PREPARATION OF SAUERKRAUT AND STUDY OF ITS REHYDRATION PROPERTIES

Name: Samina Basnet

Enrollment: 2070/74

Roll no.:23/070

S.N.: 80100

Reg. No.: 5-2-8-0023-2013

Contact: +977-9862061504

Gmail: saminabasnet23@gmail.com

PREPARATION OF SAUERKRAUT AND STUDY OF ITS REHYDRATION PROPERTIES

by

Samina Basnet

Department of Food Technology

Central Campus of Technology

Institute of Science and Technology

Tribhuvan University, Nepal

2018

PREPARATION OF SAUERKRAUT AND STUDY OF ITS REHYDRATION PROPERTIES

A dissertation submitted to the Department of Food Technology, Central Campus of Technology, Tribhuvan University, in partial fulfillment for the degree of B.Tech. in Food Technology

by

Samina Basnet

Department of Food Technology

Central Campus of Technology

Institute of Science and Technology

Tribhuvan University, Nepal

April, 2018

Tribhuvan University

Institute of Science and Technology

Department of Food Technology

Central Campus of Technology, Dharan

Approval Letter

This *dissertation* entitled *Preparation of Sauerkraut and Study of its Rehydration Properties* presented by Samina Basnet has been accepted as the partial fulfillment of the requirement for the B. Tech. degree in Food Technology

<u>Dissertation Committee</u>

1. **Head of the Department _____________________________________**

   (Mr. Basanta Kumar Rai, Assoc. Prof.)

2. **External Examiner _____________________________________**

   (Mr. Birendra Kumar Yadav, Asst. Prof.)

3. **Supervisor ____**

   (Mr. Basanta Kumar Rai, Assoc. Prof.)

4. **Internal Examiner _____________________________________**

   (Mr. Navin Gautam, Asst. Prof.)

April 10, 2018

Acknowledgements

I express my deep sense of gratitude to my guide Mr. Basanta Kumar Rai Prof., Central Campus of Technology, Dharan for his excellent guidance, encouragement and inspirations throughout the work.

I am also grateful to Prof. Dr. Dhan Bahadur Karki (Campus chief, Central Campus of Technology), Associate Professor Basanta Kumar Rai (HOD, Department of Food technology) and Associate Professor Geeta Bhattarai (Chairperson, Central Department of Food Technology) for their generosity and co-operation in providing an opportunity and facilities to perform this work successfully. My sincere thanks to all my friends Niseel Manandhar, Pankaj Dahal, Gajendra Bohora, Prajwal Pokharel, Sanjana Shrestha and Juniors Sudarshan Goshai, Porshan BK, Neeraj Adhikari, Sanjog kharel and all who assisted me directly or indirectly, throughout the work.

Thanks to all the laboratory and library staffs of Central Campus of Technology, Dharan for their kind co-operation. Finally, I am highly indebted to my parents and family members for their constant encouragement, love, inspiration and moral support without whom this work has not been completed successfully.

Date of Submission: April 10, 2018

Samina Basnet

Contents

Abstract

The main aim of this study was to prepare the sauerkraut from locally grown (Sindhuwa, Nepal) Taiwanese cabbage (confirmed to be *Brassica oleracea* L.var *capitata*)and evaluate its quality. The cabbage was shredded to~3-4 mm which is the standard size for sauerkraut and fermented at different brine concentration (2%, 2.25% and 2.5%) for 9, 12 and 15 days for each brine fermentation respectively. The sauerkraut were analyzed in terms of pH, acidity, TSS, reducing sugar and vitamin C for 15 days at every 3 days of time interval. After the completion of fermentation it was dried and rehydrated to study the rehydration property. A descriptive sensory panel used category scales to rate the flavor, colour, taste, appearance and overall acceptability of dehydrated and rehydrated sauerkrauts samples.

Acidity was found to increase with fermentation time. pH and vitamin C decreased with increase in fermentation time and the decreasing rate declined with increase in brine concentration. TSS increased as the both brine concentration and fermentation time increased. Coefficient of rehydration was found to decrease with increased salt concentration fermentation time. From the sensory analysis 2.25% brine concentration of dehydrated and rehydrated sauerkraut of 12 days fermentation was found to be superior, thus implying that both fermentation time and salt concentration have significant effect on sensory quality of sauerkraut.

List of Tables

Lists of Figures

List of Plates

Lists of Abbreviations

Abbreviation	Full form
ANOVA	Analysis of Variance
BC	Before Christ
LAB	Lactic Acid Bacteria
LSD	Least Significant Difference

Part I

Introduction

1.1 General introduction

Cabbage is the most important commercial vegetables of the cole crops, which includes cabbage, cauliflower, brussels sprouts, kale, kohlrabi, collard, broccoli, and many others. It also ranks as one of the most important of all vegetable crops and is universally cultivated as a garden, truck and general farm crop (Shoemaker, 2009). Cabbage is the king of cruciferous vegetables in defending the body against illness. It is as rich in vitamin C as citrus fruits, with all its protective and healing properties (Nixon, 2017). One of the most important commercial products obtained from brassica vegetables is sauerkraut, which results from the lactic acid fermentation of shredded and salted white cabbage. Proper cabbage fermentation depends on cabbage variety (Alden, 2005).

Sauerkraut is a naturally fermented cabbage which is an oldest ways of preserving food (Enwa, 2014). It is a low calorie food where vitamin C and other nutrients are preserved and desirable sensory properties are created by a proper fermentation (Trail *et al.*, 1996). The fermentation of cabbage has been shown to enhance its protective activities (Enwa, 2014). It is an acidic cabbage, which results from natural fermentation by bacteria indigenous to cabbage in the presence of salt. The addition of salt is one of the critical point in sauerkraut production because of the type and extent of microbial growth and the sensory properties of the final product are affected by the amount of salt used (Thakur and Kabir, 2015). The addition of salt restricts the activities of Gram negative bacteria, while the growth of lactic acid bacteria is favoured (Pundir and Jam, 2010). Salt concentration had a significant effect on sauerkraut fermentation at early stage. The LAB population and metabolic rate was reduced and the yield of lactic acid decreased with the increase of salt concentration. Suitable salt concentration can effectively inhibit the reproduction of fungi and E. coli. In comparison, high salt concentration delayed the maturation of sauerkraut and inhibited the metabolism of LAB (Xiong *et al.*, 2014). The developement of specific bacteria with desired properties is of prime importance to prepare sauerkraut of consistent quality (Desrosier and Desrosier, 1998) .The fermentation yield lactic acid as a major product. This lactic acid along with other minor products of fermentation, gives sauerkraut its characteristic flavor and texture (Steinkraus, 1996). The glucosinolate in sauerkraut induces the body's antioxidant, enzymatic activity and the flavonoid components confer protection to blood vessels from oxidative damage. Also, lacto-fermented sauerkraut provides an array of lactobacilli probiotics, vitamin C, dietary folates, manganese and pyridoxine (Enwa, 2014). Sauerkraut may store well under the wide variety of conditions (Thakur and Kabir, 2015).

Fruits, vegetables and their products are dried to enhance storage stability, minimize packaging requirements and reduce transport weight (Sagar and Suresh, 2010). Dehydration is one of the most effective means to extend the shelf life of perishable foods. The main purpose of dehydration in preserving foods is to remove moisture so that the water activity of the dehydrated product is low enough (e.g., aw < 0.6) to stop spoilage and the growth of pathogenic microorganisms and to reduce other deteriorative reactions. It is an effective method to prepare convenient food ingredients for use in products such as dry soup mixes, frozen entrees, baby foods, and dairy products, or directly as seasoning blends (Somogyi and Luh, 1988). Dehydrated products can be used in many processed or ready-to-eat foods in place of fresh foods and have several advantages such as convenience in transportation, storage, preparation and use. Dehydrated products need to be rehydrated before consumption or further processing. During rehydration, absorption of water into the tissue results in an increase in the mass. Simultaneously, leaching out of solute (sugars, acids, minerals, vitamins) occurs and both phenomena are influenced by the nature of the product and conditions employed for dehydration. Rehydration may also be referred to as a way to plump a dried food item or to reconstitute foods (Rastogi *et al.,* 2004). Dehydrated products readily take up moisture when immersed in a liquid medium, leading to significant changes in their thermophysical properties. The rehydration kinetics, the structural properties (apparent density, true density, specific volume and internal porosity), the viscoelastic behavior (compression tests), and the flavor losses were investigated during rehydration of various fruits and vegetables (Krokida and Philippopoul, 2005).

1.2 Statement of problem

Sauerkraut is clean, sound product of characterstic flavor, obtained by full fermentation, chiefly lactic of properly prepared and shredded cabbage in not less than 2.0% and more than 3.0% salt. During fermentation lactic acid is produced that acts as preservative in addition to imparting desired aroma and flavor (Chauhan *et al.*, 2008). Production of sauerkraut is a means of preserving cabbage in inexpensive, bulk storage (Ingram and

Kitchell, 1976). Sauerkraut add many nutritional benefits. It boost immune system and also provides energy. As sauerkraut is a fermented food, its shelf life is quite less. As such, sauerkraut is intended to be eaten fresh. However, it may also be dried and stored for future use (during the off season). Apparently, the dried product will never reach the quality of the fresh sauerkraut but the possibility that it can emerge itself as a distinct product-type is high. However, except for some blogs and websites such as those maintained by (Byers, 2013) and (Mcallister, 2018), very little published information is available on drying of sauerkraut, much less the effect(s) of salt, temperature, and degree of fermentation. Website literature has it that dehydrated sauerkraut (dubbed sauerkraut crisp) "adds a nice little zing to backpacking meals and goes well with ramen noodles. It can even be snacked on dry."

1.3 Objectives

1.3.1 General objective

- To prepare sauerkraut and evaluate its rehydration properties.

1.3.2 Specific objective

- To ferment cabbage at different brine concentrations.
- To analyze pH, acidity, TSS, reducing sugar and vitamin C during fermentation.
- To study the sensory characteristics of dehydrated and rehydrated sample.
- To study the rehydration properties of dried sauerkraut.

1.4 Significance of study

Sauerkraut is a nutritious fermentable vegetable food, highly appreciated for its particular sensory characteristics. Fermented vegetable products are microbiologically safe, nutritious, and flavorful; have appealing sensory characteristics; and can be conveniently stored for extended periods without refrigeration. There is strong scientific evidence that sauerkraut provides numerous health benefits, such as antioxidant and anti-carcinogenic effects, including providing fiber and a significant amount of vitamin C and K. It also boot our energy and immune system. Sauerkraut or their active principles could be used as possible preventive agents for these people with such health disorder and having such nutrient deficiency problem. Moreover sauerkraut is a natural unexplored source of probiotic bacteria that can be potentially used as a starter culture in a vegetable fermentation processes. The health promoting properties of sauerkraut are attributed to its high level of bioactive constituents, especially glucosinolates breakdown products. Development and acceptance of sauerkraut-like products from cabbage could lead to an expanded use of cabbage in contemporary foods, especially if unique properties can be identified.

As dried sauerkraut has long shelf life, it can be stored for a long period of time. With the addition of water or other fluids, dried vegetables quickly assume the flavor and texture of their fresh or frozen counterparts in vegetable dishes. Without any preparation or rehydration, dried vegetables can also be eaten as a low calorie, healthful replacement for other crispy snacks. Drying is also a suitable alternative for postharvest management. It facilitates in considerable saving in packaging, storage, etc. The fact that dried foods are lightweight and compact makes them desirable for hiking and camping trips. The brine solution optimization for fermentation helps to minimize the loss of solute and important nutrients. Rehydration helps to absorb water and increase moisture content of dried product. Also it helps to increase the volume of dried product. With little technical assistance and attention to hygiene and quality it could be commercialized, thus generating employment and income in the rural areas.

1.5 Limitations of study

- ✓ A single variety of cabbage was taken for fermentation.
- ✓ Storage stability of dried and fermented sauerkraut was not studied.

Part II

Literature review

2.1 Cabbage

Cabbage (*Brassica oleracea* L. var. *capitata*) is a popular green leafy vegetable belonging to the family Brassicaceae. Cabbage falls under cole group and all cole crops have one common trait i.e., genetic potential to thicken various part. Early Greek and Roman literature refers to the cultivation of cole crops for their perceived medicinal properties as well as a source of food. Belief that these crops relieved such conditions as gout, deafness, and headaches furthered the spread of cole crops from the Mediterranean through the Old World. Now, cabbage and many of the cole crops are cultivated throughout the world for use fresh and in processed products (Bhat *et al.*, 2017). It is a hardy cool season annual vegetable, but behaves as a biennial when grown for seed production. The head consisting of thick leaves overlapping tightly on growing bud is the economic part used as vegetable. Cabbage is an excellent source of vitamins and minerals (Bose and Som, 1993). Brassica crops comprise the large group of about 350 genera and 3000 species from family Crucifereae. The main vegetables are from *Brassica oleracea* species covering cauliflower, cabbage and kohlrabi; the important and commonly grown vegetables crops worldwide for their own significance due to their high nutritive properties and wider adaptability (Rawat and Sapkota, 2012).

Cabbage is a cool-season vegetable that grows best in well-drained sandy loam soils that have high organic content (Smith, 2016). It behaves like biennial when grown for seed production. Head consisting of thick leaves overlapping on growing bud is the economic part. Glucoside ‘sinigrin’ is the flavor principle in cabbage (Anon, 2017).

Well-known varieties of the species include the cabbages, broccoli, brussels sprouts, cauliflower, collards, kale, and kohlrabi. All grow best in cool, moist climates. They are attacked mostly by insect pests. The true cabbages (var. *capitata*) include the white and red types and the Savoy type (grown mostly in Europe), with curly, loose leaves. Inexpensive and easily stored, cabbage is important in the diet of many poorer peoples. Popular cabbage dishes include sauerkraut and slaw (raw cabbage). Chinese cabbage, or petsai, chiefly a salad plant, is a separate species (*B. pekinensis*) grown in many varieties, especially in East Asia. Cabbages with multicolored leaves are becoming popular as ornamental border plants for flower gardens. Cabbages are classified in the division Magnoliophyta, class Magnoliopsida, order Capparales, family Cruciferae (Encyclopedia.com)

2.1.1 Historical development of Brassica

Brassica vegetables are referred to as the native of Europe. The wild progenies of *Brassica* are found on the rocky Atlantic coasts of Europe (Bay of Biscay) and Britain. The free living *B.oleracea* populations found along the Mediterranean coast are merely stated as the feral and weedy escapes from cultivation. Researchers are now in an opinion that the free living *B.oleracea* populations found along the Europe and the Mediterranean as cabbage and kale dispersed into Mesopotamia and Egypt. Trade routes lead them to spread further throughout the old world ultimately competing *B. rapa* of East Asian origin in China. When trade with the New World began, all of the cole crops were taken to the Americas. Broccoli and cauliflower diffused from the Mediterranean (cauliflower earlier than broccoli) to elsewhere in the Near East, northern Africa, and Europe (Rawat and Sapkota, 2012).Cauliflower was mentioned in Turkey and Egypt in the sixteenth century and in England and France in the seventeenth century. Both broccoli and cauliflower were first described in the United States in 1806, but production did not flourish until the 1920s. Interest in broccoli in central and northern Europe increased after the crop became popular in the United States and afterwards dispersed worldwide, broccoli production is increasing (Maggioni *et al.*, 2010).

Brassica rapa has been found to have been grown naturally from the west Mediterranean region to central Asia and is still present as feral types throughout this area. The ancient reference pertains to yellow sarson in ancient Veda books and Sanskrit literary works such as the Upanisadas and the Brahmanas (c. 1500 BCE), where it was referred to black mustard (*Brassica nigra*) and yellow sarson (*Brassica rapa*) as ‘Sarshap’ and ‘Siddhartha’ respectively (Prakash and Hinata, 1980). Europe, western Russia, Central Asia and the east has been considered as the secondary centres of origin with their widest distribution. The first domestication of this crop should have probably been possible due to this wide distribution. The selection from the available variation of the leafy vegetables made it possible for the huge diversity in Chinese cabbage (Quijada *et al.*, 2007).

