins and tannins, found in vegetables have a bitter taste (Pires *et al.*, 2020). These compounds activate bitter taste receptors on the taste buds, particularly the TAS2R receptors, leading to a perception of bitterness (Soares *et al.*,2020). Carrots are perceived as sweet (Howard *et al.,* 1995; Sulaeman & Driskell, 2010) and this could contribute to masking the bitter taste.

As observed in Figure 6.9, the reconstituted powder had a grittier mouthfeel and residual aftertaste. Enhancing the smoothness of the powder could be achieved by employing a more efficient milling process than the one utilized in the study. However, the grittier mouthfeel observed in the reconstituted powder could be attributed to the imbibition of water and good rehydration characteristics of the powder. Kadam *et al.* (2017) observed that the particle size of dehydrated garlic powder influenced its rehydration characteristics. The rehydration process, facilitated by the powder's good rehydration properties, could result in a gritty mouthfeel due to water imbibition. This suggests that during cooking, the thickness or texture of a dish can be controlled by varying the amount of liquid added during reconstitution.

6.5 Conclusion

An optimum formulation was developed out of the selected vegetables using sensory evaluation procedures. The optimum formulation (composite product) was made up of approximately 33% amaranth leaves, 23% carrots, 27% turkey berries, and 17% eggplant leaves. Based on their estimated contribution, the optimum formulation could contribute to about one-third of the RDA for iron and one-fourth for zinc and vitamin A for children (2-3years) and adults. The optimum formulation (composite powder) was described as olive green, dry, gritty and herby. The reconstituted composite powder had a dark green appearance and coarse texture with a herby aroma and flavour.

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CHAPTER SEVEN

PHYSICO-CHEMICAL AND MICROSTRUCTURAL CHARACTERISATION AND STORAGE STABILITY OF A DEHYDRATED COMPOSITE VEGETABLE POWDER

7.1 Introduction

In the pursuit of a healthier lifestyle and the prevention of non-communicable diseases, fruits and vegetables have been established as a vital component in the diet (Kapoor & Feng, 2022; Vainio & Weiderpass, 2006). They are known sources of vitamins, minerals, fibres, and phytochemicals that contribute to overall human health and well-being (Pandey & Rizvi, 2009). Unfortunately, their inherent high moisture content and high metabolic activity render them very perishable (Varoquaux & Wiley, 2017). Drying, a widely employed age old, inexpensive preservation technique is used to extend the shelf life of vegetables. Dehydrated vegetables offer the advantage of prolonged storage and ease of use (Hasan *et al.*, 2019). Their concentrated micronutrient content positions them as potential ingredients in combating micronutrient deficiencies, particularly in regions with limited access to fresh produce. Egbi *et al.* (2018) demonstrated that incorporating *Amaranthus cruentus* and *Solanum macrocarpon* leafy vegetable powders into school meals substantially improved the intake of iron, zinc, and beta-carotene among rural school children. Furthermore, previous studies in this work, highlighted the potential of a composite vegetable powder, composed of dehydrated amaranth leaves, eggplant leaves, turkey berries, and carrots, to meet the recommended dietary allowances of iron, zinc, and vitamin A (retinol) for both adults and young children (2-3 years old).

In recent times, there has been a surge in the demand for dried fruits and vegetables, driven partially by their appealing sensory attributes such as flavour, colour, and texture (Mishra *et al.,* 2022). Additionally, consumers seek lightweight and portable food options for travel and outdoor activities (Kapoor & Feng, 2022). Powdered fruits and vegetables find applications in enhancing the sensory attributes of various food and beverage products, besides serving as functional food additives to boost nutritional content (Gupta & Mishra, 2021). The inherent properties of these powders fundamentally influence their utilization and commercial viability (Hussein *et al.*, 2015; Šeregelj *et al.,* 2020). Therefore, the evaluation of the physico-chemical characteristics, microstructure, and storage stability of composite vegetable powders are pivotal in ensuring handling and distribution. With the increasing demand for dehydrated vegetable products, a comprehensive understanding of their physico-chemical properties becomes necessary for quality control and consumer satisfaction. Kapoor and Feng (2022) highlighted the critical role of flavour, colour, and texture in consumer acceptance, which underscores the need to assess these attributes in composite vegetable powders. Furthermore, the shelf life of these powders and their potential impact on public health are influenced by their capacity to maintain both nutritional content and sensory attributes during storage (Ladi *et al.*, 2017; Mohammadi *et al*, 2020; Ying *et al.*, 2021; Martínez & Carballo, 2021).

The microstructure of composite vegetable powders plays an important role in their rehydration characteristics, dispersion in food matrices, and overall functionality in end products. Previous studies by Hussein *et al.* (2015) and Šeregelj *et al.* (2020) underscored the significance of particle size, morphology, and inter-particle interactions in determining the behaviour of powders in various applications.

The success of dehydrated vegetable mixes as consumer acceptable ingredient hinges on their ability to retain nutritional value, sensory attributes, and rehydration properties over time. A robust assessment of these attributes provides insights into the potential challenges and opportunities associated with utilizing composite vegetable powders as food ingredient.

Hence, studying the physico-chemical characteristics, microstructure, and storage stability of composite vegetable powders hold immense importance in meeting consumer demands for convenient, nutrient-rich products, addressing micronutrient deficiencies, and developing stable dehydrated vegetable mixes. The objective was to study the physico-chemical, microstructure and storage stability of composite vegetable powder from carrots, turkey berries amaranth and eggplant leaves.

7.2 Materials and Methods

The composite vegetable powder consisting of milled amaranth leaves (33%), turkey berries (27%), carrots (23%) and eggplant leaves (17%), was mixed uniformly using a Kenwood dry mill blender (BL335, Manchester, United Kingdom).

