DEVELOPMENT AND PERFORMANCE EVALUATION OF A MULTI-STORIED UNIVERSAL CABINET DRYER FOR DRYING OF HIGH MOISTURE VEGETABLES

A THESIS

BY

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Student ID: 1605567
Admission Semester: July–December, 2016

MASTER OF SCIENCE (MS)
IN
FOOD ENGINEERING AND TECHNOLOGY

DEPARTMENT OF FOOD ENGINEERING AND TECHNOLOGY

HAJEE MOHAMMAD DANESH SCIENCE AND TECHNOLOGY UNIVERSITY
DINAJPUR-5200

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Submitted to the
Department of Food Engineering and Technology,
Hajee Mohammad Danesh Science and Technology University, Dinajpur-5200

In partial fulfillment of the requirements for the degree of

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DEPARTMENT OF FOOD ENGINEERING AND TECHNOLOGY

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Dedicated To

My Parents, Teachers and Well Wishers

ACKNOWLEDGEMENT

I express the deepest sense of gratefulness to the ***"Almighty Allah" Who*** *has enabled me to complete the thesis work. I take this opportunity with pride and enormous gratification to express the feelings of thanks and gratefulness from the bottom of my heart to all the persons who backed me directly or indirectly throughout the materialization of this research work at this magnitude.*

First and foremost, I deem it a rare opportunity to pronounce my deep sense of gratitude to the tutelary **Dr. Md. Sazzat Hossain Sarker, Professor and Chairman***, Department of Food Engineering and Technology, Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur, for his exemplary guidance, which enabled my research efforts to come in shape with meaningful conclusions. His concern and endearing demeanor always encouraged me enthusiasm in research, which otherwise bound to be lackadaisical. His keen interest in my research progress would have been unrequited if I had not heed his remarks of excellence.*

With great pleasure I thank Co-supervisor, **Dr. S M Kamrul Hasan, Associate Professor,** *Department of Food Processing and Preservation, Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur, for his valuable advice, exclusive suggestions and provisions of facilities and supports needed to complete this research work.*

The author expresses especially grateful to ***Dr. Maruf Ahmed, Professor,*** *Department of Food Processing and Preservation, Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur, for his limitless help in performing chemical analysis of samples in laboratory. The author also thanks to the staff of the Department of Food Engineering and Technology, Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur for coordination and helping to my research work.*

Above all I would like to acknowledge my Beloved Parents, brother, sister, for vital and moral support without which this effort of mine would have not paid off.

The Author

ABSTRACT

Development of appropriate drying technique and associated dryer are important issues for quality and stable dried vegetables. The present research was carried out to design and fabricate of a multi-storied universal cabinet dryer (MSUCD) suitable for drying of high moisture vegetables. Further, drying performance of the dryer was compared to other three conventional drying methods (sun, shade and existing cabinet) in yielding quality dried mallow (napa shakh) powder. Necessary adjustments were employed for ensuring uniform distribution of drying air flow and temperature in all trays of the drying chamber. The dryer was found to be quite satisfactory functioning for drying of 13 locally grown vegetables. Drying results revealed that shorter drying time (only 1.00 to 2.67 hr) required for drying of leafy vegetables from initial high moisture content of 93% to final moisture content of 3.78% (wb). However considerably longer drying time (6.33 to 17.67 hr) required for drying of tuber vegetables from 90.20% to 6.44% (wb) final moisture content. Lesser energy (0.87kWh/kg) required in drying of leafy vegetables whereas comparatively higher energy (5.05 kWh/kg) was found to be needed in drying of tuber vegetables by this dryer. Consequently, drying cost was lower in drying of leafy vegetables than tuber vegetables. Thermal efficiency was found to be 42.19% and 7.61% in drying leafy and tuber vegetables, respectively. The drying time required for drying of the mallow leaves were 6 hr, 48 hr, 4.25 hr and 1.33 hr for sun, shade, cabinet and MSUCD, respectively. The obtained results showed that drying methods have significant effects on functional, antioxidant and sensory characteristics of dried mallow powder. Results also revealed that significantly higher amount of bioactive compounds and their antioxidant activity were found to be retained in mallow powder dried by MSUCD compared to other drying methods. Therefore, this work suggests that the MSUCD is promising for drying of all high moisture vegetables. Moreover, this work also provided the way to design prototype as well as industrial scale multi-storied universal cabinet dryer for drying of high moisture vegetable products.

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LIST OF ABBREVIATIONS

%	Percentage
^{0}C	Degree centigrade
AOAC	Association of Official Agricultural Chemists
C_a	Specific heat capacity of air
cm	Centimeter
Kg	Kilogram
db	Dry Basis
EMC	Equilibrium Moisture Content
et al.	and others
FAO	Food and Agricultural Organization
g	Gravitational acceleration
E_t	Heat utilized for effective drying
HSTU	Hajee Mohammad Danesh Science and Technology University
kWh	Kilowatt-hour
M	Meter
MC	Moisture Content
Min	Minute
M_R	Amount of moisture to be removed
MSUCD	Multi-storied Universal Cabinet Dryer
OAI	Oil Absorption Index
Q_{ht}	Heat transfer rate
RH	Relative Humidity
SPEEC	Specific Electrical Energy Consumption
TSPEEC	Total Specific Electrical Energy Consumption
TFC	Total Flavonoid Content
TPC	Total Phenolic Content
WAI	Water Absorption Index
wb	Wet Basis
WSI	Water Solubility index
BARI	Bangladesh Agricultural Research Institute

CHAPTER I

INTRODUCTION

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INTRODUCTION

1.1 Background

Food security is now considered as one of the crucial topics all over the world. However, food security is not only the production of foods but also the quality of foods. Now-a-days people are more conscious about health benefits foods. Antioxidant compounds that naturally present in foods are considered as important part of our everyday life. They have positive effect on immune system, cardiovascular diseases, gastritis, eye vision, obesity, type 2 diabetes, arthritis, chronic inflammation, mortality, aging, atherosclerosis, hypertension, heart attack, cancers and other degenerative diseases of human health by protecting the body against oxidative damage through free radicals (Joao *et al.,* 2012; Borden *et al.,* 2013; Zamora *et al.,* 2013; Asma *et al.,* 2013). Moreover, natural polyphenols present in vegetable play an important role as a health protecting factor when added to food products, especially to lipids and lipid-containing foods (Annegowda *et al.,* 2014*;* Raja *et al.,* 2017). It can also increase the shelf life of foods and prevent nutritional losses by retarding the oxidation of foods, which is one of the major cause of deterioration of food products during processing and storage (Rumit *et al.,* 2010). Fresh vegetables are rich in different natural antioxidant compounds like polyphenol, flavonoids, and carotenoids. Therefore, the development of suitable processing methods for high moisture vegetables is essential that will ensure the maximum retention of antioxidant compounds in processed vegetables through minimizing drying effects.

Drying involves the removal of water from the vegetable products that inhibit the growth of microorganisms, enzymatic and other deteriorative reactions which results the extended shelf life of dried vegetable products (Scala *et al.,* 2008; Mujumdar *et al.,* 2010). The demand of dried vegetables is increasing day by day due to their excellent quality, convenient use and longer storability at room temperature. Many scientists believe that the reason of increasing anti-oxidative compounds in dried vegetables may be due to drying methods (Hassain *et al.,* 2010; Pinela *et al.,* 2012; Zoro *et al.,* 2 015). Moreover, the shelf-life of dried product depends on how it is dehydrated, packaged and stored. Vegetables can be dried in various types of dryers, such as tray dryer, tunnel dryer, cabinet dryer, vacuum dryer, freeze dryer, and so on. Although these dryers have proved as efficient drying systems but not free from drawbacks. For instance, expensive for installation, complex to operate, higher energy cost, under or over drying of products, and improper hot air supply. Therefore, an innovative drying system is needed to dry the vegetables that will overcome such drawbacks.

1.2 Problem Statement and Justification of the Study

Bangladesh has scored third (3^{rd}) position in global vegetable production, next to China and India. According to FAO, vegetable production has increased five times in the past 40 years (BARI, 2015-16). But vegetables are seasonal crops and are mostly available during the production season. Due to high perishable nature, the postharvest loss of vegetables ranged from 23.6 to 43.5% and the annual monetary loss for vegetables were 3442 crore taka (Hassain *et al.*, 2010). In Bangladesh, heavy losses occurred during harvesting season due to poor handling procedures, lack of low cost processing technologies and improper storage facilities. Postharvest operations, like drying, alters the shelf life of vegetables to a great extent by reducing water and make them available for consumption in the off-season (Hassain *et al.*, 2010).

Improvement of product quality and reduction of postharvest losses can only be achieved by the introduction of suitable drying technologies (Bala *et al.*, 2009). Sun drying is the cheapest method but the quality of the dried products obtained by this method is far below the international standards (Bala *et al.*, 2009). Shade dying or air drying at room temperature is the most energy saving drying method compared to oven drying method and this method retains the beneficial bioactive components, which are sensitive to thermal treatment (Kamel *et al.*, 2013). Although shade drying maintains better quality but it takes longer time (several days) for drying (Agasimani *et al.*, 2008). On the other hand, application of convective drying, such as existing cabinet dryer is mostly used for drying of fruits and vegetable in many countries including Bangladesh. Its design and construction have some limitations, such as trays are arranged in only one drying chamber, constant (unchangeable) air flow rate, non-uniform hot air supply throughout the trays in the drying chambers, longer drying time, higher drying rate at the middle layer, slower drying rate in the top and bottom layer trays, color and nutritional quality loss and so on (Agasimani *et al.*, 2008; Ehiem *et al.*, 2009; Mohammed, 2013).

From the above review, it is clear that there is a scope to improve the existing cabinet dryer, which would be suitable for drying of all vegetables as well as efficient in producing quality dried vegetable products (Vinson *et al.,* 2005; Keast *et al.,* 2011; Sultana *et al.,* 2012). For convenient use, farmers of developing countries like Bangladesh need low price, energy efficient, simple operating system vegetable dryers, which can save their products from postharvest loses. This eventually contributes in earning more money for their better livings. Design and development of simple structure and operation, eco-friendly, easily adoptable, cheap and energy efficient hot air drier is the crying need for small to medium farmer of Bangladesh. Therefore, this study aims to design an improved cabinet dryer with the following set of objectives.

1.3 General Objective

The main objective of this study is to design a laboratory scale multi-storied universal cabinet dryer and to test its performance by drying of high moisture vegetables.

1.3.1 Specific Objectives

The following specific objectives will be evaluated:

1. To design and fabricate a multi-storied universal cabinet dryer.
2. To evaluate the performances of the proposed cabinet dryer for drying of high moisture vegetables.
3. To compare the physical, bioactive and sensory properties of the dried *M. verticillata* powder obtained from proposed dryer to other drying methods.

CHAPTER II

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

2.1 Theory of vegetable drying

The main purpose of drying is to extend the shelf life of food by the reduction in the water activity which inhabits microbial growth. However, the processing temperature will not normally be sufficient to cause inactivation. Although drying increases the storage value of vegetables, it also causes reduction in eating quality and nutritive value of food. To minimize such detrimental effect, drying equipment should be appropriately designed to ensure sufficient drying rates. In the design considerations, it is important to take into consideration the moisture content of the vegetable to be dried (Adzimah *et al.*, 2009).

2.2 Overview of vegetables drying methods

2.2.1 Solar drying

Solar drying has remained the cheapest means of drying fruits and vegetables in most developing countries mainly tropical and subtropical countries. This is an indication that solar drying is a time consuming operation when compared to other types of drying methods. Moreover the use of this method of drying is suitable for regions with tropical climates where hot sun and dry atmosphere exist over a period of time (Manchekar, 2008). This often lead to undesirable thermal degradation of the finished products due to long drying times at relatively high temperatures during the falling rate periods result in low drying rates in the falling rate period of drying (Clary *et al.*, 2005). The quality of the dried products is far below the international standards. Improvement of product quality and reduction of losses can only be achieved by the introduction of suitable drying technologies (Bala, 2009).

2.2.2 Shade drying

Natural drying i.e., shade drying is widely used because of its lowest cost. This method have many disadvantages due to the inability to control large quantities and to achieve consistent quality standards. Shade drying though maintains better quality takes many days to dry to constant weight. (Agasimani *et al.*, 2008). It often lead to undesirable thermal degradation of the finished products due to long drying times at relatively high temperatures during the falling rate periods result in low drying rates in the falling rate period of drying (Petrucci *et al.*, 2005).

2.2.3 Osmotic dehydration

Osmotic dehydration is a simultaneous counter-current mass transfer process in which biological materials (such as fruits and vegetables) are immersed in a hypertonic aqueous solution for a selected period. The driving force for the diffusion of water from the tissue into the solution is the higher osmotic pressure of osmotic solution and its lower water activity that results in the transfer of water from the product across the cell wall (Ramaswamy, 2010). This dehydration process is called osmotic dehydration (Riva *et al.*, 2005). Since the membrane responsible for osmotic transport is not perfectly selective, other solutes (sugar, organic acids, minerals, vitamins) present in the cells can also leach into the osmotic solution (Riva *et al.*, 2005) in amounts that are quantitatively negligible compared with the other transfer; however, they are important in terms of final product quality (Ramaswamy, 2010).

2.2.4 Hot air drying

Hot air drying is the most commonly employed commercial technique for drying of food materials. However, low energy efficiency, longer drying time and poor product quality are some of the drawbacks of hot air drying. Hot air drying employs removal of moisture by flow of hot air under controlled conditions of temperature, relative humidity and constant air flow (Agasimani *et al.*, 2008). The hot air drying process applied is a simple, low cost technique and the results prove that the dehydrated products obtained are good sources of natural antioxidants such as phenolic compounds and possess high antioxidant capacity. Since fresh fruits and vegetables are highly perishable, it is recommended to use a dehydration process as an alternative to preserve most of their beneficial properties, and dehydrated fruits and vegetables represent an excellent low cost alternative to be used as functional foods or ingredients (Lutz *et al.*, 2015). Hot air flow drying often shorter drying time, improved product quality, and flexibility in producing a wide variety of dried products. But current applications are limited to small categories of fruits and vegetables due to high start-up costs, non-uniform electromagnetic field generation, non-uniform penetration depth, too rapid mass transport and relatively complicated technology as compared to conventional convection drying.

2.2.5 Freeze drying

Freeze drying technique has been widely used for drying various fruits and vegetables such as figs, cherries, strawberries and peaches (Wanjala, 2010). Some advantages of freeze drying with respect to the quality of final product as highlighted by Sogi *et al.* (2013) includes minimal shrinkage of final product, high retention of nutritional value, high flavor and aroma retention coupled with easy rehydration characteristics of the final product. Despite the inherent advantages associated with freeze drying technique, its use is still limited due to the high capital and operating costs involved (Aminu, 2013).

2.3 Design aspects of dryer for vegetable drying

2.3.1 Principles of existing cabinet dryer for vegetables drying

The vegetables which are to be dried are loaded into the trays and the trays are then fed into the drying chamber and the door is closed sealing the system. The trays may have solid or perforated bottom depending on the food particle size. When moisture from grains is vaporized, they pass through an outlet to the surrounding. Heat is supplied by electrical heating coils and hot air is blown from the heater housing to the drying chamber by the aid of a fan (Adzimah *et al.,* 2009).

2.3.2 Overview of different types of vegetable dryer

2.3.2.1 Cabinet dryers

Cabinet drying is the most commonly employed commercial technique for drying of food materials. Cabinet drying employs removal of moisture by flow of hot air under controlled conditions of temperature, relative humidity and constant air flow (Agasimani *et al.,* 2008). It often degrades product quality such as case hardening, loss of volatile compounds, and worsening of the color and nutritional content during drying of food products. But current applications these dryers are limited to small categories of fruits and vegetables due to high start-up costs, non-uniform electromagnetic field generation, non-uniform penetration depth, too rapid mass transport and relatively complicated technology as compared to conventional convection drying (Aminu, 2013).

2.3.2.2 Vacuum dryers

Vacuum driers may be cabinet batch driers or continuous band driers with vacuum locks at in feed and outlet in either case heat transfer is by radiation and conduction. The advantage of vacuum drying is that evaporation of water takes place more readily at low pressures (Lutz *et al.*, 2015). But current applications are limited to vegetables due to high start-up costs and relatively complicated technology as compared to conventional convection drying (Aminu, 2013).

2.3.2.3 Spray dryers

In spray drying system a spray of the material to be dried, which might for example be a pored vegetable suitable diluted and stabilized, is dispersed, as atomized spray into a counter current of hot dry air. The droplets dry in the airstream, falling to the bottom of unit as they do so, and key elements are sufficient fan power and heating to achieve the required velocity and temperature, the atomizer, the drying chamber and the means of removing the dried product. The atomizer, the drying chamber may be one of the three basic types (Lutz *et al.*, 2015). Disadvantages of spray drying of food products are degrading product quality, loss of volatile compounds, lower solubility and worsening of the color and nutritional content. But current applications are limited to milk products due to high start-up costs and relatively complicated technology as compared to conventional convection drying (Aminu, 2013).

2.3.2.4 Freeze dryers

Freeze drying is one of the most advanced drying methods, which provides dry products with porous structure combined with small or negligible shrinkage, superior flavor and aroma retention and improved rehydration behavior compared to products of the alternative drying processes (Sallami *et al.*, 2013). Freeze-drying maintained a high amount of total phenolics of plants during processing (Ozcan, 2012; Annegowda *et al.,* 2014). Some drawbacks of these dryers are High start-up costs and relatively complicated technology as compared to conventional convection drying.

2.3.2.5 Tray, Tunnel and Belt dryers

These dryers are similar in that they all use hot circulating air stream to provide the energy needed for drying and the product being dried moves at a high velocity compared to the circulating air velocity. In these drier, the product to be dried is placed on the trays in the drying compartment and heated air is supplied by direct combustion with fuels or by steam or electric coils. The air stream in these drier could be arranged to flow in the same direction (parallel flow), opposite direction (counter flow) or at right angles (cross flow) with respect to the direction in which the carts move through the tunnel (Aminu, 2013). Hot air drying often degrades product quality, case hardening, loss of volatile compounds, and worsening of the color and nutritional content can occur during drying, since the products are exposed to high temperatures for a long period. But current applications are limited to small categories of fruits and vegetables due to high start-up costs, non-uniform electromagnetic field generation, non-uniform penetration depth, too rapid mass transport and relatively complicated technology as compared to conventional convection drying (Aminu, 2013).

2.3.2.6 Microwave dryers

Microwave drying has gained popularity in the food industry as an alternative method. The use of microwave rays in the drying of fruits and vegetables has several advantages including the shortening of drying time, which can maintain nutritional quality in the dried product, like higher retention of some vitamins, and a homogeneous energy distribution on the material (Ozkan, 2007). The problems connected to conventional is the lengthy drying time during the last stage of drying which may lead to serious injuries that could worsen the taste, color and nutritional content of the dried vegetables (Mujumdar, 2010). Current applications are limited to vegetables due to high start-up costs, non-uniform electromagnetic field generation, non-uniform penetration depth, too rapid mass transport and relatively complicated technology as compared to conventional convection drying (Aminu, 2013).

2.3.3 Some review on existing cabinet dryer for vegetables drying

Anonymous (1998) conducted his research to design a firewood fueled cabinet dryer for high moisture agricultural produce to make self-stable low moisture dried product for export. He remarks that high temperature of the drying chamber will destroy the volatile compounds of black pepper, so the drying temperature should maintained below 57^0 C.

Adzimah *et al.* (2009) carried out their study to design an improved cabinet dryer for small-scale grain producers which was maintained 35-40^0 C drying chamber temperature and 6-12 h drying time before which it takes 2 h as pre-drying. The results showed that the drying rate is faster and grains are moderately dried.

Ehiem *et al.* (2009) conducted their research to show the effect of sample size, air flow rate and drying time on drying efficiency of tomato using their developed bio-fueled cabinet dryer. The drying chamber temperature was 50^0 C. There were three sample size, three air flow rate and fourteen hours drying time and six replications. The results showed that the higher the drying time, the higher the drying rate as well as the higher the air flow rate, the higher the drying rate. Fashina *et al.* (2013) developed a laboratory scale as well as commercial scale batch type maize dryer of about 100 kg capacity which had temperature and air velocity controlling unit. They investigated the effects of different drying temperature, air velocity, loading and agitating speed on the quality of dried maize with that dryer. Mohammed (2013) introduced a prototype vegetable dryer that maintains $55\text{-}60^0$ C for preventing darkening or color losses and the drying time was 9-36 hours. It was observed that the original color of the vegetable, it is hygienic and no dust condition was confirmed. However, since their project is a prototype, it could be developed into bigger efficient vegetable drier. There can be diverse ways in which the project can be improved upon depending on where and the quantity of the vegetable to be dried.

Abiola *et al.* (2014) manufactured a home-scale cabinet dryer which will not only used for baking biscuits but also used for the preservation of fish, meat and meat pie etc. at a low cost. The dimension of the box shaped cabinet was 714mm x 574mm x 984mm that has the heater capacity was 1500 Watt and blower capacity was 1.02 Watt which was locally collected.

Gyanwali *et al.* (2014) developed an electric dryer for quality product drying than other types of conventional dryers. Two different performance testing was carried out with 25 kg of fresh ginger as input which was dried for 4.5 hours. The first test was 30% efficient consuming 40 kWh of electric power with output of 5.4 kg of dried ginger. When leakage of the hot and dry air from dryer was minimized in the second test, dryer was 37% efficient. Later on, electric dryer system was compared with biomass based dryer system which shows that the drying rate of electric dryer is stable and constant also the required temperature in this system can be maintained as per requirement like 60^0 C in case of ginger drying. The efficiency of the electrical dryer was much higher compared to biomass based system which lies between 10 to 13% depending upon feedstock input for gasifier. Financial analysis was performed which shows an annual revenue of NRs. 2,340,000 with total breakeven sales of the 4379.5 kg dry ginger and corresponding payback period is 0.9357 years.

Ayodele *et al.* (2016) carried out their research to design an electric corn dryer which had the inlet temperature of air varied from 50^0 C to 70^0 C and the dryer was operated without loading of corn in 30 minutes as well as the temperature in the drying chamber rose to 117 ^{0}C, which is expected to give higher drying rate than the natural sun drying and open- fired drying methods. From the results, heater (1500 W) at fan speeds I (1400 rpm), II (1420 rpm), and III (1440 rpm) attain the maximum drying chamber temperatures 117^0 C, 108^0 C and 92^0 C respectively in 30, 32, and 30 minutes. This suggests that this drying system capable of supplying as high as 117 ^{0}C drying chamber temperature, could be a substitute for local drying methods especially in poor weather conditions.

Akpan *et al.* (2016) carried out their work for design and development of an agricultural and bio-materials Cabinet Tray Dryer for presenting the drying effectiveness of three crop (okro, pepper and groundnut) and drying time (9 hours) and the drying compartment temperature was 50^0 C. They indicated that the kilogram weight of the crops decreased with increase in drying time as drying progressed. Rathnayaka *et al.*, (2017) developed a cabinet dryer for drying pepper within which temperature were able to maintain from 54^0 C to 56.8^0 C, the mean air velocity 0.70 m/s and the drying time was 23 hours. They explained that their dryer will be used for drying other crops with minor adjustments of drying temperature and air velocity and thus the quality of the final product will be retained optimally.

2.4 Overview of *M. Verticillata* L (*M. verticillata*)

2.4.1 Introduction of *M. verticillata* L.

Malva spp. is a genus of about 25–30 species of herbaceous annual, biennial, and perennial plants in the family Malvaceae, one of several closely related genera in the family to bear the common English name mallow. The genus is widespread throughout the temperate, subtropical and tropical regions of Africa, Asia and Europe (Davis, 2010).The word "mallow" is derived from old English "malwe", which was imported from Latin " malva ", which originated in Ancient Greek (malakhē) meaning "yellow" or Hebrew (maluakh) meaning "salty" (Davis, 2010). A number of species, previously considered to belong to Lavatera, have been moved to Malva. The leaves are alternate, palmately lobed. The flowers are from 0.5–5 cm diameter, with five pink or white petals. The color mauve was named in 1859 after the French name for this plant.

2.4.2 Taxonomic Hierarchy of *M. Verticillata* L

Kingdom: Plantae – plantes, Planta, Vegetal, plants

Sub-kingdom: Viridiplantae

Infra-kingdom: Streptophyta – land plants

Super-division: Embryophyta

Division: Tracheophyta – vascular plants, tracheophytes

Subdivision: Spermatophytina – spermatophytes, seed plants

Class: Magnoliopsida

Superorder: Rosanae

Order: *M.* les

Family: *M.* ceae – mallows, mauves

Genus: *M.* L. – cheeseweed, mallow

Species: *M. verticillata* L. – cluster mallow

2.4.3 Morphological description

Several species are widely grown as garden flowers, while some are invasive weeds, particularly in the Americas where they are not native. Many species are edible as leaf vegetables and commonly foraged in the West. Known as ebegümeci in Turkish, it is used as vegetable in Turkey in various forms such as stuffing the leaves with bulgur or rice or using the boiled leaves as side dish. *M. verticillata* is grown on a limited commercial scale in China; when made as a herbal infusion, it is used for its colon cleansing properties and as a weight loss supplement. Very easily grown, short-lived perennials often grown as ornamental plants. Mild tasting young mallow leaves can be a substitute for lettuce, whereas older leaves are better cooked as a leafy green vegetable. The buds and flowers can be used in salads. Cultivation is by sowing the seeds directly outdoors in early spring. The seed is easy to collect, and they will often spread themselves by seed. In Catalonia (Southern Europe) they use the leaves to cure stinging nettles sting. Bodo tribals in Bodoland, Assam (Northeast India) cultivate a sub-species of *M.* and use it extensively in their traditional cuisine, although its use is not much known among other people of India. *M.* Leaves are a highly cherished vegetable dish in north Indian state of Kashmir. It is called "Soachal". *M. sp.* leaves have been used in the traditional Austrian medicine internally as tea or externally as baths for treatment of disorders of the skin, gastrointestinal tract and respiratory tract. (Vogl *et al.*, 2013)

Fig 2.1: Photograph of plant *M. verticillata*

2.4.4 Health benefit of *M. verticillata*

M. verticillata is an important medicinal plant which shows a wide range of biological activities. According to Dipak Paul (2016) some of these are:

Pain Relief

One of the common uses of *M. verticillata* is as a pain reliever, particularly in topical applications. Malava benefits from the leaves include being a natural pain killer with antiseptic and soothing properties that can be used for skin wounds.

Immune System Production

M. verticillata can also boost the immune system by preventing bacterial infections and other foreign agents to affect those wounded areas. This can also be achieved through consumption of *M. verticillata* leaves, seeds, and supplements.

Anti-inflammatory Action

If a man have experienced any insect bites, large bruises, sunburn, or rashes on his skin, a gel or poultice made of *M. verticillata* can be very effective for reducing inflammation and swelling, while also stimulating more rapid healing. When using the essential oil or ingested varieties of *M. verticillata*, you can also apply it to joints and aches.

Respiratory Illness

If a man are suffering from any chest congestion or a respiratory condition, then using *M. verticillata* is a great idea. Not only can it increase expectoration, which can clear out the respiratory tracts, but it also soothes the throat and glands due to its anti-inflammatory aspects, while also promoting healing and more rapid recovery.