2.1.2 Diversity of Brassica

Brassica consists of five groups:

Genus	Species	Variety
Brassica	*oleracea*	*botrytis*
		capitata
		gongylodes
		acephala
		italica
		gemnifera
Brassica	*napus*	*rapifera*
Brassica	*rapa*	*pekinensis*
		rapifera
		chinensis
Raphanus	*sativus*	*sativus*
		niger
Eruca	*sativus*	

Source: Rawat and Sapkota (2012)

2.1.3 Origin and domestication of Brassica

The archaeological proof regarding the origin and domestication of Brassica crops are lost over time. Thus, the literary and linguistic studies are to be referred to figure out the origin of these crops. The linguistic, literary, and historical points of view are in a support that the domestication of *Brassica oleracea* was in the ancient Greek-speaking area of Central and

East Mediterranean (Maggioni *et al.*, 2010). Turnip (sps *rapifera*) is believed to have been originated from Europe (Quijada *et al.*, 2007). *Brassica rapa* was first domesticated in Europe as a biennial plant which later evolved to give rise to annuals through rigorous breeding and selection (Burkill, 1930). The primary center of origin of oleiferous form of *Brassica rapa* is Europe while the eastern forms were evolved in northwest India and at the same time the Chinese forms as leafy vegetables in China (Quijada *et al.*, 2007). The three ecotypes of oil yielding *B. rapa*: brown sarson, yellow sarson and toria are found in India (Singh, 2003).

Brassica seeds are found in prehistoric archaeological navigations as well. *Brassica oleracea* archaeology can be traced back before ancient Roman civilizations while *B. rapa* and *B. nigra* are better preserved and found to be studied from Neolithic and Bronze sites only (Maggioni *et al.*, 2010).

2.1.4 Varieties of cabbage

There are many varieties of cabbage that can be wildly dissimilar, but most have a short, broad stem and leaves or flowers that form a compact head. The most common cabbages are green and red cabbage, collards, kohlrabi, broccoli, Brussels sprouts, cauliflower, and kale. They're loaded with vitamin C, fiber, and possibly cancer-fighting compounds to boot (Alden, 2005).

i. Green cabbage

It is also known as cannonball cabbage which is one of the most popular cabbage varieties. It is so named for the way its leaves wound tightly over one another in a dense, compact fashion; with the final product resembling a cannonball (Tan, 2017). The outer leaves range from dark to pale green while the inside is pale green or white. When raw, the texture is somewhat rubbery and the flavor kind of peppery, but once it is cooked the green cabbage softens and takes on a sweeter taste (Masley, 2009).

ii. Red cabbage

Red cabbage belongs to the Cruciferae family, is inexpensive and is easy to grow, harvest and store (Pliszka *et al.*, 2009). Red cabbage color is being marketed commercially as a solution and as a spray dried powder for use as a food colorant. The red cabbage anthocyanins transition from purple-red to pink-red to blue-green between pH levels of 3 and 6, respectively. This red cabbage color can be widely used in wines, beverages, fruit sauces, candies and cakes (Kannan, 2011). It is also known as the purple cabbage or red kraut, the red cabbage changes its color according to the pH value of the soil it grows. The leaves of red cabbage grow reddish in acidic soil and more purplish in neutral - acting (Tan, 2017). One head yields about 8 cups shredded cabbage (Alden, 2005).

iii. Savoy cabbage

Savoy cabbage, originating in Italy, has deep green crinkly leaves and is considered the most tender and sweet. The head is less compact, due to the wrinkled leaves, but looks similar to a green cabbage. It is the better choice for stuffed cabbage since the leaves are more pliable and stand up to longer cooking times, but is also great raw in coleslaw (Filippone). Savoy cabbage is like ordinary cabbage, but with a milder flavor. It can often be used in place of green cabbage (Alden, 2005).

iv. Napa cabbage

Napa cabbage is also called Chinese cabbage, this yellow-green, oblong head has frilly leaves, and crisp, thick stems. One of the milder flavored cabbages, Napa can be eaten raw or cooked and is softer and sweeter than the other varieties (Filippone). Napa cabbage can be shredded and eaten in salads, steamed or added to stir-fries. It is not necessarily a good replacement for regular cabbage because it is delicate, bland and too "juicy".

v. Brussels sprouts

These look like small cabbages, and they're most often boiled or steamed and served as a side dish. Due to its strong flavor it's best not to pair them with anything that's delicately flavored. These cabbages do not store well (Alden, 2005). Brussels sprouts provide special nutrient support for three body systems that are closely connected with cancer development as well as cancer prevention. These three systems are the body's detox system, antioxidant system, and inflammatory/anti-inflammatory system. Chronic imbalances in any of these three systems can increase risk of cancer, and when imbalances in all three systems occur simultaneously, the risk of cancer increases significantly. Among all types of cancer, prevention of the following cancer types is most closely associated with intake of Brussels sprouts: bladder cancer, breast cancer, colon cancer, lung cancer, prostate cancer, and ovarian cancer (Matelijan, 2018).

vi. Tuscan cabbage

Tuscan cabbage is available mostly at farmers' markets and specialty produce stores. It's a mild-flavored cabbage, with long, narrow, almost feathery leaves that are dark green with white ribs. It looks like a narrow version of kale, which is a close relative. There is also a black Tuscan cabbage**,** known as cavalonero in Italy, whose leaves are such a dark purple that they appear black (Wellness, 2015)

2.1.5 Sauerkraut production technology

Danish Ballhead, Late Flat Head and Premium Late Dutch are good cabbage varieties for sauerkraut. Krautman is one of the most popular varieties for making sauerkraut, and growers are encouraged to try new varieties as well. The best cabbage for sauerkraut are the later maturing varieties due to their higher sugar content and cooler temperatures. Most varieties of cabbage available for fresh or sauerkraut production are disease resistant (Robinson and Smith).

2.1.6 Uses of cabbage

Cruciferous vegetables like cabbage, kale, and broccoli are notorious for being chock-full of beneficial nutrients. Consuming fruits and vegetables of all kinds has long been associated with a reduced risk of many adverse health conditions. Many studies have suggested that increasing consumption of plant-based foods like cabbage decreases the risk of diabetes, obesity, heart disease, and overall mortality. It can also help to promote a healthy complexion, increased energy, and overall lower weight. The fiber and water content in cabbage also help to prevent constipation and maintain a healthy digestive tract. Eating adequate fiber promotes regularity, which is crucial for the excretion of toxins through the bile and stool. The high polyphenol content in cabbage might also reduce the risk of cardiovascular disease by preventing platelet buildup and reducing blood pressure. A compound found in cabbage and other cruciferous vegetables known as 3,3'-diindolylmethane (DIM) has been shown to increase short-term survival rates in some animal studies on radiation. A popular way to consume cabbage is in a fermented form such as sauerkraut and kimchi (Murison and Napier, 2006).

Sauerkraut and Kimchi are the types of fermented foods which are used to denote a highly varied group of salted and fermented vegetable foods in Korea. Kimchi and sauerkraut contain high levels of vitamins, minerals, dietary fibers, and other functional components. Many previous studies have reported that kimchi has anticancer, antioxidative, antiatherosclerotic, antidiabetic, antiobesity effects, and so on (Park *et al.*, 2014). Kimchi fermentation is the korean method of preserving the fresh and crispy texture of vegetables for consumption during the winter when fresh vegetables are not available. It has a sour/ sweet and carbonated taste and is usually served cold (Lee, 1997). Kimchi fermentation is microbiologically similar to sauerkraut. The vitamin B content increases during sauerkraut and kimchi fermentations, and vitamin C and A are preserved fermentation, although the ingredients, flavor, and preparation methods differ (Breidt *et al.*, 2013). As cabbage ferments to produce sauerkraut, it produces a diverse population of live bacteria. These probiotics replenish the good bacteria in the gut and help to inhibit the growth of bad bacteria. They may also boost the immune system, synthesize B vitamins and relieve diarrhea caused by taking antibiotics. Sauerkraut delivers some solid health benefits, including providing fiber and a significant amount of vitamins C and K. It also boosts our energy with iron. The beneficial probiotics found in sauerkraut are important for good digestive health. Research has shown that probiotics help to reduce some digestive symptoms such as gas, bloating, constipation and may be beneficial to those suffering with conditions such as Crohn’s and ulcerative colitis. Sauerkraut also contains enzymes that help the body to break down food into smaller, and more easily digestible molecules which in turn helps the body to absorb more nutrients (Shubrook, 2017).

2.2 Fermentation

2.2.1 Introduction

Fermentation is one of the oldest forms of food preservation technologies in the world (Rhee *et al.*, 2011). Indigenous fermented foods such as gundruk, cheese, wine have been prepared and consumed for thousands of years and are strongly linked to culture and tradition, especially in rular household and village communities. China is thought to be the birth place of 12 fermented vegetables and the use of *Aspergillus* and *Rhizopus* mold to make fermented food products. Fermentation is relatively efficient, low energy preservation process which increases shelf life and decreases the need for refrigeration or other form of food preservation technology. It is therefore highly appropriate technique for use in developing countries and remote areas where access to sophisticated equipment is limited (Battcock and Ali, 1998).

Fermentation is one of the oldest processing techniques to extend the shelf life of perishable food and was particularly important before refrigeration (Swain *et al.*, 2014). Fermentation of fruits and vegetables can occur spontaneously by the natural lactic bacterial surface microflora, such as *Lactobacillus* spp., *Leuconostoc* spp., and *Pediococcus* spp.; however, the use of starter culture such as *L. plantarum*, *L. rhamnosus*, *L. gasseri*, and *L. acidophilus* provides consistency and reliability of performance. Lactic acid fermentation of vegetables has an industrial significance only for cucumbers, cabbages, and olives. Fermented fruits and vegetables have an important role in feeding the world's population on every continent today. They play an important role in preservation, production of wholesome nutritious foods in a wide variety of flavors, aromas, and textures which enrich the human diet and remove anti-nutritional factors to make the food safe to eat. Vegetables have low sugar content but are rich in minerals and vitamins and have neutral pH and thus provide a natural medium for LA fermentation (Montet *et al.*, 2014). The most significant role of fermentation is that it helps to make the nutrients naturally present in the starting food materials, more palatable and more widely available than would be possible without fermentation. The fermentation processes can have significant direct effects on the nutritive qualities of foods (Jones, 1975).

LA fermentation of cabbage to produce sauerkraut has been widely studied for many years. Cabbage is used as either raw salad or cooked vegetable. During cooking, vitamin C which is an important component of cabbage is destroyed if not processed properly. So through fermentation vitamin C and other nutrients can be preserved and availability of cabbage can be increased throughout the year (Pandey and Garg, 2015). With the popularity and success of sauerkraut, fermentation of many other vegetables has emerged, such as cucumbers, beets, turnips, cauliflower, celery, radishes, and carrots. Sauerkraut, fermented cucumbers, and kimchi are the most studied lactic acid fermented vegetables mainly due to their commercial importance. According to (Kim *et al.*, 2000) the Chinese cabbage, cabbage, tomato, carrot, and spinach provide relatively higher fermentability than other vegetables (okra and gourds) because they have more fermentable saccharides. Sauerkraut production typically relies on a sequential microbial process that involves heterofermentative and homofermentative LAB, generally involving *Leuconostoc spp*. In the initial phase and *Lactobacillus spp*. and *Pediococcus spp*. in the subsequent phases. The high nutritive value of sauerkraut is mainly due to the increased digestibility in comparison to raw cabbage and relatively low vitamin C losses (Swain *et al.*, 2014).

2.2.2 Microorganism during natural fermentation

Fresh vegetables contain numerous and varied epiphytic microflora, including many potential spoilage microorganisms and an extremely small population of Lactic Acid Bacteria. The natural or spontaneous fermentation of vegetables is therefore a concentrated action of these microorganism (Rose, 1982). Many microbiological studies deal with identification of organisms isolated from various fermented foods. During natural fermentation, there is distribution of homo and hetero lactic flora: the homo lactic forms lactic acid whereas hetero lactic forms acetic acid, co_2 and ethanol in addition to lactate which imparts typical and desirable flavor. The sauerkraut fermentation is consistently initiated by heterofermentative lactic acid bacteria (LAB), primarily *Leuconostoc mesenteroides*. As the pH decreases, *L. mesenteroides* begins to decline in number and the more acid-tolerant homofermentative LAB, predominantly *Lactobacillus plantarum*, increase in cell numbers and complete the fermentation (Johanningsmeier *et al.*, 2007). The succession of microorganism produces interesting changes in the kraut during fermentation (Rose, 1982).

2.2.3 Lactic acid bacteria and lactic acid fermentation

Lactic acid bacteria, also called LAB, are either rod-shaped (bacillus) or spherical (coccus), and are distinctly characterized by their tolerance for acidic environments with a lower pH. During fermentation, LAB's proliferate producing different genus strains of Lactobacillales, which may include *Leuconostuc, Lactobacillus, Lactococcus* and *Pediococcus*. Within each one of these genus classifications are numerous other species. Each of these anaerobic bacteria, in varying proportions, are produced at various stages of the fermentation process and supply different taste and textural qualities (Anon, 2018). Lactic acid bacteria are among the best studied microorganisms. Lactic acid bacteria are useful in producing fermented foods such as yoghurt, pickles and are also used as probiotics (Pundir and Jam, 2010). Besides being the main component in kimchi and other fermented foods, they are used to preserve edible food materials through fermentation of other raw-materials such as rice wine/beer, rice cakes, and fish by producing organic acids to control putrefactive microorganisms and pathogen (Rhee *et al.*, 2011). Important new developments have been made in the research of lactic acid bacteria in the areas of multidrug resistance, bacteriocins, quorum sensing, osmoregulation, autolysins and bacteriophages. Progress has also been made in the construction of food grade genetically modified Lactic acid bacteria. These have opened new potential applications for these microorganisms in various industries (Konings *et al.*, 2000).

The desirable characteristics of industrial microorganisms are their ability to rapidly and completely ferment cheap raw materials, requiring minimal amount of nitrogenous substances, providing high yields of preferred stereo specific lactic acid under conditions of low pH and high temperature, production of low amounts of cell mass and negligible amounts of other byproducts. The choice of an organism primarily depends on the carbohydrate to be fermented. *Lactobacillus delbreuckii* subspecies *delbreuckii* are able to ferment sucrose. *Lactobacillus delbreuckii* subspecies *bulgaricus* is able to use lactose. *Lactobacillus helveticus* is able to use both lactose and galactose. *Lactobacillus amylophylus* and *Lactobacillus amylovirus* are able to ferment starch. *Lactobacillus lactis* can ferment glucose, sucrose and galactose. *Lactobacillus pentosus* have been used to ferment sulfite waste liquor (Narayanan *et al.*, 2004).

Lactobacillus has complex nutritional requirements, as they are those groups of microorganisms that have lost their ability to synthesize their own growth factors. They cannot grow solely on carbon source and inorganic nitrogen salts. Organisms such as *Rhizopus oryzae* have less limiting nutritional requirements and can utilize starch feed stocks. They are able to produce pure L (+) lactic acid (Skory *et al.*, 1998). Studies have also been carried out with *Saccharomyces cerevisiae* and *Kluyveromyces lactis* for production of pure L (+) lactic acid because of their ability to tolerate high concentration of hydrogen ions which is desirable (Porro *et al.*, 1997). Lactic acid bacteria perform this essential function in preserving and producing a wide range of foods: fermented fresh vegetables. Lactic acid bacteria are generally fastidious on artificial media, but they grow readily in most food substrates and lower the pH rapidly to a point where competing organisms are no longer able to grow (Lee, 1997).

Lactic acid fermentation or lacto-fermentation is generally the most common type used to convert foods into their cultured variations. During this procedure the sugars are converted to lactic acid, which in turn gives birth to different genus strains of the lactic acid bacteria. Varying proportions of these microorganisms are produced at various stages of the fermentation process, supplying different tastes and textural qualities. Lacto-fermentation is created in an oxygen-free (anaerobic) environment that supports the growth of desirable bacteria and eliminates pathogenic varieties when kept at the appropriate temperature designated for each particular food or beverage (Rai, 2009).

2.2.3.1 Three phases of lacto-fermentation

1) Beneficial anaerobic bacteria, mold or yeast strains begin the fermentation process by creating an acidic environment in which they can multiply.
2) As the acid level of fermentation increases, this allows for various other species of friendly flora to proliferate.
3) The pH continues to lower as any remaining proteins, sugars and starches are fermented by other species, like *Lactobacillus* for example. This phase improves flavor significantly increasing palatability and unique taste qualities inherent to the type of food or liquid (Anon., 2018).

2.2.3.2 Basic purpose of lactic acid fermentation

1) Improves digestibility of the food
2) Enhances flavor and texture
3) Acts as a natural preservative (Anon., 2018).

2.2.4 Biochemistry of lactic acid fermentation

The Lactic Bacteria are a group of Gram-positive non spore forming bacteria. Most of them work best at temperature range between 18 to 22°C (Shrestha, 2002). The formation of lactic acid from glucose is shown in Fig. 2.1.