7.2.1 Determination of Colour

The hunter lab colour meter (LABSCAN XE Hunter lab, Virginia, USA), was used for the analysis. The equipment was calibrated with black and white ceramic tile for L*=0 and L*=96 respectively. Samples were placed in a dish and colour readings were taken on three different regions on the sample surface and readings were taken for L*- varying from lightness to darkness (100 – 0), a* varying from redness to greenness (+ve to –ve), and b* values varying from yellowness to blueness (+ve to –ve).

7.2.2 Determination of water activity (a_w)

Water activity was determined using the Aqualab 4TE Decagon (Decagon Devices Inc., US). The determination was based on the detection of dew on the mirror when the sample and the headspace are in equilibrium in terms of relative humidity and temperature. Measurements were performed at 25°C (±0.1°C). The water activity was determined in duplicates with a precision of ±0.007.

7.2.3 Bulk density

The method of Cai and Corke (2000) was used to determine the bulk density of the composite powder (optimum formulation). Loose bulk density was determined by measuring the volume of 10 g of the sample in a measuring cylinder, after shaking to level it off. For tapped bulk density, 10 g of sample was weighed into a 100 mL graduated pyrex measuring cylinder and gently tapped for 5 min on a laboratory bench damped with a single layer of cotton napkin. The final volume was recorded and used to calculate the bulk density of the powdered samples in g/cm^3.

7.2.4 Powder flowability

Flow properties of the composite powder, based on Carr Index (CI) and Hausner Ratio (HR), were determined as described by Asokapandian *et al.* (2016). CI and HR were calculated using equations 1 and 2 as follows:

Carr Index (CI)=$\frac{Td-Bd}{Td}$ (1)

Hausner ratio (HR)=$\frac{Td}{Bd}$ (2)

Where *Td* and *Bd* correspondingly represent tapped bulk density and loose bulk density.

7.2.5 Rehydration Ratio

Five grams (5g) of the composite powder were rehydrated in 50ml distilled water at room temperature (28°C) in glass beakers. After 15, 30, 60, 120, 180 and 240 min the water was carefully decanted and the sediment was weighed with an electronic balance (Kern 510, Kern & Sohn, GMbH, Germany) with sensitivity of ±0.001g (Chaudhary & Kumar, 2020). The rehydration ratio calculated as shown in equation 3.

Rehydration ratio (RR)= $\frac{weight\ of\ rehydrated\ sample}{weight\ of\ dry\ sample}$ (3)

7.2.6 Particle Size Distribution

The particle size distribution of the composite powder was determined using a Meinzer II mechanical shaker (Advantech Manufacturing, Inc., New Berlin, USA) fitted with 2.380, 2.000, 1.000, 0.500, 0.250, 0.149, 0.125mm screen sieves. One hundred grams (100 g) of the sample was shaken for about 5 min, with the fitted sieves, at a frequency of 50 Hz. After shaking was completed, the particles retained on each sieve were determined by weighing. The weight of the samples on each sieve was then divided by total weight of sample to obtain percentage retained on each sieve. The cumulative percent of the sample retained was determined and the cumulative percent passing was calculated by subtracting the percent cumulative retained from 100% (Chisenga *et al.*, 2019).

7.2.7 Scanning Electron Microscopy

A sample of the composite powder was examined under a scanning electron microscope (Bruker Nano Berlin, Germany). The sample was coated with a fine layer of gold (15nm) using a sputter gold coater (Technics Hummer V, Anatech, San Jose, CA). An accelerating voltage of 20 kilovolts was used for imaging at x150, x500, x1000 magnification. The average diameter of granules at 20 µm was reported as the granule size of the composite powder.

7.2.8 Moisture Sorption Studies

The standard gravimetric method was used for the equilibrium moisture studies, following the procedure described by Andrade *et al.* (2011). This involved measuring moisture sorption with six different concentrations of sulfuric acid (H_2SO_4) solution, spanning five, fifteen, thirty-five, fortyfive, fifty-five, and sixty-five percent, creating water activities (a_w) ranging from 0.1 to 0.9. These solutions were carefully placed in glass containers. The powders were placed in plastic containers, suspended above the acid solution using threads, and positioned in an oven set at 25, 30, and 35°C. Samples were periodically weighed using an electronic balance (Kern 510, Kern & Sohn, GMbH, Germany, ±0.001) every twenty-four hours until consecutive readings showed a change of less than 0.05% of the sample weight. This indicated that the material's moisture content had reached equilibrium with the surrounding humidity, and further changes were negligible. The moisture sorption isotherms were constructed by plotting equilibrium moisture content (EMC, expressed as grams of water per gram of dry solids) against water activity (a_w) with EMC values calculated as averages of triplicates, forming the basis for determining moisture sorption isotherms.

7.3 Results and Discussion

7.3.1 Colour

The colour of food is an important factor in determining the acceptance as consumers prefer food with a natural appearance (Kapoor & Feng, 2022). The colour values as observed in Table 7.1 (L* = 50.74, a* = -0.74, b* = 12.37) represent the overall colour of the composite vegetable powder, which is a combination of dehydrated amaranth leaves, eggplant leaves, carrots, and turkey berries. The presence of carrots in the composite powder may have contributed to the positive b* value (12.37), indicating a shift towards the yellow end of the colour spectrum. Carrots are known for their characteristic orange colour, which likely contributes to the yellowish hue.