Anti-aging Effects

The impact that topical *M. verticillata* use can have on the body is impressive. In fact, for those worried about aging too quickly, or check to the mirror every day for wrinkles, use a gel or cream with mallow as an ingredient and keep your skin looking young and rejuvenated.

Digesting Issues

For those people who feel backed up or unable to properly move their bowels, it can be an uncomfortable feeling. Using powerful laxatives can have a range of other effects on the body, but by steeping some seeds or dried leaves into a tea, you can create a mild laxative beverage that will regulate your digestive system and relieve any strain on that organ system and rejuvenated.

Sleep Problems

Many people struggle to fall asleep, but you can turn to the use of *M. verticillata* essential oil or a relaxing cup of mallow tea to relax the mind and body, letting you drift off into relaxing, restful sleep.

2.4.5 Use of *M. verticillata*

Toxic parts

When grown on nitrogen rich soils (and particularly when these are cultivated inorganically), the plant tends to concentrate high levels of nitrates in its leaves (Cooper and Johnson, 1984)

Edible uses

Leaves - raw or cooked (Facciola, 1990) the leaves of well-grown plants can be 15 cm or more across. They have a mild and very pleasant flavor that makes an excellent addition to salads. We use them as a tasty alternative to the lettuce. Young seeds - raw or cooked. Used when green and immature (Harrington, 1967) pleasant nutty taste but the seed is too small and fiddly for most people to want to harvest. The peoples of northern district of Bangladesh, especially in Dinajpur consume *M. verticillata* leaves as raw or cooked vegetable due to huge production and low cost.

Leaves and flowers

A tea made from the leaves or flowers may be used as a remedy for a cough, catarrh and hoarseness. The flowers and leaves should be allowed to soak for a few hours in lukewarm water before use. To preserve the medical properties of the plant, it should not be boiled. Tea made from the herb is said to help nursing mothers to produce more milk. The leaves and stems are said to be digestive and given to women in the advanced stages of pregnancy (Chopra *et al.*, 1986).

Material uses

Cream, yellow and green dyes can be obtained from the plant and the seed heads (Grae, 1974)

Seed

M. verticillata seed are used to boost the immune system by preventing bacterial infections and other foreign agents to effect those areas.

Medicinal uses

The seed contains mucilage, polysaccharides and flavonoids (WHO, 1998). It is demulcent, diuretic, emollient, galactogogue and laxative (Ayensu, 1985). The seeds are used in Tibetan medicine, where they are considered to have a sweet and astringent taste plus a heating potency. They are used in the treatment of renal disorders, the retention of fluids, frequent thirst and diarrhea **(**Tsewang, 1994). The root is used to cause vomiting in the treatment of whooping cough (Chopra *et al.,* 1986).

2.4.6 Drying and processing of *M. verticillata*

There were limited researchers who study on the drying or processing of *M. verticillata*. Since *M. verticillata* belongs to *M.*ceae family, researchers should follow similar plants of this species. Most of the investigation, the *Abelmoschus esculentus* leaves were dried at ambient air (shade drying) or oven dryer at low temperature generally ranged from 25 – 45^{o} C (Caluete *et al.,* 2015; Raja *et al.,* 2017).

Caluete (2015) researched on nutritional, antinutritional and phytochemical status of okra leaves (Abelmoschus esculentus) subjected to different processes. During their experiment, the okra leaves were blanched for 2 minutes and then dried at 25 ^{0}C and stored.

Raja *et al.* (2017) studied the effect of pre-treatment and different drying methods on the physicochemical properties of *Carica papaya* L. leaf powder. They dried their samples in oven dryer (OD) at below 50° C.

2.5 Performance evaluation aspect of dryers for drying vegetables

2.5.1 Pretreatment and drying characteristics of high moisture vegetables

Microwave drying characteristics of parsely leaves were assessed by Soysal (2004). At seven different microwave output powers ranging from 360-900W were used for drying parsley. The Results indicated that, as the microwave output power increased to 900W from 360W, the drying time decreased significantly (64%). Microwave drying at 900 W output power instead of 30, 40, 50 and 65°C in hot air oven, the drying time can be shortened by 111, 92, 37 and 31 fold respectively. Drying rates of parsely leaves ranged from 0.48 to 1.33 kg water/kg DW/ minute for the output power between 360 and 900W respectively.

Singh *et al.* (2006) investigated the effect of drying conditions on the drying rate of five leafy vegetables. The leaves were dried under cabinet drier (58-60° C), low temperature drier (40 ± 2° C and 25-40% RH) and solar drier (40-50° C, 60-80% RH) to a moisture content of four to five per cent. The drying rate was faster in cabinet drier followed by low-temperature drier and solar drier. Drumstick leaves took seven hours for drying in cabinet drier whereas amaranth, curry leaves, and fenugreek required six hours in the same drying condition. Kaur and associates (2006) studied the time taken for drying of coriander leaves as affected by pretreatments and method of drying. temperature; blanching in boiling water for 30s followed by dipping for 15 minutes in solutions either of magnesium chloride (0.1%), sodium bicarbonate (0.1%) or potassium metabisulphite (2.0%) in water at room temperature; dipping for 15 minutes in solutions of magnesium chloride (0.1%) + sodium bicarbonate z (0.1%) + potassium metabisulphite (2.0%) at 60°C all the pretreated samples were dried in cabinet (55° C), open sun, forced convection air, domestic solar dryer with covered and uncovered trays, minimulti-rack solar dryer (45° C) and portable farm type solar dryer. The results indicated that, the pretreatments did not influence the time taken for drying. Coriander pretreated with different solutions and untreated took five hours to dry to constant weight. Minimum time (5h) was taken by cabinet drier while drying under open sun, domestic solar drier with uncovered trays and minimulti-rack solar drier took nine hours. An investigation was carried out by Manchekar and associates (2008) to dry the curry leaves under shade (24-28° C), sun (29.7° C) and conventional method 40 100, 140 and 180° C. Time taken for drying and physiological loss in weight (PLW) was recorded. The results depicted that, conventional drying method was faster (8h) compared to sun drying (20h) and ambient drying (34h). Higher the temperature in conventional drying lower was the time taken for drying to a constant weight.

Agasimani *et al.,* (2008) studied value addition to the coriander through drying and dehydration. The cleaned coriander leaves were dried under three different drying methods viz., shade drying (28°C, 32.5% RH), sun drying (7h) and conventional drying (40, 100 and 140° C). The results indicated that, coriander leaves dried by conventional method of drying showed a uniform physiological loss in weight and color at lower levels of air temperature. In case of sun drying physiological loss in weight was more rapid at initial period of drying followed by gradual decrease in moisture content in the later part of drying. The weight of leaves dried at 40° C reduced from 25g to 6g at the end of drying period. Similarly, the weight was reduced to 4.2g at the conventional drying temperature of 140° C.

Karva (2010) evaluated the effect of pretreatments and methods of drying on yield and drying time of green leafy vegetables. Fenugreek, spinach, *rajagira, shepu* and *kiraksali* leaves were subjected to different pretreatments viz., blanching (1min), sulphitation (1min), blanching + sulphitation (blanching followed by sulphitation) which were compared with control (without any treatment). The pretreated leaves were dried under microwave oven (2250 mHz frequency at 100% power), hot air oven (60° C), sun (38-42° C) and shade drying (24.5-25° C). The results indicated that irrespective of the treatments, microwave drying took less time while more under shade drying. Shepu could be dried in shorter time of 1.10h (sun), 33.82h (shade), 1.48h (hot air oven) and 2.24 minutes (microwave) irrespective of pretreatment compared to other greens. Yield was found to be higher in shade dried greens (12.75%) while least in sun dried leaves (4.41%).

Influence of different drying techniques on the quality of spearmint (*Mentha spicaata)* was assessed by Kaur and associates (2009). Spearmint was dried using conventional drying like sun, room air, solar drying (using polythene tent dryer) and compared with convective drier, which was carried out at air temperature of 45, 50, 55, 60 and 65°C and velocities of 0.5, 1.0, 1.5, 2.0, 2.5 m/s. Both leaves and leaves with stalks were chemically pretreated by dipping in solution containing 0.1 per cent magnesium oxide, 0.1 per cent sodium bicarbonate and two per cent potassium metabisulphate for 15 minutes and dried. The results indicated that, in leaves drying ratio increased with increase in temperature up to The dry ash was converted in to solution and used for mineral estimations as out lined in AOAC (Anon, 1990) followed by decrease, while in leaves with stalk, it increased up to the temperature of 55° C and further decreased at 60° C and finally increased at 65° C.

Characterization of microwave vacuum drying and hot air drying of mint leaves was carried out by Therdthai *et al.* (2009). For microwave vacuum drying, intensities of 8.0, 9.6 and 11.2 Wg-1 were applied with pressure controlled at 13.33 K Pa and for hot air drying, drying temperatures of 60 and 70° C were adopted. The result revealed that, microwave vacuum drying could reduce drying time of mint leaves by 85-90 per cent, compared with the hot air drying. Hot air drying required 90 and 60 minutes respectively, whereas microwave vacuum drying at 1600W, 1920W and 2240W required 13, 12 and 10 minutes respectively.

Esturk *et al.* (2010) studied drying properties and quality parameters of dill dried with intermittent and continuous microwave-convective air treatments in a custom designed and fabricated air drying system. The cleaned leaves were subjected to continuous or intermittent microwaving with convective air drying at 30, 40 and 50°C. The results indicated that, the drying time in continuous microwave convective air drying to reach the moisture content of 0.10 Kg^{-1} was 9-10 minutes, while microwaving for 30 seconds followed by discontinuing for 30, 60 and 90 seconds and further convective air drying took 17-84 minutes. Drying rate increased with decrease in pulse ratio. The drying rates for 30, 40 and 50°C air temperature were found to be 0.21, 0.21 and 0.23 Kg^{-1} respectively. The studies indicated that higher the temperature lower will be the time taken for drying which again depends on with the drying method. Ideal drying temperature was reported to be 60° C.

2.5.2 Energy usage and drying cost for drying vegetables

Singh (1994) researched on the development of a small capacity dryer for vegetables. The dryer was tested with different vegetables (cauliflower, cabbage and onion). At a constant air in flow rate of 033 m^3/s, it took about 11 h to reduce the percent moisture content dry basis/wet basis from 1260.56 dry basis (92.65 wet basis) to 8.69 (8), 14 h from 1233.33 (92.50) to 8.69 (8) and 12 h from 900 (W) to 8.11 (7.5) with inlet air temperatures of 65, 55 and 56°C respectively for 50 kg batches of cauliflower, cabbage and onion slices. The overall energy utilization efficiencies of the dryer for these vegetables were 30.83, 28.21 and 29.51% respectively. The cost of the dryer was Indian Rs 12000 (US $480) and the estimated costs of processing cauliflower, cabbage and onion slices were Rs 2.16 (US $0086), Rs 2.76 (US $011) and Rs 2.37 (US $O+I95) per kg of raw material.

Nwakuba *et al.* (2016) reviewed on energy requirements for drying of sliced agricultural crops in order to produce high quality and shelf-stable products. Work on the estimation of energy requirement for drying different sliced crops such as potato, carrot, garlic, onions, mango, banana, apple, tomato etc. and factors affecting their energy requirement were reported. Obtained results showed that crop functional characteristics, initial and desired moisture contents, slice thickness, air temperatures, specific heat capacity, relative humidity, and air velocity are the major parameters affecting sliced crop drying energy requirement. Generally, the minimum energy requirement for drying moisture-laden sliced crops like tomatoes, apples, carrot, mango, cucumber etc. were found to be between 4.22 and 24.99 MJ/kg water removed. Field test results by other researchers for different drying systems and crops were also presented.

2.6 Quality assessments of green leafy vegetables powder

2.6.1 Effect of drying on physical properties of green leafy vegetables powder

Seshadri *et al.* (1997) studied retention and storage stability of β-carotene in dehydrated drumstick leaves. Dehydrated leaves were packed in polyethylene containers and stored at room temperature. The results indicated that, up to 90 days of storage losses occurred in blanched and blanched + sulphited samples. The retention of total carotene and ascorbic acid was significantly higher in blanched + sulphited samples compared to blanched leaves at 30, 60 and 90 days of storage. Rehydration ratio showed deterioration with increasing duration of storage in both the pretreated samples but superior with the blanching + sulphiting compared to only blanched leaves.

The effect of processing and storage on β-carotene content of green leafy vegetables was evaluated by Seema (1997). Honagone, harvi, pundi, hakarki and dodagooni leaves were blanched, sulphited, packed in LDPE and stored in air tight aluminum container. The results revealed that, moisture content ranged from 7.78 to 9.06 per cent and in all the greens it increased significantly at every point of storage. The rehydration ratio of samples ranged from 4.05 to 6.59 per cent during storage where honagone recorded highest (5.75 %) on zero day of storage while hakarki recorded highest (4.36%) at the end of storage. Honagone registered highest (72.4%) retention of _ carotene followed by harvi (69.62%), dodagooni (67.98%), pundi (58.27%) and hakarki (54.18%). Shade dried leaves exhibited significantly higher β- carotene than oven and sun dried.

Ramalakshmi *et al.* (2001), worked on storage stability of dehydrated curry leaf, rosemary and marjoram in different packaging materials. The results depicted that, absorption of moisture was more in the samples stored in PET jars at 38°C and 27°C compared to other packaging materials. Retention of chlorophyll was maximum (90%) in rosemary leaves stored in aluminum foil laminate pouches at ambient condition while those stored in other packaging material showed 40-80 per cent retention. The loss of green color was more in the samples stored in glass and PET jars than the others and also the loss was more in elevated temperature than in ambient. Curry leaves had minimum color loss compared to other leaves.

Fathima *et al.* (2001) studied microwave drying of selected greens and their sensory characteristics during storage. The dried greens were packed and sealed in polythene pouches and stored under refrigeration at 5° C for 60 days. The results revealed that, the scores for appearance of the fresh greens were significantly different from dried greens. During storage (60 days) of the dried greens, a decline in the rating for appearance, odor and color was observed. The reduction was found to be proportional to the increase in storage time.

Retention of quality characteristics of dehydrated greens during storage was studied by Negi *et al.* (2001). The dried *savoy* beets and fenugreek leaves were packed in 200 gauze HDPE bags in a single or double layers and stored at ambient (15.0-37.5°C and 35- 90% RH) and cold storage (7.5-8.5°C and 75-80% RH) condition for nine months. The results indicated that, chlorophyll content of samples continuously declined during storage with samples packed in double layers retaining higher amounts throughout the nine months in both crops compared to single packed samples. At the end of storage, leaves of *savoy* beets and fenugreek retained 57 and 67 per cent of β-carotene in double packed samples when stored at 7.5-8.5°C. Ascorbic acid content was retained only to an extent of 10.62 mg/100g in single packed *savoy* beets at the end of storage. The double packed cold stored samples retained 17.08 mg/100g. On the contrary, a drastic reduction was recorded in fenugreek leaves during storage.

Negi *et al.,* 2001 studied the effect of blanching on quality attributes of dehydrated carrots during long term storage. The dried carrot slices were packed in single or double layers of 50μm thick HDPE films and stored at ambient condition (15.0- 37.5°C, 40-85% RH) and cold storage (7.5-8.5°C, 70-75% RH) for nine months. The results revealed that, a spontaneous loss of β-carotene was observed in both unblanched and blanched carrots during storage. Higher carotene retention was observed under cold storage conditions and the samples packed in double layer of HDPE film. Ascorbic acid retention was found to be higher in blanched samples throughout the storage. Invariably, cold stored samples retained higher ascorbic acid and double packaging reduced the losses.

Singh *et al.* (2003) assessed the effect of storage on nutritional composition of dehydrated green leafy vegetables and carrot after packing in polythene bags and stored for two months at room temperature. The moisture content of samples increased gradually with increase in storage period ranging from 2.20 to 3.90 per cent. After 60 days of storage, it varied from 2.74 to 4.55 per cent. Protein, β-carotene and ascorbic acid contents of all the dried vegetables decreased significantly during storage. Minimum loss of β-carotene was observed in spinach (12.26%) and maximum in amaranthus (31.20%). Total iron content ranged between 7.1 mg/100g in carrots to 84.44 mg/100g in bengal gram leaves and it remained similar throughout the storage period. Protein, ascorbic acid and β- carotene decreased significantly on storage. During storage a decline in the appearance, odor and color was evident, reduction being proportional to the storage time.

Therdthai *et al.* (2009) studied the characterization of microwave drying and hot air drying of mint leaves. The results indicated that, the lightness, greenness and yellowness of microwave dried mint leaves were significantly higher than hot air dried counterparts. The microwave vacuum drying at 1920 and 2240W yielded significantly higher rehydration rates than the hot air drying at 60 and 70°C.

Kaur *et al.* (2009) conducted a research on influence of different drying techniques on the quality of spearmint (*Mentha spicata*). Convective dried spearmint had slightly higher rehydration ratio compared to conventionally dried samples. Among conventionally dried samples air dried vegetable had highest rehydration ratio. Retention of green color was higher in leaves compared to leaves with stalks, convective dried compared to samples dried at temperature of 50-55° C.

Roongruangsri *et al.* (2016) evaluated the effect of air-drying temperature on physico-chemical, powder properties and sorption characteristics of pumpkin powders. This study examined the use of hot-air drying in the preparation of pumpkin powder. The results showed that a drying temperature of 70°C removes moisture from pumpkin slices faster than the lower drying temperatures of 50 and 60°C. The moisture content and water activity values of the pumpkin powder dried at 60 and 70°C were within acceptable limits for safe storage. Pumpkin powder dried at 70°C exhibited the darkest yellow color, while pumpkin powders dried at 50 and 60°C were lighter. Moreover, pumpkin powder dried at 70°C showed the highest percent decrease in carotenoid content (56%) compared to those dried at 50 and 60°C (18% and 33%, respectively).

Raja *et al.* (2017) studied the effect of pre-treatment and different drying methods on the physicochemical properties of *Carica papaya* L. leaf powder. The results showed that blanching helps in improving the powder physical properties and preserving the phenolic compounds and ascorbic acid. Blanching also increases the bulk density and improves flowability in all drying methods except for FD. Pretreated oven dried powder resulted in better physicochemical properties in other drying methods except for vitamin C content, which was higher in freeze-dried powder. OD at below 50°C resulted in powder with maximum bulk density (659 kg/m^3), excellent flowability and color change and maximum retention of total phenolic content (374 mg GAE/g).

Figiel *et al.* (2016) evaluated the overall quality of fruits and vegetables products affected by the drying processes with the assistance of vacuum-microwaves. The results showed good physical parameters such as color, shrinkage, porosity and texture. A higher stability of total monomeric anthocyanins during storage at 38^0C aimed at providing food products with excellent health-promoting properties and attractive sensory attributes.

2.6.2 Effect of drying on antioxidant activities of green leafy vegetables powder

The effect of microwave drying on quality of parsely leaves was investigated by Soysal (2004). The leaves were dried at seven different microwave output powers ranging from 360-900 W. Microwave drying did not significantly influence the color of fresh and microwave dried leafy vegetables, a brilliant green color close to that of the original fresh parsely leaves was maintained.

Mavi *et al.* (2006) studied the antioxidant properties of Thymus Sipyleus Boiss. Sub sp. sipyleus var. sipyleus, *Teucrium chamaedrys* L., *Mentha longifolia* L., *Hudson sub* sp. longifolia, Salvia limbata C.A. Meyer, and Thymus fallax Fisch. & Mey. Antioxidant and 2, 2-diphenyl- 1-picrylhydrazyl (DPPH) radical scavenging activities, and the amount of total phenolic compounds of the extracts were studied. The highest antioxidant activity was shown by T. chamaedrys (decoction, IC_{50}: 9.2 mg/ml), and the lowest one was S. limbata (decoction, IC_{50}: 619.5 mg/ml). The highest DPPH radical scavenging activity was shown by T. fallax [decoction, IC_{50}: 56 mg/ml (IC_{50}S is the extract concentration (mg/ml) required for 50% inhibition of the DPPH solution absorbance at 517 nm)] while the lowest one was S. limbata (decoction, IC_{50}S: 335.8 mg/ml). The highest amount of total phenolic compounds was shown by T. chamaedrys (decoction, 29.9 mg/ml ascorbic acid equivalent, 27.9 mg/ml gallic acid equivalent, respectively), and the lowest one was S. limbata (decoction, 5.1 mg/ml ascorbic acid equivalent, 9.9 mg/ml gallic acid equivalent, respectively) at 250 mg/ml extract concentration.

Singh *et al.* (2006) assessed the effects of drying conditions on the quality of dehydrated leafy vegetables. The leaves were blanched and dried under cabinet (58-60°C), solar (40-50°C, 60-80% RH) and low temperature drier (40 ± 2°C and 25-40% RH). The moisture content was found to be higher in dried drumstick leaves dried in cabinet (5.5%), solar (6.1%) and low temperature (6.7% driers). Ascorbic acid and chlorophyll contents were maximum in curry leaves (212.4 & 130.3 mg/100g respectively) and minimum in palak (14.2 and 70mg/100g).

Quality of dried coriander leaves as affected by pretreatments and methods of drying was evaluated by Kaur *et al.* (2006). Dipping for 15 minutes in solution of magnesium chloride (0.1%), sodium bicarbonate (0.1%) and potassium metabisulphite (2.0%) water at room temperature was best for maintaining quality of dried coriander leaves. Irrespective of cost, solar drying in minimulti-rack dryer was the best method for coriander leaves, as closest to fresh.

Karva (2010) studied the effect of dehydration on composition of green leafy vegetables. Fenugreek, shepu, spinach, rajagira and kiraksali leaves were subjected to pretreatments viz., blanching (1 min), sulphitation (1 min), blanching and sulphitation, all treated leaves were compared with control. The leaves were then dried under microwave oven (2250 mHz frequency, at 100% power), hot air oven (60°C), sun (38-42°C) and shade (24.5-25°C) drying. The results revealed that, rehydration ratio was found to be higher in microwave dried leaves (6.29) while sun dried samples exhibited lowest (4.10) irrespective of pre-drying treatments. Microwave drying of rajagira resulted in highest chlorophyll content (12.40 mg/g) irrespective of the treatments followed by drying in hot air oven (12.38 mg/g), and sun drying resulted in minimum chlorophyll content (6.85 mg/g). Among pretreatments sulphitation without blanching resulted in minimum chlorophyll (10.32 mg/g) but blanching before sulphitation had maximum retention

(11.48 mg/g). Iron content was found to be highest in rajagira (222.57 mg/100g) while fenugreek had lowest amount (26.19 mg/100g). Therdthai *et al.* (2009) studied the characterization of microwave drying and hot air drying of mint leaves. The results indicated that, the lightness, greenness and yellowness of microwave dried mint leaves were significantly higher than hot air dried counterparts. The microwave vacuum drying at 1920 and 2240W yielded significantly higher rehydration rates than the hot air drying at 60 and 70° C.

Kaur *et al.* (2009) conducted a research on influence of different drying techniques on the quality of spearmint (*Mentha spicata*). Convective dried spearmint had slightly higher rehydration ratio compared to conventionally dried samples. Among conventionally dried samples air dried vegetable had highest rehydration ratio. Retention of green color was higher in leaves compared to leaves with stalks, convective dried compared to samples dried at temperature of 50-55° C.

Esturk *et al.* (2010) carried out a study on drying properties and quality parameters of dehydrated dill leaves. Cleaned leaves were subjected to continuous or intermittent microwaving with convective air drying at 30, 40 and 50°C. Microwave-convective air drying resulted in reduced lightness, greenness and yellowness. Continuous microwave application preserved the green color of dill leaves compared to the intermittent microwave drying.

Wanjala (2010) studied the Effect of Different Drying Methods i. e., shade, sun, vacuum, and by freeze drying on the Quality of Jute (*Corchorus olitorius* L.). Sun-dried leaves had the highest loss of vitamin C (90%), followed by the vacuum- and the shade-dried leaves. Freeze-dried leaves, on the other hand, had the lowest vitamin C loss of 19%. The variation in ascorbic acid loss in dried jute leaves can be attributed to the effect of light, drying temperature, and exposure time, which may have resulted in the volatilization of the acid.

Tabaraki *et al.* (2011) researched on the Chemical Composition and Antioxidant properties of the leaves and petioles of the *M. sylvestris* L. The plants have medicinal value i.e., antioxidative phytochemicals and antimicrobial properties due to Presence of many substances, including flavonoids, vitamins, terpenoides, minerals, phytochemicals, etc. The phenolic compounds and the flavonoid content ranged 11.82-15.11 and 1.40-1.97 mg GAE/gdw 21.85-27.18 and 3.50-4.95 mg CE/g dw, respectively in leaves and petioles respectively. Antioxidants assay. IC_{50} values ranked from 0.071-0.077 $mg.ml^{-1}$ for leaves and 0.711-0.747 $mg.ml^{-1}$ for petioles.

Jaiswa *et al.* (2011) researched on the Phenolic Composition, Antioxidant Capacity and Antibacterial Activity of Selected Irish Brassica Vegetables which is rich in polyphenols, flavonoids and glucosinolates and which may have antibacterial, antioxidant and anticancer properties. Results obtained showed that York cabbage extract had the highest total phenolic content, which was 33.5, followed by 23.6, 20.4 and 18.4 mg GAE/g of dried weight (dw) of the extracts for broccoli, Brussels sprouts and white cabbage, respectively. All the vegetable extracts had high flavonoid contents in the order of 21.7, 17.5, 15.4 and 8.75 mg QE/g of extract for York cabbage, broccoli, Brussels sprouts and white cabbage, respectively.

Raksakantong (2011) investigated the changes in total phenolic content, total flavonoid content of two holy basil leaves (kaprow in Thai) Ocimum sanctum L. cultivars, kaprow khao and kaprow daeng, after hot air (HA) drying treatments i.e., $50^{o}C$ and air velocity at 1.5 m/s.. Total phenolic content (TPC), total flavonoid content (TFC), were 19.12 ± 0.84, 17.78 ± 0.74, 11.09 ± 0.42 and 9.01 ± 1.82 in fresh sample and 14.23 ± 0.69c 12.47 ± 0.39, 8.01 ± 0.27 and 7.53 ± 0.45 of hot air dried of Kaprow daeng Kaprow khao Kaprow daeng Kaprow khao respectively.

Oliveira *et al.* (2012) analyzed the total phenolic content and antioxidant activity of four *M.*ceae Family Species. The results showed that the total phenolic contents were 63.21 ± 2.40, 50.88 ± 2.78, 34.02 ± 1.48 22.75 ± 1.66 and Antioxidant Activity (DPPH assay) were 97.93 ± 0.68, 159.267 ± 6.02, 91.28 ± 0.43, 111.88 ± 1.50 in *n*-butanol (*n*-BF) extracts of *Herissantia crispa*, *Sidastrum micranthum*, *Wissadula periplocifoli*a and *Sida rhombifolia* respectively.

Liao (2012) opined that *Abelmoschus esculentus* L. is a healthy vegetable belonging to the family *M.*ceae, have high antioxidant activity due to presence of phytochemical constituents. They reported that the contents of total phenolics (TP), total flavonoids (TF) and DPPH scavenging activity in 80% methanol extracts of the flower, fruit, leaf and seed of *A. esculentus* were 4.7574 ± 0.1595, 10.4416 ± 0.0329 and 4.8634 ± 0.0193 respectively.