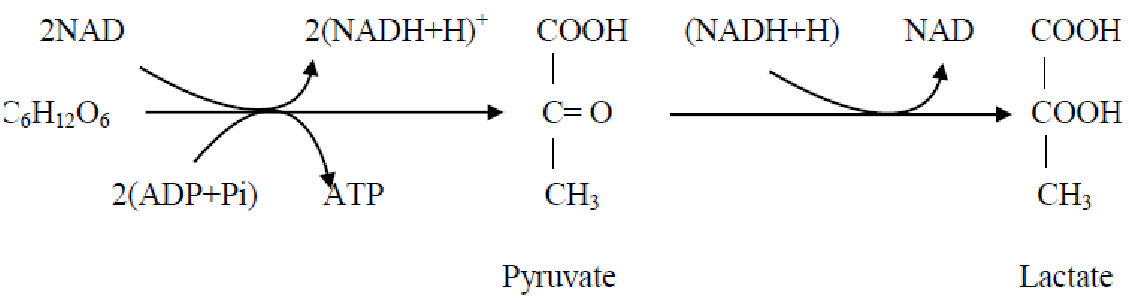


Fig. 2.1 Lactic Acid Fermentation Pathway

In Fig. 2.1, glucose is oxidized into pyruvate molecule by the process of glycolysis. In this process 2 molecule of ATP is formed from 2 molecules of ADP. Also 2 molecule of NAD is oxidized to release 2 molecule of NADH and hydrogen ion. Further pyruvate is reduced to lactate where NADH is returned to its oxidized state, i.e. NAD^+.

Sauerkraut fermentation is a lactic acid fermentation in which lactic acid and other compounds are produced by microorganisms from sugary or starchy components present in the substrate. On the basis of the end products formed, lactic acid fermentation may be a homo- or a hetero fermentation. The lactic acid bacteria involved, by analogy are designated as homo lactic (homo fermentative) and hetero lactic (hetero fermentative) (Shrestha, 2002)

The homo lactic fermentation produce mainly lactic acid via Embden-Meyerhof scheme of glycolysis as lactic fermentation pathway and is carried out by *Streptococcus, Pediococcus* and various *Lactobacillus* species (Shrestha, 2002). The hetero lactic fermentation produces lactic acid and appreciable amount of ethanol, acetate and CO_2 in addition to lactic acid using phospho- ketolase pathway of glycolysis as shown in Fig. 2.2

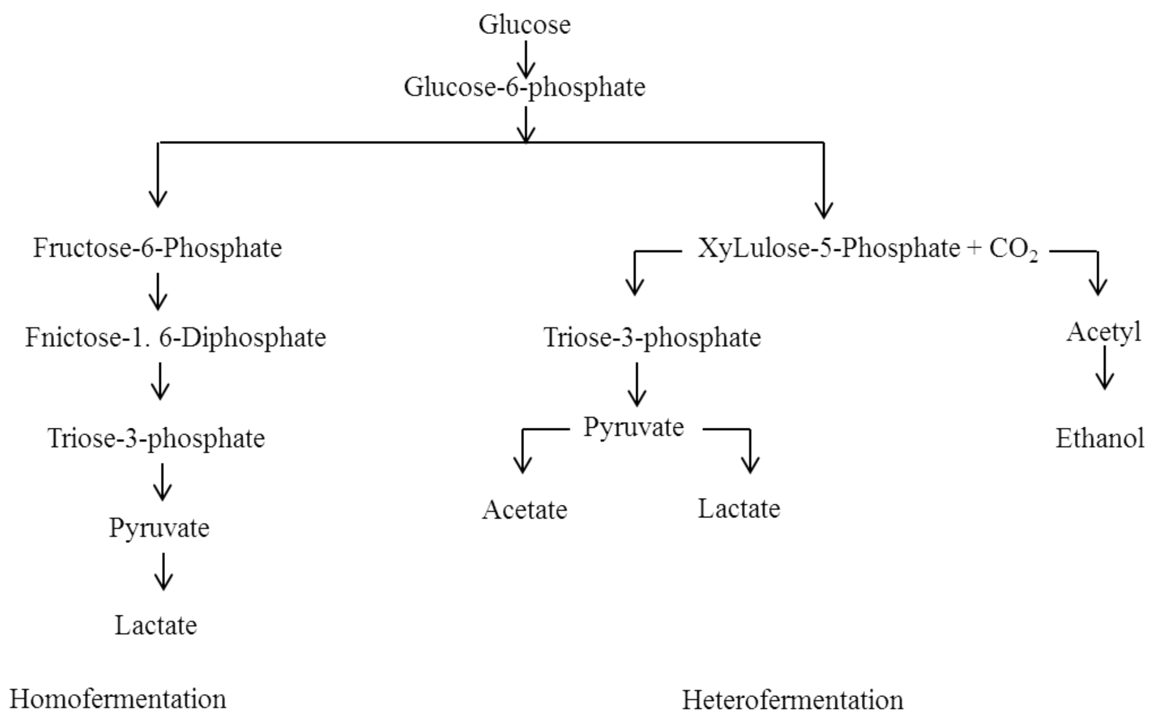
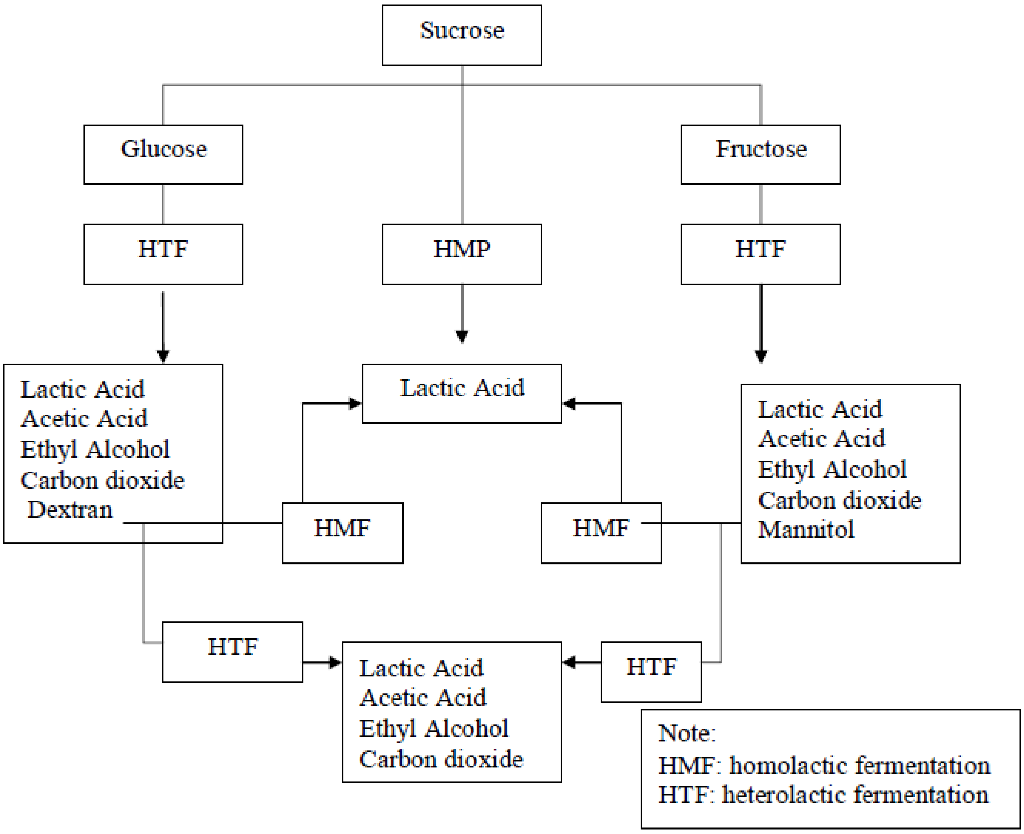


Fig. 2.2 Glycolysis

Source: Shrestha (2002)

2.2.5 Complexity of LAB fermentation

Many lactic acid fermentation particularly those involving vegetable are invariablby initiated by strains of *L.mesenteroids*, whereby lactic acid, CO_2, ethanol and acetic acids are major end products. In the fermentation of fructose, mannintol is produced, and from sucrose, dextran may be an important by product. The heterofermenters are noted for their ability to ferment the pentose sugar, arabinose and xylose. The heterolactic fermenter differs fundamentally from the homolactic fermentation. Glucose, after conversion to glucose-6-phosphate, is oxidized to 6-phosphogluconate, an important intermediate. This is converted to pentose phosphate, ribose-5-phosphate, which in turns splits into a three carbon unit finally to yield lactic acid and a two carbon unit to yield ethyl alcohols and/or alcohols and/or acetic acids. In the fermentation of fructose, three molecules of fructose are reduced to two molecules of mannintol with one molecule each of lactic acid, acetic acids and ethyl alcohol, and carbondioxide The heterolactic bacteria, particularly the strains of L.mesenteroids, use glucose to form dextran molecules while the fructose portion of sucrose is fermented to lactic acid, acetic acid, ethyl alcohol and CO_2 (Fig. 2.3). Dextran's are used as food stabilizers (Pederson, 1971).



Source: Upadhaya (2002)

Fig. 2.3 Hetero and homo fermentation of sucrose by lactic acid bacteria

2.2.6 Beneficial effects claimed for lactic acid bacteria

It has been acknowledge that lactic fermented food products have several advantages, the more important of which are as follows (Upadhaya, 2002):

1. Nutritional improvement of food
2. Inhibition of enteric pathogens
3. Hypothetical esteemed value
4. Anticancer activity
5. Stimulation of immune system

2.3 Sauerkraut

2.3.1 History of sauerkraut

Sauerkraut, long thought to be a creation of German, or East European descent is actually theorized to be a Chinese invention. Additionally, it is actually suggested that vegetable fermentation itself started in China. This theory stems from the belief that sauerkraut was used as food for laborers of the Great Wall of China, a little over 2,000 years ago (Terroir, 2016). During the construction of the Great Wall in the 3rd century BC., The Chinese workers nourished mainly on leavened cabbage and rice (R. K. Pundir and Jain, 2010).

Sauerkraut is thought to have originated in the north of China among the Mongols and was introduced in Europe by migrating tribes. Eastern Europeans, in particular, consume a large amount of sauerkraut. Jews adopted sauerkraut as part of their cuisine and are thought to have introduced it in the northern countries Western Europe and the United States. Sauerkraut is a staple of the winter diet in Germany and the Netherlands. While sauerkraut is customarily prepared with pork, Jews customarily use goose or duck meat (R. K. Pundir and Jain, 2010).

Cabbage is easy to grow in large quantities and is very reasonably priced. Therefore it was later often used to supply large groups of people. In 1804 a French chef managed to preserve cooked foods in closed containers. Henceforth Napoleon's Grande Armée carried besides sauerkraut in casks also boiled cabbage in jars and soldered cans with it. This procedure was adopted by the competing powers and so sauerkraut became during wars in Europe an important food for the armies. For this reason the Germans were referred primarily by the Americans as "The Krauts" in the First World War (Lonergan and Lindsay, 1979).

Although the average consumption in France and America is higher than in Germany, sauerkraut has remained an important part of German cuisine for many centuries until today. Industrial sauerkraut is produced since the end of the 19th century. About 200,000 tons of white cabbages are processed into sauerkraut in Germany per year. Previously it was mainly served as a side-dish accompaniment to severe, fatty meats. Today sauerkraut is now an important part of a healthy, balanced and varied diet. It can now be found in savory and fruity salads as well as in soups, stews, stir-fries and casseroless (Lonergan and Lindsay, 1979).

2.3.2 Technology of sauerkraut preparation

The first stage of sauerkraut fermentation involves anaerobic bacteria, which is why the shredded cabbage and salt need to be packed in an airtight container. At this stage the surrounding environment is not acidic, just cabbage. The bacteria, mostly *Leuconostoc* species, produce carbon dioxide (replacing the last vestiges of oxygen in the jar) and lactic acid, which is a natural byproduct of anaerobic respiration. Eventually, the conditions within the jar become too acidic for these bacteria to survive and they die out, replaced with bacteria that can better handle the acidic conditions such as *Lactobacillus* species (Gould, 2014).

The *lactobacillus* further ferments any sugars remaining in the cabbage, using anaerobic respiration. This produces more lactic acid, until the sauerkraut reaches a pH of about 3. These bacteria are inhibited by high salt concentrations (so most sauerkraut contains around 2-3% salt) and low temperatures. The high salt concentration and low temperature inhibit lactic acid bacteria to some extent (FAO, 1998). At pH 3 the *lactobacillus* stop fermenting and the sauerkraut can be stored until needed. All these bacteria help to create the tangy acidic taste, however there are ways that microbial growth can go wrong. Overgrowth of the lactobacillus, for example if the jar is stored at too high a temperature during fermentation, can cause the sauerkraut to form the wrong consistency. Likewise if the sauerkraut gets too acidic too early the lactobacillus gets in on the action early leading to soft sauerkraut. Although the finished sauerkraut is far too acidic for pathogens to live in, fungal spores may settle on the surface and spread, spoiling the food (Gould, 2014).

2.3.3 Sauerkraut fermentation

Sauerkraut is an important fermented product prepared out of cabbage (Lakshmana and Rajanna, 2001). Sauerkraut fermentation requires almost no work on the part of the operator. Cabbage contains enough lactic acid bacteria in order to ferment and produce sauerkraut with salt alone. In order to obtain product of the highest quality all those bacteria strains must ferment in a certain sequence. This happens naturally as long as sauerkraut is fermented around 65°F (18°C).

1. *Leuconostoc mesenteroides* - they are the smallest and start the fermentation first producing around 0.25 to 0.3% lactic acid. They are heterofermenters, this means that they produce different compounds such as lactic acid, acetic acid (vinegar),

ethyl alcohol, carbon dioxide (soda gas) and mannitol. The last one is a bitter flavored compound which is metabolized later by *Lactobacillus plantarum*. All those acids, in combination with alcohol from aromatic esters, contribute to the characteristic flavor of the high quality sauerkraut. If the temperature is higher than 72°F (22°C) they might not grow and that would be detrimental to the flavor of sauerkraut. In about 2 days *Leuconostoc mesenteroides* will produce 0.3% lactic acid and this increased acidity will restrict its growth. Nevertheless, the enzymes it produced will continue to develop flavor.

2. *Lactobacillus plantarum* - this strain takes over the production of lactic acid from *Leuconostoc mesenteroides* and continues fermenting until an acidity level of 1.5 to 2% is achieved. *L. plantarum* will ferment at temperatures higher than 72°F (22°C) and it can grow at higher acidity levels. It will ferment at lower temperatures as well, albeit at much slower rate. *Lactobacillus plantarum* is the most popular lactic acid bacteria strain and it ferments sauerkraut, pickles, cheese and even meat. This bacteria is a homofermenter what means that it produces one compound only. It consumes sugar and produces lactic acid which imparts acidic taste to fermented food. At the end of this stage sauerkraut has an acceptable quality and can be served or canned. If there is enough sugar left, the fermentation will continue until all sugar supply is exhausted.

3. *Lactobacillus pentoaceticus (L.brevis)* - continue fermenting until an acidity level of 2.5 - 3% is obtained. As there is no more sugar left in the cabbage the fermentation comes to the end (Anon).

2.3.4 Effect of fermentation temperature

The best quality sauerkraut is produced at 65-72°F (18-22°C) temperatures. Temperatures 45.5°F (7.5°C) to 65°F (18°C) favor the growth and metabolism of *L.mesenteroides*. Temperatures higher than 72°F (22°C) favor the growth of *Lactobacillus* species. Generally, lower temperatures produce higher quality sauerkraut, although at 45.5°F (7.5°C) bacteria are growing so slow that the cabbage might need 6 months to complete fermentation. Higher temperatures produce sauerkraut in 7-10 days but of the lesser quality. This creates such a fast fermentation that some types of lactic acid bacteria don't grow at all and less reaction take place inside what results in a less complex flavor.

- Below 45.5°F (7.5°C) fermentation time is up to 6 months.
- At 65°F (18°C) fermentation time is 20 days.
- At 90-96°F (32-36°C) fermentation time is 10 days (Anon).

2.3.5 Health benefits of sauerkraut

Sauerkraut gives plenty of health benefits. Some of them are as follows:

1. Digestion

As fiber is a star in sauerkraut nutrition facts, it is undeniable that one of the best health benefits of sauerkraut is to facilitate the digestion. For long, it has been well-known that the consumption of fiber rich vegetables will boost the digestion effectively (McDougall *et al.*, 2007).Sauerkraut, a product from cabbage, will supply the body with a high amount of fiber to fight against digestive disorders . The supplement of dietary fiber will have positive effects on the bowel movements, making stools soft and smooth (Carney, 2016).