7.3.2 Water Activity (a_w)

Understanding the water activity (a_w) of powders is crucial to avoid issues like caking, clumping, and stickiness in various stages of processing, handling, packaging, and storage (Juarez-Enriquez *et al.*, 2019). Elevated a_w levels may contribute to microbial growth, impacting the microbial safety, physical and chemical stability, and overall acceptability of powders. As indicated in Table 7.1, the composite vegetable powder displayed a water activity value of 0.56, signifying biochemical and microbiological stability. A_w is a measure of the amount of water available for microbial growth and chemical reactions in a product. The scale ranges from 0 to 1, with 0 being completely dry (no available water) and 1 being pure water. The low water activity would contribute to the extension of the shelf life of the powder and maintain its stability over time. Water activity has an influence on the flowability of powders. Increasing water activity leads to reduced flowability due to an increase in liquid bridges and capillary forces acting between the powder particles (Juarez-Enriquez *et al.*, 2019). For amorphous materials, increase of water activity leads to an increase of moisture content (sorption isotherms) that has a plasticizing effect and therefore reduce the glass transition temperature (Tg) (Roos, 2020). When Tg is decreased close or below the storage temperature, then sintering mechanism (viscous flow) triggers stickiness and caking (Crouter & Briens, 2014). Food powder stability is better correlated to the water activity because during shelf-life storage, all moisture transfers are driven by the difference between the relative humidity of the environment and the a_w of the product that will always tend to equilibrate (Juarez-Enriquez *et al.,* 2019). Therefore, controlling a_w levels to maintain stability of powders and to prevent caking and other conformational changes is critical to powder quality. Powders with a higher a_w should be stored at low temperature and humidity in order to maintain the storage stability.

7.3.3 Bulk density and Flowability of Composite Powder

The tapped bulk density and loose bulk density values of the composite powder provide insights into its particle packing and flow properties (Kapoor & Feng, 2022), which can impact various aspects of the product's use and manufacturing processes. When the difference between the tapped and loose bulk densities of a powder is relatively small, it suggests that the particles are relatively cohesive and can form stable arrangements with minimal void space (Kapoor & Feng, 2022). From Table 7.1, (tapped bulk density = 0.71 g/cm³ and loose bulk density = 0.63 g/cm³), the relatively small difference between the tapped and loose bulk densities (0.08 g/cm³) suggests that the particles in the composite powder might tend to pack relatively well on their own, even without significant external compaction. This could have positive implications, including reduced costs for packaging, storage, and transportation.

Powder flow characteristics are crucial in assessing how freely a powder moves and the likelihood of clumping. The Hausner Ratio (HR) and Carr Index (CI) are two closely linked empirical methods that evaluate flow behaviour based on bulk and tapped density (Santhalakshmy *et al.,* 2015). Table 7.1 displays the HR and CI values. To ensure adequate flowability, the CI should be within 15%, and HR should be within 1.18, based on standard values from Shah *et al.* (2008) and Asokapandian *et al.* (2015), as outlined in Table 7.2. Results obtained (Table 7.1) for the Hausner ratio and Carr index were 1.13 and 11.43 respectively, which shows that the composite powder has good flowability properties. The specific behaviour of powders can vary widely depending on factors such as particle size distribution, shape, surface properties, and inter-particle interactions (Shah *et al.*, 2017; Shah *et al.,* 2023).

Table 7.1: Physicochemical and functional properties of the composite vegetable powder

Property	Value
Water activity	0.56±0.02
Loose bulk density (g/cm^3)	0.63±0.01
Tapped bulk density (g/cm^3)	0.71±0.01
Hausner ratio	1.13±0.01
Carr index (%)	11.43±0.66
L	50.74±0.42
a*	-0.74±0.07
b*	12.37±0.12

Table 7.2: Specifications for Carr's compressibility index (CI) and Hausner Ratio (HR)

Flowability	**Carr Index**	**Hausner Ratio**
Excellent	0-10	1.00-1.11
Good	11to 15	1.12-1.18
Fair	16-20	1.19-1.25
Passable	21-25	1.26-1.34
Poor	26-31	1.35-1.45
Very poor	32-37	1.46-1.59
Very, very poor	>38	>1.60

Source: Shah *et al.*(2008); Asokapandian *et al.* (2015).

7.3.4 Rehydration Ratio of the composite powder

Rehydration ratio is a quality measure of how well the product can absorb water when rehydrated. Higher values of rehydration ratio (RR) indicates that the dried product has good quality because the pores allow water to re-enter the cells (Hanan *et al.,* 2020). Rehydration ratio of the composite powder, increased with time from 1 to 11 (Figure 7.1). This shows that the powder has satisfactory rehydration, which is good for their incorporation into food preparations. Similar trends of increased rehydration ratio were reported by Ng and Sulaiman (2018) and Borges *et al.,* 2022 for beet root and collard greens powders. It is also observed that the rate of rehydration of the composite powder was steadily high during the initial period (0-15min) and then increased gradually with time until the commencement of saturation. The high rate of water uptake in the initial period, could be as a result of high-water activity gradient between the sample and surrounding media (water), and with time, this difference reduces with consequent lower rate of rehydration (Chaudhary & Kumar, 2020). Similar behaviour of rehydration rate was reported by Pervin *et al.,* 2002 and Chaudhary & Kumar, 2020 on powders of beetroot and lablab beans. Products with a high rehydration capacity are more acceptable in terms of taste and retention of their fresh appearance (Jokic *et al.*, 2009). The overall physical structure of the powder can influence how water is absorbed. A more porous or open structure might lead to faster rehydration. The particle size of a product gives an indication of whether it will have a good or bad reconstitution property (Tontul &Topuz, 2017).