Basu *et al.* (2012) researched on the phytochemical evaluation and in vitro study of antioxidant Potency of *Amorphophallus campanulatus, Alocasia indica* and *Colocasia esculenta* which are very popular for their edible corms and leaves, especially in Assam and Bengal and are cultivated there as common food crops. TPC of ethanolic extract of *Amorphophallus campanulatus, Alocasia indica and Colocasia esculenta* is 190.42 ± 2.2 mg w/*w,* 87.54 ± 1.3 mg w/*w* and 66.25 ± 1.5 mg w/*w* respectively. Total flavonoid of ethanolic extract of *Amorphophallus campanulatus, Alocasia indica and Colocasia esculenta* is 6.23 ± 0.3 mg w/w, 3.5 ± 0.58 mg w/w and 1.48 ± 0.87 mg w/w respectively.

Duy *et al.* (2012) studied the effects of drying methods on bioactive compounds of vegetables (carrot, taro, tomato, red beetroot and eggplant) and correlation between bioactive compounds and their antioxidants. The drying temperature was 55^oC. The results show that phenolic and flavonoid compounds were mainly located in free form in the vegetables which was easily extracted by alcoholic solvent. A high temperature in the heat-drying method in sample preparation significantly reduced total free and bound phenolics, total free and bound flavonoids and their antioxidant capacity. The antioxidant capacity of the extracts highly correlated with free phenolic compounds ($r^2 = 0.8936$) and free flavonoid compounds ($r^2 = 0.6682$). In contrast, the antioxidant capacity of the extract did not correlate with the bound phenolic and flavonoid compounds ($r^2 = 0.0124$ and $r^2 = 0.0854$, respectively).

Basu *et al.* (2012) showed the phytochemical evaluation and in vitro study of antioxidant potency of *Amorphophallus campanulatus, Alocasia indica* and *Colocasia esculenta.* The results of ethanolic extracts of these tubers were 190.42 ± 2.2 mg w/*w,* 87.54 ± 1.3 mg w/*w* and 66.25 ± 1.5 mg w/*w*; 6.23 ± 0.3 mg w/w, 3.5 ± 0.58 mg w/w and 1.48 ± 0.87 mg w/w and 67.79 µg/ml, 682.58 µg/ml, 1008.78 µg/ml and 1343.88 µg/ml for 2, 2-diphenyl-1- picrylhydrazyl (DPPH) radical, total phenolic and flavonoid contents respectively.

Igwemmar (2013) showed the effect of heating on the vitamin C content of five choice vegetables was determined by redox titration with potassium iodate in the presence of potassium iodide. The results obtained in raw vegetables showed that pepper (61.56mg/100ml) has the highest vitamin C content while the least was in carrot (21.72mg/100ml). The vitamin C content of the vegetables analyzed were found to be in the order: Pepper > Green peas > Spinach > Pumpkin > Carrot. It was also observed that the heating time has significant effect on the vitamin C content of all the vegetables, as the heating time increases, the percentage loss of vitamin C increases too. The percentage loss of vitamin C in the vegetables ranged between (9.94-16.57%), (29.94-37.43%) and (49.91- 64.71%) at 5, 15 and 30 mins respectively. Of all the vegetables assayed pepper gave the highest percentage loss of 64.71% at 30 mins. Vitamin C is easily destroyed by excessive heat and water, as well as exposure to air. For retention of vitamin C in cooked foods, it is recommended that foods containing vitamin C be cooked as fast as possible with less heat and small amount of water.

Sogi *et al.* (2013) researched on the total phenolics, antioxidant activity, and functional properties of 'Tommy Atkins' mango peel and kernel as affected by drying methods. Mango peel and kernel were dried using different techniques, such as freeze drying, hot air, vacuum and infrared. Freeze dried mango waste had higher antioxidant properties than those from other techniques. The water and oil absorption index of mango waste powders ranged between 1.83 – 6.05 and 1.66–3.10, respectively. Freeze dried powders had the lowest bulk density values among different techniques tried. The cabinet dried waste powders can be potentially used in food products to enhance their nutritional and antioxidant properties.

Al-Owaisi *et al.* (2014) investigated on GC-MS analysis for determination of total phenolics, flavonoid content and free radical scavenging activities of various crude extracts of *Moringa peregrina* (Forssk.) Fiori leaves. The total phenolics and total flavonoids ± of Chloroform Ethyl acetate Methanol were 75.53 ± 1.65 81.26 ± 3.90 94.56 ± 3.53 and 6.55 ± 0.55 8.39 ± 1.83 20.81 ± 4.02 respectively.

Abas *et al.* (2014) investigated the effects of Different Drying Methods and Storage Time on Free Radical Scavenging Activity and Total Phenolic Content of *Cosmos caudatus.* The study was conducted to determine the effect of air (AD), oven (OD) and freeze drying (FD) on the free radical scavenging activity and total phenolic content (TPC) of *Cosmos caudatus* and the effect of storage time by the comparison with a fresh sample (FS). Among the three drying methods that were used, AD resulted in the highest free radical scavenging activity against 1,1-diphenyl-2-picrylhydrazyl (DPPH) (IC_{50} = 0.0223 mg/mL) and total phenolic content (27.4 g GAE/100 g), whereas OD produced the lowest scavenging activity and TPC value. After three months of storage, the dried samples showed a high and consistent free radical scavenging activity when compared to stored fresh material. The drying methods could preserve the quality of *C. caudatus* during storage and the stability of its bioactive components can be maintained.

Nwachukwu *et al.* (2014) explained that the mature okra leaves have high chlorophyll content, phytochemical and antioxidant activity. The result showed that the total chlorophyll content, TPC and TFC were 32.99 mg/1 g, 0.203mgTNE/1 g and 0.796 mg QE/1 g in mature leaves, respectively.

Kumar *et al.* (2012) researched on the phytochemical properties and Antioxidant Activity of *Hibiscus sabdariffa* Linn. The results showed that Phenol content of aqueous, 95% ethanol extract and ethyl acetate fraction were 6.8, 17.83 and 43.11 respectively. On the other hand, Antioxidant activity of aqueous , 95% ethanol extract and ethyl acetate fraction were 94.16 ± 1.52, 46.13 ± 3.37 and 53.87 ± 2.56 respectively by DPPH assay.

Geng *et al.* (2015) researched on the Extraction and Antioxidant Activity of Phenolic Compounds from *Okra* flowers. The result obtained by traditional solvent (ethanol) extraction, total phenolics yield under the optimum conditions was 40.77±0.83 mg GAE /g material.

Garg (2012) researched on *In-vitro* antioxidant activity and phytochemical analysis in extracts of *Hibiscus rosa-sinensis* stem and leaves. The results showed that the Phytochemical constituents in Hibiscus rosa-sinensis stem and leaf of standard equivalent in methanolic have total phenol content 2.55 ± 0.15 and 1.4 ± 0.17 mg/g , Total flavonoid content 3.0 ± 0.075 and 1.1 7 ± 0.04 mg/g and Tannin content 1.17 ± 0.07 and 0.62 ± 0.02 mg/g for leaves and stem respectively. On the other hand, Antioxidant activity of Hibiscus rosa-sinensis stem and leaf standard equivalent in methanolic extracts (mg/g) has DPPH scavenging assay 11.85 ± 3 and 19.75 ± 1.15 mg/g for leaves and stem respectively. The total chlorophyll content in hibiscus leaves was found to be 0.017 g/l.

Caluete (2015) researched on nutritional, antinutritional and phytochemical status of okra leaves (Abelmoschus esculentus) subjected to different processes. During their experiment, the okra leaves were blanched for 2 minutes and then dried at 25 ^{0}C and stored. The results showed that the total phenolic content of fresh leaves *Abelmoschus esculentus* extracts was 19.27 ± 0.9 mg GAE/g.

Gemede (2015) explained antioxidant activity and nutritional value of okra with their mode of action in human body. The results provides total phenolic content of pulped and seeds of okra extracts were 10.75 ± 0.02 mg GAE/100g extract and 142.48 ± 0.02 mg GAE/100g extract which corresponds with scavenging activities.

Kamiloglua *et al.* (2015) reviewed the role of antioxidants in human nutrition which has gained increased interest, especially due to their associated health beneficial effects for a number of chronic diseases, including cardiovascular diseases and certain types of cancer. Hot-air drying is often preferred for short drying times but the high temperature causes higher losses in e.g. antioxidants. Different drying techniques may affect the major antioxidants activity of fruits and vegetables. Another reason could be the application of various pretreatments in different studies, e.g. pre-drying, blanching, freezing, sulphiting, and vacuuming, which can all have a strong influence on the recovery of bioactive compounds.

Judita B *et al.* (2015) analyzed the antioxidant activity of carrot. The content of the total polyphenols was determined by using the Folin-Ciocalteu reagent (FCR). The content of ß-carotene was determined spectrophotometrically at 450 nm. Antioxidant activity was measured using a compound DPPH (2.2-diphenyl-1-picrylhydrazyl) at 515.6 nm using spectrophotometer. Total polyphenols content in samples ranged from 81.25 ± 13.11 mg/kg to 113.69 ± 11.57 mg/kg and content of ß-carotenes ranged from 24.58 ± 2.38 mg/kg to 124.28 ± 3.54 mg/kg. We also evaluated and compared the antioxidant activity in selected varieties of carrot, which varied from 6.88 ± 0.92 % to 9.83 ± 0.62 %. Statistically significant the highest value of total polyphenols was recorded in variety of Koloseum (113.69 ± 11.57 mg/kg).

Roongruangsri *et al.* (2016) evaluated the effect of air-drying temperature on physico-chemical, powder properties and sorption characteristics of pumpkin powders. This study examined the use of hot-air drying in the preparation of pumpkin powder. The drying temperature was varied (50, 60 and 70°C) to determine the effect of temperature on physico-chemical properties, powder properties and sorption characteristics of pumpkin powders. The results showed that a drying temperature of 70°C removes moisture from pumpkin slices faster than the lower drying temperatures of 50 and 60°C. The moisture content and water activity values of the pumpkin powder dried at 60 and 70°C were within acceptable limits for safe storage. Pumpkin powder dried at 70°C exhibited the darkest yellow color, while pumpkin powders dried at 50 and 60°C were lighter.

Ayushi *et al.* (2016) investigate the phytochemicals of *A. esculentus* Leaves and their therapeutic role as an antioxidant using different assays viz. total phenolics, total flavonoids, total flavonols, reducing power and free radical scavenging capacity for 1,1-diphenyl-2-picrylhydrazyl (DPPH). The total phenolics, flavonoids and flavonols present in the *Abelmoschus esculentus* leaf extract were 9.61 mg of Gallic Acid Equivalent (GAE)/g, 9.25 mg of Quercetin Equivalent (QE) /g and 6.12 mg of QE/g of dry extract, respectively.

Alnashi *et al.* (2016) analyzed the antimicrobial activity, total phenolic compounds (TPC) and total antioxidant activities (TAA) of three different spinach extracts (Spinacia Oleracea. Levels of TPC ranged from 6.9 to 112.5 mg of Gallic acid equivalent per gram extract. The highest content in TPC was found in ethanol extract of *S. oleracea*. Antioxidant activity ranged from 31.1% to 63.7%. The highest value of TAA was found in aqueous ethanol extract (50%). The proximate analysis showed that *S. oleracea* examined contained a high level of moisture with low fat content and crude fiber. Results indicate that spinach can be used as potential source of natural antioxidants and antimicrobials agent.

Raja *et al.* (2017) studied the effect of pre-treatment and different drying methods on the physicochemical properties of *Carica papaya* L. leaf powder. The *Carica papaya L.* leaves are often considered as wastes, but they are actually beneficial for health. The study is aimed to explore the effect of pre-treatment and different drying methods on the physicochemical properties of *Carica papaya L.* leaves powder. The leaves were blanched in hot water before they went through the drying process, which consisted of oven drying (OD), shade drying (SD) and freeze drying (FD). The results showed that blanching helps in improving the powder physical properties and preserving the phenolic compounds and ascorbic acid. Blanching also increases the bulk density and improves flowability in all drying methods except for FD. Pretreated oven dried powder resulted in better physicochemical properties in other drying methods except for vitamin C content, which was higher in freeze-dried powder. OD at 40°C resulted in powder with maximum bulk density (659 kg/m^3), excellent flow ability, the least lightness and color change, the highest hue angle and maximum retention of total phenolic content (374 mg GAE/g).

2.6.3 Effects of drying on sensory quality of dried *M. verticillata* powder

Singh *et al.* (1997) studied the sensory evaluation of rehydrated green leafy vegetables on a four point scale. A desirable color was obtained in cabinet drying while that of sun dried products was unacceptable. Flavor of sun dried vegetables were scored higher compared to cabinet dried. The overall acceptability of cabinet dried fenugreek and spinach was better than sundried. But in case of bathu and mustard leaves method of drying did not influence the sensory quality.

While studying the acceptability of dehydrated vegetables, Lakshmi and Vimala (2000) showed that, the acceptability of rehydrated green leafy vegetables ranged from average to excellent. It was found that blanching prior to dehydration, retained bright green color of the leaves. However, the original flavor could be retained in gogu and amaranth compared to curry leaves and mint.

Sensory characteristics of microwave dried greens incorporated in products were studied by Fathima *et al.* (2001). The greens were dried and incorporated in the preparation of coriander chutney, mint chutney, amaranth palya, fenugreek rotti and shepu rotti. The results depicted that, among the products shepu *rotti* scored higher (3.09) while coriander chutney recorded lowest (2.41) but was highly acceptable and scored higher than fresh coriander leaves. The products of stored dry leaves also did not alter significantly with the sensory characteristics. Microwave drying of selected green leafy vegetables and their sensory characteristics were studied by Fathima *et al.* (2001). It was reported that, dehydration resulted in significant decrease in the scores for appearance, color and odor compared to the fresh greens. During storage (0-60 days) of the dried greens there was a decline in the ratings for appearance was found to be proportional duration of storage. However, the green pigment was appreciably retained even after drying.

Shah (2005) carried out a study to develop value added products by incorporating bengal gram leaf powder. Sixteen recipes, based on cereals, pulses, oil seed, were developed by incorporation of Bengal gram leaf powder at four, eight, 12 and 16 per cent. The products were evaluated for sensory attributes using five point hedonic scale. The results indicated that among the cereal based recipes (stuffed paratha, puri, dhapate and thalipeeth), the scores for overall acceptability ranged from 4.41 to 5.00, for pulse based recipes (plain dal, mung dal, masoor dal and moth bean usal) from 4.66 to 5.00, for nuts and oil seed based *chutneys* (prepared from ground nut, sesamum, niger and linseed) from 4.58 to 5.00 and snacks (udad dal wada, chakli, mung dal wada and shev) from 4.75 to 4.83.

Effect of drying conditions on the sensory quality of dehydrated leafy vegetables was studied by Singh *et al.* (2006). Amaranth, fenugreek, spinach and curry leaves were blanched, dried under cabinet drier, solar drier and further evaluated for overall acceptability. The results revealed that, all the green leafy vegetables dried under cabinet drier received excellent scores for sensory quality. Amaranth was excellent in color, flavor and good in texture. Curry leaves and palak scored alike as excellent in flavor and texture while good in color.

Dried coriander was analyzed for sensory parameters by Kaur *et al.* (2006). The results indicated that, dipping for 15 minutes in solution of magnesium chloride (0.1%), sodium bicarbonate (0.1%) and potassium metabisulphite (2.0%) at room temperature received the score of nine out of ten for over all acceptability. Color of rehydrated coriander obtained from drying in mini multi-rack solar dryer was nearest to fresh followed by cabinet dryer and forced convection air dried leaves. Rehydration ratio was highest for leaves dried under portable farm-type solar drier followed by open sun dried leaves.

Nande *et al.* (2007) studied acceptability of recipes prepared from different varieties of betel leaves. Three recipes namely coconut burfi, cutlet and muthia were developed and the recipes prepared from spinach served as control. Sixty grams of leaves was incorporated in coconut *burfi* and cutlet while in muthia, 70 g leaves were incorporated. Coconut burfi prepared from sweet betel leaves was given high scores ranging from 4.17 (color) to 4.34 (taste) on five point scale followed by kapuri betel leaves (3.16 to 4.17) and bangle betel leaves (2.54 to 3.50) respectively. Burfi with spinach received high scores of 4.5. Cutlets prepared from kapuri betel leaves were highly acceptable (3.83 to 4.49) and very close to spinach cutlets (4.17 to 4.16) for all sensory characteristics followed by cutlets prepared from sweet betel leaves (3.67 to 4.34) and bangle betel leaves (2.45 to 4.17). Muthia with betel leaves and control showed better overall acceptability.

Manchekar *et al.* (2008) studied the effect of processing on sensory quality of curry leaves. The leaves dried at ambient condition retained maximum green color and aroma followed by convectional drying at 40°C and sun drying. Drying at 100, 140 and 180°C exhibited better flavor but leaves turned brown.

Agasimani *et al.* (2008), studied the effect of drying on sensory quality of coriander leaves. The results indicated that, the leaves dried at ambient condition retained better organoleptic qualities compared to shade drying. The sun dried samples showed had retained olive green color while shade dried samples had bright green color. The leaves dried at 100 and 140°C turned brown to reddish brown and gave burnt appearance and flavor, while those dried at 40°C recorded better color and organoleptic attributes.

Dill leaves dried in continuous or intermittent microwaving in comparison with convective air drying were evaluated for sensory attributes (Esturk, 2010). The results revealed a significant influence of drying air temperature on the visual appearance. Microwave-convective air dried dill leaves were acceptable with scores of five out of nine, in terms of visual appearance, color, texture and flavor at all drying applications. Although continuous microwave convective air drying at 40°C received the highest scores, no significant difference was found among treatments. Flavor of sun dried vegetables were scored higher compared to cabinet dried. Blanching prior to dehydration retained bright green color of the leaves.

2.7 Summary of the review of literature

Vegetables are important source of food for human. As they are produced on seasonal basis, it is essential to store the vegetables for late consumption for periods varying from one month upto one year. Drying is the most proficient vegetable preservation method that enables vegetables to attain the moisture content sufficiently low to ensure good quality vegetable that is safe from microorganisms. Even though many people conducted their research for drying high moisture vegetables by using traditional dryers but very few of them focused on energy requirements, drying time, drying temperature, hot air supply for improving the final vegetable powder's physical, antioxidants and sensory quality. In terms of huge production of *M. verticillata*, low cost and raw material availability, its preservation is very necessary to make it available year-round and maintain the food security in our country. That's why mallow specimen was selected to produce powder by MSUCD and to evaluate the drying behavior, energy consumption, drying cost and quality characteristics of mallow powder over the powder obtained by other conventional drying methods (sun, shade and cabinet) for this research work.

CHAPTER III

METHODOLOGY

CHAPTER III

METHODOLOGY

3.1 Research location

This research work was accomplished in the Department of Food Engineering and Technology, Hajee Mohammad Danesh Science and Technology University, Dinajpur during the period of July, 2017 to June, 2018.

3.2 Design and fabrication of multi-storied universal cabinet dryer

This section involves the design and fabrication approaches of the dryer for conducting the research work. The common materials used for this dryer are shown in Appendix II.

3.2.1 Design considerations

In order to design and development of the proposed dryer named as multi-storied universal cabinet dryer, the following considerations were taken into account.

- Drying of various types of vegetables.
- Drying of high moisture vegetables.
- Cross sectional area of the drying chamber was 406.4 x 406.4 mm.
- Use of locally available materials and equipment will be used for the fabrication of the dryer.
- Ensuring proper insulation will be provided to make the dryer energy efficient.
- Compact in size.
- Manual loading and unloading system.
- Variable air flow (0.30-0.50 m^3/s) and temperature (50–90^{o}C).
- Operated by single-phase 220V power source.

3.2.2 Determination of physical properties of fresh vegetables to be dried

3.2.2.1 Bulk density of fresh vegetables

A rectangular box made of mild steel sheet was taken. The length (L), width (W) and height (H) of the box were measured. The weight of the mild steel sheet box was noted. Then the weight of vegetables filled in the box was recorded. The volume of the box was calculated using equation (3.1). The calculations are shown in Appendix III.

$$\text{Volume of rectangular box (V)} = \text{Lenght} \times \text{Width} \times \text{Height} \quad (m^3) \tag{3.1}$$

Then the bulk density of vegetables was calculated using the equation (3.2):

$$\text{Bulk density} = \frac{\text{Weight of vegetable}}{\text{Volume of rectangular box}} \quad (kg\ m^{-3}) \tag{3.2}$$

Bulk density of the most common vegetables were determined to select suitable dimension of the drying chamber for particular hold up (1.50-2.75 kg) so that it can be used as versatile dryer. During this research a rectangular box having 0.1 m height, 0.1 m width, and 0.1 m depth was made for calculating the bulk densities of vegetable.

Table 3.1: Bulk density of the vegetables to be dried

Name	Local name	Scientific name	Bulk density (kg/m^3)
Mallow	Napa Shakh	*Malva verticillata*	413.39 ± 1.05
Mustard leaves	Sorisa shakh	*Brassica nigra*	349.75 ± 1.41
Colocacia leaves	Kochu shakh	*Colocasia esculenta*	395.49 ± 3.24
Jute leaves	Pat shakh	*Corchorus olitorius*	294.41 ± 2.39
Moringa leaves	Sagina pata	*Moringa oleifera*	333.62 ± 2.04
Spinach leaves	Palong shakh	*Spinacia oleracea*	634.47 ± 3.19
Red amaranth leaves	Lal shakh	*Amaranthus cruentus*	436.48 ± 5.52
Brinjal	Begun	*Solanum melongena*	383.31 ± 1.89
Carrot	Gagor	*Daucus carota*	1058.38 ± 3.05
Bitter gourd	Korolla	*Momordica charantia*	780.99 ± 2.49
Garlic	Rosun	*Allium sativum*	485.95 ± 1.52
Cauliflower	Ful kopi	*Brassica oleracea var. botrytis*	260.38 ± 3.49
Cabbage	Badha kopi	*Brassica oleracea var. capitata*	371.01 ± 0.98

3.2.3 Calculations for multi-storied universal cabinet dryer

In this section, computation formula for selecting suitable dimension of the different components of the dryer such as holding capacity, air flow rate, blower motor power and heater power are represented.

3.2.3.1 Selection of height of the drying chamber

To make the dryer suitable to use and to ensure uniform air flow rate in all sections of the dryer, the height of the drying chambers and location of the tray in each shelf was determined by trial and error method with considering the knowledge of bulk density of vegetables to be dried. By the use of cross sectional area (Section 3.2.1) of the dryer and the values of bulk density of the vegetables to be dried, total height of the drying chamber was calculated as 584 mm. Total height of the dryer was then equally divided into four sub shelf. Finally, the tray was positioned in the middle of the each shelf by allowing a space of about 70 mm from both top and bottom of each shelf, respectively.

Total height of the drying chamber was expressed using the following equation (3.3):

$$H = h + h' \qquad (3.3)$$

Where, H= total height of the drying chamber (m), h= total border/edge thickness of the shelves (m) and h'= total clearance for trays between both top and bottom layer of four shelves of the drying chamber (m).

3.2.3.2 Calculation of holding capacity of the dryer

Holding capacity of the dryer was calculated using the following equation (3.4):

$$h_u = \rho_b \, A \, h \times N_s \qquad (3.4)$$

Where, h_u is the holdup mass (kg), ρ_b is bulk density (kg/m^3) of vegetables, N_s is the no of shelf, h is the product bed thickness (m) and A is bed area (m^2) of each shelf. There were four shelves in the dryer.

The bed area of the each shelf (A_s) and total bed area (A_T) of the dryer were calculated using equations (3.5) and (3.6), respectively.

$$A_s = L \times W \qquad (3.5)$$

Then total area,

$$A_T = N_s \text{ x } A_s \qquad (3.6)$$

Where, L and W are the length (m) and width (m) of the shelves, N_s is the no of shelves in the dryer.

Several hold-up mass were calculated for different vegetable bed thickness. The minimum and maximum bed thicknesses were selected as 0.01 m and 0.02 m respectively. The minimum and maximum holds up mass were calculated as 1.98 kg and 3.97 kg respectively using equation (3.3) and equation (3.5) for experimental vegetables.

3.2.3.3 Calculation of air flow rate of blower

The amount of air flow rate was considered as sufficient that was less the flow which tends to flow out the product placed for drying in trays. The air flow rate was calculated using the following equation (3.7).

$$Q = A \times v \qquad (3.7)$$

Where, Q = Air flow rate (0.119 m^3/s); A = Total area of drying chamber (0.234 m^2); and v = Velocity of air (0.50 m/s).

From previous research (Misha *et al.*, 2013; Marcelo *et al.*, 2015; Godwin *et al.*, 2016), it was found that air velocity in cabinet dryer usually ranges 0.40 m/s to 0.65 m/s. Finally, design air flow rate of the blower was considered as 0.15 m^3/s assuming 30% excess air flow.

3.2.3.4 Calculation of blower fan motor power requirement

The Blower fan power was calculated for the drying of vegetables by the following equation (3.8) and (3.9). The calculations are shown in Appendix IV.

$$P = \frac{Q \times P_w}{6356 \times \eta} \qquad (3.8)$$

Where, P is the power of electric motor (hp) for driving the blower fan, Q is the air flow rate (ft^3/min); P_w is the pressure drop (inch of water) and η is the efficiency of the motor of the blower fan. The efficiency of the blower fan motor available in Bangladesh normally 70-80% (Airtechnics Bangladesh Ltd.). In this research, 75% efficiency blower fan was selected.

$$\text{Pressure drop, } \Delta P = \frac{h_u}{\rho_b A} (\rho_b - \rho_a)\, g \tag{3.9}$$

Where, h_u = hold up mass of samples (kg); ρ_b = density of vegetables (kg/m^3); A = cross sectional area of the drying chamber (m^2); ρ_a = density of air (kg/m^3); and g = gravitational acceleration (m/s^2).

The calculated maximum blower power for drying of vegetables was 18.57 W while the corresponding pressure drop was 0.375 inches of water. Even though the calculated blower power was 18.57 W, for this study a blower motor of 50 W capacity was purchased.

3.2.3.5 Calculation of heater power requirement

The heater power of the dryer was calculated by the following formula proposed by Madhiyanon *et al.* (2006) after little modification for using the equation (3.10) in SI unit:

$$P_{heater} = 1 \cdot 21 \times Q \times (T_1 - T_0) \tag{3.10}$$

Where, P_{heater} = power of heater (kW); Q= air flow rate, m^3/s, T_1 = drying temperature (^{0}C) and T_0 = ambient temperature (^{o}C).

In order to make the proposed dryer suitable for drying vegetables with good quality dried products in terms of color and nutritional property drying air temperature were chosen up to 55^o C (Bala *et al.*, 2009). For this reason, with the purpose of making the MSUCD versatile for drying of various local vegetables with lower to higher moisture content, heater power was finally calculated by considering expected drying temperature and air flow rate. The electrical heater unit of 4.5 kW capacity constructed with parallel connection of three electric heaters (Xuanyuan, China) each of 1.5 kW capacity providing air temperature up to 90^o C. Each heater can separately be operated as and when necessary.