2. Immunity

The immune system serves as a protective shield to prevent bacteria and virus from damaging human health (Strohle and Hahn, 2009). When immune system is strong, there will be less likely to experience problems, such as common colds or flu. And one of the easiest and best ways to strengthen the immune system is to provide vitamin C (Wintergerst *et al.*, 2006). With a high amount of vitamin C in sauerkraut, to enhance the immunity is definitely one of the best sauerkraut health benefits. The content of vitamin C in sauerkraut can meet 35% of the daily need of an ordinary person (Carney, 2016).

3. Bone

With a variety of minerals in sauerkraut nutrition, bones can profit from this ingredient as well. In fact, among top health benefits of sauerkraut, its effects on the bone health are amazing. Sauerkraut can provide a certain amount of vitamin K that is equal to 23% of a person's daily need. Particularly, vitamin K is a quite uncommon mineral that exists only in a certain number of foods. Many studies have concentrated on the importance of vitamin K in bone health (Weber, 2001).The results indicated its effectiveness in the prevention against osteoporosis, a common bone-related problem for the old (Adams and Pepping, 2005).

4. Eyes

In addition to vitamin C and K, vitamin A is also another outstanding point in sauerkraut nutrition facts. It is responsible for health benefits of sauerkraut in the eyes. Vitamin A, along with other carotenes in sauerkraut, can accelerate the eradication of free radicals. Furthermore, there is an association between the high intake of vitamin A and the lower risk of cataracts and macular degeneration (Li-Quan *et al.*, 2014).

5. Energy boost

Sauerkraut contains approximately 8 percent of iron, which constitutes various sauerkraut health benefits (Carney, 2016). The first benefit of iron is to boost energy level almost instantly. Iron has positive influence on the blood circulation, which enables different organs in the body to get more oxygen (SACN, 2010). As a result, one can be more energetic and perform daily activities more effectively. Moreover, the intake of iron will protect you from some problems caused by its deficiency, such as anemia (16).

6. Anti-inflammatory properties

If the vitamins and minerals present in sauerkraut weren't enough, there are also certain organic compounds found in this cabbage variant that work as anti-inflammatory agents. Phytonutrient antioxidants in sauerkraut can double as anti-inflammatory agents, reducing the pain and discomfort of joints, muscles, or other inflamed areas (Ostermann *et al.*, 2014)

7. Cancer prevention

Sauerkraut fermentation prevent the growth of cancer cells (Pandey and Garg, 2015). Although research is still underway to reveal the exact impact of sauerkraut on cancerous cell.The presence of antioxidant compounds in sauerkraut (as with all cruciferous vegetables) means that free radicals can be eliminated, which are noted as one of the main causes of cancerous cell formation (Ostermann *et al.*, 2014).

8. Helps lose weight

Sauerkrauts are great when it comes to losing weight. A mere half a cup of sauerkraut contains 20 calories. These vegetables have also been considered one of the healthiest foods of the world. They prevent constipation, cramping, bloating and make the process of digestion smooth (Ostermann *et al.*, 2014).

9. Treats skin infections

Sauerkrauts are excellent for our skin health. They provide relief from acne and heal wounds and bruises effectively. Sauerkrauts also treat skin infections as they are rich sources of antioxidants. They are rich in Vitamin B and C which work wonders for hair and skin (Ostermann *et al.*, 2014).

10. Treats morning sickness

Morning sickness is a health condition that affects 50% of all pregnant females. It includes vomiting and feelings of nausea. A few symptoms of morning sickness are vomiting blood, racing heartbeats, headaches and dark coloured urine. A smart and easy way to eliminate morning sickness is by adding more sauerkraut to our diet. It will treat morning sickness effectively and reduce symptoms significantly (Ostermann *et al.*, 2014).

11. Reduces oxidative stress

Cruciferous vegetables such as sauerkraut reduce oxidative stress effectively. Oxidative stress is understood as a load of harmful molecules known as oxygen free radicals which are generated by the body. Reducing these free radicals will prevent breast, lung and other cancers (Ostermann *et al.*, 2014).

2.3.6 Nutritional value of sauerkraut

Sauerkraut is very low-calorie, but it’s an anti-inflammatory and is packed with benefits. Besides having probiotics to offer, sauerkraut is a good source of antioxidants and dietary fiber too. As an added bonus, the proliferation of lactobacilli in fermented vegetables enhances their digestibility and increases absorption of their various vitamins. Sauerkraut contains high levels of dietary fiber, as well as significant levels of vitamin A, vitamin C, vitamin K, and various B vitamins. It is a good source of iron, manganese, copper, sodium, magnesium, and calcium, in addition to contributing a moderate amount of protein to the diet (Holzapfel *et al.*, 2003).

The nutritional composition of sauerkraut is presented in Table 2.1.

Table 2.1 Nutritional value of sauerkraut

Parameters	% Daily Value
Total Fat	0.2
Sodium	19.55
Total carbohydrate	1.0
Dietary fiber	7.5
Protien	1.3
Vitamin A	0.3
Vitamin C	17.4
Iron	5.8

Source: Anon. (2015)

2.4 Drying of fruits and vegetable products

From the engineering point of view, drying is the unit operation in which nearly all the free moisture in food stuff is removed by evaporation or sublimation as a result of application of heat at controlled condition. This definition doesn't include alternate method of moisture removal like filtration, membrane separation, centrifugation, distillation etc (Greensmith, 1998).

Fruits and vegetables are important sources of essential dietary nutrients such as vitamins, minerals and fiber. Since the moisture content of fresh fruits and vegetables is more than 80%, they are classified as highly perishable commodities. Keeping the product fresh is the best way to maintain its nutritional value, but most storage techniques require low temperatures, which are difficult to maintain throughout the distribution chain. On the other hand, drying is a suitable alternative for postharvest management. It is noted that over 20% of the world perishable crops are dried to increase shelf-life and promote food security. Fruits, vegetables and their products are dried to enhance storage stability, minimize packaging requirements and reduce transport weight (Sagar and Suresh, 2010). Fruits, vegetables, and their products in the dried form are good sources of energy, minerals, and vitamins. However, during the process of dehydration there are changes in quality parameters in dried products (Sablani, 2006). Drying is the process which is done in uncontrolled condition whereas dehydration refers to the application of heat under controlled conditions in order to remove the majority of water normally present in food (Harrison and Andress, 2012).

Dehydration is one of the most effective means to extend the shelf life of perishable foods. The main purpose of dehydration in preserving foods is to remove moisture so that the water activity of the dehydrated product is low enough (e.g., aw < 0.6) to stop spoilage and the growth of pathogenic microorganisms and to reduce other deteriorative reactions. Dehydration is also used in combination with other hurdles, such as low pH and use of preservatives, to extend the shelf life of foods. Dehydration significantly reduces the costs of transportation and storage, because of the significantly reduced weight and volume of the dehydrated products and because the products do not require refrigeration. In addition, dehydration is an effective method to prepare convenient food ingredients for use in products such as dry soup mixes, frozen entrees, baby foods, and dairy products, or directly as seasoning blends (Somogyi and Luh, 1988). Dehydration, being one of the oldest methods of food preservation, represents a very important aspect of food processing (Lin *et al.*, 1998). Longer shelf life, product diversity and volume reduction are the reasons for the popularity of dried fruits and vegetables (Prakasha *et al.*, 2004). Dehydration removes water from foods to a final concentration, which assures microbial stability of the product and minimizes chemical and physical changes of the material during storage. In most drying processes water is removed by convective evaporation, in which heat is supplied by hot air (Lewicki and Jakubczyk, 2004).

2.4.1 Mechanism of drying

When hot air is blown over a wet food, heat is transferred to the surface, and latent heat of vaporization causes water to evaporate. Water vapor diffuses through a boundary film of air and is carried away by the moving air. This creates a region of lower water vapor pressure at the surface of food and a water vapor surface gradient is established from the moist interior of food to the dry air. This gradient provides the driving force for water removal from food. Water moves to the surface by following mechanisms (Mcallister, 2018).

1. Liquid movement by the capillary forces
2. Diffusion of the liquids, caused by difference in the concentration of solutes in different regions of food.
3. Diffusion of the liquid which is adsorbed in layers at the surface of solid components of food.
4. Water vapor diffusion in air spaces within the food caused by vapor pressure gradients.

Movement of moisture during drying is illustrated in Fig 2.4

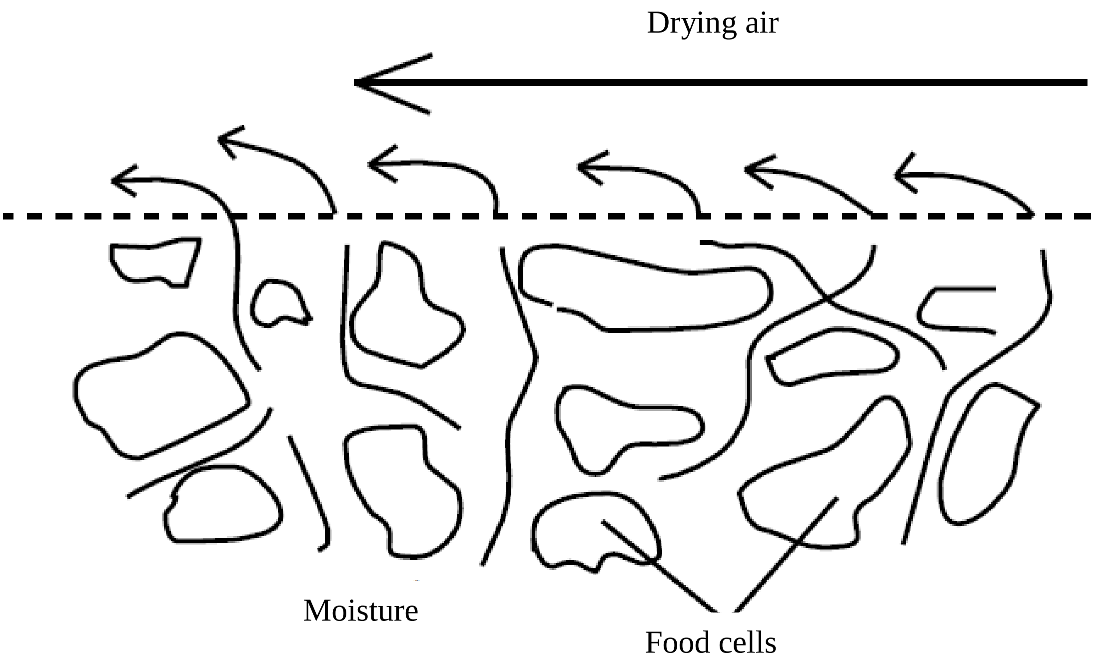


Fig. 2.4 Movement of moisture during drying (Kharel, 2004)

In foods, water is present as free water and bound water. Free or unbound water is present within the pores and spaces between plant cells. It has the same characteristics as pure water. It exerts the same vapor pressure and same latent heat of vaporization as pure water. It is easily removed during drying. Bound water is held on the surfaces of solid compounds, such as cellulose, hemicelluloses, in cell wall by molecular interactions between water and the solid. It exerts a vapor pressure less than that of pure water and doesn't evaporate easily. Also the latent heat of vaporization is greater than that of pure water at a given temperature. It requires more heat to release and therefore bound water is not usually removed during drying. During drying of a wet solid in a heated air, the air supplies necessary sensible and latent heat of evaporation, act as a carrier gas for the removal of water vapor formed from the vicinity of evaporating surface (Kharel, 2004).

2.4.2 Different methods of drying

The main methods used for drying vegetables are outlined as follows:

a. Sun drying

Sun drying is a natural method of drying, makes use of sunlight, requires time and some effort by man to spread and collect the produce (Hall, 1970). Sun drying has little or no operating cost but is space consuming and has poor control over the drying rates which might enhance mold growth (Anon, 1986). Sun drying is the oldest method of food drying particularly in developing countries. However, this technique is extremely weather dependent, and has the problems of contamination with dust, soil, sand particles and insects, and being weather dependent. Also, the required drying time can be quite long. Moreover, this is the most labor intensive method of food drying. Large number of workers is required to spread the foods in the morning, turn it during the day and collect it in the evening. Therefore, using solar dryers, which are far more rapid, providing uniformity and hygiene are inevitable for industrial food drying processes (Diamante and Munro, 1993)

Sun drying temperature varies with the variation in geographical regions. In tropics, a produce spread on matting in a layer not thicker than about 5cm receives a drying temperature of about 30ºC on an average (Desrosier, 1987). In such slow drying process, natural antioxidant of the vegetable tissue will be poorly retained (Desrosier, 1987). The time of sun drying depends on the product characteristics and drying conditions and typically ranges from 3 to 4 days but can be longer, for example, 3 to 4 weeks for raisins and apricots (Sokhansanj and Jayas, 1995).

b. Solar drying

Sun drying is not as sanitary as other methods of drying. An improved indirect solar dryer, a natural draft dryer is used recently which consists of a rectangular box dryer with two chambers for heating and drying respectively. This method uses sun's energy for drying but excludes open air sun drying. Solar drying is more effective than sun drying and has low operating cost than the other mechanical dryers. A simple principle involved in solar dryer is that, air is drawn through the dryer by natural convection. The air is heated as it passes through the collector and then partially cooled as it picks up moisture from the produce. The produce is heated both by the hot air and sun (Olivia, 2009).

c. Cabinet drying

Cabinet drier consist of an insulated cabinet fitted with shallow mesh or perforated trays, each of which carries a thin layer of food. Hot air is circulated through the cabinet tray. A system of duct and baffles is used to direct air, over and/ or through each tray, to promote uniform air distribution either horizontally between the trays of food materials or vertically through the trays and food. Air heaters may be direct gas burners, steam coil exchangers or electrical resistance heaters. The air is blown past the heaters and thus heated air is used for dying. It is relatively cheap to build and maintain, flexible in design, and produces variable product quality due to relatively poor control. It is used singly or in groups, mainly for small- scale production (1-20 ton/day) of dried fruits and vegetables (Fellows, 2000).

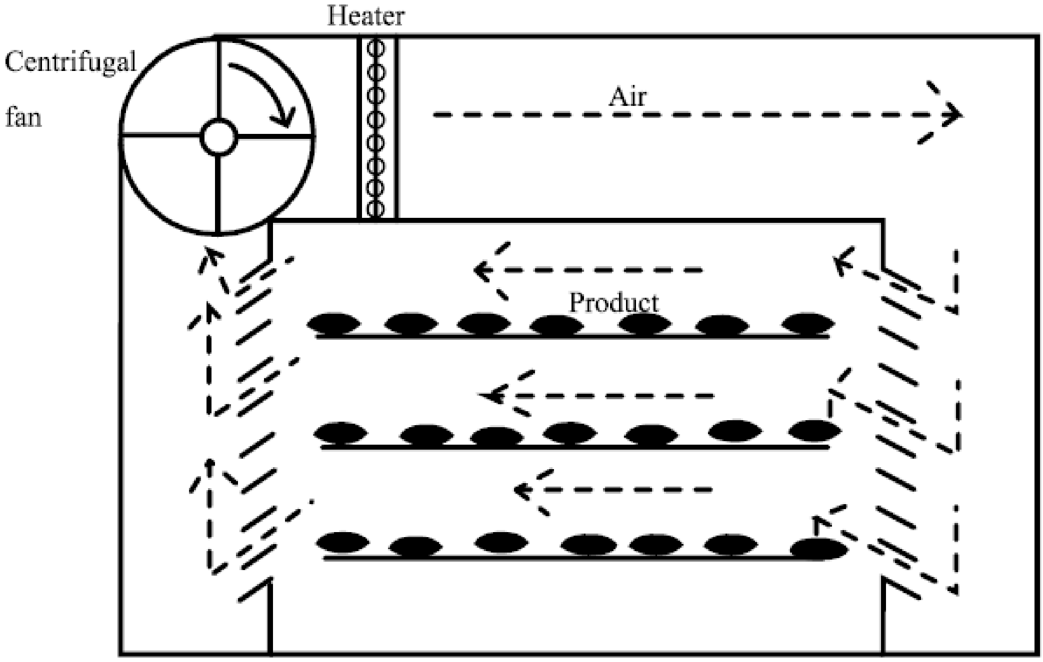


Fig. 2.5 Cabinet drier

2.4.3 Preservation of food by drying

Drying removes the moisture from the food so bacteria, yeast and mold cannot grow and spoil the food. Drying also slows down the action of enzymes (naturally occurring substances which cause foods to ripen), but does not inactivate them. Because drying removes moisture, the food becomes smaller and lighter in weight. When the food is ready for use, the water is added back, and the food returns to its original shape. Foods can be dried in the sun, in an oven or in a food dehydrator by using the right combination of warm temperatures, low humidity and air current. In drying, warm temperatures cause the moisture to evaporate. Low humidity allows moisture to move quickly from the food to the air. Air current speeds up drying by moving the surrounding moist air away from the food (Harrison and Andress, 2012).