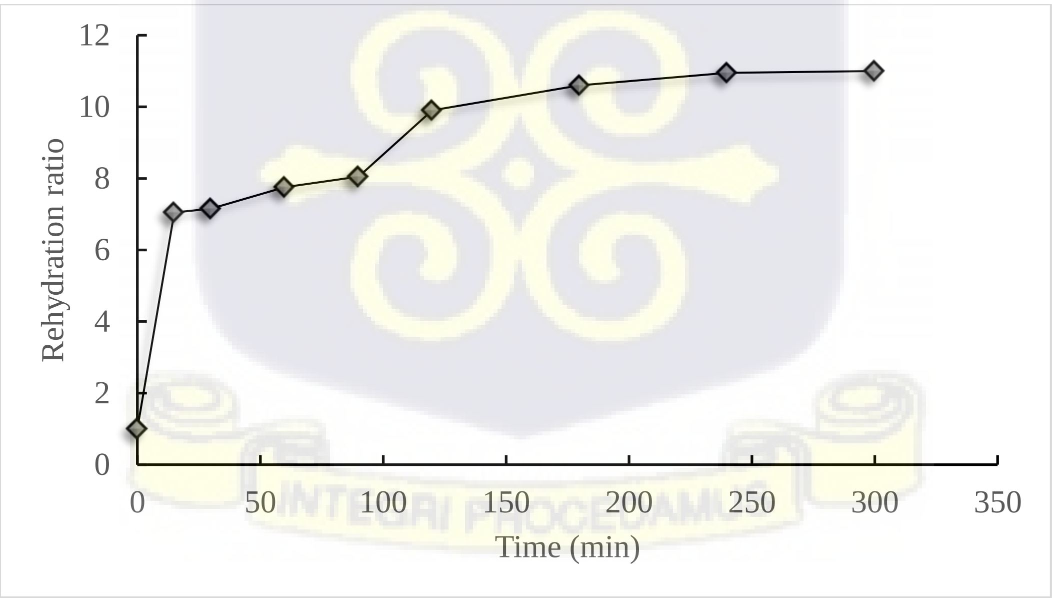

Figure 7.1: Rehydration ratio of the composite powder with time

7.3.5 Particle size and microstructure

Particle size distribution is a fundamental characteristic influencing the behaviour of food powders. Servais *et al.* (2002) and Shah *et al.* (2008) emphasized that particle size distribution directly affects flowability and functionality of food powders. Sieve analysis, a prevalent method in particle characterization, was employed to assess the distribution of particles in the composite vegetable powder. The powder exhibited a unimodal particle size distribution (Figure 7.2). The mode is the centre of the size class that contains most of the composite powder material. The distribution curve showed fine (< 60µm) and coarse (>80µm) particle sizes, with most of the particle sizes retained at the peak point of 60µm.The various particle sizes can be attributed to the diverse structural compositions of the constituent vegetables. The particle size of powders affects the rate of water absorption during processing. Smaller particles lead to faster water absorption due to the increased surface area, impacting processes like rehydration, dispersion, and mixing efficiency (Oladunmoye *et al.* 2014). It also influences the mouthfeel and texture of reconstituted products (Mazo Rivas *et al.*, 2018) and can affect the stability of powders during storage. Fine particles might be more prone to caking and moisture absorption, impacting shelf life (McClements, 2015; Chang *et al.*, 2018). The heterogeneity of the particle size is further emphasized in the structural differences of the particles viewed under the scanning electron microscope (SEM), as shown in Figure 7.3. The granules were observed to be of different shapes and sizes and this could be attributed to the different structural composition of the vegetables that constitute the composite product. Observations of different shapes and sizes of granules in composite products due to the different structural composition of the vegetables were reported by Dereje *et al.* (2020) and Thakaeng *et al.* (2021). The particle size distribution and microstructure of the composite vegetable powder profoundly impact its behaviour during processing, rehydration, and overall product quality.

Utilizing insights from particle size distribution and microstructure allows for informed decisions in formulation, processing, and product design, ultimately leading to enhanced consumer satisfaction and efficiency in food manufacturing.