3.3 Fabrication of the multi-storied universal cabinet dryer

The fabrication and assembly works of the different parts of the multistoried universal cabinet dryer were carried out using the data from the above computations (Section 3.2.2). Finally, the individual parts of the dryer such as drying chamber, perforated trays for air distribution, heater unit and blower fan was fabricated separately using locally available materials with the help of local experienced technicians. Then all the parts were assembled properly with necessary heated air inlet orifices for maintaining uniform parallel air flow through all the trays of the drying bed. The schematic diagram of the multi-storied cabinet dryer are shown in Figure 3.1 and Figure 3.2.

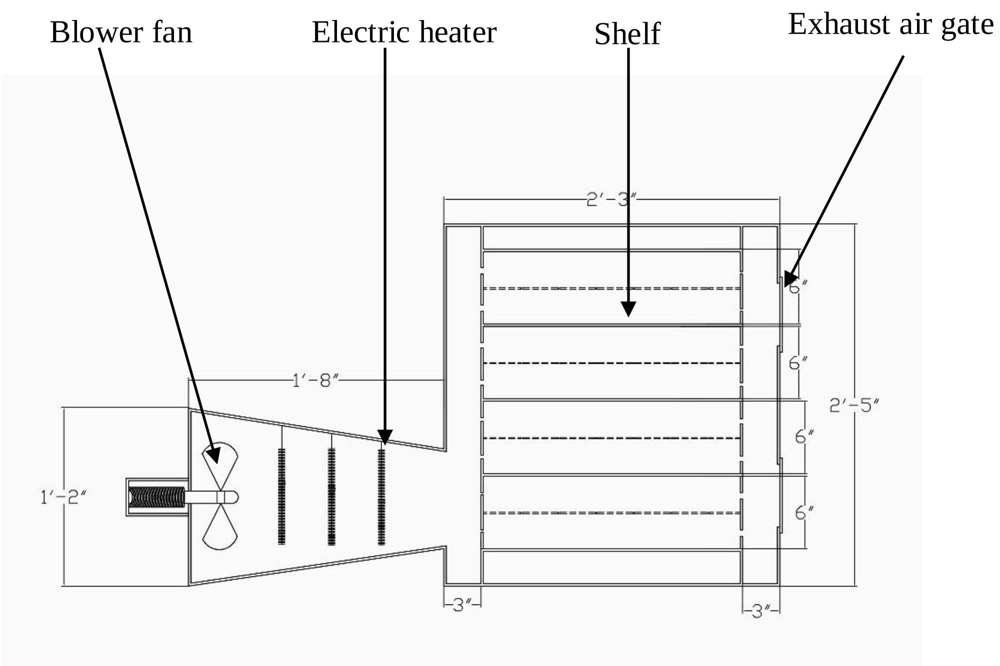
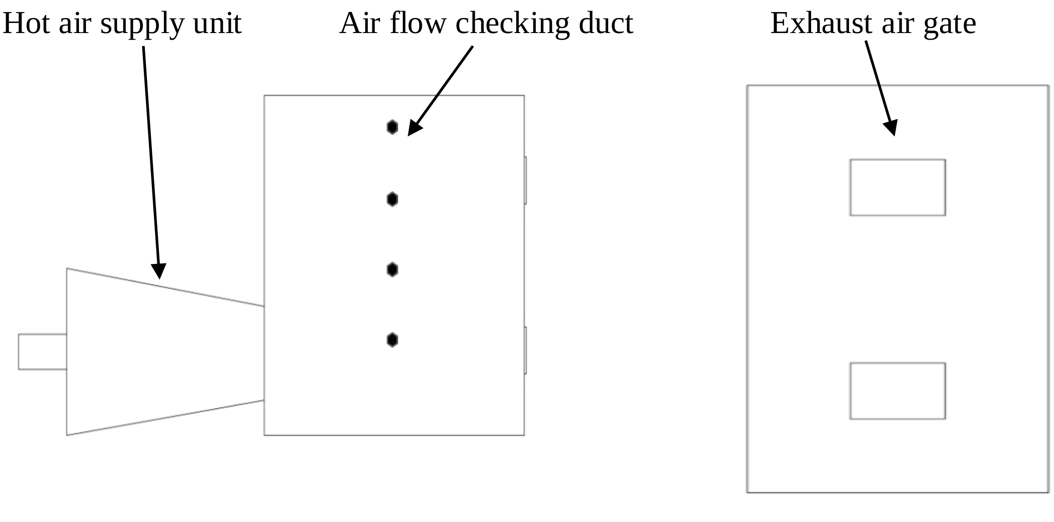


Fig 3.1: Schematic diagram of Multi-Storied Universal Cabinet Dryer

The dimensions of the rectangular dryer was 686 x 404 x 737 mm. It consists of a drying chamber, hot air distribution section, heating unit and blower section. The details specifications are given in Appendix 1.



(a) **(b)**

Fig 3.2: (a) Side view and (b) Front view of Multi-Storied Universal Cabinet Dryer

3.3.1 Drying chamber

The dimension of the drying chamber is 406.4 x 406.4 x 584.2 mm. The drying chamber is equipped with 4 trays which are arranged in middle of each of the four separated storied for the ease of drying the product. The walls of the drying chamber were made of 22 gauge mild steel sheet and the outer layer was insulation with colored coating. Each shelf contains two orifices at the middle which diameter were gradually increasing from bottom to top for equal parallel distribution of hot air. The height of each shelf is 152.4 mm and the tray is set at the center of the shelf. The perforated trays were made with mild steel sheet. The front side is opened for the door for loading and unloading of the trays and a hot air discharging gate is kept with the door.

3.3.2 Hot air distribution section

The hot air distribution chamber, a rectangular shape, is made of coated galvanized mild steel. A mild steel sheet attached with drying chamber where each shelf contains two orifices at the middle of the shelf and their diameter were gradually increasing from bottom to top for equal parallel distribution of hot air. The diameter of the orifices for the uniformly entrance of hot air to the drying chamber were 51, 66, 107 and 132 mm for the first, second, third and fourth shelves, respectively.

3.3.3 Heating unit

The heating chamber was also made with mild steel sheet and was equipped with three electric coils having capacity of 1500 Watt for each coil. The drying air temperature was controlled by a thermostat.

3.3.4 Blower section

A centrifugal blower fan capable of flowing air @ 0.13 m^3/s was used. A 50 W and 2900 rpm blower motor was used to run the blower fan. This type of fan is desired because of its steady air flow characteristics and its low cost. The total area of the blower section was 0.88 m^2.

3.4 Collection of samples

Fresh and mature leafy and tuber vegetables were collected from Dinajpur, the northern region of Bangladesh, during the harvesting season (November-December 2017). These samples were brought into the laboratory, cleaned and stored in refrigerator at 4^o C for further use.

3.4.1 Determination of moisture content

The moisture content of all vegetables were determined by oven method (AOAC, 2005). 5 g of each fresh sample was taken and dried at 105° C until constant weight (bone dry weight) was obtained. The experiment was triplicated.

The moisture content was calculated using the equation (3.11).

$$MC_{wb} = \frac{\text{Initial sample weight} - \text{Bone dry sample weight}}{\text{Initial sample weight}} \times 100 \quad (3.11)$$

Where, MC_{wb} = moisture content in wet basis.

3.5 Drying of selected high moisture vegetables in the MSUCD

Leafy vegetables such as mallow (*M. verticillata*), red amaranth (Lal shakh), moringa leaves (Sogina pata), jute leaves (Pat shakh), colocacia leaves (Kochu shakh), mustard leaves (Sorisa shakh) and tuber vegetables such as: brinjal (Begun), bitter gourd (Korolla), carrot (Gagor), garlic (Rosun), cabbage (Badha kopi) and cauliflower (Ful kopi) were collected, cleaned with pure water and then cut them into desirable shape for increasing surface area, so that the drying time will be faster and uniform. All the vegetables were dried in the MSUCD at 50 ± 2^0 C and air velocity 0.13 m^3/s.

3.6 Dryer Performance evaluation of MSUCD

3.6.1 Calculation of moisture removed (M_R)

Amount of moisture to be removed in kg (M_w) was calculated based on method with little modification of Ehiem (2008) given as:

$$M_R = M\left(\frac{M_i - M_f}{1 - M_f}\right) \quad (3.12)$$

Where,

M = dryer capacity per batch (2 kg); M_i = initial moisture content (% wb) of the vegetables to be dried and M_f = maximum desired final moisture content (% wb).

3.6.2 Calculation of quantity of energy required in effecting drying (E_r)

The quantity of energy utilized to evaporate water from the vegetables (E_r) was calculated using the approaches presented by Matuam *et al.* (2015) with little modification, as expressed by the equation (3.13).

$$E_r = M_R \times L_v \qquad (3.13)$$

The latent heat of vaporization was calculated using the equation (3.14) given by Youcef *et al.* (2001) as follows:

$$L_v = 4.186 \times 10^3 [597 - 0.56 (T_p)] \qquad (3.14)$$

Where, T_p = the product temperature (° C)

3.6.3 Calculation of thermal energy required for drying of vegetables (E_s)

The thermal energy passed by the heated air was calculated according to equation (3.15).

$$E_s = \dot{m}.C_p (T_d - T_a).t \qquad (3.15)$$

Where, $\dot{m}$ = the mass flow rate of drying air (kg/h); C_p = the specific heat of drying air (kJ/kg°C); T_d = the dying air temperature (°C); T_a = the ambient temperature (°C) and t = the total drying time of each vegetable (hr).

3.6.4 Calculation of thermal efficiency of the dryer

The thermal efficiency of the dryer was calculated using the equation (3.16) presented by Ehiem (2008) with little modification as below:

$$\eta_t = \frac{E_r}{E_s} \times 100 \qquad (3.16)$$

Where, η_t = thermal efficiency of the dryer; E_r= thermal energy utilized for effective drying (kJ) and E_s= thermal energy supplied for effective drying (kJ).

3.6.5 Calculation of drying rate

The drying rate equation (3.17) was used with little modification of the formula given by Ehiem, 2008. The calculated data are represented in Appendix VI to IX.

$$R = -\frac{L_s}{A_t}\frac{\Delta X}{\Delta t} \qquad (3.17)$$

Where, R = drying rate (g H_2O/min. m^2); L_s = Bone dry sample (vegetable) weight (kg); A_t = Total surface area of the trays (m^2); ΔX = changes in weight (% MC_{db}) and Δt = drying time difference (min).

The free moisture at t time was calculated according to equation (3.18).

$$X_t = \frac{W_t - W_e}{W_s} \times 100 \quad (3.18)$$

Where, X_t = Equilibrium moisture content at t time (% db); W_t = Weight of sample at time t (min); W_e = Weight of sample at equilibrium moisture content (g H_2O/g solid) and W_s = Constant weight (Bone dry weight) of the sample (g).

3.6.6 Assessment of specific energy consumption

The following formula (3.19) was used for calculating the electrical energy actually consumed by the blower fan motor. Voltage and current were recorded approximately at 30 min interval.

$$E_{blower} = \frac{VI \cos\theta \text{ x } t}{\eta \text{ x } 1000} \quad (3.19)$$

Where, V is the line voltage (volt); I is the line current (ampere); Cosθ is the power factor; t is the blower operating time in a batch (hr) and η is the blower motor efficiency.

The following formula (3.20) was used for calculating the electrical energy actually consumed by the electric heater. Voltage and current were recorded approximately at 30 min interval.

$$E_{heater} = \frac{VI \cos\theta \text{ x } t}{1000} \quad (3.20)$$

Where, V is the line voltage (volt); I is the line current (ampere); Cosθ is the power factor and t is the heater operating time (hr).

The electrical energy was calculated using the equation proposed by Sarker *et al.* (2014). The specific electrical energy consumption for blower motor ($SPEEC_{blower\ motor}$) and the specific electrical energy consumption for electric heater ($SPEEC_{electric\ heater}$) were calculated in kWh per kg water evaporated according to equation (3.21 and 3.22), respectively. Total specific electrical energy consumption (TSPEEC) was calculated using the equation (3.23).

$$SPEEC_{blower\ motor} = \frac{E_{blower}}{M_R} \quad (3.21)$$

$$SPEEC_{electric\ heater} = \frac{E_{heater}}{M_R} \quad (3.22)$$

$$TSPEEC = SPEEC_{blower\ motor} + SPEEC_{electric\ heater} \quad (3.23)$$

Where, TSPEEC is the total specific electrical energy consumption (kWh/kg); M_w is the amount of moisture to be evaporated for each raw vegetable (kg) in a batch.

3.6.7 Calculation of drying cost

The costs of drying of vegetable was calculated according to the formula (3.24).

$$\text{Drying cost}\left(\frac{\text{Tk}}{\text{kg}}\right) = \text{TSPEEC}\left(\frac{\text{kWh}}{\text{kg}}\right) \times \text{Electricity cost}\left(\frac{\text{Tk}}{\text{kWh}}\right) \qquad (3.24)$$

3.7 Drying experiment of *M. verticillata* samples

Drying time and final moisture content of dried sample were recorded for drying of each type of vegetable. The experimental working procedure of mallow (napa shakh) by various drying methods is shown in Fig. 3.3. The drying operations and some functional and chemical testing activities of mallow powder is shown in Fig. 3.4.

3.7.1 Design of experiment for drying of *M. verticillata* in MSUCD

Experimental design was considered to know the effects of drying methods and storage periods. Freshly harvested *M. verticillata* was dried by different drying methods. Therefore, to know the effect of drying methods on drying characteristics of *M. verticillata* and functional, antioxidant and sensory quality of dried vegetable, two factor experiment in completely randomized design (CRD) was employed. The first factor was drying method which has four levels such as Sun $(35 \pm 3)^0$C, Shade $(25 \pm 3)^0$ C, Cabinet $(50 \pm 2)^0$ C and MSUCD $(50 \pm 2)^0$ C. On the other hand, the second factor was storage period which has also four levels (0, 30, 60 and 90 days). Triplicate drying and quality analysis experiment were carried out.

3.7.2 Drying of *M. verticillata*

The leaves were dried using the following methods: (a) air drying under shade and room temperature (25° C); (b) sun drying (30-38° C); (c) drying in an existing cabinet dryer at 50 ± 2° C and (d) drying in designed multistoried universal cabinet dryer at 50 ± 2° C. Shade drying was carried out under natural air flow and surrounding’s temperature (mean temperature = 25° C). In the case of sun drying, leaves were dried into trays under direct sunlight at temperatures between 30 and 38° C. In this research, all the drying methods were conducted until the leaves reached a constant weight and moisture content below 10%. Because, this moisture content is the recommended value for drying of leaves and their powder production (Roongruangsri *et al.*, 2016; Raja *et al.*, 2017).

3.7.3 Preparation of *M. verticillata* powder

The dried leaves of *M. verticillata* were grounded to make powder by high speed electric grinder and then sieved manually by using sieve of 425 mesh size for uniform particle sized *M. verticillata* powder.

3.7.4 Packaging and storage of dried Leaves and powder of *M. verticillata*

The dried powder of *M. verticillata* was packaged and sealed in high density polyethylene (HDPE). Then the packaged powder was stored at refrigerated conditions (4^{o} C) until further analysis.

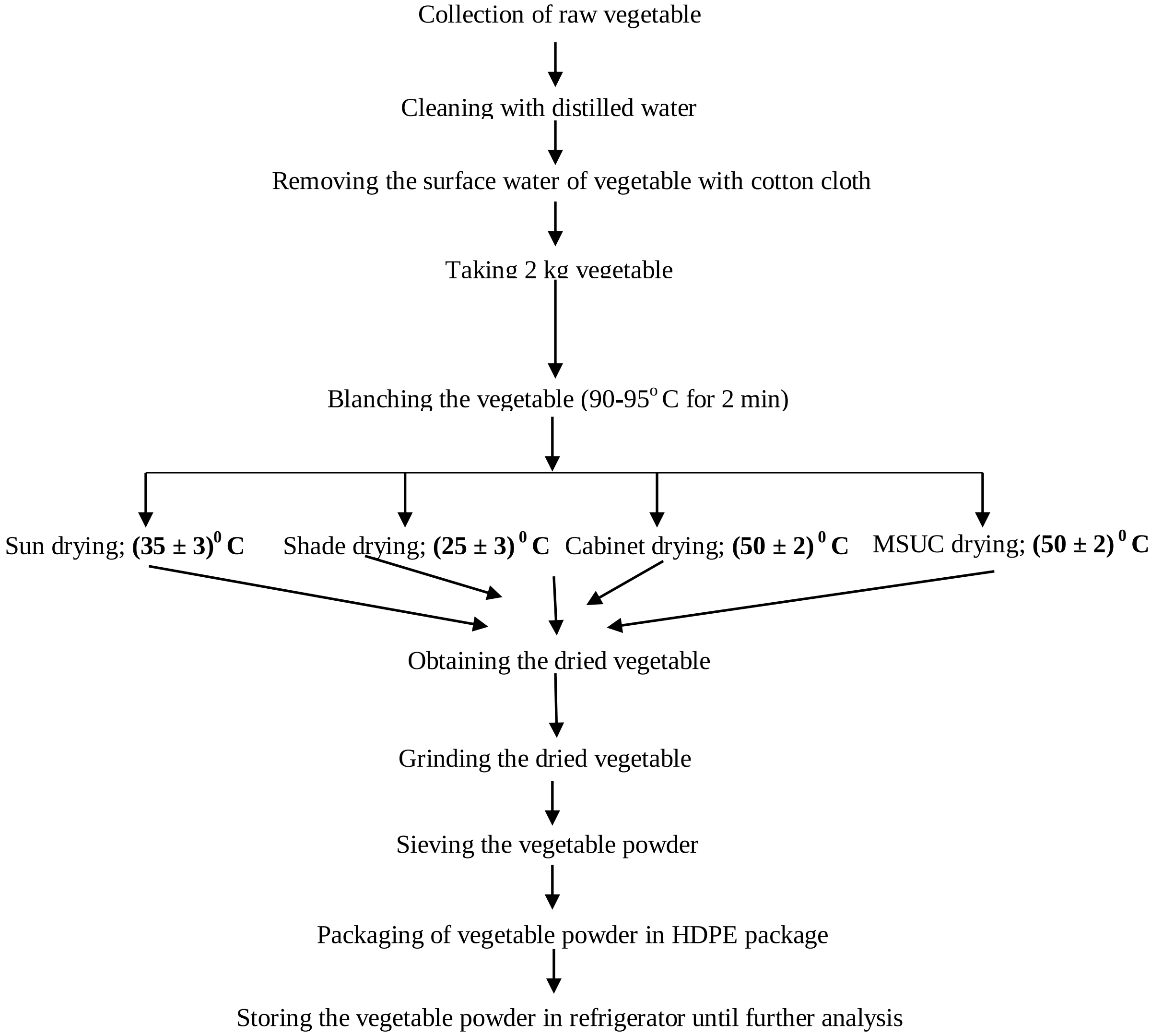


Fig 3.3: Experimental flow chart

(a) Collection of *M. verticillata*

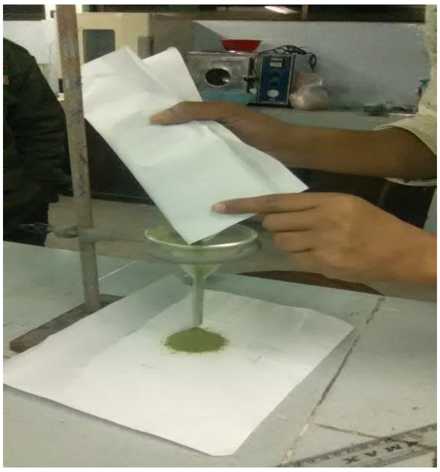
(b) Sorting and cleaning of *M. verticillata* leaves

(c) Sun drying of *M. verticillata* leaves

(d) Shade drying of *M. verticillata* leaves

(e) *M. verticillata* leaves for cabinet drying

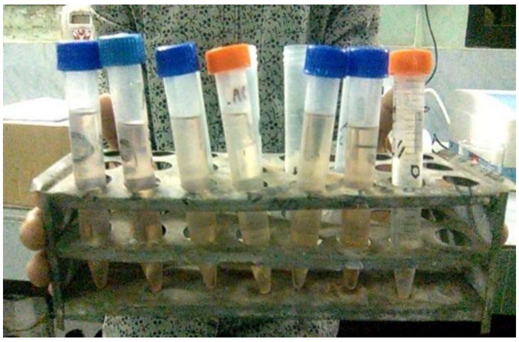
(f) *M. verticillata* leaves for MSUC drying



(g) Determination of angle of repose *M. verticillata* powder

(h) Determination of total phenol content *M. verticillata* powder

(i) Determination of total flavonoid content *M. verticillata* powder



(j) Determination of DPPH radical scavenging activity of *M. verticillata* powder

Fig 3.4: Few experimental activities for drying of *M. verticillata* leaves and functional and chemical analysis of *M. verticillata* leaves powder

3.7.5 Construction of drying curves and drying rate curves of *M. verticillata* samples

The drying curves of *M. verticillata* represented by plotting the loss of moisture against the drying time at different drying methods. The drying rate curves were also showed by plotting drying rate against % free moisture of *M. verticillata* sample.

3.8 Evaluation of the quality of *M. verticillata* powder

3.8.1 Calculation of physical and functional attributes of *M. verticillata* powder

3.8.1.1 Calculation of bulk density

The bulk density of all samples of mallow powder was determined according to the method reported by Raja *et al.* (2017). The bulk density was measured manually with the aid of cylindrical and rectangular shape, respectively. First, the mallow powder was added in each shape until it filled up to the top mark. The mass occupied by mallow powder was measured and recorded. Bulk density of the powder was calculated from the relationship of mass of the powder and volume of the powder. The process was replicated three times and the bulk density for each replication was calculated from the following relation:

$$\rho_b = \frac{Ws}{Vs} \tag{3.25}$$

Where, ρ_b is the bulk density, kg m^{-3}; W_S is the weight of the sample, kg; and V_s is the volume occupied by the sample, m^3.

3.8.1.2 Calculation of apparent density

The apparent density of all samples of mallow powder was determined using the method reported by Raja *et al.* (2017). First, the mallow powder was added until it filled up to the top mark of cylindrical and rectangular shape, respectively. Then hammering on the mallow with a solid body for keeping no void space within the mallow powder of the shapes. The mass occupied by the powder was measured and recorded. The process was replicated three times and the apparent density for each replication was calculated from the following relation:

$$\rho_a = \frac{M}{V} \tag{3.26}$$

Where, ρ_a = apparent density, $kg.m^{-3}$; M = mass of mallow powder, kg and V = volume of the shape, m^3.

3.8.1.3 Calculation of porosity

Porosity is a value that expresses the relative amount of pore space in the powder. The porosity of mallow powder was recorded after calculating the bulk density and the apparent density of the mallow powder. The process was replicated three times.

$$\text{Porosity } (\varphi) = 1 - \frac{\text{Bulk Density}(\text{kg/m } 3\ )}{\text{Apparent Density } (\text{kg/m } 3\ )} \qquad (3.27)$$

3.8.1.4 Calculation of angle of repose

The angle of repose (θ_s) of mallow powder was calculated based on the method reported by Ankita *et al.* (2015).

$$\theta_s = \tan^{-1}(\frac{h}{r}) \qquad (3.28)$$

Where, h is the height of bottom to lower tip of the funnel (mm) and r is the radius of the cone shape produced by the mallow powder (mm).

3.8.1.5 Calculation of water absorption index (WAI)

The water absorption index of all samples of mallow powder was determined according to the method reported by Kha *et al.* (2010) with some modifications. Firstly, the weight the cleaned falcon tubes was measured. Afterwards, 1 g of sample was suspended in 10 ml of distilled water and poured into a 15 ml falcon tube, which were then placed in a water bath at 60°C. The tubes were held in the water bath for 20 min, followed by centrifugation for 10 min at 4000 rpm. The water was then decanted from the tube without loss of the mallow particles. The percentage of residue, with respect to the amount of mallow powder used in the test, was taken as water absorption index, with the formula:

$$\text{Water absorption index} = \frac{\{W_3 - (W_2 + W_1)\}}{W_2} \qquad (3.29)$$

Where, W_1 = the falcon tube weight (gm), W_2 = mallow powder weight (gm) and W_3 = weight of the mallow gel (gm).

3.8.1.6 Calculation of water solubility index (WSI)

The water solubility index of all mallow powder was determined by the method given by Kha *et al.* (2010). Firstly, the weight of the falcon tubes was measured and recorded.

Afterwards, 1 g of mallow powder was suspended with 10 ml of distilled water into a 15 ml falcon tube, then the falcon tubes was placed in a water bath at 60°C for 20 min. The falcon tubes containing mallow powder was centrifuged for 10 min at 4000 rpm. The water was then decanted from the tube without loss of the mallow particles. The weight of petridish was recorded as W_4 and the mallow gel was taken that petridish. The supernatant was dried at 70°C until a constant weight. The weight petridish with sample was recorded as W_5. This experimental procedure were performed in triplicate.

$$\text{WSI (\%)} = \frac{W_5 - W_4}{W_2} \times 100 \qquad (3.30)$$

Where, W_s= weight of petridish and dried residue of mallow powder, W_2= mallow powder weight (gm), and W_4= weight of petridish (gm).

3.8.1.7 Calculation of oil absorption index (OAI)

The oil absorption index of all mallow powder was determined using the method reported by Que *et al.* (2008) with some modifications. 1 g mallow powder and 6 ml soybean oil were mixed in a falcon tube and stirring it for 30 s with a vortex mixer, which were then placed in a water bath at 60° C for 20 min. The mixture was centrifuged for 10 min at 4000 rpm. The supernatant was decanted carefully for the protection of loss of the mallow particles. The percentage of mallow residue, with respect to the amount of mallow powder used in the test, was taken as oil absorption index, with the formula:

$$\text{Oil absorption index} = \frac{\{W_3 - (W_2 + W_1)\}}{W_2} \qquad (3.31)$$

Where, W_1 = the falcon tube weight (gm), W_2 = mallow powder weight (gm) and W_3 = weight of the oily mallow gel (gm).

3.8.2 Determination of Antioxidant Activities of *M. verticillata*

3.8.2.1 Calculation of Chlorophyll

The contents of chlorophyll of all samples were determined using the method described by Negi *et al.* (2000). All pigments in 100 mg sample were extracted with 4 mL of 80 % acetone in a mortar. The suspension was collected in a 15 mL falcon tube. The mortar was rinsed with 4 ml of acetone and again pouring the residual portion of mallow particles into falcon tube. The volume of the falcon was adjusted to 10 ml with acetone. Then the tubes were centrifuged at 3000 rpm for 10 min. The absorbance of the supernatant were taken at 663.2 nm, 646.8 nm and 470 nm by spectrophotometer. Chlorophyll concentrations were calculated in mg/g DW of mallow powder according to the formula:

$$C_a \text{ (mg/l)} = (12.25 * A663.2) – (2.79 * D646.8) \quad (3.31)$$

$$C_b \text{ (mg/l)} = (21.50 * D646.8) – (5.10 * D663.2) \quad (3.32)$$

$$C_a \text{ (mg/gMF)} = [Ca \text{ (mg/l)} / \text{weight (g)}] * [10 \text{ (mg)} /1000] \quad (3.33)$$

$$C_b \text{ (mg/gMF)} = [Cb \text{ (mg/l)} / \text{weight (g)}] * [10 \text{ (mg)} /1000] \quad (3.34)$$

3.8.2.2 Calculation of Ascorbic Acid (Vitamin C)

Chemical preparation procedures:

1. **Preparation of L-ascorbic acid standard curve**
   To make 500 PPM L- Ascorbic acid standard curve, add 0.05 g L- Ascorbic acid in 500 ml volumetric flask and made the volume upto the mark with distilled water. The data and standard curve are displayed in Appendix XIII.
2. **Preparation of meta-phosphoric acid solution**
   To make Meta-phosphoric acid solution, add 15 g Meta-phosphoric acid and 40 ml Glacial Acetic Acid in 500 ml volumetric flask and made the volume upto the mark with distilled water.
3. **Preparation of 2, 6 dichlorophenol indophenol (Dye) solution**
   To make 2, 6 Dichlorophenol Indophenol (Dye) Solution, add 130 mg 2, 6 Dichlorophenol Indophenol (Dye) and 105 mg $NaHCO_3$ in 500 ml volumetric flask and made the volume upto the mark with distilled water.