2.4.4 Benefits of dehydrated food

The benefits of dehydrated food (Kent, 2009) are as follows:

- Dried vegetables and sprouts, naturally low in "high-cholesterol" fats, are high in fiber (Ronberg, 2017).
- Dried food doesn't need to be refrigerated.
- Dried food takes up much less space than fresh or canned food.
- It is a great way to add variety to the long term food storage.
- It maximizes the shelf life.
- They are shelf stable. Unaffected by power outages.
- Dehydrated foods save cooking time. (Kent, 2009)

2.4.5 Nutritional value of dried foods

Dehydrated foods are usually dried with low heat thus having minimal effects of the nutritional value of the food. This produces a high quality product, which when compared with the extreme temperatures involved when canning or freezing, is the least damaging form of food preservation. Fresh food dried from the own garden and commercially dehydrated or freeze-dried foods may even contain more nutritional value than fresh foods Dried foods can be bought from the grocery store because they are usually dried within hours of being picked, at their peak of freshness and then processed to preserve their nutritional benefit (Kent, 2009).

2.5 Rehydration

Rehydration capacity is one of the indices of water absorption of dried plant tissues expressed as the ratio of weight after rehydration to initial weight (Levi *et al.*, 1988) and it is a quality parameter that is associated with the level to which a dried product can regain its original structure. Dehydrated products can be used in many processed or ready-to-eat foods in place of fresh foods and have several advantages such as convenience in transportation, storage, preparation and use (Mazza and LeMague, 1980). Dehydrated products need to be rehydrated before consumption or further processing (Oliveira and Ilincanu, 1999). Solids eaten after rehydration should be characterized by color, size, shape and texture resembling the raw material. Hence, the rehydration rate and the rehydration degree are important parameters determining the quality of the product (Lewicki, 2006).

Rehydration is an important step in the utilization of dried fruits and vegetables. For rehydrated vegetables, the most pertinent properties are related to the texture and flavor. The rate and extent of rehydration may be used as an indicator of food quality; those foods that are dried under optimum conditions suffer less damage and rehydrate more rapidly and completely than poorly dried foods (Fellows, 2000). Rehydration is influenced by several factors, grouped as intrinsic factors (product chemical composition, pre-drying treatment, product formulation, drying techniques and conditions, postdrying procedure, etc.) and extrinsic factors such as composition of immersion media, temperature, hydrodynamic conditions. Some of these factors induce changes in the structure and composition of the plant tissue, which results in the impairment of the reconstitution properties (Akonor and Tortoe, 2014). Consumers usually tend to prefer processed rehydrated vegetables with a firmer texture than those typically produced by a conventional (well controlled) process. Therefore, textural improvement has become essential outcome of dehydration (Quintero-Ramos *et al.*, 1992).

The loss of texture in this product is caused by gelatinization of starch, crystallization of cellulose and localized variations in the moisture content during drying which set up internal stresses. These rupture cracks, compress and permanently distort the relatively rigid cells to give the food a shrunken shriveled appearance. On rehydration the product absorbs water more slowly and does not regain the firm texture of the fresh material. There are substantial variations in the degree of shrinkage and rehydration with different foods (Fellows, 2000) . Dried dehydrated products are usually subjected to reconstitution test in which water is added to the product to restore to a condition similar to that when the material was fresh. The rehydration ratio (RR) is given by the ratio of drained dehydrated weight to weight of sample before drying:

$$\text{Rehydration ratio} = \frac{WR}{WD} \quad \text{[Eq. 1]}$$

Where: WR = Drained weight of rehydrated sample; WD = Weight of dried/dehydrated sample.

In the same light dehydration ratio (DR) can be expressed (Hiremath *et al.*, 2009) as:

$$\text{Dehydration ratio}=\frac{\text{WD}}{\text{WRm}} \quad [\text{Eq. 2}]$$

Where: WRm = Weight of raw material (before drying).

It is obvious, for a host of reasons stated by Fellows (2000), DR is always less than DR, implying that reconstitution can never be 100%.

Dauthy (1995) and Ranganna (1986) have given an expression for calculating rehydration coefficient (Rcoeff), another metric used to test rehydration property:

$$\text{Rehydration coefficient}=\frac{\text{WR}\times(\text{100-MD})}{(\text{WD-WMd})\times 100} \quad [\text{Eq. 3}]$$

Where: MD = Moisture content of material before drying (i.e., of the fresh material), WMd = Amount of moisture present in the dried sample taken for rehydration

Data from [Eq. 3] can then be used to calculate the moisture content (MR) in the rehydrated sample by the following expression (Ranganna, 1986):

$$\text{Moisture content}=\frac{\text{WR-DR}}{\text{WR}}\times 100 \quad [\text{Eq. 4}]$$

Where: DR = Dry matter content in the sample taken for rehydration.

2.6 Sensory properties

Sensory analysis provides complementary information on human perception of fermented vegetable. According to Han *et al.* (2014) the sensory parameters of cabbage fermented by the mixed starter *Lb. delbrueckii* IWQ and *Lb. paracasei* J21 were significantly higher than that of the cabbage fermented by local plant starter ($P < 0.05$) in terms of color, pungent odor, taste, sour, texture, and overall acceptance of fermented cabbage except crisp. And for the all sensory evaluation, panelists preferred the Chinese cabbage fermented by the combination *Lb. delbrueckii* IWQ and *Lb. paracasei* J21 rather than the sample inoculated starter culture from the local fermented cabbage plant. Texture is the principal quality attribute that influences consumer acceptability of fermented vegetable and is dependent upon several characteristics like cell wall composition, cell structure, and tissue turgescence (Han *et al.*, 2014).

Panelists perceived the raw cabbage-like flavor in all sauerkraut assessed with low intensity. Low scores for this attribute can be considered a positive characteristic for consumers, because raw cabbage-like taste is associated with green or immature sauerkraut. Natural fermentation performed at 1.5% NaCl received the highest score for this descriptor, and no significant differences ($P<0.05$) were found between this sauerkraut and those obtained by *L. plantarum* at both salt concentrations. In addition, no significant differences were found ($P<0.05$) for raw cabbage flavor between commercial sauerkrauts and *L. mesenteroides* and the mixed starter culture at both NaCl levels and with natural fermentation and *L. plantarum* at 0.5% NaCl. Isothiocyanates generated from glucosinolates by the action of myrosinase have been reported to be responsible for this pungent raw-cabbage flavor. Kraut sulfur,which is the typical sulfurous flavor associated with properly fermented sauerkraut, was slightly lower at 0.5% NaCl than at 1.5% NaCl, in all fermentation trials, although no significant differences ($P<0.05$) between salt concentrations were observed. Sulfur compounds derived from S-methylcysteine sulfoxide and some glucosinolates in raw cabbage appeared to be important for kraut flavor developed during fermentation (Penas *et al.*, 2010).

With respect to the acid flavor, commercial sauerkrauts and those obtained in the presence of the mixed culture were awarded the highest scores. These results are directly linked to the lowest pH values obtained at the end of fermentation, as was stated above. Among them, commercial sauerkraut A and sauerkraut obtained with the mixed starter culture at 0.5% NaCl presented significantly ($P<0.05$) higher values for this attribute than the other three sauerkrauts, possibly due to their similar pH values. In contrast, natural fermented sauerkraut at 1.5%NaCl and sauerkrauts obtained at 0.5% using *L. plantarum* and *L. mesenteroides* showed the lowest values. These fermented products earned higher ratings for overall acceptability than the more acid commercial sauerkrauts, indicating that consumers prefer mild-flavored sauerkrauts, in terms of acid content. In general, the lowest raw cabbage flavor scores corresponded with the highest acid flavor scores, and these results thus indicate that the acid flavor may be responsible for masking the typical cabbage like flavor (Penas *et al.*, 2010).

Part III

Materials and methods

3.1 Raw materials

Several varieties of cabbage were found in market. Collection of sample was done in the first week of manghsir. Cabbage was collected from local market of Dharan and the variety was identified as 'Taiwanese' variety.

3.2 Equipment

Stainless steel vessel, knives, chop board, Hand refractometer (0-30, ATAGO, made in Japan), electric balance (PHOENIX instrument, 620 g), pan balance, pH meter (LABTRONICS, made in india), gas stoves and daily routine glassware were used that were available in the campus.

3.3 Methods

3.3.1 Shredding of cabbage

All the equipment, working surfaces were washed with clean water. Cabbage sample purchased from local market were sorted out from sound ones according to color and quality of flesh. Outer leaves and cores of cabbage were removed. Plastic jars were sterilized properly by steeping in hot water. With the help of sharp knife, cabbage was cut into thin shreds of about 3-4 mm thickness (Penas *et al.*, 2017).

3.3.2 Adding salt

Thinly sliced cabbage was placed in a large bowl. Salt was sprinkled over it. Sample was prepared as shown in Table 3.1. Cabbage was then left for sometimes. After a few minutes, the cabbage started releasing water that was enough to cover the cabbage entirely.

3.3.3 Moving it to fermentation jar

Cabbage was then stuffed into the jar. Previously released water was poured into the jar. Jar was then covered with a lid. Plastic bag with the amount of water was adjusted to give just enough pressure to keep the fermenting cabbage covered with brine.

3.3.4 Fermentation

Fermentation was done in room temperature by varying brine concentration that last for 15 days.

Table 3.1 Outline of experimental design

Sample code	Salt (%)	Fermentation Time (days)
A	2	9
B	2	12
C	2	15
D	2.25	9
E	2.25	12
F	2.25	15
G	2.5	9
H	2.5	12
I	2.5	15

3.3.5 Dehydration

Fermented sauerkraut was taken out from the jar. Any liquid present on sauerkraut was removed by squeezing with hands. Then those squeezed sauerkraut was spread on to dehydrator trays. It was dehydrated for 6 h at 60˚C.

3.3.6 Packaging

Dried sauerkraut was then stored properly by packaging in a plastic packaging material. LDPE was used as a packaging material which was done by vacuum packaging.

3.3.7 Rehydration

Rehydration of dried sauerkraut was done in water per (Ranganna, 1986).

The flowchart of sauerkraut preparation is shown in Fig. 3.1.

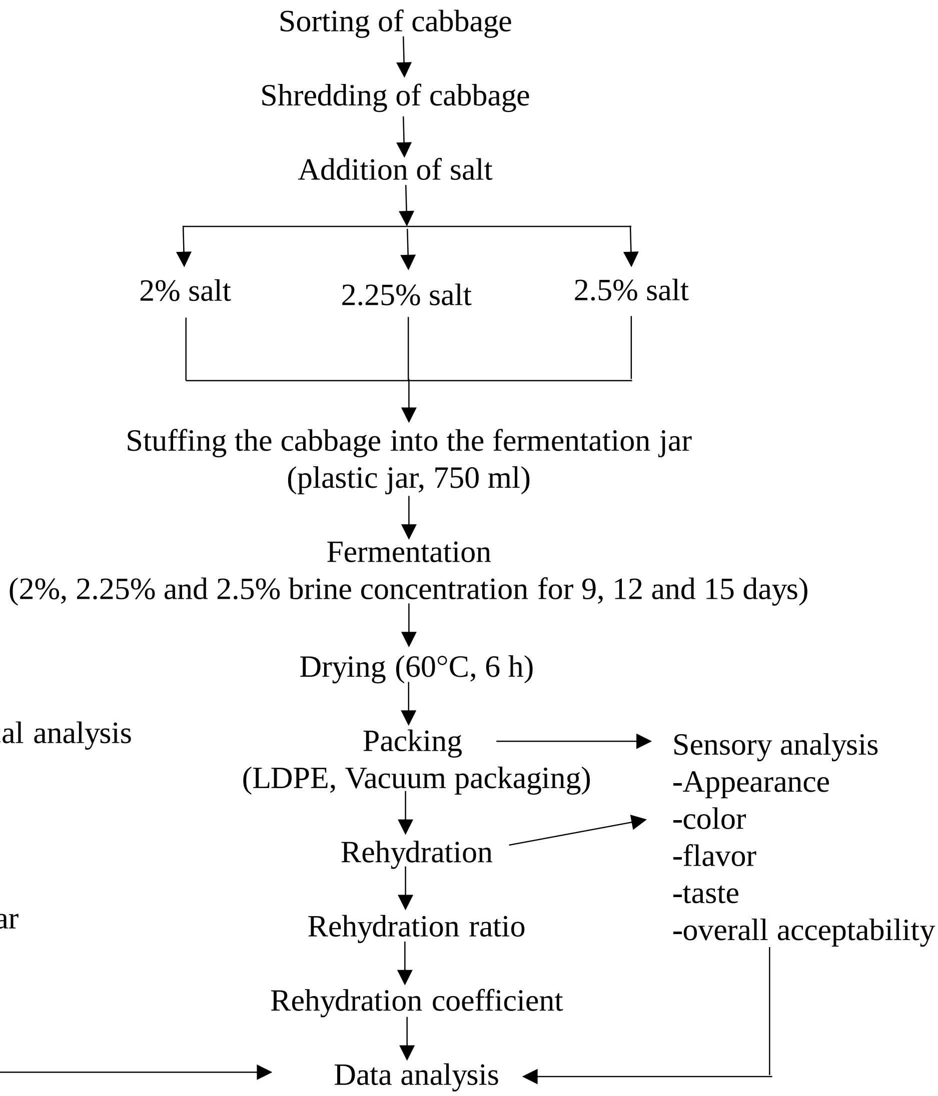


Fig. 3.1 Flowchart of sauerkraut preparation

3.4 Determination of physicochemical composition of sauerkraut

The different physicochemical quality parameters of sauerkraut like; total soluble solid, total solid, acidity, pH, reducing sugar and vitamin C were determined.

3.4.1 Total soluble solid

Total soluble solid (◦Bx) was determined by using pocket refractometer. The refractometer was washed with distilled water and dried using blotting paper. The macerated sample juice prepared was taken. 2-3 drops were applied on refractometer and observed.

3.4.2 Acidity

Ten g of ground sample was poured in 100 ml volumetric flask and volume was made up with distilled water a0nd filtered with cotton. 10 ml of aliquot was pipette out and it was titrated with 0.1N NaOH solution. The acidity of the sample was expressed as % lactic acid as given in Ranganna (1986).

3.4.3 pH

pH was determined by using digital pH meter. The pH meter was calibrated at pH 7 and 4 using citrate- phosphate and phthalate buffer respectively before measuring pH (Ranganna, 1986).

3.4.4 Sugar

Total sugar and reducing sugar were determined by using Lane and Eynon method. 10 g of ground sample was poured in 100 ml volumetric flask and half of volume was made up with distilled water. Then the solution was neutralized by NaOH and carrez I and carrez II was added respectively at the interval of 1 min and the volume was made upto 100 ml using distilled water. The prepared sample was filtered and 10 ml of aliquot was taken for titration with Fehling's solution as described by Ranganna (1986).

3.4.5 Vitamin C

Ascorbic acid was determined by the 2, 6-dichlorophenol-indophenol visual titration method as described by Ranganna (1986). The sample was prepared by taking 10 g of ground sauerkraurt in 100 ml volumetric flask. The volume was made up using 3% H_3PO_4 solution.

3.4.6 Sensory analysis

Sensory evaluation of dehydrated and rehydrated sauerkraut for various sensory characteristics was carried out. The dried and rehydrated samples were presented to 10 semi-trained panelists (including teachers and research students) using the method described by Ranganna (2010). The different dehydrated and rehydrated samples with different concentration and fermented time were coded as A, B, C, D, E, F, G, H and I. The panelists were asked to indicate their observations using a 9 point hedonic rating scale for color, appearance, flavor, taste and overall acceptability. Like extremely and dislikes extremely were ranked 9 and 1 respectively.

3.4.7 Statistical analysis

The mean values with standard deviation were computed. Data were subjected to Analysis of Variance statistical software GenStat Release 12.1 (Discovery Edition 12 developed by VSN International Limited). Fischer's least significant difference (LSD) test was used to define the differences between the means at the 5% level of significance.