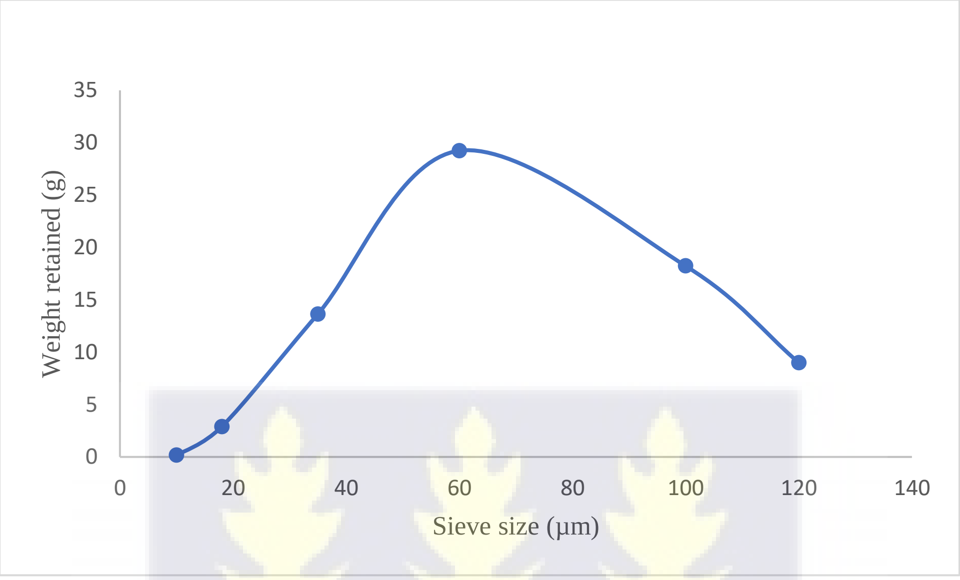

Figure 7.2: Particle size distribution of the composite powder

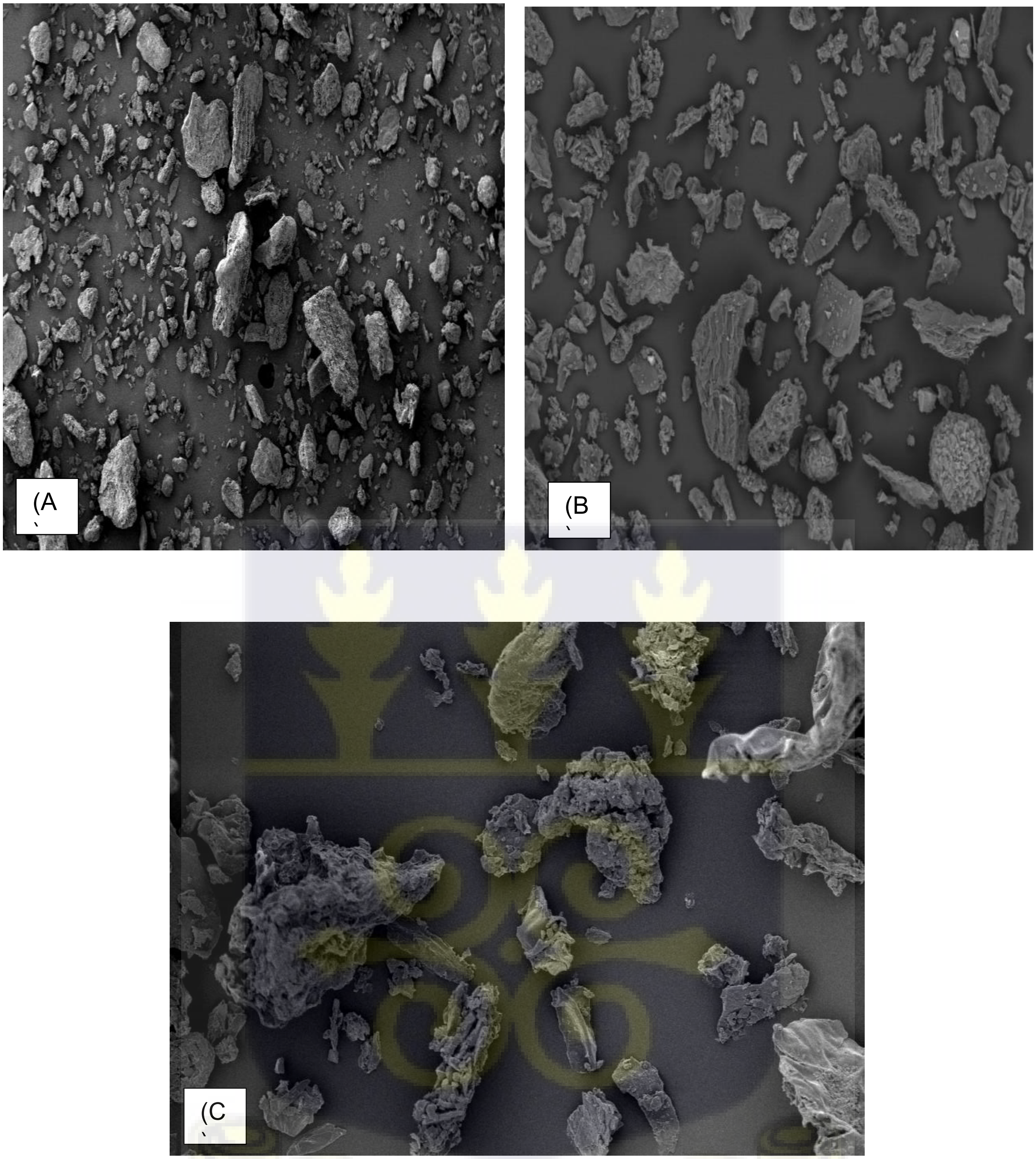

Figure 7.3: The scanning electron micrographs for the composite powder at different magnifications: x 150 (A), x 500 (B), x1000 (C).

7.3.6 Moisture Sorption Behaviour of Composite Vegetable Powder

The sorption behaviour of the composite powder is summarized in Figure 7.4 and Table 7.3. From the figure, it is observed that the powder had the classical sigmoid-shaped curve as expected of dried food ingredients such as flours and powders (Andrade *et al.*, 2011). It was also observed that beyond 10% EMC and a_w of about 0.5, the powder began to absorb higher moisture under constant temperature and pressure. This implies that the maximum allowable moisture content for safekeeping at 10%, beyond which they may cake or become lumpy during storage. Adsorption of moisture from the environment makes it more susceptible to deterioration. Therefore, to maximize the shelf life of the powder, special attention must be given to storage conditions. It may be necessary to store the powder in airtight containers with desiccants or packaging materials that provide efficient barrier against moisture ingress.