Working procedure

The ascorbic acid content of all samples was determined using the method described by Garba *et al.* (2014). 1 gm of each mallow powder was weighted and this was macerated in a mortar. Fifty ml of the metaphosphoric acid solution was added onto the macerated sample to form a solution. The mortar was rinsed with 4 ml metaphosphoric acid solution and again pouring the residual portion of mallow particles into falcon tube. Finally, the volume of the falcon tube was adjusted to 50 ml with metaphosphoric solution. The mixtures was filtered through Whatman filter paper (Grade 1) with the aid of vacuum pump which helps to clarify the solution. This procedure was replicated for thrice. Then, 1 ml of the filtrate (aliquot) and 2 ml of dye were taken in a cuvette. The reading was taken within 15 to 20 seconds. The absorbance was measured at 518 nm. The final content of ascorbic acid was determined by using the equation 3.35.

$$\text{Ascorbic Acid } \left(\frac{\text{mg}}{100\text{g}}\right) = \frac{\text{Absorbance value x Vol. made up x 100}}{\text{Weight of sample x Vol. of sol. taken x 1000}} \qquad (3.35)$$

3.8.2.3 Calculation of total phenol content (TPC)

Reagent

Folin-Ciocalteau reagent (10 times dilution), Sodium carbonate solution (Na_2CO_3) 7.5 %

Methanol, Gallic acid (Reagent grade).

Equipment and materials

Micropipette (10-100 µL), Pipette (10-1000 µL), UV-Spectrophotometer

Chemical preparation

Preparation of methanol (80 % v/v) solution

80 ml concentrated methanol was poured in a 100 ml volumetric flask and finally made the volume up to mark by adding distilled water.

Preparation of stock solution

0.0128 g gallic acid was dissolved into 50 ml distilled water, so the concentration of the solution 0.256 mg/ml or 256 µg/ml. This is called stock solution. Then serial dilution was performed in order to prepare different concentrated solutions (0. 20, 30, 40, 50, 60, 70, 80, 90 and 100 µg/ml). The data and standard curve are displayed in Appendix X.

Preparation of Folin-Ciocalteu Reagent (FCR) solution

10 ml FCR was taken in a beaker and 90 ml water was added for 10 times dilution.

Preparation of 7.5 % Na_2CO_3 solution

7.5 g Na_2CO_3 was taken in a 100 ml volumetric flask and a small amount of distilled water was added in it and then shaken the solution to dissolve Na_2CO_3. The volume was made upto the mark by adding distilled water.

Preparation of blank solution:

Blank consists of 1.5 ml Folin-Ciocalteu reagent, .5 ml methanol and 3 ml sodium carbonate solution and 5 ml distilled water.

Working procedure

Total phenolic content of all samples of mallow powder was determined using the Folin-Ciocalteu reagent (Prieto *et al.,* 1999) with some modification. The extracted solution was obtained using 0.1 g sample mixed with 10 ml 100% methanol and 40 ml distilled water in a mortar and macerated the mixture for 4-5 minutes. Then the mixture was filtered through Whatman filter paper (Grade 1). From the mixtures, aliquots of 0.5 ml of each sample was added to 1.5 ml of 10% (v/v) Folin-Ciocalteu reagent. The mixture was then allowed to stand at dark place for 8 minutes and 30 seconds and then add 3 ml Na_2CO_3. Immediately, distilled water was added to bring the final volume to 25 ml with distilled water. Then vortex the solution for few seconds and then allowed to stand at dark place for 30 min. The absorbance of sample was measured at 765 nm using spectrophotometer.

Calculation:

$$\text{TPC as mg GAE/g} = \frac{\text{C x V}}{\text{m}} \quad (3.36)$$

Where, c = concentration of gallic acid (mg/ml); v = volume of the sample solution (ml) and m = weight of the sample (g)

3.8.2.4 Calculation of total flavonoid content (TFC)

Preparation of reagents and chemical:

Aluminium Chloride ($AlCl_3$) – 10 %, Sodium Hydroxide (NaOH) - 1 M, Methanol – 80 %, Quereetin (Reagent grade).

Equipments and materials

Micropipette (10-100 µL), Pipette (10-1000 µL), UV-Spectrophotometer

Preparation of methanol (80 % v/v) solution

80 ml concentrated methanol was poured in a 100 ml volumetric flask and finally made the volume up to mark by adding distilled water.

Preparation of standard Quercetin acid solution

0.0049 g quercetin acid was dissolved into 10 ml methanol, so the concentration of the solution 4.9 mg/ml or 450 µg/ml. This is called stock solution. Then serial dilution was performed in order to prepare different concentrated solutions (0. 20, 40, 60, 80 and 100 µg/ml). The data and standard curve are displayed in Appendix XI.

Preparation of 1 M sodium hydroxide solution

2 g sodium hydroxide was taken in a 100 ml volumetric flask and small amount of distilled water was added and dissolved in it. Finally add distilled water upto the mark.

Preparation of 10 % $AlCl_3$ solution

5 g $AlCl_3$ was taken in a 50 ml volumetric flask and a small amount of distilled water was added in it and dissolved in it. Finally add distilled water upto the mark.

Preparation of 5 % $AlCl_3$ solution

5 g $AlCl_3$ was taken in a 100 ml volumetric flask and a small amount of distilled water was added in it and dissolved in it. Finally add distilled water upto the mark.

Preparation of blank solution:

Blank consists of all the reagent except for the quercetin standard solution is submitted with 1 ml of methanol.

Working procedure

Total flavonoid compounds of all mallow powder samples were determined using the method described by Prieto *et al.* (1999). The extracted solution was obtained using 0.1 g sample mixed with 10 ml 100% methanol in a mortar and macerated for 4-5 minutes. Then 1 ml aliquots of the extract solution were mixed with 4 ml distilled water and 0.3 ml of 10% $NaNO_2$ solution. After 5 min, 0.3 ml of 10% $AlCl_3$ solution was added and allowed to stand for further 1 min; Then 2 ml of 1 M NaOH solution was added to the mixture. Immediately, distilled water was added to bring the final volume to 10 ml. Then vortex the solution for few seconds and then allowed to stand at dark place for 30 min. The absorbance of sample was measured at 510 nm using spectrophotometer.

Calculation:

$$\text{TFC as QAE} = \frac{C \times V}{m} \quad (3.37)$$

Where, c = concentration of quercetic acid (mg/ml); v = volume of the sample solution (ml) and m = weight of the sample (g).

3.8.2.5 Calculation of DPPH radical scavenging activity

The ability of the mallow (napa shakh) extract and reference substance to scavenge 2, 2-diphenyl-1-picrylhydrazyl (DPPH) free radicals was assessed using the method described by Stankovic *et al.* (2012).

Equipment and Reagents:

2, 2-Diphenyl-1-Picryl hydrazyl, Methanol, Apparatus and Instruments, UV-Spectrophotometer, Pipette (1-20 ml), Pipette (10-100 µl), Pipette (10-1000 µl), Test tube, Beaker, Measuring cylinder, volumetric flask.

Reagent preparation:

i. Preparation of DPPH radical solution (0.3 mM)

   In order to prepare 0.3 mM DPPH solution, 0.0059 g of DPPH was dissolve in 100 ml of 80 % methanol and then kept the solution in a dark place. The data and standard curve are displayed in Appendix XII.

ii. Preparation of stock solution

   0.0025 g of trolox was dissolved in 10 ml of methanol to prepare 0.25 µg/ml solution.

Working procedure:

The DPPH free radical scavenging activity of methanolic extracts of mallow powder was assessed by the method of William *et al.* (1995) where 2, 2- diphenyl-1-picrylhydrazyl (DPPH) was used as standard. The extracted solution was obtained using 0.1 g sample mixed with 10 ml 100% methanol in a mortar and macerated for 4-5 minutes. Then 1 ml aliquots of the extract solution were mixed with 1.9 ml of 0.3 mM DPPH solution. Immediately, distilled water was added to bring the final volume to 10 ml. Then the solution was kept in the dark place for 30 min. The absorbance of the mixture solution was taken at 517 nm using UV-Visible Spectrophotometer. The results was expressed as mg TEAC/100 g dried mallow powder. The measurements were taken in triplicate for each sample and results were averaged.

Calculation:

$$\text{DPPH free radical scavenging activity as mg TAE/g} = \frac{C \times V}{m} \qquad (3.38)$$

Where

c = concentration of trolox standard (mg/ml), v = volume of the sample solution (ml) and m = weight of the sample (g)

3.8.3 Determination of sensory attributes of dehydrated *M. verticillata* Powder

The consumer acceptability of *M. verticillata* powder was evaluated in Hedonic Rating Scale. There were 25 semi-trained panel members and score were collected as; 5 = excellent, 4 = good, 3 = Fair, 2 = Poor and 1 = not accepted. The questionnaire of data collection for evaluation are displayed in Appendix XIV.

3.9 Selection of appropriate drying option for quality vegetable powder

After drying of high moisture vegetables by various drying methods, appropriate drying options were selected by analyzing drying rate, thermal efficiency of dryer, energy consumption and analyzing quality parameters such as functional, antioxidant and sensory quality of mallow powder.

3.10 Statistical analysis

Two factors completely randomized design (CRD) was employed in this experiment to know the effects of the drying methods (four levels, such as sun, shade, existing cabinet and MSUCD) and storage periods (four levels, such as 0, 30, 60 and 90 day) on drying characteristics of mallow leaves and functional, antioxidant and sensory quality of the dried mallow powder. Each experiment was replicated for thrice and analyzed by using SPSS (Version - 22.0) for ANOVA analysis to evaluate the variability among the drying methods and storage periods. The Duncan Multiple Range Test (DMRT) applied for multiple comparisons at $P \leq 0.05$ among the drying methods and storage duration.

CHAPTER IV

RESULTS AND DISCUSSION

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Design and fabrication success of the multi-storied universal cabinet dryer (MSUCD)

A multi-storied universal cabinet dryer (MSUCD) was successfully designed and fabricated as per the specifications mentioned in the chapter III (Section 3.2 and 3.3). The photographic views of the newly developed dryer are shown in Figure 4.1 which was installed in the Food and Process Engineering Laboratory-2 at Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur. The dryer was operated successfully for drying numerous types of high moisture vegetables. Drying results obtained from the MSUCD during drying of high moisture vegetables are shown in Table 4.1, 4.2 and 4.3. Detailed discussions are presented in the following sections.

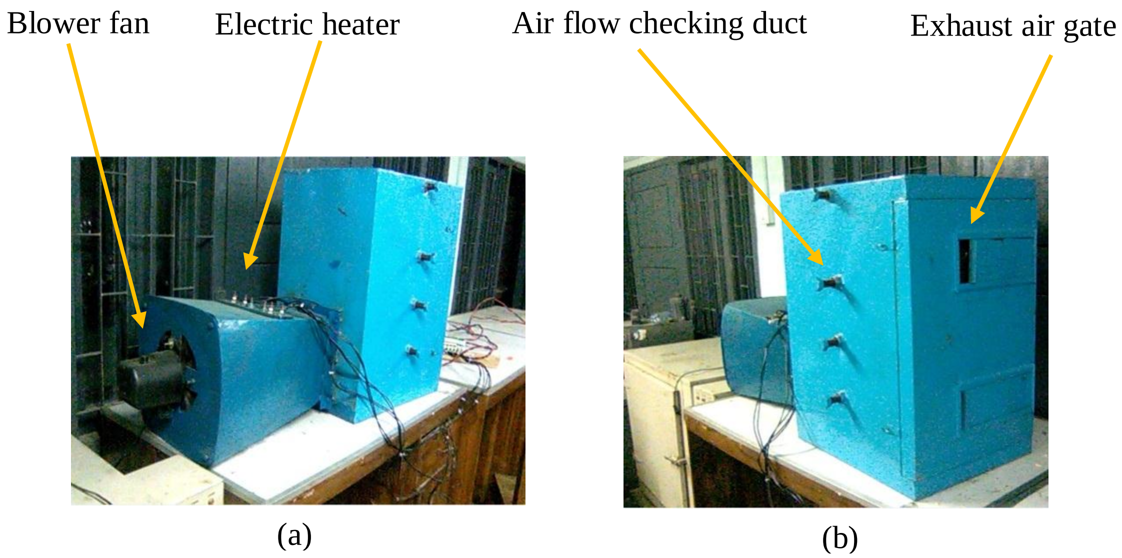


Fig 4.1: The schematic view of Multi-Storied Universal Cabinet Dryer (MSUCD)

4.2 Drying results of high moisture vegetables

Table 4.1 and 4.2 revealed that the locally available leafy vegetable took shorter drying time (only 1.00 to 2.67 hr) for drying from initial high moisture of 93% to 3.78% (wb) final moisture content. On the other hand, longer drying time (6.33 to 17.67 hr) required for tuber vegetables for drying from initial high moisture of 90.20% to 6.44% (wb) final moisture content. Drying time taken by the MSUCD was comparatively lower than drying time of the existing cabinet dryer for drying similar vegetables (Akpan *et al.*, 2016; Rathnayaka *et al.,* 2017; Raja *et al.,* 2017). Photographic views of raw and dried vegetables are shown in Figure 4.2. It can be seen the color of dried vegetables or vegetable powder was looking good.

Table 4.1: Drying of high moisture leafy vegetables in the MSUCD

Vegetable	Sample Weight (kg)	Drying temperature (^{0}C)	Initial moisture content (% db)	Final moisture content (% db)	Drying time (hr)
Mallow (Napa Shakh)	2	50 ± 2	557.89 (*84.80)	3.73 (*3.60)	1.33
Red amaranth (Lal shakh)	2	50 ± 2	880.39 (*89.79)	3.88 (*3.74)	1.67
Moringa leaves (Sogina pata)	2	50 ± 2	367.29 (*78.60)	3.56 (*3.44)	1.00
Jute leaves (Pat shakh)	2	50 ± 2	447.87 (*81.75)	3.64 (*3.51)	1.17
Spinach leaves (Palong shakh)	2	50 ± 2	1415.15 (*93.39)	3.93 (*3.78)	2.67
Colocacia leaves (Kochu shakh)	2	50 ± 2	663.36 (*86.90)	3.92 (*3.77)	2.17
Mustard leaves (Sorisa shakh)	2	50 ± 2	890.10 (*89.90)	3.79 (*3.65)	1.67

(*indicates moisture content values in wet basis)

Table 4.2: Drying of high moisture tuber vegetables in the MSUCD

Vegetable	Sample Weight (kg)	Drying temperature (^{0}C)	Initial moisture content (% db)	Final moisture content (% db)	Drying time (hr)
Brinjal (Begun)	2	50 ± 2	532.91 (*84.20)	6.77 (*6.34)	11.17
Bitter gourd (Korolla)	2	50 ± 2	687.40 (*87.30)	6.86 (*6.42)	10.83
Carrot (Gagor)	2	50 ± 2	762.07 (*88.40)	6.81 (*6.38)	13.50
Garlic (Rosun)	2	50 ± 2	189.02 (*65.40)	6.62 (*6.21)	17.67
Cabbage (Badha kopi)	2	50 ± 2	861.54 (*89.60)	6.91 (*6.46)	6.33
Cauliflower (Ful kopi)	2	50 ± 2	920.41 (*90.20)	6.95 (*6.44)	18.67

(*indicates moisture content values in wet basis)

(a): Raw *M. verticillata*

(b): *M. verticillata* Powder

(c): Raw Amaranth leaves

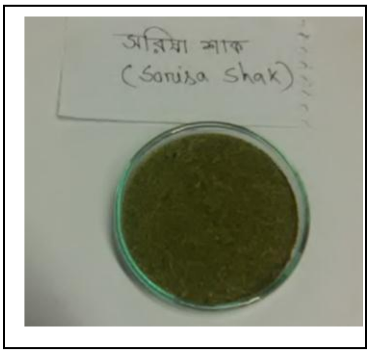
(d): Amaranth Powder

(e): Raw Moringa Leaves

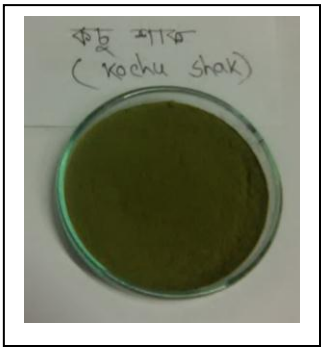
(f): Moringa Leaves Powder

(g): Dried Jute Leaves

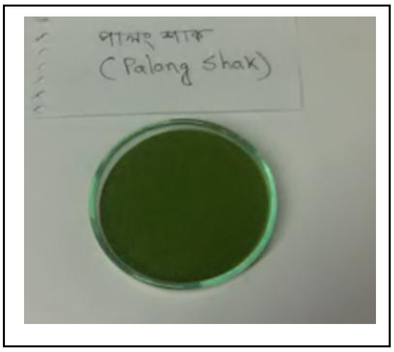
(h): Jute Leaves Powder



(i): Mustard Leaves Powder



(j): Colocacia Leaves Powder

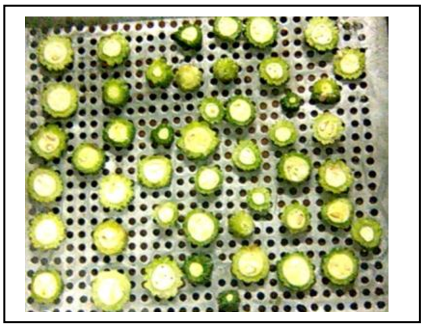


(k): Spinach Leaves Powder

(l): Raw Brinjal

(m): Dried Brinjal

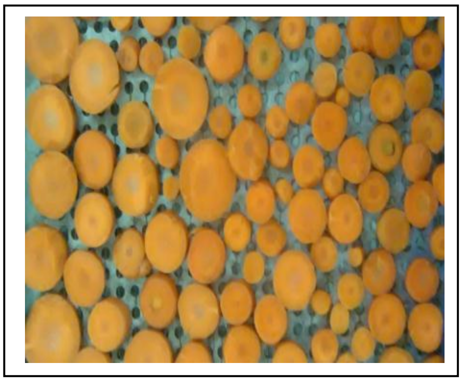
(n): Raw Bitter Gourd



(o): Drying of Bitter Gourd

(p): Dried Bitter Gourd

(q): Raw Carrot



(r): Drying of Carrot

(s): Dried Carrot

(t): Raw Garlic

(u): Raw Cauliflower

(v): Raw Cabbage

Fig 4.2: Schematic representations for drying of various fresh high moisture vegetables by MSUCD

4.3 Performance evaluation of MSUCD in terms of energy consumption and drying cost for high moisture vegetables

The experimental results of energy usage, thermal efficiency and drying costs for drying of local vegetables by MSUCD is shown in Table 4.3. Total energy consumption results revealed that lesser energy (only 0.87 to 2.03 kWh/kg) required for leafy vegetables for drying from initial high moisture of 93% to 3.78% (wb) final moisture content. On the other hand, comparatively higher energy (5.05 to 19.85 kWh/kg) required for tuber vegetables for drying from initial high moisture of 90.20% to 6.44% (wb) final moisture content. Thermal efficiency results revealed that higher thermal efficiency (18.89 to 42.19%) shown for leafy vegetables for drying from initial high moisture of 93% to 3.78% (wb) final moisture content. On the other hand, comparatively lower thermal efficiency (1.84 to 7.61%) was shown for tuber vegetables for drying from initial high moisture of 90.20% to 6.44% (wb) final moisture content. The highest energy and drying costs were taken for garlic drying and the lowest for moringa leaves. The higher energy consumption and drying costs and lower thermal efficiency were observed in tuber crops which may be due to thicker slice, lesser surface area, harder outer surface and cell structure and so on. Similarly, the reasons for lower energy consumptions and drying costs and higher thermal efficiencies for leafy vegetables drying which may be due to their soft and porous outer surface and larger surface area. So, the overall energy consumptions and drying costs may be reduced by lowering slice thickness, uniform spreading the samples on the trays, tempering of samples etc. Singh (1994) and Nwakuba *et al.* (2016) found the drying costs (Tk/kg) and drying efficiency (%) of dried vegetables (cauliflower, cabbage and onion, potato, carrot, garlic, onions, mango, banana, apple and tomato) were 4.38-5.69 Tk/kg and 28.21 and 30.83%, respectively. In our study, the drying time and energy consumption for drying of tuber vegetables took comparatively higher than other studies for drying of similar vegetables (Ehiem *et al.,* 2008; Misha *et al.,* 2013; Gyanwali *et al.,* 2014). Therefore, it can be concluded that leafy and tuber vegetables are possible to dry in developed MSUCD using lesser energy at lower drying cost compared other cabinet type drying convective dryer (Marcelo *et al.,* 2015; Godwin *et al.,* 2016; Akpan *et al.,* 2016).

Table 4.3: Energy consumption and drying cost for drying of high moisture vegetables in MSUCD

Vegetables	TSPEEC (kWh/kg)	Thermal Efficiency (%)	Costs (Tk./kg raw)
Mallow (Napa Shakh)	1.12	34.33	3.92
Red amaranth (Lal shakh)	1.26	29.02	4.63
Moringa leaves (Sogina pata)	0.87	42.19	3.19
Jute leaves (Pat shakh)	1.02	37.55	3.58
Spinach leaves (Palong shakh)	2.03	18.89	7.11
Colocacia leaves (Kochu shakh)	1.70	21.56	6.23
Mustard leaves (Sorisa shakh)	1.26	29.05	4.63
Brinjal (Begun)	9.53	4.04	33.34
Bitter gourd (Korolla)	8.88	4.33	31.09
Carrot (Gagor)	10.93	3.52	38.24
Garlic (Rosun)	19.85	1.94	69.48
Cabbage (Badha kopi)	5.05	7.61	17.67
Cauliflower (Ful kopi)	14.79	2.60	51.75

TSPEEC means Total Specific Electrical Energy Consumption

4.4 Comparative drying performance for drying of *M. verticillata* leafs in the MSUCD over traditional methods

Drying kinetics of mallow (napa shakh) during drying by four different methods (sun, shade, cabinet and MSUCD) is shown in Figs. 4.3 to 4.6. Drying time required for drying of mallow from the initial moisture content of 84.96 ± 0.31% (wb) to the final moisture content of around 3.59 ± 0.01% (wb) was 6 hr, 48 hr, 4.25 hr and 1.33 hr for sun, shade, cabinet and MSUCD, respectively. The initial moisture removal rate of mallow was faster and then gradually reduced with gradual reduction of free moisture from the sample until to reach the equilibrium moisture content. The final moisture content of the products dried by sun, shade, cabinet and MSUCD were 6.18%, 5.49%, 3.84% and 3.73% (db), respectively. It was noticed from Figs. 4.3 to 4.6 that the MSUCD took the lowest drying time (only 80 min) than the time needed for sun, shade, cabinet dryer for drying of mallow to achieve constant weight. The plots also showed the “settling down” period for drying of mallow which occurred in the first stage of drying of around 10 minutes. It noticed from Figs. 4.3 and 4.4 that the sample dried by sun and shade drying method took longer drying time. During drying operation, the boundary layer around the mallow leaves becomes thinner and the heat energy transferred by hot air and thus increases the drying rate and reduces the drying time **(**Ran *et al.*, 2016; Coklar *et al.*, 2017). The drying time of mallow is comparatively higher in sun and shade drying method which may be due to dependency on atmospheric temperature during the drying process (Saxena, *et al.*, 2015). On the other hand, the drying time was comparatively lower in MSUCD which may be due to proper distribution of hot air in the drying chamber. The collapse of the drying curves at the beginning of the process indicated that drying was controlled by internal or external resistances which was related to increased moisture diffusivity at higher temperatures (Diamante *et al.*, 2010**;** Hihat *et al.*, 2017). As noted from Figs. 4.3 to 4.6, drying kinetics were not a linear function of time, and moisture content decreased exponentially with increasing drying time; the last step was represented by an almost horizontal line, which marked the end of the drying process. The moisture content of mallow reduced exponentially with drying time which evidently matched with other foodstuffs such as drum stick leaves, coriander leaves and fenugreek, spinach, rajagira, shepu and kiraksali leaves (Kaur *et al.*, 2006; Singh *et al.*, 2006; Karva, 2010).