3.4.8 Coefficient of rehydration

The coefficient of rehydration of rehydrated samples was calculated as per Ranganna (1986) as shown in Eq 3.

Part IV

Results and discussion

Sauerkraut was prepared from cabbage with the variation in salt concentration. Fermentation was done for 9, 12 and 15 days having 3 sample each with 2%, 2.25% and 2.5% salt concentration.

4.1 Physicochemical analysis of cabbage

The physicochemical analysis of cabbage was shown in Table 4.1.

Table 4.1 Physicochemical analysis of cabbage

Parameter	Value
pH	6.53 (0.13)
Acidity (%)	0.30 (0.05)
TSS (° Bx)	7.30 (0.36)
Reducing sugar (%)	2.137 (0.06)
Vitamin C (%)	9.309 (0.16)
Moisture content (%)	58.09 (0.75)

The result of physicochemical analysis of cabbage was similar to (Faltmarsch *et al.*, 2010)

4.2 Changes in pH and acidity during fermentation

The pH for the fermentation in 2% brine concentration was found to decrease from 6.51 for 0 day to 3.17 for 15 days fermentation. The pH for fermentation in 2.25% brine concentration was found to decrease from 6.48 for 0 day to 3.35 for 15 days fermentation.The pH for the fermentation in 2.5% brine concentration was found to decrease from 6.63 for 0 day to 3.31 for 15 days fermentation. The pH value was found to decrease until 9th days of fermentation and goes on increasing pattern on succesive fermentation days till last (15 days) of fermentation. The changes in pH during fermentation is shown in Fig. 4.2.

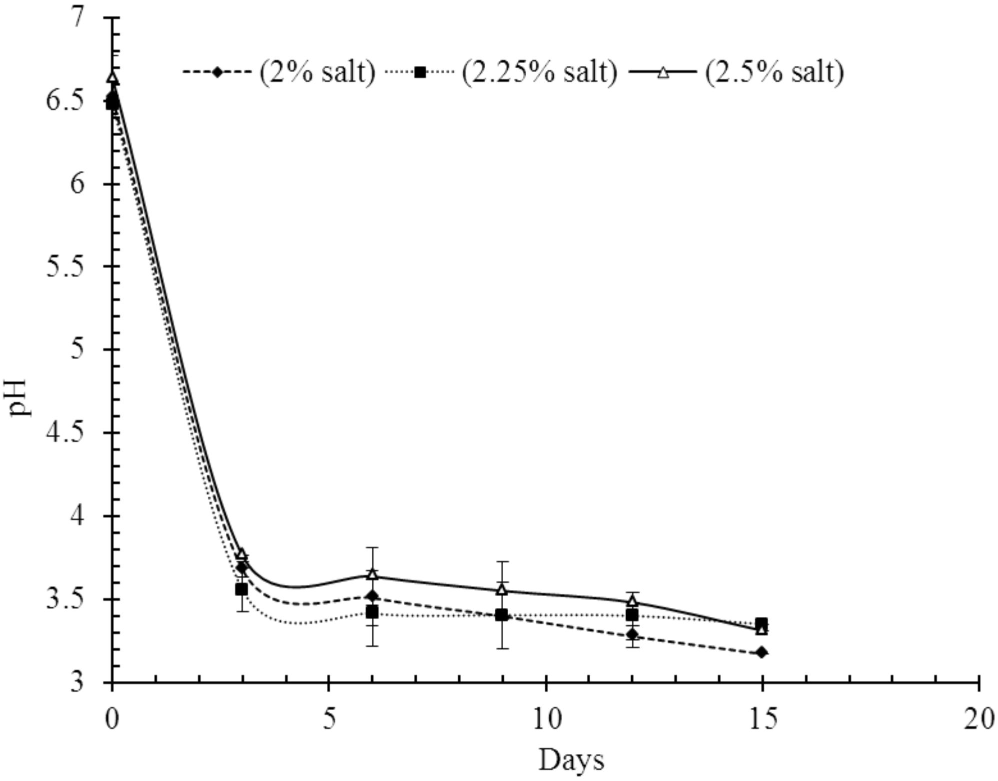


Fig. 4.2 Change in pH during fermentation at different brine concentration

*Vertical error bars represent standard deviation of triplicate data.

The acidity for the fermentation in 2% brine concentration was found to increase from 0.33 for 0 day to 2.13 for 15 days fermentation. The acidity for fermentation in 2.25% brine concentration was found to increase from 0.39 for 0 day to 1.95 for 15 days fermentation.The acidity for the fermentation in 2.5% brine concentration was found to increase from 0.3 for 0 day to 1.91 for 15 days fermentation. The changes in acidity during fermentation is shown in Fig. 4.3.

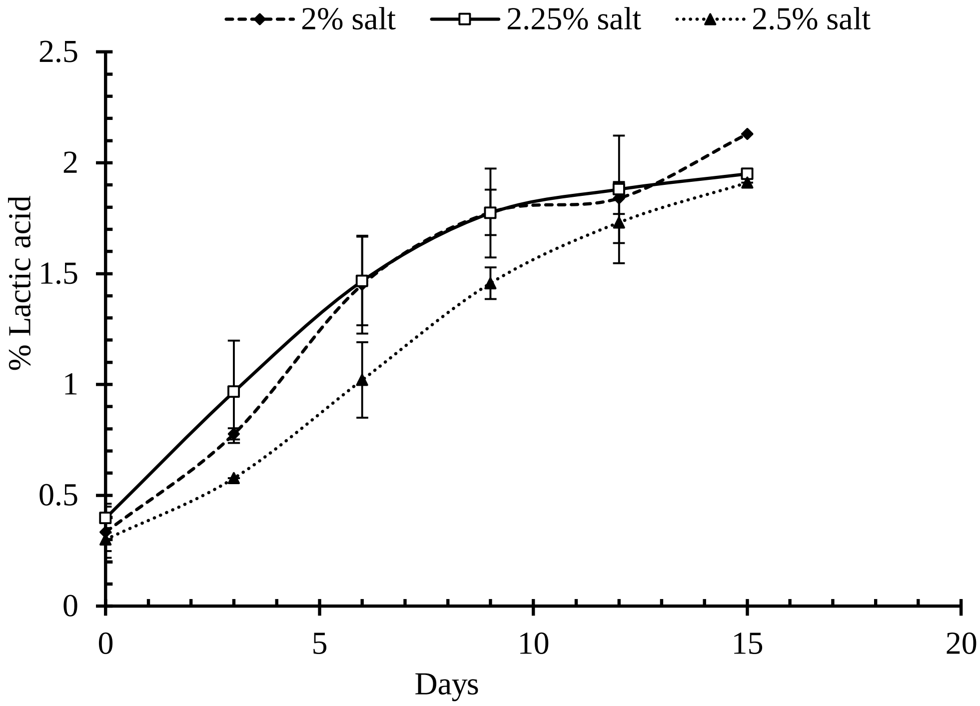


Fig. 4.3 Change in acidity during fermentation at different brine concentration

*Vertical error bars represent standard deviation of triplicate data.

According to Lakshmana and Rajanna (2001) the pH of saurkraut decreases as the fermentation time increaes and acidity of saurkraut increases as the fermentation time increases for the fermentation of saurkraut of different cabbage hybrids for 45 days.This result is analogous to the result of our study. Thakur and Kabir (2015) found the acidity of saurkraut as 1.28 and 1.15% for fermentation in 2% and 2.5% brine concentration respectively for 7 days. This was similar to our study. Thakur and Kabir (2015) reported that the pH is higher in case of higher salt concentration and acidity is lower at higher salt concentration. But decreasing rate of pH and increasing rate of acidity remains constant for different salt concentration during the fermentation of saurkraut at different salt concentration.

The decrease in pH and increase in acidity may be due to the fermentation of reducing sugar present in cabbage to lactic acid by naturally present lactic acid bacteria. The malic acid and citric acid diffuse from the cabbage as soon as the fermentation started which may contribute the slight decrease in pH during first day of fermentation (Xiong *et al.*, 2014).

The addition of high amount of salt brine would have an inhibitory effect on the bacterial flora, mainly involved in the fermentation process (R. K. Pundir and Jam, 2010). So, at high concentration of salt there was slight decrease in the rate of change of pH and acidity.

4.3 Changes in TSS during sauerkraut fermentation

The TSS for the fermentation in 2% brine concentration was found to increase from 7.33 for 0 day to 10 for 15 days fermentation. The TSS for fermentation in 2.25% brine concentration was found to increase from 7.467 for 0 day to 10 for 15 days fermentation.The TSS for the fermentation in 2.5% brine concentration was found to increase from 7.467 for 0 day to 10.8 for 15 days fermentation. The changes in TSS during fermentation is shown in Fig. 4.4.

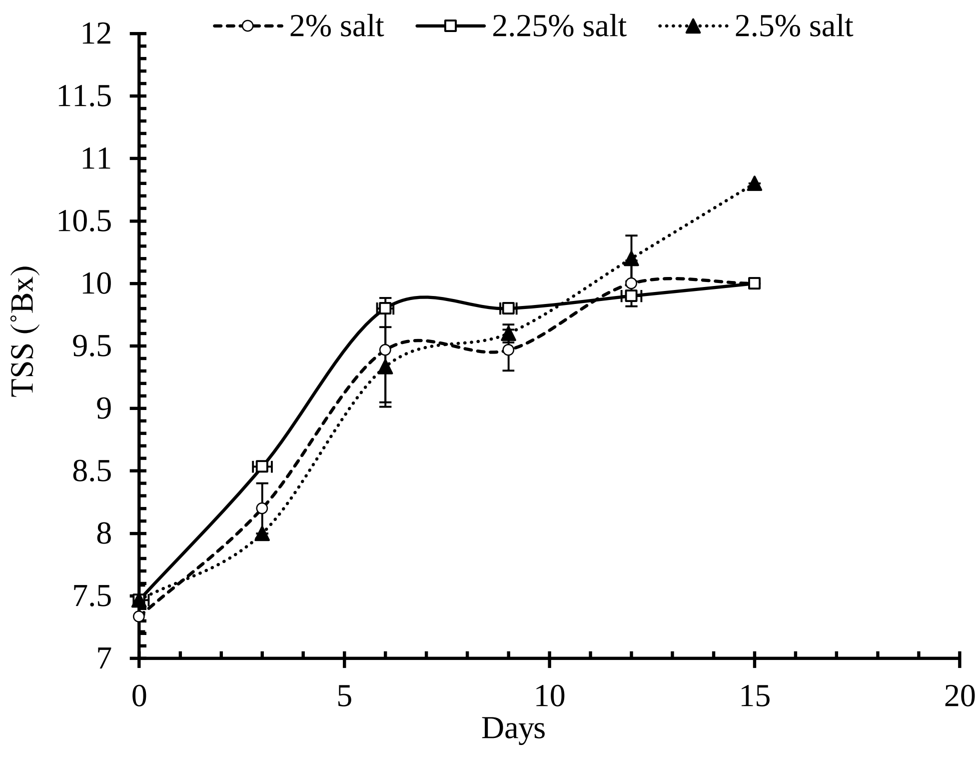


Fig. 4.4 Change in TSS during fermentation at different brine concentration

*Vertical error bars represent standard deviation of triplicate data.

According to (Lakshmana and Rajanna, 2001) TSS of sauerkraut increases as fermentation time increases. This result is similar to the result of our study. Thakur and Kabir (2015) found that on 21 day, TSS of sauerkraut was 7.8 in 2% salt and TSS increased with the increase in salt concentration and on 28th day TSS reduced in all the brine concentration during the fermentation of cabbage at different brine concentration for 28 days. This study also found that the TSS was higher for the sauerkraut fermentation in higher salt concentration.

The increase in TSS of sauerkraut by extending the days for fermentation, may be due to the activity of lactic acid bacteria (Jones, 1975). The higher TSS in greater salt concentration may be due to the increase in soluble solids by the contribution of salt.

4.4 Changes in reducing sugar during sauerkraut fermentation

The reducing sugar for the fermentation in 2% brine concentration was found to decrease from 2.137 for 0 day to 0.5 for 15 days fermentation. The reducing sugar for fermentation in 2.25% brine concentration was found to decrease from 2.396 for 0 day to 0.6 for 15 days fermentation.The reducing sugar for the fermentation in 2.5% brine concentration was found to decrease from 2.66 for 0 day to 0.56 for 15 days fermentation. The changes in reducing sugar during fermentation is shown in Fig. 4.5.

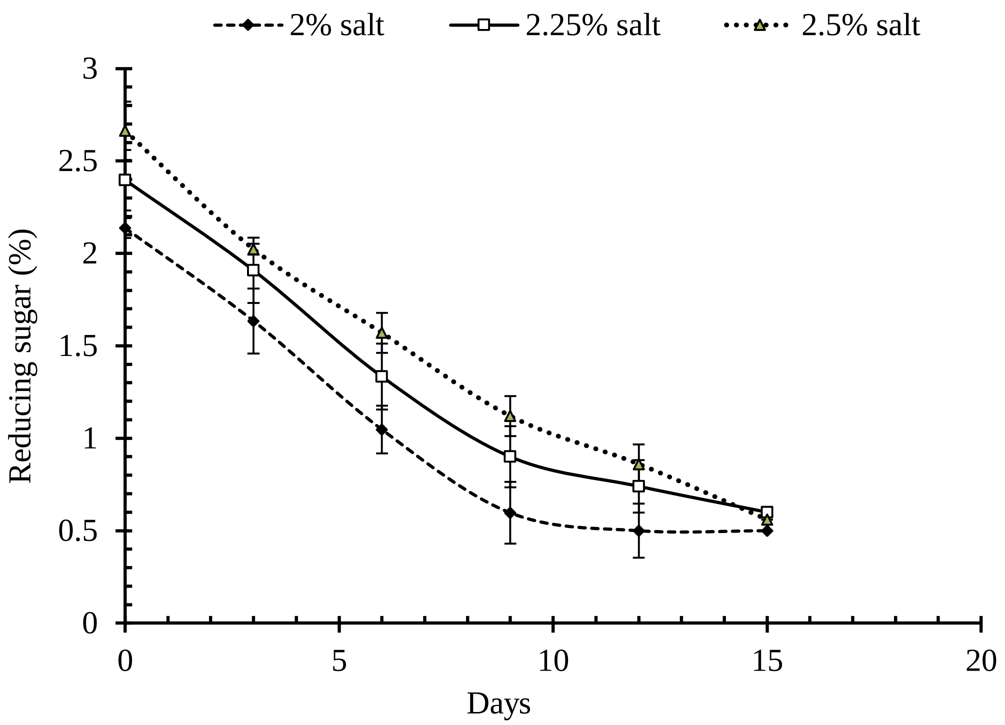


Fig. 4.5 Change in Reducing sugar during fermentation at different brine concentration

*Vertical error bars represent standard deviation of triplicate data.

Rhee *et al.* (2011) found the reducing sugar decreases from 2% to about 0.5% during kimchi fermentation for 2 months. This is similar to our data. According to Pandey and Garg (2015) the initial total sugar was found to be low, but as the fermentation proceeds the soluble sugars of cabbage released in the brine and total sugar increases after 6 days of fermentation. As the total sugar degrades, the amount of reducing sugar increases after 6 days of fermentation. While our study also shows that the reducing sugar increases at first 2^{nd} days of fermentation and decreases after 2 days. The reducing sugar was metabolized by the microorganisms to organic acids and thus both reducing sugar as well as total sugar may be decreased respectively. As increase in salt concentration the reducing sugar formed is less and the fermentation of reducing sugar to lactic acid is also less. This may be due to the inhibition of lactic acid bacteria due to increased amount of salt concentartaion (R. K. Pundir and Jam, 2010). Johanningsmeier *et al.* (2007) found that the residual glucose for higher salt concentration fermentation was high. This result was similar to that of our study. This may be due to low fermentation rate.

4.5 Changes in vitamin C during sauerkraut fermentation

The vitamin C for the fermentation in 2% brine concentration was found to decrease from 9.33 for 0 day to 10.67 for 15 days fermentation. The vitamin C for fermentation in 2.25% brine concentration was found to decrease from 9.59 for 0 day to 10.09 for 15 days fermentation.The vitamin C for the fermentation in 2.5% brine concentration was found to decrease from 10.067 for 0 day to 8.98 for 15 days fermentation. The changes in vitamin C during fermentation is shown in Fig. 4.6.