Several models are used to explain the moisture sorption characteristics of foods. The popular models include the BET, GAB, Oswin, Smith, Iglesias and Cherife models (Andrade *et al.*, 2011). This study fitted the data into the five models, as shown in Table 7.3. These models' parameters (A and B) reflect their respective characteristics, with A relating to the monolayer sorption capacity and B to isotherm shape parameters. The BET model fitted well, however, the GAB model seemed to offer the best fit to the sorption isotherm data of the composite vegetable powder at the different temperatures. It demonstrated the lowest χ^2 value (value being very close to zero suggests an excellent fit) and the highest R^2 value (indicating that the model explains a substantial portion of the variability in the data) among the tested models. The powders stored under 25ºC had the highest monolayer moisture content of 0.08 and 0.17, suggesting a lower safekeeping tendency while in storage under standard conditions (Andrade *et al.*, 2011) compared to powders stored under 30ºC and 35ºC. This means that, at 25°C, the powder's surface had adsorbed more water molecules as a monolayer compared to the other temperatures. This could be due to the higher equilibrium vapour pressure of water at 25°C according to the Clausius-Clapeyron relationship. Temperature affects moisture sorption by powders through its impact on vapor pressure, as described by the Clausius-Clapeyron relationship (Cagabhion & Emnace, 2021). A lower safekeeping tendency implies that the powder is more susceptible to moisture adsorption, which could lead to caking or lumping during storage, as mentioned in the initial statement.

The GAB model, which is based on multilayer sorption, is commonly used to describe adsorption on heterogeneous surfaces, such as food materials (Aviara, 2020). It accounts for monolayer and multilayer adsorption, which can provide more accurate representations of complex sorption behaviors compared to simpler models like the BET model (Majd *et al.,* 2022). Knowledge on the model of best fit has practical implications across various aspects of production, quality control, and product design, contributing to the overall success of the product in the market. The choice of the right model can greatly impact the efficiency and effectiveness of these processes.

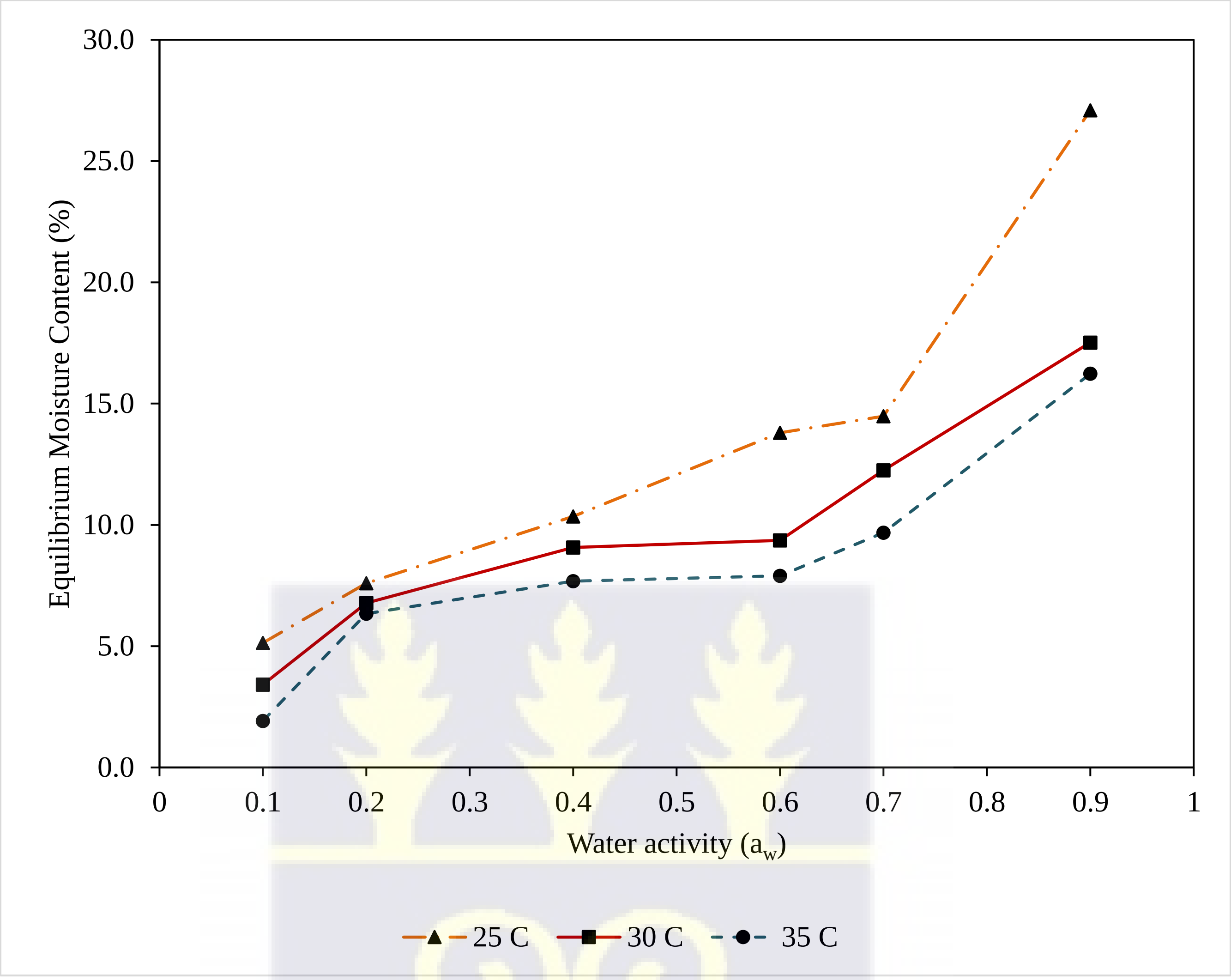

Figure 7.4: Moisture Sorption of Composite Vegetable Powder

Table 7.3: Parameters obtained from isotherm models for composite vegetable powder.