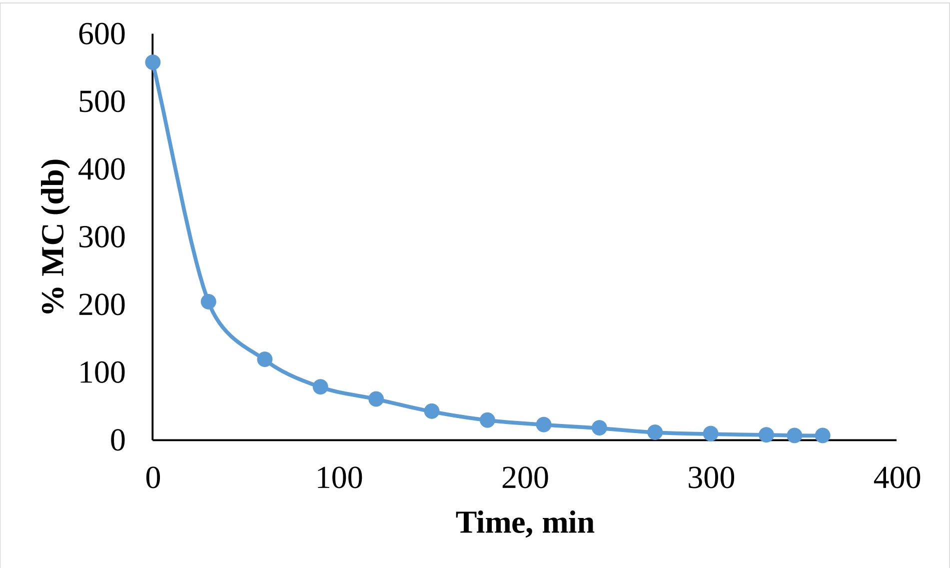


Fig 4.3: Drying characteristics of *M. verticillata* in Sun drying

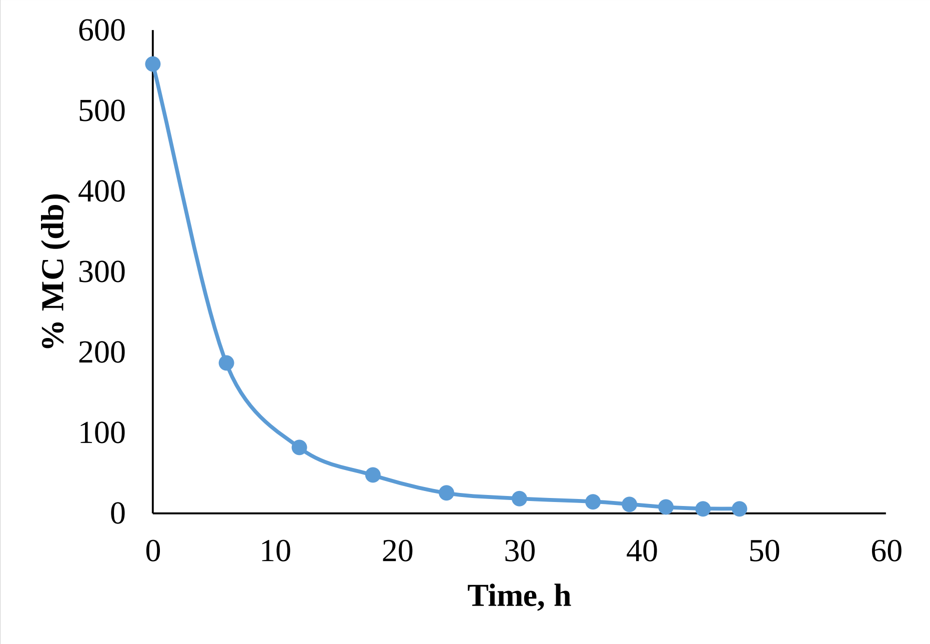


Fig 4.4: Drying characteristics of *M. verticillata* in Shade drying

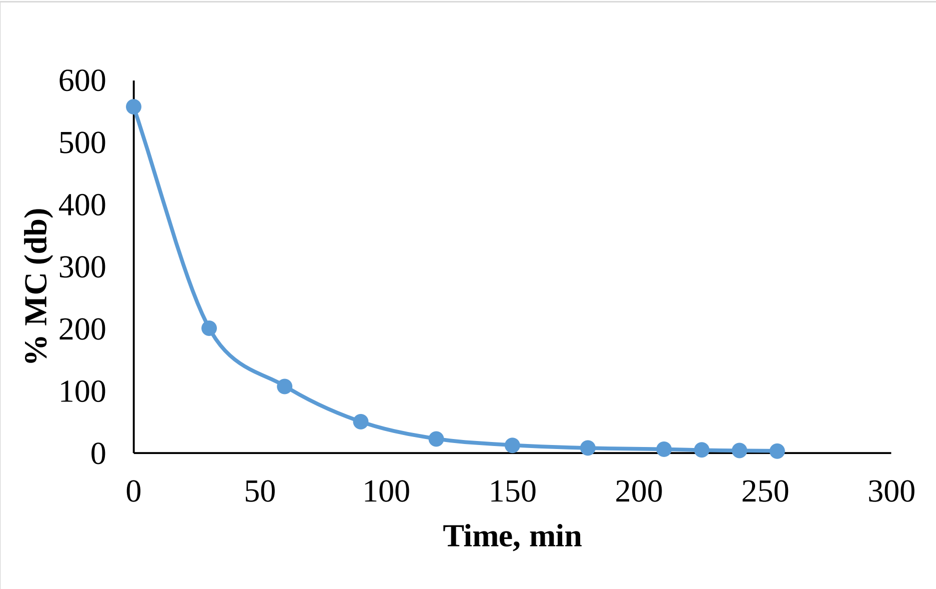


Fig 4.5: Drying characteristics of *M. verticillata* in Cabinet dryer

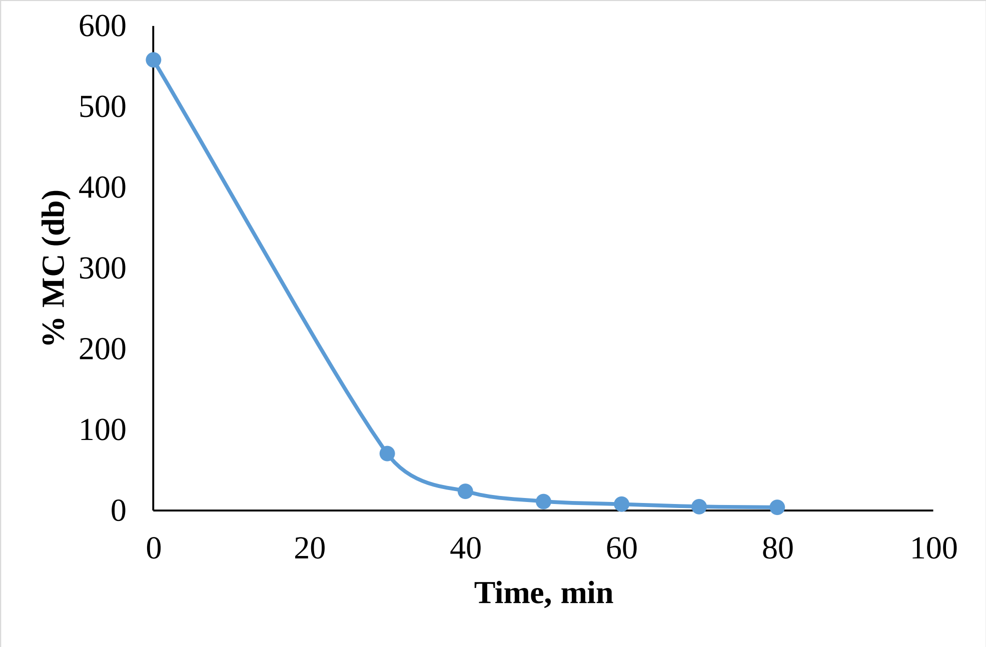


Fig 4.6: Drying characteristics of *M. verticillata* in Multi-Storied Universal Cabinet dryer

Figs. 4.7 to 4.10 exhibits the variation of drying rate with free moisture content of mallow powder at different methods. The higher the free moisture of the sample, the higher the drying rate. Drying process generally occurs in two different periods; namely the constant rate period and the falling rate period. It was seen from Figs. 4.7 to 4.10 that constant drying rate period was very short because mallow could not provide a constant supply of moisture during the drying process and the falling rate period is divided into two parts. The falling rate period represents the mass transfer mechanism in the material, which was controlled by the molecular diffusion. First falling rate period was continued till moisture content of mallow reach to approximately 50% of the initial mass which was longer than second falling rate period. It had been reported that the drying behavior of fruit and vegetables generally occurs in the falling rate period (Sharma *et al.*, 2001; Singh *et al.*, 2006). It was evident that the drying rate falls (sharply) at higher temperature compared to lower temperature. Drying rates for mallow is given in Appendix VI to IX. The drying rate was gradually decreased until complete loss of free moisture from the sample. The Figs. 4.9 and 4.10 showed a higher rate of moisture removal during hot air drying in cabinet and MSUCD, respectively. MSUCD dries the samples at comparatively higher rate than sun, shade and cabinet dryer at the same temperature due to uniform parallel flow of hot air through the trays of the drying chamber. On the other hand, the drying rate was comparatively too low in sun and shade drying method over cabinet and MSUCD due their dependency on environmental temperature (Kalathur *et al.*, 2009; Saxena *et al.*, 2015**)**. All the drying rate curves were not showed uniform smooth drying rate which may be due interrupted weather conditions, failure of electricity supply or mishandling of samples during drying of sample. This behavior is consistent with previously published literature on the drying of onion slices, green beans, potato and peas, okra, and chestnut, garlic cloves and carrot slices (Prabhajan *et al.*, 1995; Sharma *et al.*, 2001; Singh *et al.*, 2006). The reduction in drying time could lead to produce quality dried products and save energy during processing.

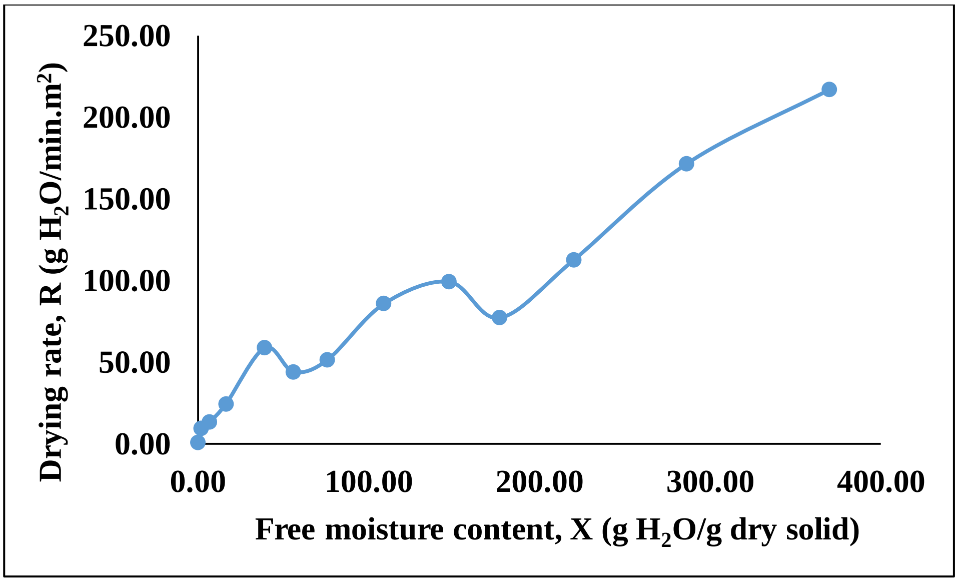


Fig 4.7: Drying characteristics of *M. verticillata* in Sun drying

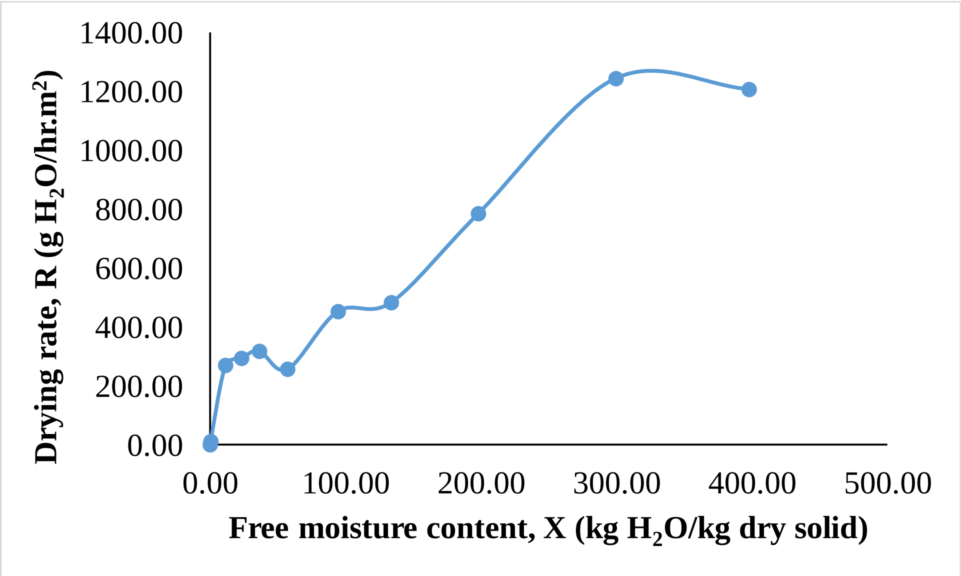


Fig 4.8: Drying characteristics of *M. verticillata* in Shade drying

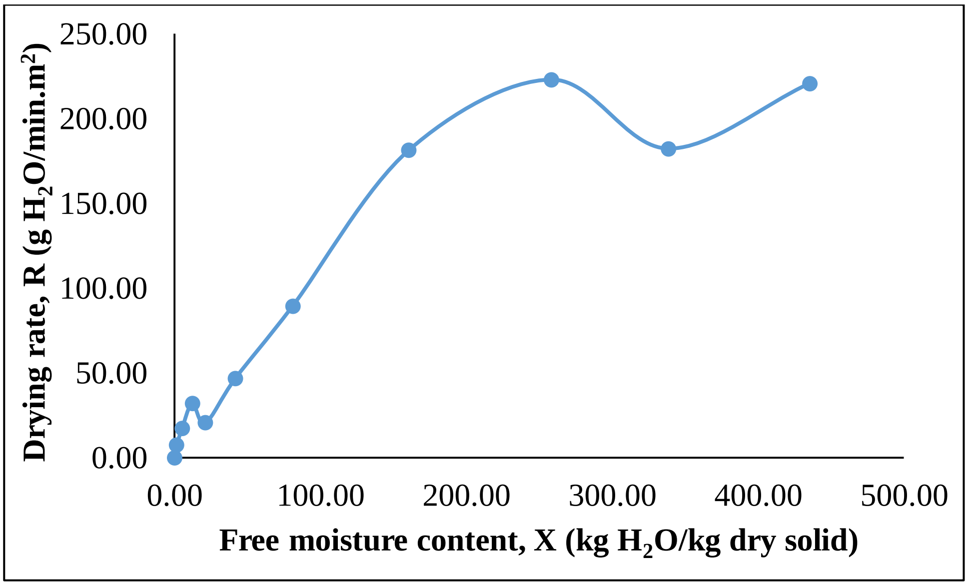


Fig 4.9: Drying characteristics of *M. verticillata* in Cabinet dryer

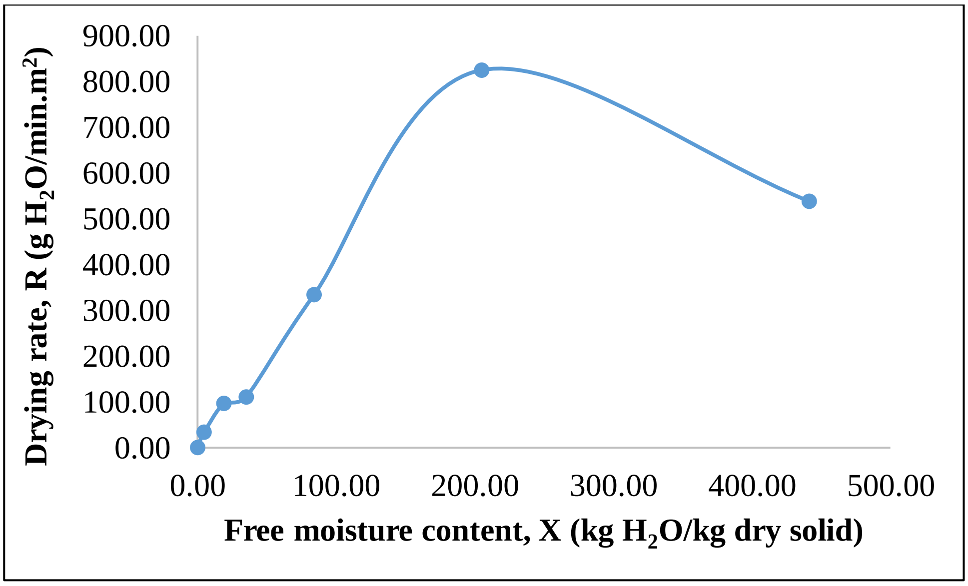


Fig 4.10: Drying characteristics of *M. verticillata* in Multi-Storied Universal Cabinet dryer

4.5 Effect of Drying Methods and Storage Period on Functional, Antioxidant and Sensory Properties of *M. verticillata* Powder

Effect of drying methods and storage period on functional properties of *M. verticillata* powder is explained in section 4.5.1 while antioxidant characteristics of mallow powder is presented in section 4.5.2. Similarly, sensory qualities of the powder are presented in section 4.5.3.

4.5.1 Effect of drying methods and storage period on physical properties of *M. verticillata* powder

Effect of drying methods and storage period on functional characteristics of mallow powder are presented in section 4.5.1.1 to 4.5.1.3.

4.5.1.1 Moisture content, bulk density and apparent density characteristics of *M. verticillata* powder

As can be seen in Table 4.4 that the final moisture content of the mallow powder prepared was ranged from 3.73 - 6.18 % (db). The cabinet and MSUC drying method resulted in lowest final moisture content (3.21-3.38 % db) of mallow powder than the others (sun and shade). Moreover, the significant difference ($P < 0.05$) in moisture content and bulk density was observed among the *M. verticillata* (mallow) powder obtained by different drying methods and during storage periods (Table 4.4). Such results may be due to the fact that the blanching treatment helps to accelerate the overall drying process by softening the texture of the leaves cell, which makes the water removal process easier. Results revealed that the moisture content of mallow powder was increasing gradually with the advancement of the storage time (Table 4.4). This results may be due to moisture absorption during experimental work, hygroscopic nature of the sample, poor sealing in package and so on. Several studies reported similar results for moisture content of different dried green leafy vegetables during storage (Singh *et al.*, 2010; Sengkhamparn *et al.*, 2013).

Table 4.4: Effects of drying methods and storage periods on the moisture content of *M. verticilata* powder.

Drying Methods	Moisture content at different storage seriod (Days)			
	0	30	60	90
Sun	$^{C}3.17 \pm 0.003^{d}$	$^{B}4.51 \pm 0.03^{c}$	$^{B}6.14 \pm 0.04^{b}$	$^{B}7.24 \pm 0.044^{a}$
Shade	$^{A}3.51 \pm 0.017^{d}$	$^{A}4.64 \pm 0.04^{c}$	$^{A}6.91 \pm 0.39^{b}$	$^{A}8.22 \pm 0.067^{a}$
Cabinet	$^{C}3.21 \pm 0.018^{d}$	$^{C}4.14 \pm 0.02^{c}$	$^{C}5.05 \pm 0.02^{b}$	$^{C}5.51 \pm 0.026^{a}$
MSUCD	$^{B}3.38 \pm 0.026^{d}$	$^{D}3.42 \pm 0.03^{c}$	$^{D}4.20 \pm 0.06^{b}$	$^{D}5.08 \pm 0.019^{a}$

Values are Mean ± Standard Error of the Mean (Mean ± SEM)
$^{A\text{-}D}$Different uppercase letters in the same column were differ significant ($P < 0.05$) with drying methods
$^{a\text{-}d}$Different lowercase letters in the same row were differ significant ($P < 0.05$) with storage periods.

The present study reported that bulk density of mallow powder ranged from 402.00 to 432.47 kg/m^3 (Table 4.5). The highest bulk density was shown in powder dried by MSUCD whereas it was found to be the lowest in sun dried sample. This variation in the bulk density might be due to the breakdown of the cell walls and formation of compact structure, the collapse and shrinkage of the product, the decrease in the inter-particle voids of smaller sized particles with a larger contact surface areas per unit volume and so on for mallow (napa shakh) powder at high temperature (Kalathur *et al.,* 2009; Adejumo *et al.,* 2013; Ankita *et al.,* 2015). Similar observation was reported for bulk density of ginger powder at different particle sizes (Xiaoyan, 2008). Besides, the bulk density of mallow powder was increasing during storage period probably due to the fact that the powder water activity reached equilibrium with the relative humidity (RH) inside the packages (Alessandra *et al.,* 2004). The apparent differences in bulk density of mallow powder would be due to hygroscopic nature, poor material handling, poor sealing in the package, drying method, temperature, particle size, percentage loss of dietary fiber and final moisture content (Amid, 2013).

Table 4.5: Effects of drying methods and storage periods on the bulk density (kg/m^3) of *M. verticillata* powder.

Drying Methods	Bulk density at different storage period (Days)			
	0	30	60	90
Sun	^{C}402.00 ± 0.24^{a}	^{C}396.78 ± 0.52^{b}	^{C}389.38 ± 0.09^{c}	^{C}381.62 ± 0.37^{d}
Shade	^{D}240.58 ± 0.44^{a}	^{D}227.65 ± 0.28^{b}	^{D}218.66 ± 0.08^{c}	^{D}211.33 ± 0.06^{d}
Cabinet	^{B}412.00 ± 0.24^{a}	^{B}407.45 ± 0.20^{b}	^{B}399.33 ± 0.19^{c}	^{B}395.29 ± 0.104^{d}
MSUCD	^{A}432.47 ± 0.62^{a}	^{A}428.20 ± 0.46^{b}	^{A}422.75 ± 0.60^{c}	^{A}418.55 ± 0.45^{d}

Values are Mean ± Standard Error of the Mean (Mean ± SEM)
$^{A-D}$Different uppercase letters in the same column were differ significant (P < 0.05) with drying methods
$^{a-d}$Different lowercase letters in the same row were differ significant (P < 0.05) with storage periods.

The apparent density of mallow powder was found to be ranged from 253.25 to 501.73 kg/m^3 (Table 4.6). The result implies that the apparent density was decreasing with increasing storage period of the powder. Higher apparent density was shown in MSUCD dried mallow powder, whereas the lowest was seen in shade dried sample. The reason behind this change could be due to the breakdown of cell walls and development of compact structure of powdered sample (Adejumo *et al.,* 2013; Ankita *et al.,* 2015). Besides, the apparent density of mallow powder was observed to be increased during storage period, probably due to the fact that the powder water activity reached equilibrium with the relative humidity (RH) inside the packages (Alessandra *et al.*, 2004). The apparent differences at the determined values as in powder of mallow would be due to due to hygroscopic nature, poor material handling, poor sealing in the package, drying method, temperature, particle size, percentage loss of dietary fiber and final moisture content (Amid, 2013).

Table 4.6: Effects of drying methods and storage periods on the apparent density (kg/m^3) of *M. verticillata* powder

Drying Methods	Apparent density at different storage period (Days)			
	0	30	60	90
Sun	$^{D}432.00 \pm 0.003^{a}$	$^{B}416.78 \pm 0.52^{b}$	$^{B}406.38 \pm 0.52^{c}$	$^{B}399.62 \pm 0.37^{d}$
Shade	$^{B}253.25 \pm 0.25^{a}$	$^{D}232.81 \pm 0.06^{b}$	$^{D}222.83 \pm 0.03^{c}$	$^{D}214.66 \pm 0.105^{d}$
Cabinet	$^{C}418.22 \pm 0.018^{a}$	$^{C}411.33 \pm 0.11^{b}$	$^{C}402.45 \pm 0.20^{c}$	$^{C}396.83 \pm 0.054^{d}$
MSUCD	$^{A}501.73 \pm 0.49^{a}$	$^{A}488.21 \pm 0.45^{b}$	$^{A}472.75 \pm 0.60^{c}$	$^{A}458.55 \pm 0.450^{d}$

'Values are Mean ± Standard Error of the Mean (Mean ± SEM)
$^{A-D}$Different uppercase letters in the same column were differ significant (P < 0.05) with drying methods
$^{a-d}$Different lowercase letters in the same row were differ significant (P < 0.05) with storage periods.

4.5.1.2 Porosity and angle of repose characteristics of *M. verticillata* powder

The experimental results showed that the porosity of mallow powder was 0.01 to 0.14 and found to differ significantly (p<0.05) with the drying methods (Table 4.7). Sun and shade dried mallow powders had significantly lower porosity compared to cabinet and MSUCD dried products (P ≤ 0.05). Sun dried mallow powder exhibited low porosity compared to MSUCD dried mallow powder but significantly higher than shade and cabinet dried powder (P ≤ 0.05). The high temperature used in MSUC drying may have caused collapse cell which resulted in more compact and rigid product. These characteristics resulted in lower porosity when compared to other method dried mallow powder. This results could be due to the decrease in the inter-particle voids of smaller sized particles with larger contact surface areas per unit volume for mallow (napa shakh) powder. Similar observation was reported for porosity of ginger powder at different particle sizes (Xiaoyan, 2008). In effect, the collapse and shrinkage of the product is prevented thereby resulting in a porous dried material (Karel, 1975; Eren *et al.*, 2007). Khalloufi *et al.* (2009) stated that the porosity as a function of moisture content, it decreases with the increase in storage period. The apparent differences at the determined porosity values as in the powder would be due to the differences in variety, the drying technology and the processing conditions such as temperature, pressure, humidity, transportation, mechanical and textural problems and air speed (Chen, 2008).

Table 4.7: Effects of drying methods and storage periods on the porosity of *M. verticillata* powder.

Drying Methods	Porosity at different storage period (Days)			
	0	30	60	90
Sun	$^{B}0.069 \pm 0.0003^{a}$	$^{B}0.048 \pm 0.0000^{b}$	$^{B}0.041 \pm 0.0014^{c}$	$^{B}0.043 \pm 0.0000^{d}$
Shade	$^{C}0.050 \pm 0.0030^{a}$	$^{C}0.022 \pm 0.0003^{b}$	$^{C}0.018 \pm 0.0003^{c}$	$^{C}0.0157 \pm 0.0003^{d}$
Cabinet	$^{D}0.015 \pm 0.0008^{a}$	$^{D}0.009 \pm 0.0003^{b}$	$^{D}0.008 \pm 0.0003^{c}$	$^{D}0.0037 \pm 0.0020^{d}$
MSUCD	$^{A}0.138 \pm 0.0150^{a}$	$^{A}0.123 \pm 0.0000^{b}$	$^{A}0.107 \pm 0.0000^{c}$	$^{A}0.0870 \pm 0.0000^{d}$

Values are Mean ± Standard Error of the Mean (Mean ± SEM)
$^{A-D}$Different uppercase letters in the same column were differ significant ($P < 0.05$) with drying methods
$^{a-d}$Different lowercase letters in the same row were differ significant ($P < 0.05$) with storage periods.

The value of the angle of repose of mallow powder were ranged from 28.75 to 55.58^{o} (Table 4.8). However, the excellent results of angle of repose was found in cabinet and MSUCD dried powder, which were dried at 50 °C. The higher value of angle of repose was found in shade dried mallow powder, whereas the lowest was in cabinet drier. The compact structure with less frictional force contributes to the better angle of repose of the samples. Hamed *et al.* (2013) and Nep *et al.* (2011) reported that high temperature dying methods provides the higher value of angle of repose and they observed that the durian fruit seed and grewia powder angle of repose were 30.83^{o} and 42.22^{o}, respectively. The variation in the angle of repose of powder can be due to various reasons e.g., moisture content, pretreatment, particle size and bulk density (Hamzah *et al.*, 2018). The experimental value of angle of repose was found to be similar to papaya leaves (Ankita *et al*., 2015), spinach powder (Ankita *et al*., 2013) and other green leafy vegetable powder (Singh *et al*., 2013). Results also showed that the angle of repose was decreasing with increasing storage period of mallow powder which may be due to increases of surface area for particle, size reduction and absorption of water held by fibers, but when particle size is too small, its net structure is disrupted and the centrifugal force will be weak, and so will increase the water imbibing properties (Zhiqing, 2007).

Table 4.8: Effects of drying methods and storage periods on the angle of repose (^{0}) of *M. verticillata* powder.

Drying Methods	Angle of repose at different storage period (Days)			
	0	30	60	90
Sun	^{B}51.50 ± 0.11^d	^{B}53.32 ± 0.10^c	^{B}55.33 ± 0.03^b	^{B}57.34 ± 0.13^a
Shade	^{D}28.75 ± 0.36^d	^{D}32.28 ± 0.37^c	^{D}34.67 ± 0.28^b	^{D}37.25 ± 0.32^a
Cabinet	^{A}55.58 ± 0.19^d	^{A}57.70 ± 0.08^c	^{A}59.91 ± 0.03^b	^{A}61.51 ± 0.16^a
MSUCD	^{C}45.30 ± 0.09^d	^{C}47.58 ± 0.09^c	^{C}49.69 ± 0.07^b	^{C}52.38 ± 0.16^a

Values are Mean ± Standard Error of the Mean (Mean ± SEM)
$^{A-D}$Different uppercase letters in the same column were differ significant (P < 0.05) with drying methods
$^{a-d}$Different lowercase letters in the same row were differ significant (P < 0.05) with storage periods.