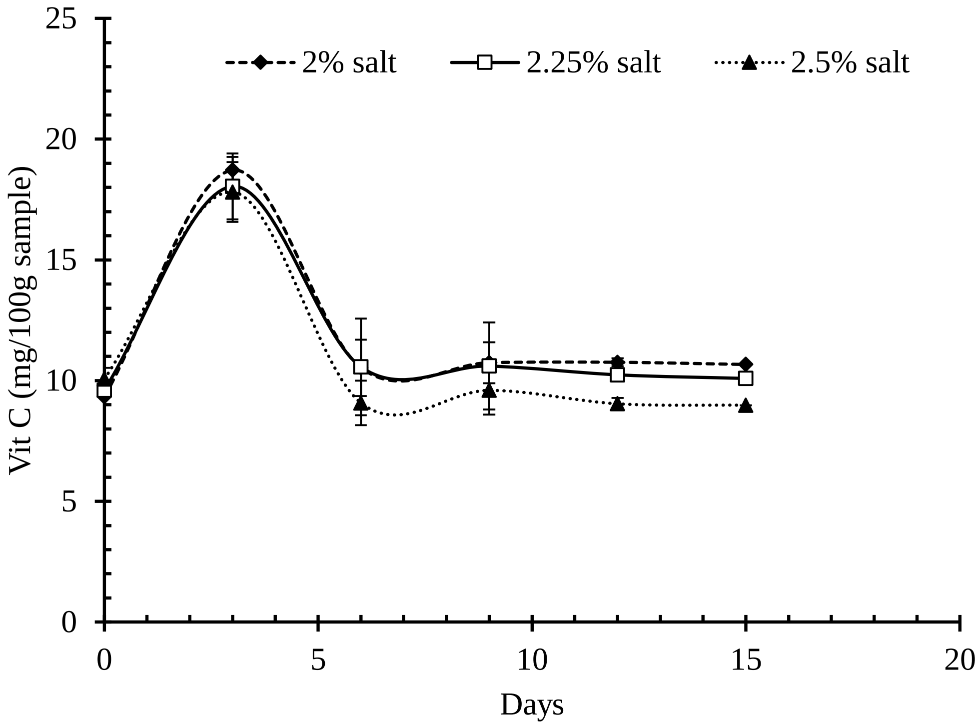


Fig. 4.6 Change in vitanin C during fermentation at different brine concentration

*Vertical error bars represent standard deviation of triplicate data.

According Lee (1997) the initial vitamin C content of shredded cabbage was about 8-10 mg/100 g which intially sharply increases and then decreases to about 18 mg/100 g when cabbage was fermented to form kimchi and stored for 80 days by addition of sodium chloride. This study is similar to our result. According to Thakur and Kabir (2015) on 7th day of sauerkraut preparation ascorbic acid content was maximum (20.89 mg/100 g) in 2.5% brine concentration followed by 16.40 mg/100 g in 4% brine concentration , 15.73 mg /100 g in 3% brine concentration , 14.15 in 3.5% brine concentration and 13.34 mg/100 g in 2% brine concentration respectively. Ascorbic acid increased continuously up to 21 days and thereafter on 28 day of sauerkraut preparation ascorbic acid content of all the treatment decreased. This pattern was similar to the results obtained in our study.

4.6 Sensory evaluation of sauerkraut before and after rehydration

4.6.1 Color

The mean sensory scores for color of dehydrated sauerkraut A, B, C, D, E, F, G, H and I were found to be 5.9±0.73, 7.7±0.82, 6.7±0.67, 5.7±0.82, 8.1±0.74, 7.1±0.74, 6.4±0.69, 6.9±0.57 and 6.4±0.69 respectively. The statistical analysis shows that color of different samples are significantly different (P<0.05). Among 9 samples, sample E is most preferable in terms of color. The sample E and B are not significantly different from each other but the sample E is significantly different from other samples. The mean sensory score for color of dehydrated sauerkraut is shown in Fig. 4.7.

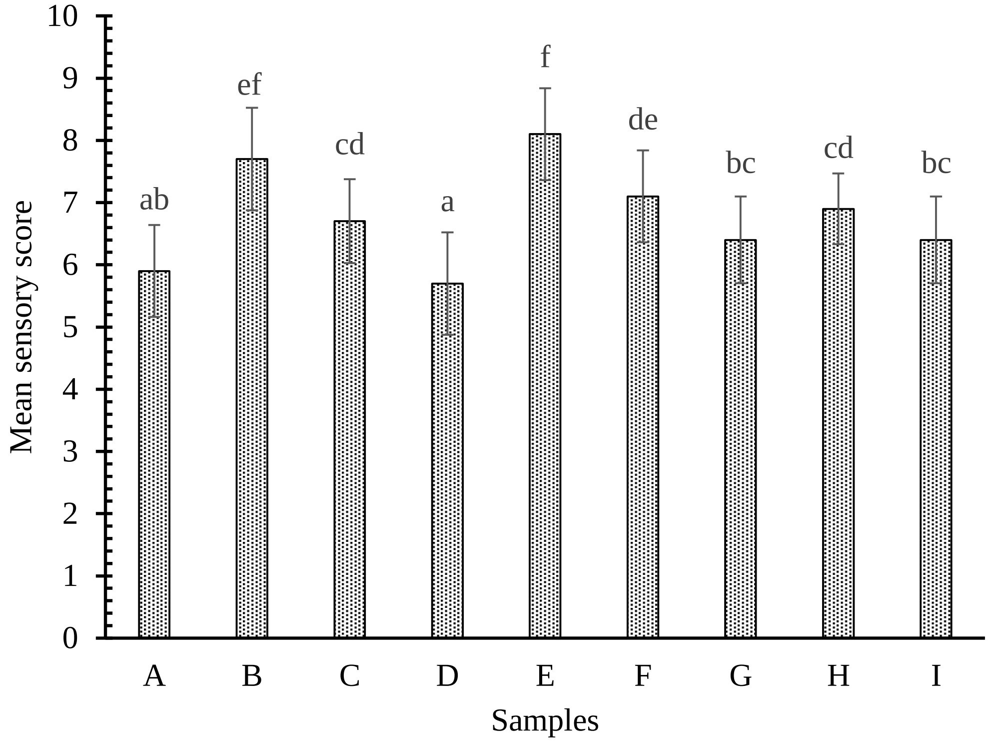


Fig. 4.7 Mean sensory score for color of dehydrated sauerkraut

*Vertical error bars represent standard deviation of triplicate data.

The mean sensory scores for color of rehydrated sauerkraut A, B, C, D, E, F, G, H and I were found to be 5.9±0.74, 7.7±0.82, 6.7±0.67, 5.7±0.82, 8.1±0.74, 7.1±0.74, 6.4±0.69, 6.9±0.57 and 6.4±0.69 respectively. The statistical analysis shows that color of different samples are significantly different (P<0.05). Among 9 samples, sample E is most preferable in terms of color. The sample E and B were not significantly different from each other but the sample E was significantly different from other samples. The mean sensory score for color of rehydrated sauerkraut is shown in Fig. 4.8.

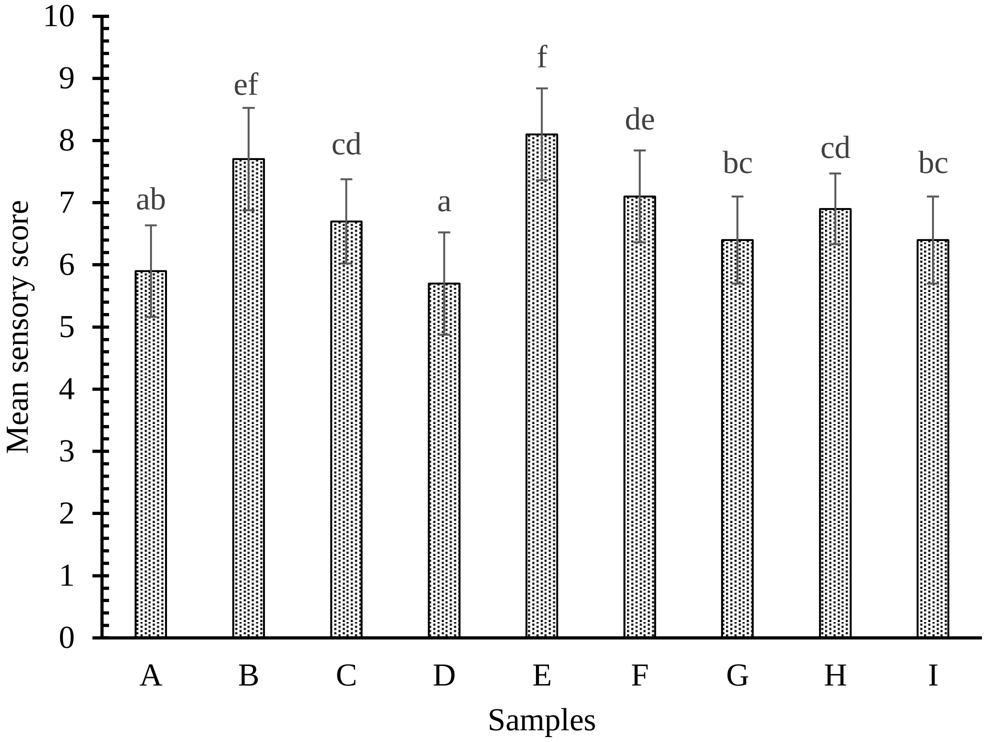


Fig. 4.8 Mean sensory score for color of rehydrated sauerkraut

*Vertical error bars represent standard deviation of triplicate data.

The addition of salt is one of the critical point in sauerkraut production because of the type and extent of microbial growth and the sensory properties of the final product are affected by the amount of salt used (Holzapfel *et al.*, 2003). The color may be changed during variation in fermentation time and salt concentration. Apparently the polyphenolase enzyme system of the cabbage was effectively inhibited by the low pH and chelating effects of citric acid. All of the directly-acidified sauerkraut-like products appeared off-white in color, and did not exhibit noticeably green coloration due to the presence of chlorophyll (Lonergan and Lindsay, 1979).

4.6.2 Appearance

The mean sensory scores for appearance of dehydrated sauerkraut A, B, C, D, E, F, G, H and I were found to be 6±1.05, 6.6±0.84, 6.5±0.85, 6.7±0.82, 8±0.816, 6.4±1.07, 6.3±0.67, 6.1±0.73 and 6.8±0.63 respectively. The statistical analysis shows that color of different samples are significantly different ($P<0.05$). Among 9 samples, sample E is most preferable in terms of appearance. The sample E is significantly different from other samples. The mean sensory score for appearance of dehydrated sauerkraut is shown in Fig. 4.9.

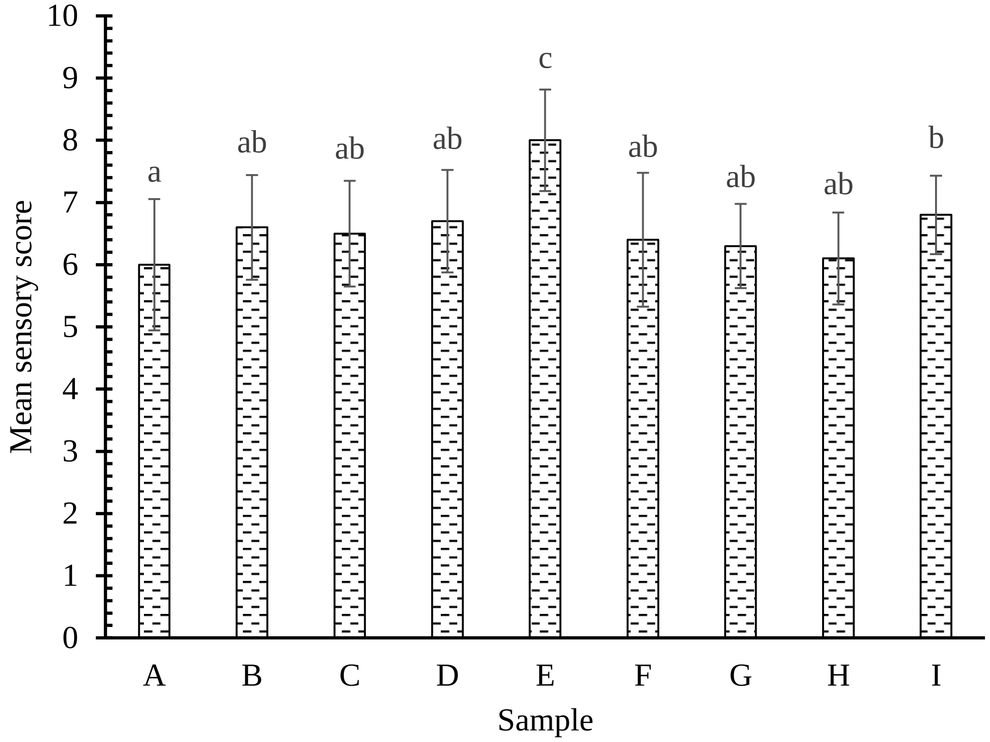


Fig. 4.9 Mean sensory score for appearance of dehydrated sauerkraut

*Vertical error bars represent standard deviation of triplicate data.

The mean sensory scores for appearance of rehydrated sauerkraut A, B, C, D, E, F, G, H and I were found to be 6±1.05, 6.6±0.84, 6.5±0.85, 6.7±0.82, 8±0.816, 6.4±1.07, 6.3±0.67, 6.1±0.74and 6.8±0.63 respectively. The statistical analysis shows that color of different samples are significantly different ($P<0.05$). Among 9 samples, sample E was most preferable in terms of appearance and found to be significantly different from other rest samples. The mean sensory score for appearance of rehydrated sauerkraut is shown in Fig. 4.10.

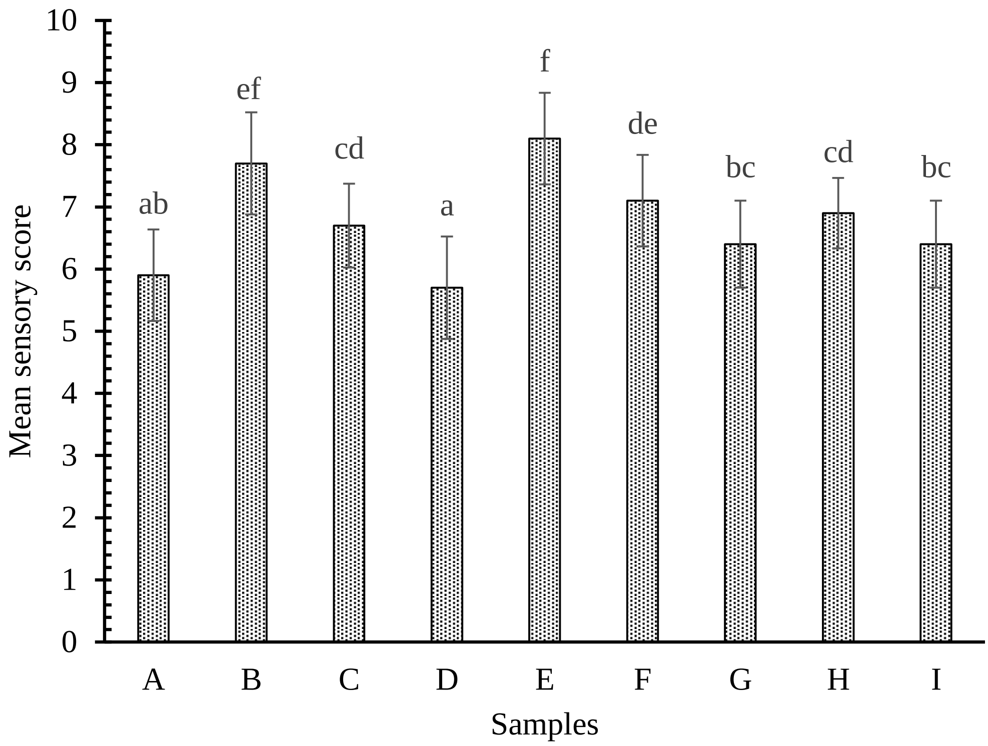


Fig. 4.10 Mean sensory score for appearance of rehydrated sauerkraut

*Vertical error bars represent standard deviation of triplicate data.

The changes in appearance may be due to changes in fermentation time and in salt concentration. According to Holzapfel *et al.* (2003) the sensory quality of sauerkraut is affected by the salt concentration used.

4.6.3 Flavor

The mean sensory scores for flavour of dehydrated sauerkraut A, B, C, D, E, F, G, H and I were found to be 6.4±0.69, 7.1±0.74, 7.7±0.82, 6.4±0.84, 7.2±0.79, 6.2±0.63, 5.9±0.57, 6.9±0.74 and 6.5±0.70 respectively. The statistical analysis shows that flavour of different samples are significantly different ($P<0.05$). Among 9 samples, sample B, C and E were not significantly different and found to be superior in terms of flavor. The mean sensory score for flavour of dehydrated sauerkraut is shown in Fig. 4.11.