Model	Model parameters	Temperature		
		25 °C	30 °C	35 °C
GAB	X_m (g H_2O / g solid)	0.08129	0.07612	0.05866
	C	2.06817	1.305236	1.16821
	K	0.76174	0.63179	0.70169
	χ^2_{red}	1.0451E-4	1.08503E-4	1.76501E-4
	R^2	0.9694	0.95503	0.91969
	RMSE	0.00029	0.00041	0.00053
BET	X_m (g H_2O / g solid)	0.1692602	0.1493	0.12704
	C	0.01458	0.01035	0.00932
	χ^2_{red}	2.97573E-4	6.42794E-4	3.75316E-4
	R^2	0.89843	0.85248	0.87473
	RMSE	0.00239	0.00137	0.00110
Oswin	A	0.24251	0.20513	0.15616
	B	0.0635	0.04205	0.03292
	χ^2_{red}	2. 02091E-4	3.20974E-4	2.94533E-4
	R^2	0.88608	0.86187	0.86599
	RMSE	0.00286	0.00128	0.00178
Smith	A	0.05863	0.0518	0.03765
	B	0.08353	0.05079	0.04954
	χ^2_{red}	2.11274E-4	2.662E-4	2.42693E-4
	R^2	0.96409	0.88544	0.88957
	RMSE	0.00035	0.00106	0.00191
Iglesias and Cherife	A	0.09071	0.07275	0.05807
	B	0.01535	0.00888	0.0088
	χ^2_{red}	9.2284E-4	7.3197E-4	5.72611E-4
	R^2	0.84314	0.68499	0.73946
	RMSE	0.000371	0.00296	0.00229

R^2 = Coefficient of regression, χ^2 = Chi-square, “Xm= Monolayer moisture content (gH_2O/g solid), C = BET constant, C and K = GAB constants, A and B” = Oswin,Smith, Iglesias and Cherife constants. RMSE= Root Mean Square Error

7.4 Conclusions

The study investigated the physical and chemical properties of a composite vegetable powder made using dehydrated amaranth leaves, eggplant leaves, carrots, and turkey berries. The powder had a moderately bright greenish colour. Its low water activity (a_w) ensures stability during storage. Controlling a_w levels is crucial to maintain good flowability and prevent caking. The particle packing and flow properties were favourable. The powder's moisture absorption capacity increased with higher equilibrium moisture content (EMC) and a_w values and was best described by the GAB model.

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CHAPTER EIGHT

GENERAL CONCLUSIONS AND RECOMMENDATIONS

General Conclusions

The comprehensive study delved into various aspects of processing and dehydration of selected vegetables. The findings highlight the distinct behaviors of different vegetables in response to blanching and drying methods, emphasizing the importance of tailored approaches for each type. Steam blanching demonstrated effectiveness in stabilizing the colour of certain vegetables, while the rate of drying, varied among blanched and unblanched vegetables.

The impact of drying methods on the nutritional and phytochemical content underscored the significance of freeze-drying in preserving these beneficial compounds. The nutritional analysis of dehydrated vegetables emphasized their low moisture content, water activity, fat, and crude fiber, while highlighting essential mineral content such as iron, zinc, potassium, calcium, magnesium, and manganese.

The development of an optimum formulation for a composite product, based on sensory evaluation, demonstrated a nutrient-dense product, combined of amaranth leaves, carrots, turkey berries, and eggplant leaves. It provides a practical approach to creating nutrient-rich blends, addressing specific dietary needs and preferences. The composite product exhibited promising nutritional contributions, potentially meeting a significant portion of the Recommended Dietary Allowances (RDA) for iron, zinc, and vitamin A for both children and adults.

The investigation into the properties of a composite vegetable powder revealed favourable characteristics, including colour, water activity, flow properties, and rehydration ratio. The study provided crucial insights for the development and utilization of composite vegetable powders in various industries, addressing factors like stability during storage and effective moisture absorption. Dehydrated vegetables have great potential for commercialization and should be promoted.

Recommendations

The following recommendations are suggested:

1. Given the varied responses of the vegetables to blanching, further research into optimizing blanching conditions for each vegetable type is recommended. This includes exploring different blanching durations and temperatures to achieve the best colour stability without compromising nutritional content.
2. Further sensory evaluations and optimization studies can be conducted to fine-tune the composition of composite products, considering not only nutritional aspects but also, the incorporation into various food matrixes.
3. Future studies can be carried out on storage trials of the composite powder under varying conditions, assessing parameters such as sensory analysis over time.
4. Conducting consumer studies to assess the acceptance and preferences for composite vegetable powders in various foods can provide valuable market insights. Understanding consumer behaviour and preferences will aid in tailoring products to meet market demands.
5. Considering the growing emphasis on sustainability, future research could explore environmentally friendly packaging options for vegetable powders.
6. Collaborate with food industry partners to translate research findings into real-world applications. This involves working with food manufacturers to incorporate the optimized processing techniques and formulations into commercial production.

7. Also, policies could be developed to incorporate dehydrated vegetables into the school feeding programme, especially when fresh vegetables are scarce during lean seasons.

These recommendations aim to enhance the practical application of the study's findings, contributing to the development of more efficient and sustainable practices in vegetable processing and the production of composite vegetable powders. The recommendations for further research can be taken up by students and researchers in the universities and relevant research institutions. The Ministry **of Gender, Children, and Social Protection (MoGCSP) in collaboration with other ministries such as the Ministry of Education and the Ministry of Health, can make policies** to incorporate dehydrated vegetables into the school feeding programme, **to ensure its effectiveness in improving nutrition, education, and health outcomes for school children.**

APPENDICES

Appendix 1. Analysis of Variance of amaranth pretreatments (L*)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	4	90.1303	22.5326	2954.45	0.000
Error	10	0.0763	0.0076		
Total	14	90.2066			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.087331	99.92%	99.88%	99.81%

Appendix 2. Analysis of Variance of amaranth pretreatments (a*)

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	4	14.0635	3.51587	1578.99	0.000
Error	10	0.0223	0.00223		
Total	14	14.0858			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.047188	99.84%	99.78%	99.64%