4.5.1.3 Water absorption index (WAI), Water solubility index (WSI) and Oil absorption index (OAI) characteristics of *M. verticillata* powder

As shown in Table 4.9, the water absorption index of mallow powder ranged from 1.46 to 1.63, which varied significantly with drying methods used and with the extension of storage periods. The higher value of the water absorption index was shown in MSUCD dried mallow powder, whereas the lowest was shown in sun dried sample. Such results may be due use of high temperature drying by MSUCD, which results in production of porous smaller particle sized mallow powder than sun dried one. This result was well corroborated with the findings of Sogi *et al.* (2013) for mango by-product powder. Results also showed that the water absorption index was decreasing with increasing storage period of mallow powder, which could be due to increases of absorption of water held by fibers, weakening of the centrifugal force, and so will increase the water imbibing properties (Zhiqing, 2007).

Table 4.9: Effects of drying methods and storage periods on the water absorption index of *M. verticillata* powder

Drying Methods	Water absorption index at different Storage Period (Days)			
	0	30	60	90
Sun	^{C}1.46 ± 0.002^a	^{B}1.39 ± 0.003^b	^{D}1.32 ± 0.001^c	^{C}1.29 ± 0.002^d
Shade	^{A}1.63 ± 0.003^a	^{A}1.59 ± 0.002^b	^{B}1.51 ± 0.002^c	^{A}1.49 ± 0.002^d
Cabinet	^{B}1.48 ± 0.001^a	^{B}1.39 ± 0.009^b	^{C}1.39 ± 0.005^c	^{B}1.30 ± 0.001^d
MSUCD	^{A}1.63 ± 0.002^a	^{A}1.59 ± 0.002^b	^{A}1.53 ± 0.001^c	^{A}1.49 ± 0.003^d

Values are Mean ± Standard Error of the Mean (Mean ± SEM)
$^{A-D}$Different uppercase letters in the same column were differ significant (P < 0.05) with drying methods
$^{a-d}$Different lowercase letters in the same row were differ significant (P < 0.05) with storage periods.

In this study, the water solubility index of mallow powder decreased with the increase in storage period, and also found to be varied significantly (P <0.05) with the drying methods. Table 4.10 represents that, the water solubility index of mallow powder ranged from 19.97 to 29.10%. The higher value of WSI was shown in MSUCD dried powder, whereas the lowest was observed in shade dried sample. The variation may be due to the use of favorable drying temperatures MSUCD (50^{o}C), which could safeguards the water binding sites and resulted in the increasing of WAI and WSI of mallow powder (Roongruangsri, 2016). In general, drying and heating can modify the physical properties of the fiber matrix that alter the fiber's hydration properties (Bejar *et al.*, 2011). On the other hand, the values of WSI of mallow powder were decreased with the extension of storage time. One possible reason for the lower solubility of those samples can be that the cell structure of mallow was not disrupted and smaller amounts of solids were dissolved to become part of the supernatant. Moreover, the phenomenon of decreasing WSI and WAI may be due to the damage of the fiber matrix and the collapse of the pore during grinding, Maillard reaction and so on (Lorenzen, 2010; Vissotto *et al.*, 2010). In addition, processing conditions, composition, particle size, density, pH and storage conditions can also contribute to the change in WAI and WSI of dried powder (Amid, 2013; Ankita *et al.*, 2013).

Table 4.10: Effects of drying methods and storage periods on water solubility index (%) of *M. verticillata* powder

Drying Methods	Water solubility index at different storage period (Days)			
	0	30	60	90
Sun	^{C}25.35 ± 0.12^{a}	^{C}24.39 ± 0.02^{b}	^{C}23.79 ± 0.02^{c}	^{C}23.16 ± 0.03^{d}
Shade	^{D}19.97 ± 0.24^{a}	^{D}18.78 ± 0.05^{b}	^{D}17.55 ± 0.02^{c}	^{D}17.10 ± 0.05^{d}
Cabinet	^{B}26.80 ± 0.16^{a}	^{B}26.17 ± 0.03^{b}	^{B}25.74 ± 0.03^{c}	^{B}25.42 ± 0.25^{d}
MSUCD	^{A}29.55 ± 0.02^{a}	^{A}29.10 ± 0.04^{b}	^{A}28.70 ± 0.02^{c}	^{A}28.08 ± 0.04^{d}

Values are Mean ± Standard Error of the Mean (Mean ± SEM)
$^{A-D}$Different uppercase letters in the same column were differ significant (P < 0.05) with drying methods
$^{a-d}$Different lowercase letters in the same row were differ significant (P < 0.05) with storage periods.

The oil absorption index (OAI) of mallow powder ranged from 1.23 and 1.67 (Table 4.11). The OAI was found to be significantly (p<0.05) highest in the mallow powder dried in MSUCD, whereas this value was lowest in cabinet dried sample. The possible reason of lower value of OAI in cabinet dried mallow powder may be due prolong drying period which may causes disruption oil binding site of particle of the powder. This range is well corroborated by the findings of Sogi *et al.*, (2013) reported for waste mango peel powders. Again, storage period was found to have a significant effect on the OAI, since it was decreased with the increasing in storage period. It was previously reported that increased drying temperature has direct effect on the OAI of vegetable powders, which resulted in decreases of the oil adsorption index (Roongruangsri, 2016). The OAI of fruits and vegetables has significant implications on the bakery products and other food applications because it can impart on water-retention and fat-binding properties (Traynham *et al*., 2007). Several factors can affect the OAI including drying methods and conditions applied and fiber content of powder (Garau *et al*., 2007).

Table 4.11: Effects of drying methods and storage periods on oil absorption index of *M. verticillata* powder

Drying Methods	Oil absorption index at different Storage Period (Days)			
	0	30	60	90
Sun	$^{C}1.37 \pm 0.008^{a}$	$^{C}1.29 \pm 0.001^{b}$	$^{C}1.17 \pm 0.004^{c}$	$^{C}1.05 \pm 0.020^{d}$
Shade	$^{A}1.77 \pm 0.002^{a}$	$^{A}1.67 \pm 0.03^{b}$	$^{A}1.56 \pm 0.002^{c}$	$^{A}1.43 \pm 0.003^{d}$
Cabinet	$^{D}1.23 \pm 0.003^{a}$	$^{D}1.18 \pm 0.002^{b}$	$^{D}1.03 \pm 0.001^{c}$	$^{D}0.83 \pm 0.13^{d}$
MSUCD	$^{B}1.67 \pm 0.002^{a}$	$^{B}1.59 \pm 0.03^{b}$	$^{B}1.50 \pm 0.002^{c}$	$^{B}1.38 \pm 0.004^{d}$

Values are Mean ± Standard Error of the Mean (Mean ± SEM)
$^{A-D}$Different uppercase letters in the same column were differ significant ($P < 0.05$) with drying methods
$^{a-d}$Different lowercase letters in the same row were differ significant ($P < 0.05$) with storage periods.

4.5.2 Effect of drying methods and storage period on antioxidant characteristics of *M. verticillata* powder

Effect of drying methods and storage period on antioxidant characteristics of *M. verticillata* powder is presented in section 4.5.2.1 to 4.5.2.4.

4.5.2.1 Chlorophyll Characteristics of *M. verticillata* powder dried by different drying methods

Chlorophyll content of dried mallow powder is presented in Figure 4.11. It observed that the significantly highest amount of chlorophyll (chlorophyll a of 11.65 mg/100g and chlorophyll b of 15.76 mg/100g) was retained in powder obtained by MSUCD whereas these values become lower in shade dried powder (chlorophyll a of 7.67 mg/100g and chlorophyll b of 9.61 mg/100g). It was also seen in Figure 4.11 that the degradation of chlorophyll pigments in mallow powder was found to be increased with the increasing storage time. It is well argued by the scientists and previous literatures that pigment degradation can be occurred due to the action of heat, reactions of food components such as oxidation of phenolic compounds, food enzymes, storage conditions used, pretreatment and also drying time (Arslan, 2012; Rahimmalek, 2013; Kidmose *et al.*, 2005; Komes, 2010; Sahar *et al.*, 2016). The MSUCD retains more chlorophyll content may be due to multiple factors, such as uniform air throughout all trays in the dying chamber, lesser scope of oxidation for shorter drying time, higher moisture diffusion rate and so on which were stated in the previous section 3.2.1.

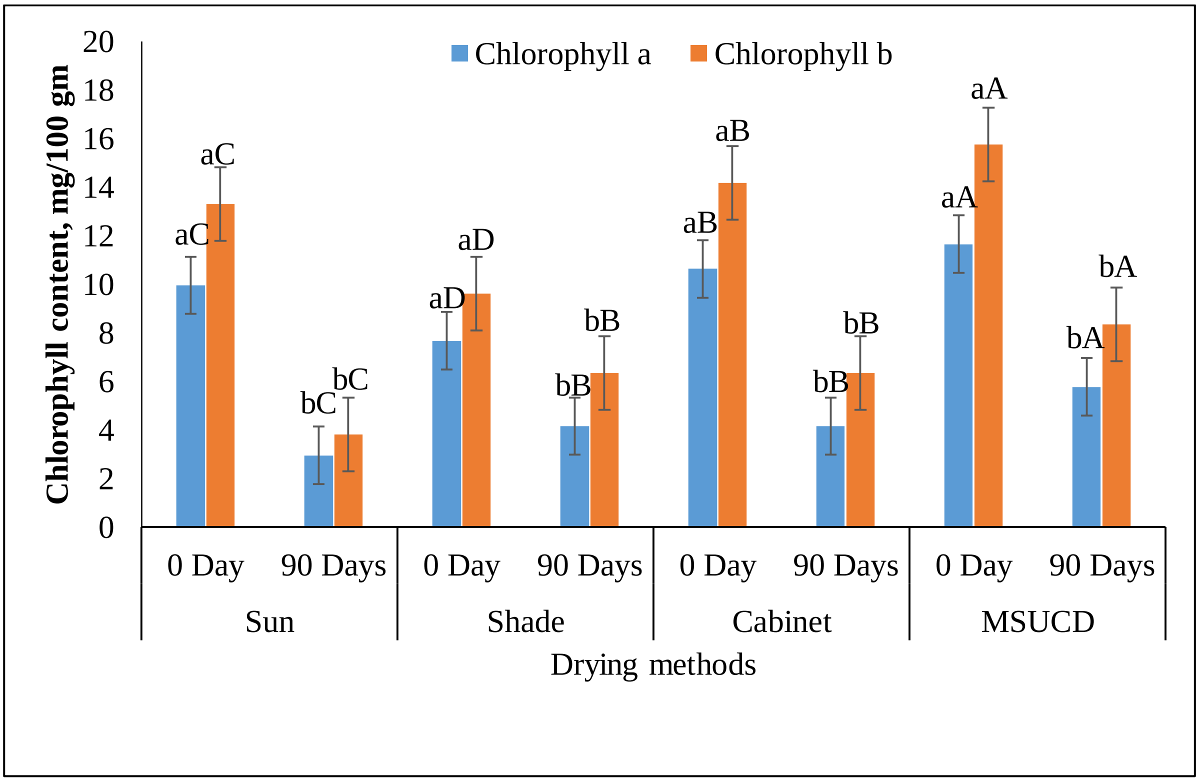


Fig 4.11: Comparison on Chlorophyll content (mg/100 g) of dried *M. verticillata* in different drying methods during storage ([A-D]Different uppercase letters in each bar were differ significant ($P < 0.05$) with drying methods; [a-b]Different lowercase letters in each bar were differ significant ($P < 0.05$) with storage periods)

4.5.2.2 Vitamin C characteristics of *M. verticillata* powder

According to Figure 4.12, the mallow powder has retained considerable amounts of ascorbic acid ranging between 6.69 to 9.92 mg/100g. The highest amount of vitamin C was obtained from the cabinet dried (9.92 mg/100g DW) powder and the lowest was obtained in shade dried powder (6.69 mg/100g DW). Guine *et al.*, (2015) claimed that the lower drying temperature and prolonged drying time had a less damaging effect on vitamin C content. However, vitamin C is heat sensitive and prolonged exposure to higher temperature will destroy the compounds (Bruno *et al.*, 2017). In relation to preservation of the antioxidant capacity of dehydrated vegetables, a negative correlation between ascorbic acid and antioxidant activity was observed. Similar decline in ascorbic acid content was noticed in other studies in potato, pulses, muskmelon, cauliflower, and onion (Abadio *et al.*, 2004; Goula *et al.*, 2004; Patil, 2014). During storage, the ascorbic acid was found to be decreased and value was 2.48 –3.53 mg/100g. This value confirmed the negative effect of high temperatures and storage on ascorbic acid (Alessandra *et al.*, 2004). The variations in vitamin C content in mallow vegetable may be due to multiple factors, such as maturity of mallow leaves, drying methods and temperatures, drying times, freezing and thawing methods etc. (Vega *et al.*,2009; Goula *et al.*, 2010; Gupta *et al.*,2013; Garba *et al.*,2014; Jin *et al.*,2014; Sahar *et al.*,2016).

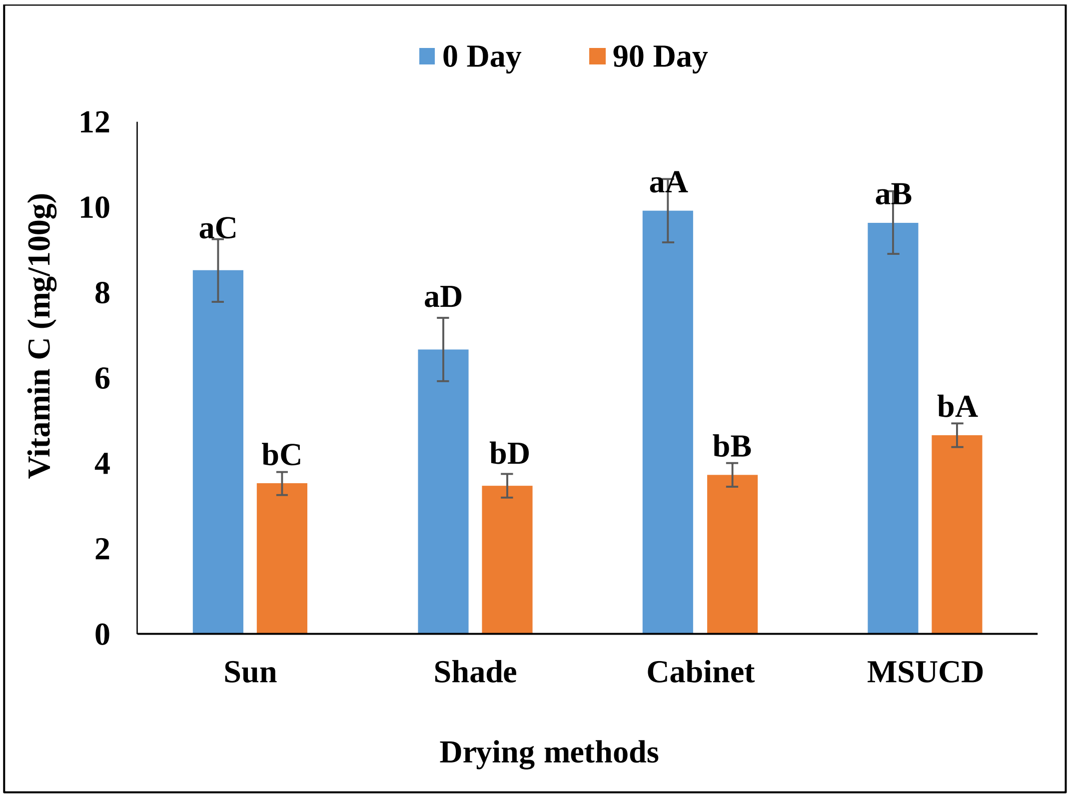


Fig 4.12: Comparison on Vitamin C content (mg/100 g) of dried *M. verticillata* in different drying methods during storage ([A-D]Different uppercase letters in each bar were differ significant ($P < 0.05$) with drying methods; [a-b]Different lowercase letters in each bar were differ significant ($P < 0.05$) with storage periods)

4.5.2.3 Total phenolic and flavonoid content of *M. verticillata* powder

According to Figure 4.13, it is shown that the highest phenolic content was shown in MSUCD dried mallow powder (15.71 mg GAE / g DW) whereas the lowest phenolic content was shown in shade dried sample (10.71 mg GAE /g DW). In both the cabinet and MSUCD dried mallow powder have higher amounts of phenolic compounds than in the sun and shade dried powder. The cabinet drying method compared to the sun drying method could have protected the phenolic content against prolonged oxidative degradation. On the other hand, the amount of TPC decreased with the increasing in storage period at room temperature. This could be due to increase in moisture content, which might have released the bound phenols from the cell wall during storage (Quek *et al.*, 2007). Drastic decreases in the phenolic compounds of mallow powder could be due to the polyphenol binding with other compounds (Caro *et al.*, 2004), alterations in their chemical structure (Montsko *et al.*, 2008), activity of polyphenol oxidase (Garg, 2012), organic acid content (Figueiredo *et al.*, 2013), sugar content, product pH, thermal degradation and/or oxidation (Ahmed *et al.*, 2014), UV radiation, genotypic, nature of the substrate (Guine *et al.*, 2015), sample thickness, storage period and conditions prior to analysis, extraction method, leaching during pre-treatment, extraction procedures, methods of analysis (Adiletta *et al.*, 2016) and so on. A similar report was previously obtained for apple cubes (Wojdyło *et al.* 2007), carrot peel and lime residue (Kuljarachanan *et al.*, 2009), green tea (Sahar *et al.*, 2016) and in papaya leaf (Raja *et al.*, 2017).

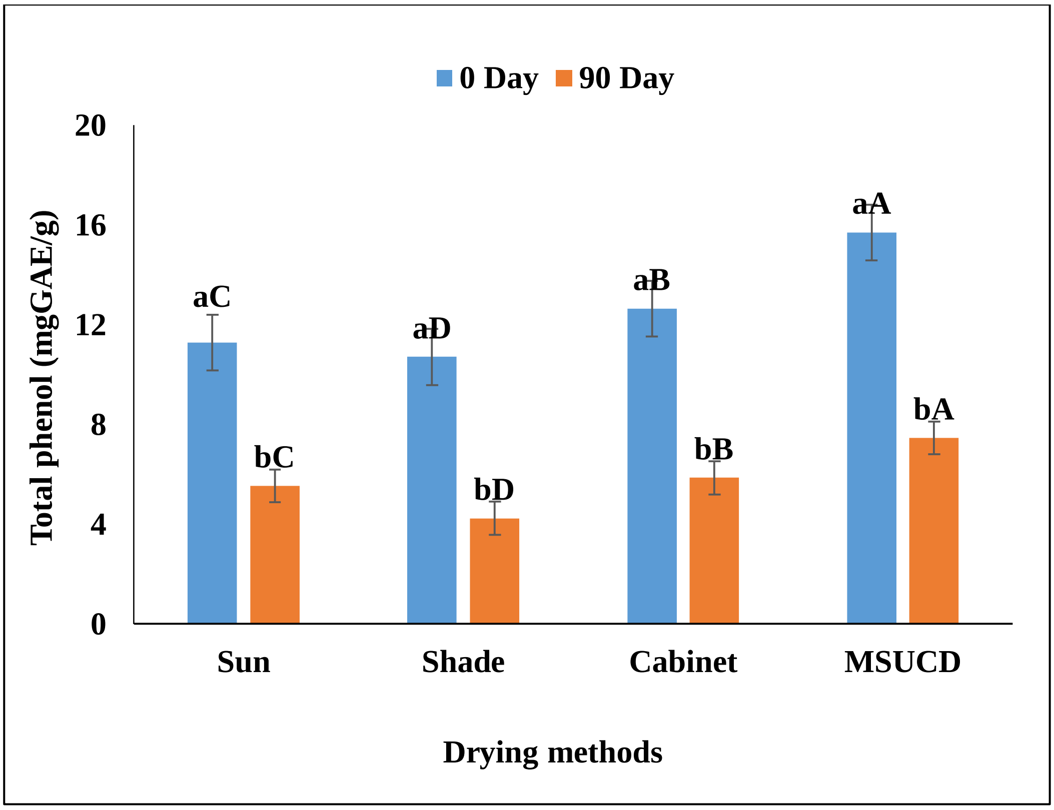


Fig 4.13: Comparison on Total Phenol Content (mg/ g) of Dried *M. verticillata* in different drying methods during storage ([A-D]Different uppercase letters in each bar were differ significant (P < 0.05) with drying methods; [a-b]Different lowercase letters in each bar were differ significant (P < 0.05) with storage periods)

The flavonoid content of mallow powder ranges from 10.73 to 15.71 mg QE/g DW (Figure 4.14). The highest flavonoid content was found in cabinet dried powder (15.71 mg Quercitin/g DW) whereas the lowest in shade dried powder (10.73 mg Quercitin/g DW). Moreover, during storage the flavonoid content of mallow powder can increase or decrease depending on the drying conditions. According to research on senescence of mallow leaves during short-time storage, stress storage conditions (20 °C, open air) enhance mallow tissue defense mechanisms producing radical scavenging compounds. These differences could be caused either by genotypic factors or by the storage period and conditions prior to analysis. From Fig. 4.14 it can be seen that the total flavonoids content in mallow powder significantly decreased with the advancement of storage time. The degradation of flavonoids during storage might be due to the enzymatic and non-enzymatic reaction. It is evidenced that different enzymes e.g. glycosidase, polyphenol oxidase and peroxidase are responsible for the degradation of flavonoids (Odriozola *et al.*, 2009; Terefe *et al.*, 2009). Other factors which have strong influence on the quantity of TFC in vegetable powders are duration of drying, drying air conditions (temperature and relative humidity) and so on (Sikora *et al.*, 2008; Rakesh, 2014; Lou *et al.*, 2015).

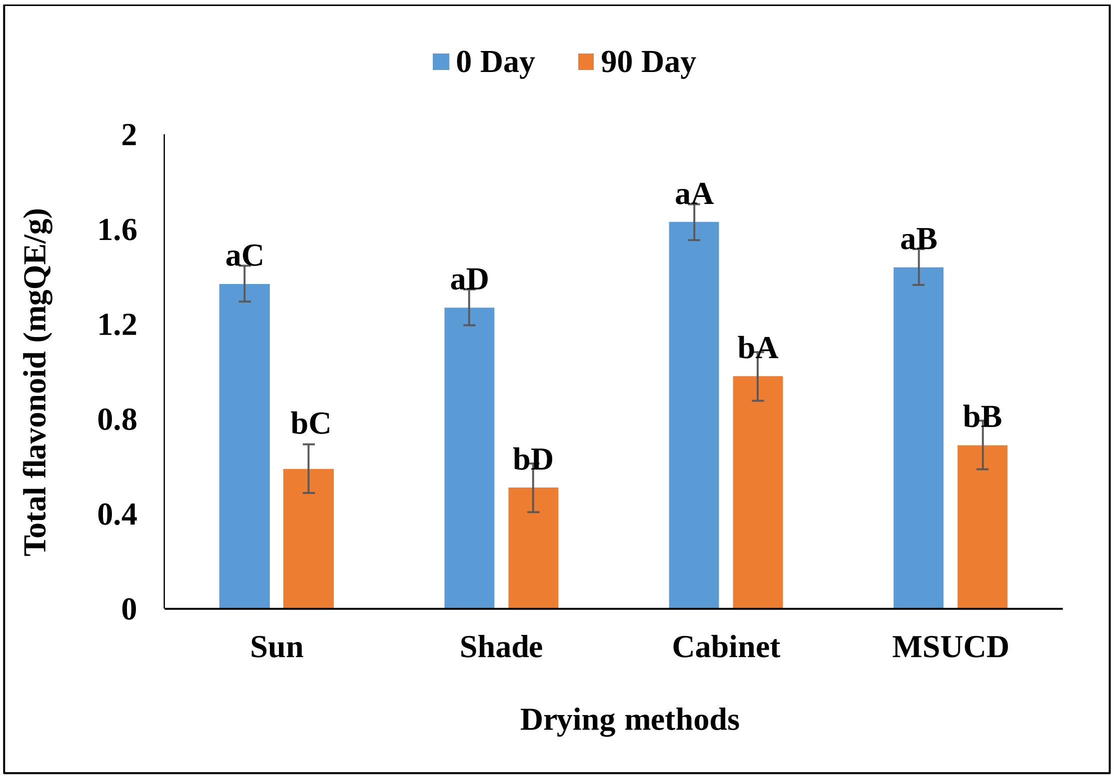


Fig 4.14: Comparison on Total Flavonoid Content (mg/ g) of Dried *M. verticillata* in different drying methods during storage ($^{A-D}$Different uppercase letters in each bar were differ significant (P < 0.05) with drying methods; $^{a-b}$Different lowercase letters in each bar were differ significant (P < 0.05) with storage periods)

4.5.2.4 DPPH assay of *M. verticillata* powder

The results revealed that a significant ($p < 0.05$) difference exists among the values of DPPH of mallow powder dried by different drying method (Figure 4.15). The DPPH radical scavenging of mallow powder were ranged from 4.94 to 8.82 mg TEAC/g DW (Figure 4.15). On the other hand, the DPPH activity was found to decrease with the increasing in storage time. Around 10 mg TEAC/g at 90 days was found in MSUCD dried powder (Figure 4.15). Similar results for dried green leafy vegetables during storage has been reported in several studies (Oliveira *et al.*, 2012; Lee *et al.*, 2013). It is reported that drying temperature and flavonoids content might contribute to the change in antioxidant activity (Lee *et al.*, 2013; Lou *et al.*, 2015). Since TPC and vitamin C contents was decreased with the increasing storage time, so this phenomenon supports the degradation of DPPH radical scavenging activity of mallow powder. Moreover, Vlatka *et al.* (2015) reported that being secondary metabolites phenolics groups may be broken down or synthesized in new components which may or may not be having DPPH free radical scavenging activity.