Appendix 3. Analysis of Variance of amaranth pretreatments (b*)

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	4	18.7694	4.69236	2315.31	0.000
Error	10	0.0203	0.00203		
Total	14	18.7897			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.045019	99.89%	99.85%	99.76%

Appendix 4. Analysis of Variance of pretreated carrots (L*)

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	7	164.864	23.5521	98.26	0.000
Error	16	3.835	0.2397		
Total	23	168.699			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.489575	97.73%	96.73%	94.89%

Appendix 5. Analysis of Variance of pretreated carrots (a*)

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	7	274.911	39.273	1046.58	0.000
Error	16	0.6	0.0375		
Total	23	275.512			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.193714	99.78%	99.69%	99.51%

Appendix 6. Analysis of Variance of pretreated carrots (b*)

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	7	329.415	47.0593	2017.19	0.000
Error	16	0.373	0.0233		
Total	23	329.788			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.152739	99.89%	99.84%	99.75%

Appendix 7. Analysis of Variance of pretreated turkey berries (L*)

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	12	3317.03	276.419	1778.55	0.000
Error	26	4.04	0.155		
Total	38	3321.07			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.394231	99.88%	99.82%	99.73%

Appendix 8. Analysis of Variance of pretreated turkey berries (a*)

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	12	227.347	18.9456	9595.83	0.000
Error	26	0.051	0.002		
Total	38	227.399			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.044434	99.98%	99.97%	99.95%

Appendix 9. Analysis of Variance of pretreated turkey berries (b*)

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value

Treatment	12	502.098	41.8415	3253.88	0.000
Error	26	0.334	0.0129		
Total	38	502.433			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.113397	99.93%	99.90%	99.85%

Appendix 10: Analysis of Variance of Tannins (Eggplant leaves, freeze drying; treatment)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	1	14.4769	14.4769	141.74	0.007
Error	2	0.2043	0.1021		
Total	3	14.6812			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.319587	98.61%	97.91%	94.43%

Appendix 11: Analysis of Variance of Phytates (Eggplant leaves, freeze drying; treatment)

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	1	13.6435	13.6435	361.18	0.003
Error	2	0.0756	0.0378		
Total	3	13.7190			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.194358	99.45%	99.17%	97.80%

Appendix 11: Analysis of Variance of Tannins (Amaranth leaves, oven drying; treatment)

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	1	5.5059	5.5059	16.98	0.054
Error	2	0.6486	0.3243		
Total	3	6.1545			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.569472	89.46%	84.19%	57.85%

Appendix 12: Analysis of Variance of Oxalates (Carrots, oven drying; treatment)

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	1	0.013159	0.013159	343.25	0.003
Error	2	0.000077	0.000038		
Total	3	0.013236			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0061917	99.42%	99.13%	97.68%

Appendix 13: Mineral analysis: Turkey Berry (Ca-FD, Ca-OD)

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	1	1.848	1.848	1.56	0.280
Error	4	4.743	1.186		
Total	5	6.591			

Appendix 14: Mineral analysis: Turkey Berry (Mg -FD, Mg- OD)

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	1	320.617	320.617	22420.74	0.000
Error	4	0.057	0.014		
Total	5	320.674			

Appendix 15: Mineral analysis: Turkey Berry (Mn - FD, Mn-OD)

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	1	2.0417	2.0417	16.12	0.016
Error	4	0.5067	0.1267		
Total	5	2.5483			

Appendix 15: pH of freeze dried (blanched and unblanched) amaranth leaves

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	1	0.007350	0.007350	220.50	0.000
Error	4	0.000133	0.000033		
Total	5	0.007483			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0057735	98.22%	97.77%	95.99%

Appendix 16: pH of oven dried (blanched and unblanched) amaranth leaves

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	1	0.201667	0.201667	12100.00	0.000
Error	4	0.000067	0.000017		
Total	5	0.201733			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0040825	99.97%	99.96%	99.93%

Appendix 17: pH of solar dried (blanched and unblanched) amaranth leaves

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	1	0.098817	0.098817	1482.25	0.000
Error	4	0.000267	0.000067		
Total	5	0.099083			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0081650	99.73%	99.66%	99.39%

Appendix 18: Ash of freeze dried (blanched and unblanched) eggplant leaves

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	1	15.8210	15.8210	232052.51	0.000
Error	4	0.0003	0.0001		
Total	5	15.8213			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0082570	100.00%	100.00%	100.00%

Appendix 19: Ash of oven dried (blanched and unblanched) eggplant leaves

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	1	0.043560	0.043560	434.50	0.000
Error	4	0.000401	0.000100		
Total	5	0.043961			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0100127	99.09%	98.86%	97.95%

Appendix 20: Ash of solar dried (blanched and unblanched) eggplant leaves

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	1	1.77612	1.77612	17304.78	0.000
Error	4	0.00041	0.00010		
Total	5	1.77653			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0101310	99.98%	99.97%	99.95%

Appendix 21: Fiber of freeze dried (blanched and unblanched) carrots

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	1	0.012150	0.012150	121.50	0.000
Error	4	0.000400	0.000100		
Total	5	0.012550			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.01	96.81%	96.02%	92.83%

Appendix 21: Fiber of oven dried (blanched and unblanched) carrots

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	1	0.277350	0.277350	2773.50	0.000
Error	4	0.000400	0.000100		
Total	5	0.277750			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.01	99.86%	99.82%	99.68%

Appendix 22: Fiber of solar dried (blanched and unblanched) carrots

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	1	0.003750	0.003750	37.50	0.004
Error	4	0.000400	0.000100		
Total	5	0.004150			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.01	90.36%	87.95%	78.31%