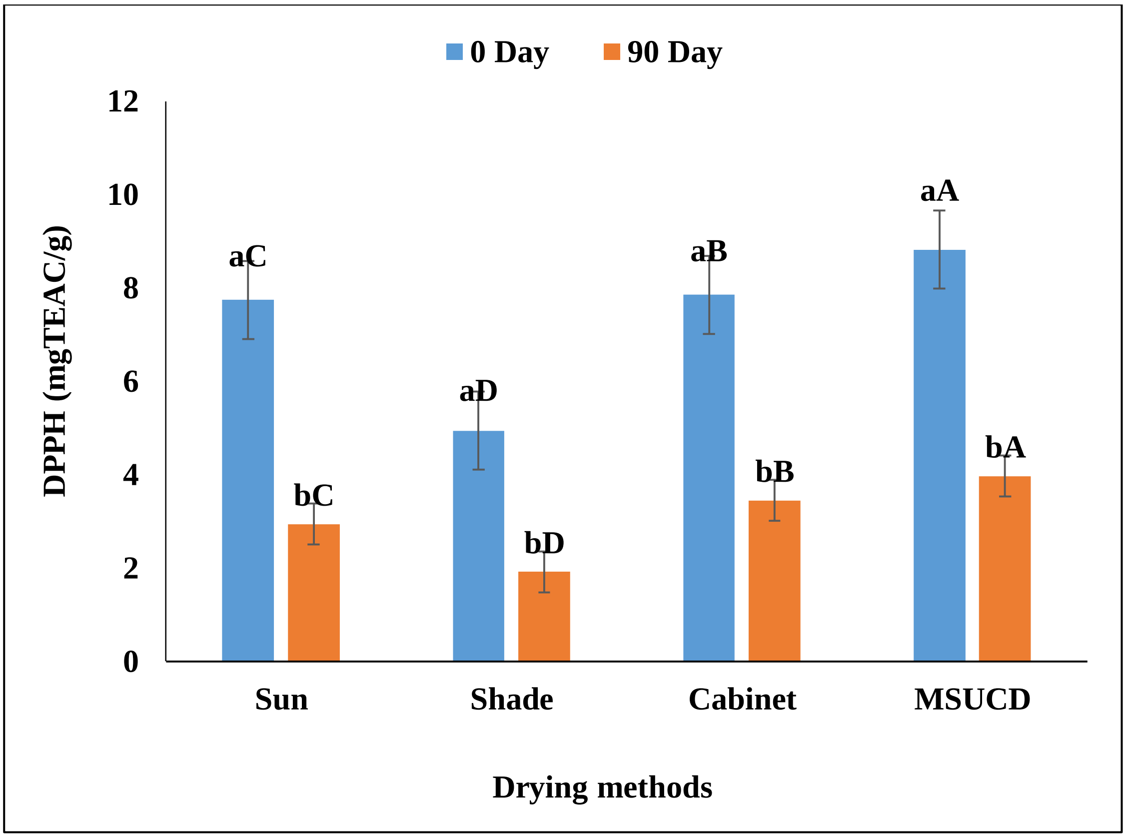


Fig 4.15: Comparison on DPPH assay (mg TAE/g) of dried *M. verticillata* in different drying methods during storage ([A-D]Different uppercase letters in each bar were differ significant ($P < 0.05$) with drying methods; [a-b]Different lowercase letters in each bar were differ significant ($P < 0.05$) with storage periods)

4.5.3 Effect of drying methods and storage period on sensory properties of *M. verticillata* powder

Figure 4.16 shows that MSUCD is most suitable for retaining sensory properties of mallow over sun, shade or cabinet dried mallow. It is observed that the highest score for appearance of the powder was obtained in MSUCD (4.67) and lowest in shade dryer (3.33). Similarly, the highest score for color, odor, texture and wetness was also observed in MSUCD dried powder in comparison with other samples dried under sun, shade and cabinet drier. These values were found to change with the advancement of storage time and also with different drying methods. The changes in sensory properties during drying as well as with the elevation of storage time might be affected by various factors such as drying methods (Addis *et al.*,2009), enzymatic reactions (Kidmose *et al.*, 2005), packaging materials (Oluremi *et al.*,2007), chemicals and time need for pre-treatment (Ojha *et al.*,2016) etc. MSUCD dried powder achieved highest score in sensory evaluation due to better retention of color resulting from the natural pigment present in the green leafy vegetables (Magda *et al.*, 2008; Ojha *et al.*, 2016).

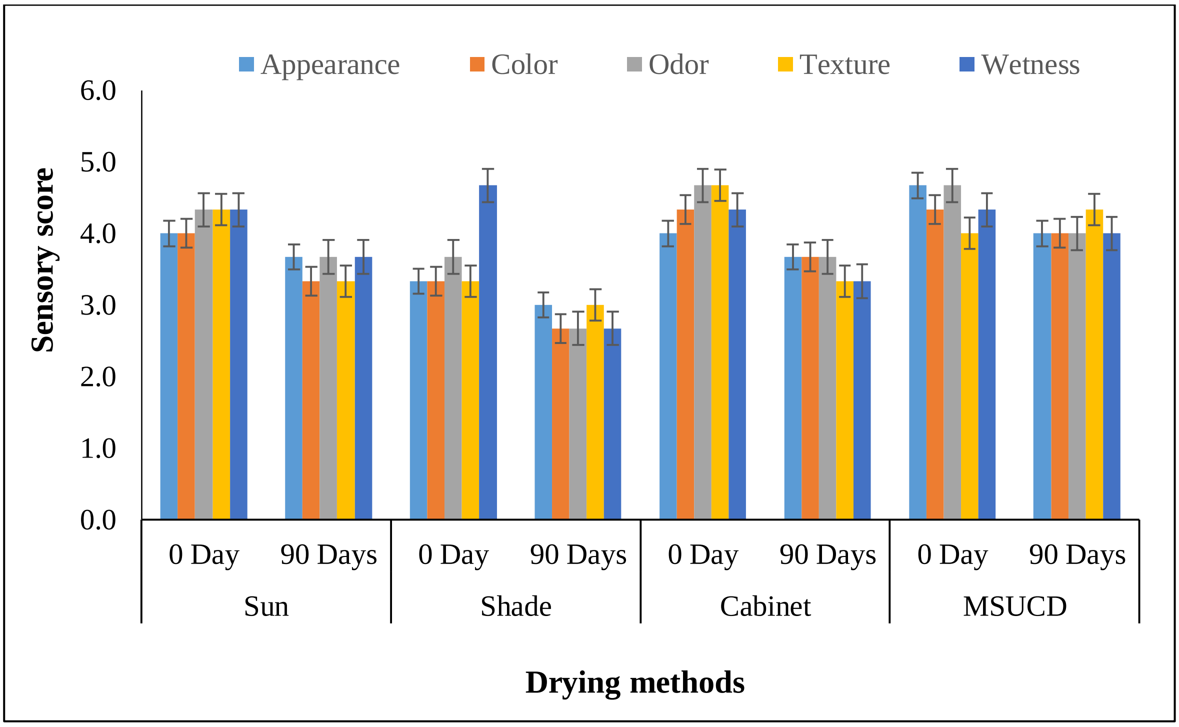


Fig 4.16: Comparison on Sensory Quality of Dried *M. verticillata* in different drying methods during storage.

CHAPTER V

SUMMARY AND CONCLUSIONS

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A laboratory scale multistoried universal cabinet dryer (MSUCD) was designed and developed, which was fabricated using locally available materials by local technicians. The dryer was found to be operated readily in drying of high moisture vegetables. Comparatively shorter drying time required for drying of leafy vegetable than tuber vegetable. The higher energy consumption and drying costs and lower thermal efficiency were observed in drying of tuber vegetables compared to leafy vegetables. Based on the performance, the dryer has some advantageous features such as simple design, affordable costs, convenient to transport, easy operation and installation, uniform air distribution in all shelves, superior drying performance and quality retention compared to cabinet dryer and traditional sun and shade drying system.

Further, the drying behavior and physio-functional and antioxidant quality of mallow (napa shakh) powder dried in MSUCD was compared with that of obtained from other three drying methods (sun, shade, and existing cabinet). Results revealed that drying time for drying of mallow leaves were 5 to 10 times shorter in MSUCD in contrast to other drying methods. The results exposed that drying operation at low temperature (50 °C) in MSUCD have many benefits in providing significantly higher retention of functional, antioxidant and sensory properties during storage of dried mallow powder over sun, and cabinet dried mallow powder. Additionally, MSUCD drying maintained higher amounts of TPC, TFC and antioxidant activity, while cabinet was less efficient to retain chlorophyll and vitamin C content of mallow powder.

Conclusively, the proposed MSUCD can be one of the most suitable dryer for drying of high moisture vegetables. However, this study paved the ways for design, development and fabrication of MSUCD to suit the small farm holding units in the country as well as large capacities for commercial scale production for quality dried vegetable products.

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APPENDICES

APPENDICES

Appendix I: Technical specification of MSUCD

Items/Parameters	Specifications
Overall dimension	68.58 cm x 40.39 cm x 73.66 cm
Drying chamber dimension	53.34 cm x 58.42 cm x 25.15 cm
Hot air section dimension	50.80 cm x 40.64 cm x 35.66 cm
Tray size	41.15 cm x 33.02 cm
Number of shelf	4 Nos
Holding capacity/Batch	Leafy vegetables: 2 – 3 kg and Tuber vegetables: 4 - 5 kg
Temperature range	50 – 85^{o}C
Air inlet duct	8 Nos
Air outlet duct	8 Nos
Air outlet gate	2 Nos
Blower motor	50 W, 2900 rpm

Appendix II: List of the Components needed for the Construction

S/NO	Parts	Quantity (Nos.)	Materials Used
1	Drying chamber, heating casing	4	Mild steel (18 gauge)
2	Miscellaneous items (nut, bolt etc.)	7 pairs	Cast iron
3	Perforated trays	4	Sheet metal (Aluminum)
4	Fan blades or fins	3	High density Plastic
5	Heat Exchanger coil	3	Standard
6	The Thermostat	1 set	Standard
7	Insulator	0.01 m thickness	Jute Sacks and rope, Cotton channel
8	Centrifugal fan	1	Standard
9	Dryer Door	1	Mild steel (18 gauge)
10	Handle of the Trays	4	Stainless steel
11	Air outlet gate	2	Mild steel (18 gauge)
12	Logging Materials	2 pairs	Cast iron
13	Tray holders	8	Mild steel (24 gauge)
14	Miniature Circuit Breaker (MCB)	4	Standard
15	Electric Cables	25 gauge	Copper (7 and 10 RM)
16	Thermocouple	1	Standard
17	Temperature Meter	1	Standard
18	Miscellaneous items (nut, bolt etc.)	7 pairs	Cast iron

Appendix III: Calculation of the Bulk Density of vegetables

Bulk density of vegetables was calculated using the following equation:

$$\text{Bulk density} = \frac{\text{Weight of any vegetable}}{\text{Volume of rectangular box}} \quad (\text{kg m}^{-3})$$

$$\text{Volume of rectangular box (V)} = \text{Lenght} \times \text{Width} \times \text{Height} \quad (\text{m}^3)$$

$$= 10\ \text{cm} \times 10\ \text{cm} \times 10\ \text{cm} = (0.1 \times 0.1 \times 0.1)\ \text{m}^3$$

$$= 1 \times 10^{-3}\ \text{m}^3$$

For Mallow (Napa shakh):

Weight of mallow = 413.39 g = 0.41339 kg

Volume of rectangular box = 1×10^{-3} m^3

Therefore, bulk density of mallow = $\frac{0.41339\ \text{kg}}{1 \times 10^{-3}\ \text{m}^3}$ = 413.39 kg/m^3

Similar calculated value of bulk density for raw mustard leaves, colocacia leaves, jute leaves, moringa leaves, red amaranth leaves, brinjal, carrot, bitter gourd, garlic, cauliflower, cabbage were 349.75 ± 1.41, 395.49 ± 3.24, 294.41 ± 2.39, 333.62 ± 2.04, 536.48 ± 5.52, 383.31 ± 1.89, 1058.38 ± 3.05, 780.99 ± 2.49, 485.95 ± 1.52, 260.38 ± 3.49 and 371.01 ± 0.98 kg/m^3, respectively.

Appendix IV: Calculation for blower motor power

For Cabbage:

Blower motor power, $P = \frac{Q \times P_w}{6356 \times \eta}$ (1)

Pressure drop, $\Delta P = \frac{h_u}{\rho_b A} (\rho_b - \rho_a)\, g$ (2)

Here, h_u= 2kg, A= 0.21 m^2, ρ_a= 1.246 kg/m^3, ρ_b= 260.38 kg/m^3, g= 9.81 m/s^2, Q= 317.88 cfm and η= .75.

Putting the above values in equation 2, pressure drop was obtained-

$$\Delta P = 92.98 \text{ Pa}$$

Pressure drop in inches of water were-

P_w= 0.373 inches of water (Since, 1 inches of water= 249.089 Pa)

Putting the value of P_w, Q and η in equation 2, we obtained the value of blower motor powe-

P= 0.0249 hp

= 18.57 W (Since, 1 hp= 745.7 W)

Similarly for Carrot:

Here, h_u= 2kg, A= 0.21 m^2, ρ_a= 1.246 kg/m^3, ρ_b= 1058.38 kg/m^3, g= 9.81 m/s^2, Q= 317.88 cfm and η= .75.

Putting the above values in equation 2, pressure drop was obtained-

$$\Delta P = 93.32 \text{ Pa}$$

Pressure drop in inches of water were-

P_w= 0.375 inches of water (Since, 1 inches of water= 249.089 Pa)

Putting the value of P_w, Q and η in equation 2, we obtained the value of blower motor powe-

P= 0.025 hp

= 18.63 W (Since, 1 hp= 745.7 W)

Appendix V: Drying Curve data for drying of *M. verticillata*

Sun Drying		Shade Drying		Cabinet Drying		MSUC Drying	
Time (min)	% MC db	Time (min)	% MC db	Time (min)	% MC db	Time (min)	% MC db
0	557.89	0	557.89	0	557.89	0	557.89
30	201.02	6	186.53	30	201.02	30	70.36
60	107.9	12	81.16	60	107.9	40	23.92
90	50.83	18	47.06	90	50.83	50	11.23
120	23.3	24	24.84	120	23.3	60	7.64
150	13.12	30	18.06	150	13.12	70	4.71
180	8.44	36	14.29	180	8.44	80	3.73
210	6.5	39	10.99	210	6.5		
225	5.04	42	7.41	225	5.04		
240	4.28	45	5.59	240	4.28		
255	3.84	48	5.49	255	3.84		

Appendix VI: Drying Rate of *M. Verticillata* during Sun Drying

Time (min)	Sample weight (g)	Free Moisture, X (%)	ΔX (g H20/g dry solids)	ΔT (min)	A_t (m^2)	L_s (g)	Drying rate ($g/min.m^2$)
0	500.00	369.81	83.491	-30	0.00136	0.106	216.91
30	411.50	286.32	66.038	-30	0.00136	0.106	171.57
60	341.50	220.28	43.396	-30	0.00136	0.106	112.75
90	295.50	176.89	29.717	-30	0.00136	0.106	77.21
120	264.00	147.17	38.208	-30	0.00136	0.106	99.26
150	223.50	108.96	33.019	-30	0.00136	0.106	85.78
180	188.50	75.94	19.811	-30	0.00136	0.106	51.47
210	167.50	56.13	16.981	-30	0.00136	0.106	44.12
240	149.50	39.15	22.642	-30	0.00136	0.106	58.82
270	125.50	16.51	9.434	-30	0.00136	0.106	24.51
300	115.50	7.08	5.189	-30	0.00136	0.106	13.48
330	1100	1.89	1.792	-15	0.00136	0.106	9.31
345	108.10	0.1	0.189	-15	0.00136	0.106	0.98
360	107.90	0	0.000	0	0.00136	0.106	0.00

Appendix VII: Drying Rate of *M. Verticillata* during Shade Drying

Time (hr)	Sample weight (g)	Free Moisture, X (%)	ΔX (g H20/g dry solids)	ΔT (min)	A_t (m^2)	L_s (g)	Drying rate (g/min.m^2)
0	500.00	398.00	0.985	-6	0.00136	0.1	12.07
6	401.50	299.50	1.015	-6	0.00136	0.1	12.44
12	300.00	198.00	0.640	-6	0.00136	0.1	7.84
18	236.00	134.00	0.395	-6	0.00136	0.1	4.84
24	196.50	94.50	0.370	-6	0.00136	0.1	4.53
30	159.50	57.50	0.210	-6	0.00136	0.1	2.57
36	138.50	36.50	0.130	-3	0.00136	0.1	3.19
39	125.50	23.50	0.120	-3	0.00136	0.1	2.94
42	113.50	11.50	0.110	-3	0.00136	0.1	2.70
45	102.50	0.50	0.005	-3	0.00136	0.1	0.12
48	102.05	0.05	0.000	0	0.00136	0.1	0.00

Appendix VIII: Drying Rate of *M. Verticillata* during Cabinet Drying

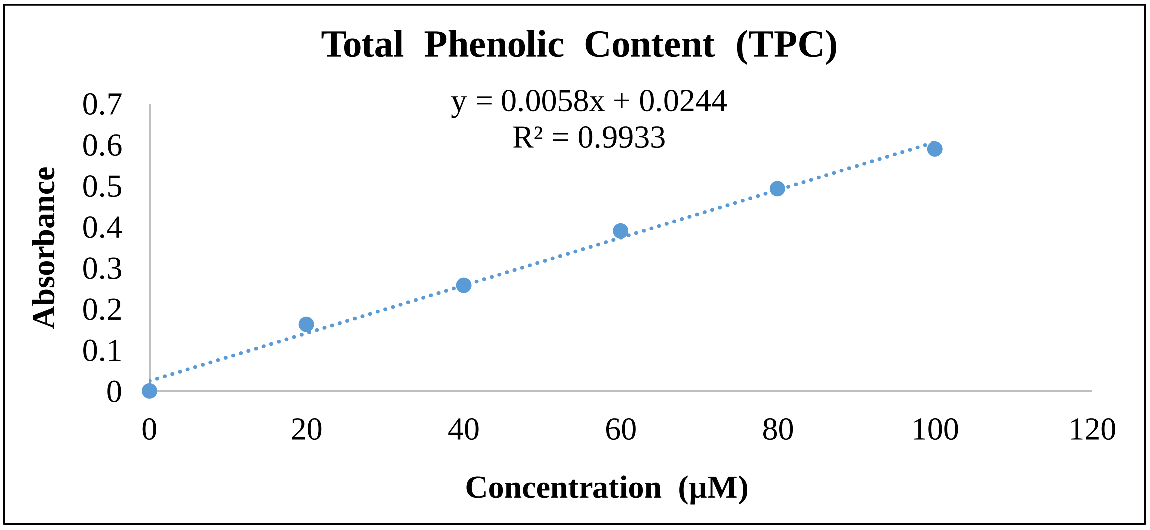
Time (min)	Sample weight (g)	Free Moisture, X (%)	ΔX (g H20/g dry solids)	ΔT (min)	A_t (m^2)	L_s (g)	Drying rate (g/min.m^2)
0	500	435.48	0.969	-30	0.00136	0.093	2.21
30	409.9	338.60	0.800	-30	0.00136	0.093	1.82
60	335.5	258.60	0.978	-30	0.00136	0.093	2.23
90	244.5	160.75	0.796	-30	0.00136	0.093	1.81
120	170.5	81.18	0.392	-30	0.00136	0.093	0.89
150	134	41.94	0.205	-30	0.00136	0.093	0.47
180	114.9	21.40	0.090	-30	0.00136	0.093	0.21
210	106.5	12.37	0.070	-15	0.00136	0.093	0.32
225	100	5.38	0.038	-15	0.00136	0.093	0.17
240	96.5	1.61	0.016	-15	0.00136	0.093	0.07
255	94.5	0.00	0.000	0	0.00136	0.093	0.00

Appendix IX: Drying Rate of *M. Verticillata* during MSUC Drying

Time (min)	Sample weight (g)	Free Moisture, X (%)	ΔX (g H20/g dry solids)	ΔT (min)	A_t (m^2)	L_s (g)	Drying rate (g/min.m^2)
0	500.00	441.30	2.364	-30	0.00136	0.093	5.39
30	282.50	204.89	1.207	-10	0.00136	0.093	8.25
40	171.50	84.24	0.489	-10	0.00136	0.093	3.34
50	126.50	35.33	0.163	-10	0.00136	0.093	1.11
60	111.50	19.02	0.141	-10	0.00136	0.093	0.97
70	98.50	4.89	0.049	-10	0.00136	0.093	0.33
80	94.00	0.00	0.000	0	0.00136	0.093	0.00

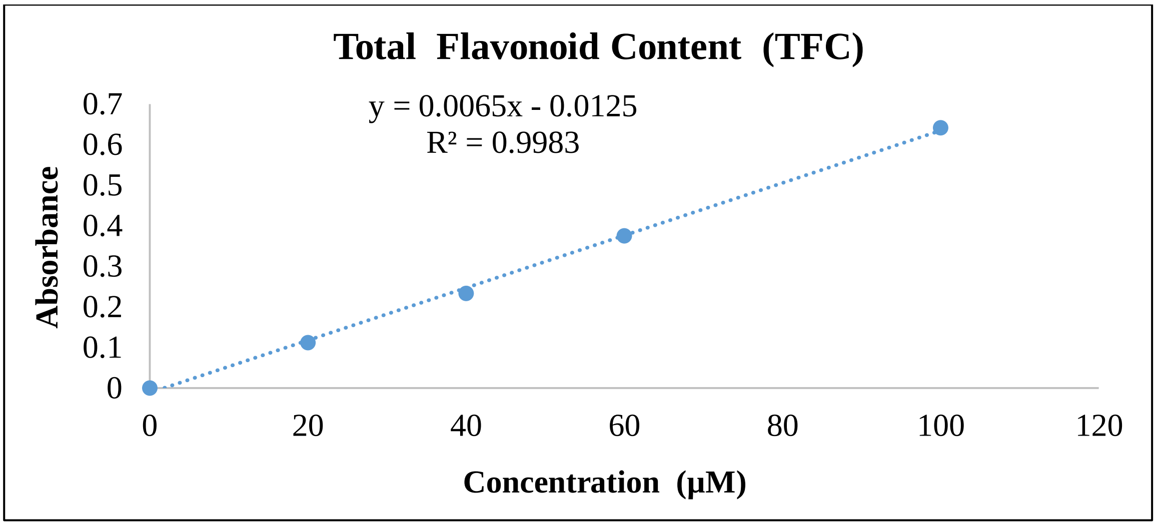
Appendix X: Standard Curve for Total Phenolic Content (TPC)

Concentration (μM)	Absorbance
0	0
20	0.162
40	0.258
60	0.39
80	0.493
100	0.59



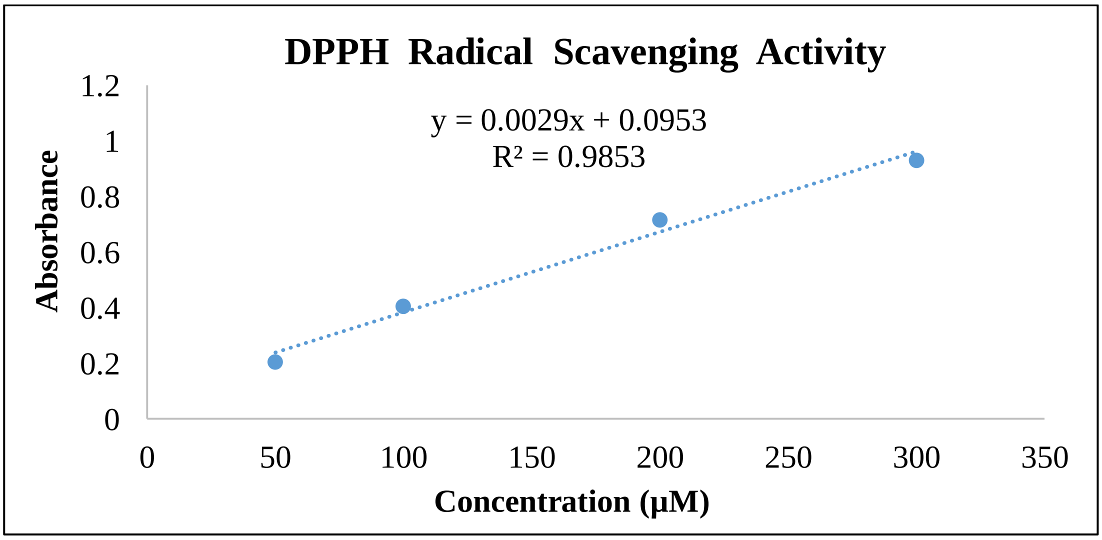
Appendix XI: Standard Curve for Total Flavonoid Content (TFC)

Concentration (µM)	Absorbance
0	0
20	0.112
40	0.232
60	0.375
100	0.641



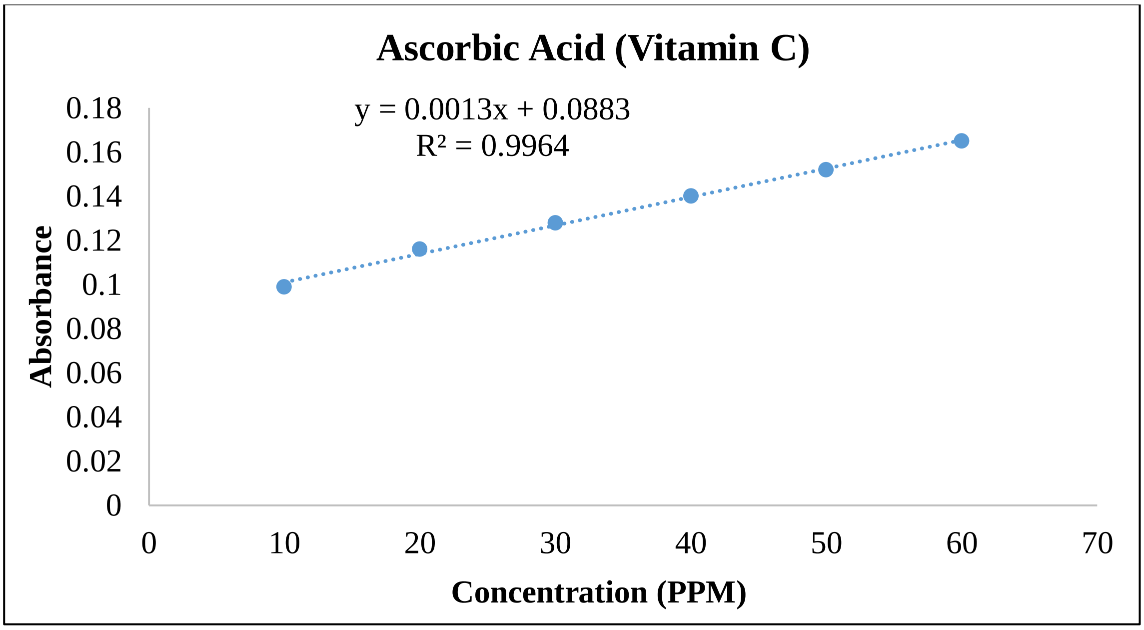
Appendix XII: Standard Curve for DPPH Radical Scavenging Activity

Concentration (µM)	Absorbance
0	0
50	0.205
100	0.406
200	0.718
300	0.932



Appendix XIII: Standard Curve for Ascorbic Acid (Vitamin C)

Concentration (PPM)	Absorbance
10	0.099
20	0.116
30	0.128
40	0.14
50	0.152
60	0.165



Appendix XIV: Questionnaire of Hedonic Rating Test for dried mallow (Napa Shakh)

HEDONIC RATING TEST FOR DRIED NAPA SHAKH

Name: …………………………… Date: ………………

See the sample carefully and give value for each parameter.

SI No	Parameter	Comments Value
I	Appearance	……………......
II	Colour	……………......
III	Odour	……………......
IV	Texture	……………......
V	Wetness	……………......

Comments score:

Score	Odour
5	Excellent
4	Good
3	Fair
2	Poor
1	Very poor

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Signature of the Panel