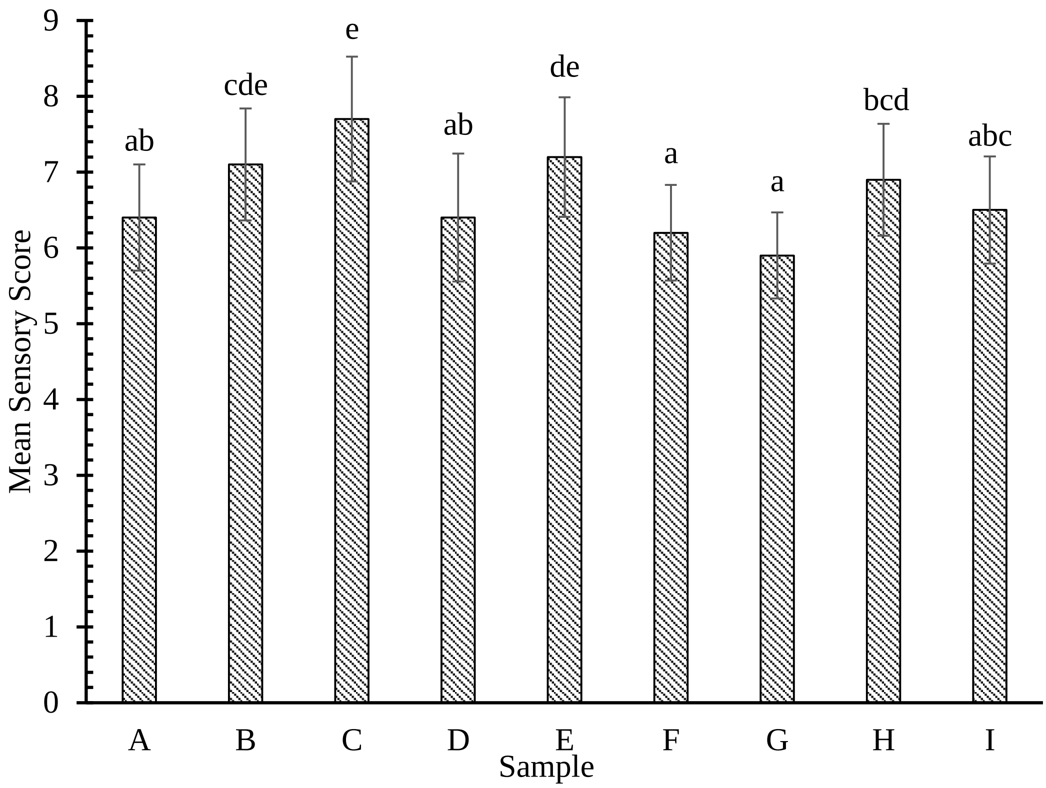


Fig. 4.11 Mean sensory score for flavor of dehydrated sauerkraut

*Vertical error bars represent standard deviation of triplicate data.

The mean sensory scores for flavour of rehydrated sauerkraut A, B, C, D, E, F, G, H and I were found to be 6.4±0.69, 7.1±0.74, 7.7±0.82, 6.4±0.84, 7.2±0.79, 6.2±0.63, 5.9±0.57, 6.9±0.74 and 6.5±0.70 respectively. The statistical analysis shows that flavour of different samples are significantly different ($P<0.05$). Among 9 samples, sample B, C and E were not significantly different and found to be superior in terms of flavor. The mean sensory score for flavour of rehydrated sauerkraut is shown in Fig. 4.12.

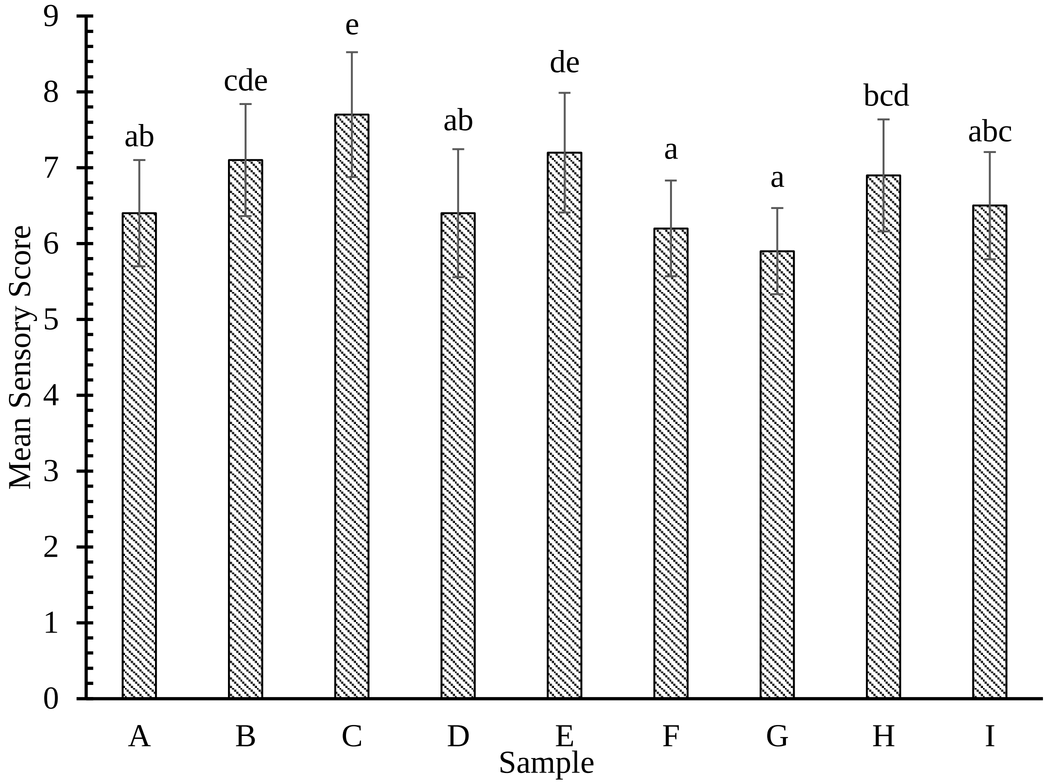


Fig. 4.12 Mean sensory score for flavor of rehydrated sauerkraut

*Vertical error bars represent standard deviation of triplicate data.

The end products of a normal kraut fermentation are lactic acid along with smaller amounts of acetic and propionic acids, a mixture of gases of which carbon dioxide is the principal gas, small amounts of alcohol and a mixture of aromatic esters. The acids, in combination with alcohol form esters, which contribute to the characteristic flavour of sauerkraut. The high salt concentration and low temperature inhibit lactic acid bacteria to some extent. Finally, *L. pentoaceticus* continues the fermentation, bringing the acidity to 2 to 2.5% thus completing the fermentation (FAO, 1998).

4.6.4 Taste

The mean sensory scores for taste of dehydrated sauerkraut A, B, C, D, E, F, G, H and I were found to be 5.7±0.67, 7.5±0.85, 6.3±0.67, 6.6±0.69, 8±0.82, 7.2±0.92, 6.3±0.67, 7±0.67,and 6.8±0.78 respectively. The statistical analysis shows that taste of different samples are significantly different ($P<0.05$). Among 9 samples, sample B and E were not significantly different from each other and found to be superior in terms of taste. The mean sensory score for taste of dehydrated sauerkraut is shown in Fig. 4.13.

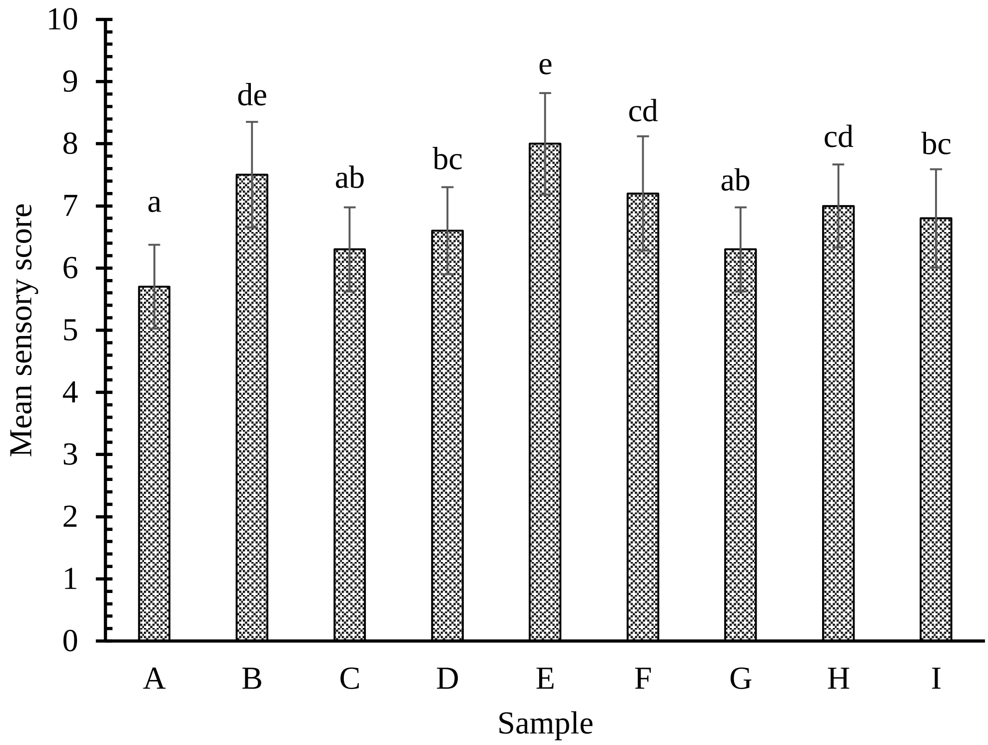


Fig. 4.13 Mean sensory score for taste of dehydrated sauerkraut

*Vertical error bars represent standard deviation of triplicate data.

The mean sensory scores for taste of rehydrated sauerkraut A, B, C, D, E, F, G, H and I were found to be 5.7±0.67, 7.5±0.85, 6.3±0.67, 6.6±0.69, 8±0.82, 7.2±0.92, 6.3±0.67, 7±0.67,and 6.8±0.78 respectively. The statistical analysis shows that taste of different samples are significantly different ($P<0.05$). Among 9 samples, B and E were not significantly different from each other and E was found to be superior in terms of taste. The mean sensory score for taste of rehydrated sauerkraut is shown in Fig. 4.14.

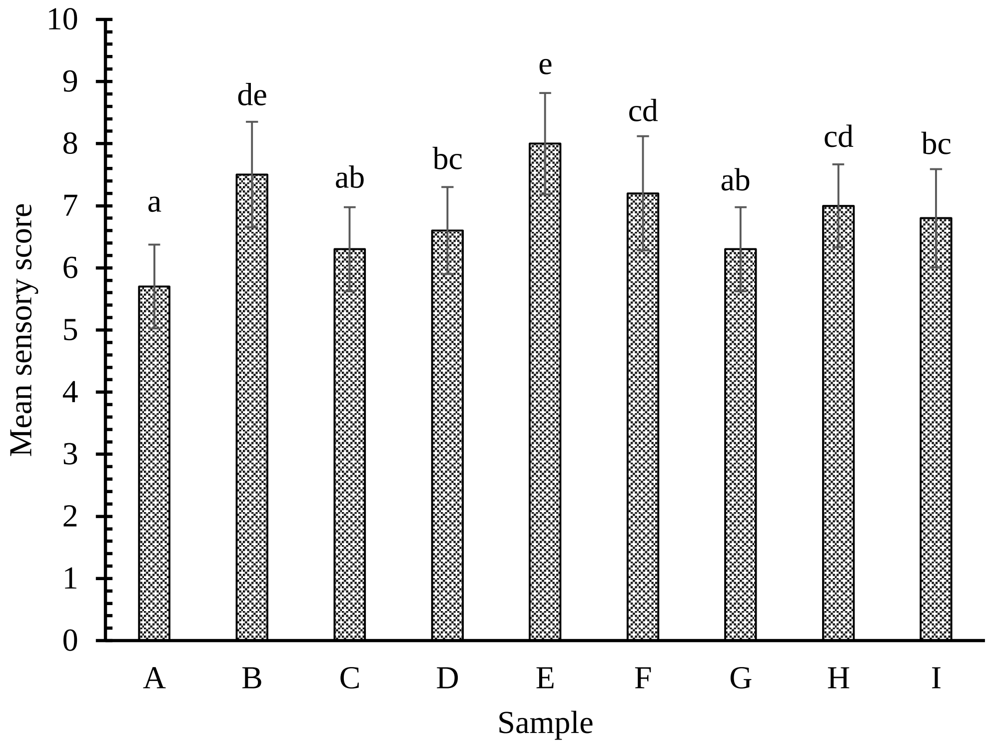


Fig. 4.14 Mean sensory score for taste of rehydrated sauerkraut

*Vertical error bars represent standard deviation of triplicate data.

According to Lonergan and Lindsay (1979) the taste of sauerkraut was only slightly tart, and a sweet aftertaste was noted along with a hint of putrefaction which could have been caused by the slow release of acid.

4.6.5 Overall

The mean sensory scores for overall of dehydrated sauerkraut A, B, C, D, E, F, G, H and I were found to be 5.8±0.63, 7±0.82, 7.3±0.67, 6.3±0.48, 8.1±0.74, 5.9±0.57, 6.2±0.63, 6.8±0.78 and 6.5±0.53 respectively. The statistical analysis shows that overall of different samples are significantly different ($P<0.05$). Among 9 samples, sample E was more preferable in terms of overall acceptability and was significantly different from the rest samples. The mean sensory score for overall of dehydrated sauerkraut is shown in Fig. 4.15.

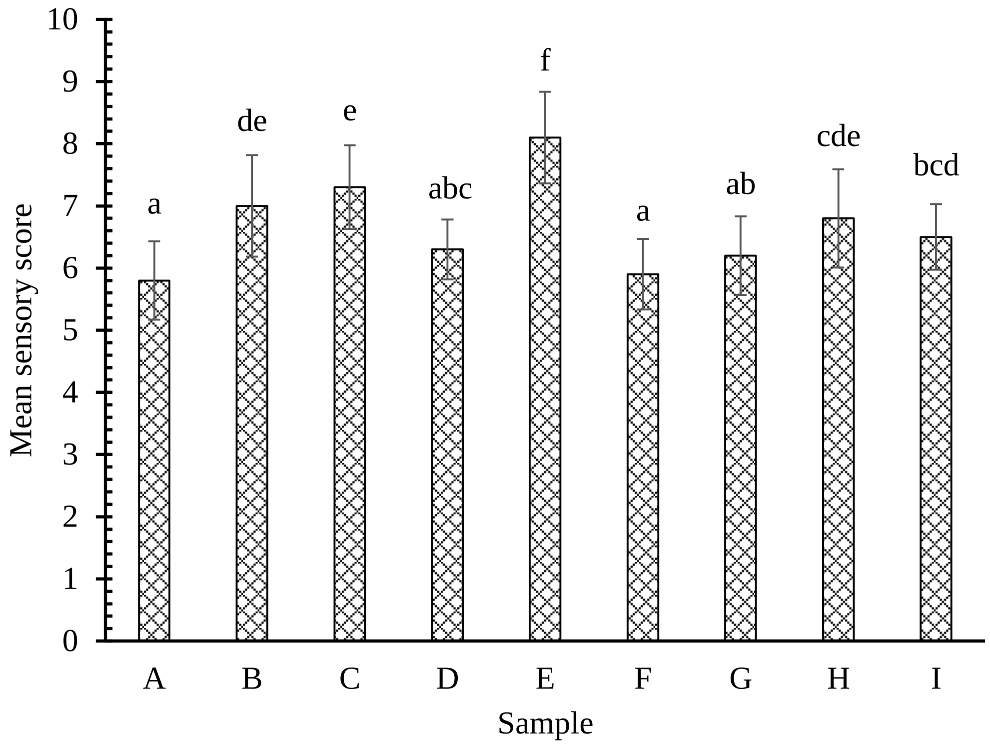


Fig. 4.15 Mean sensory score for overall acceptability of dehydrated sauerkraut

*Vertical error bars represent standard deviation of triplicate data.

The mean sensory scores for overall acceptability of rehydrated sauerkraut A, B, C, D, E, F, G, H and I were foumd to be 5.8±0.63, 7±0.82, 7.3±0.67, 6.3±0.48, 8.1±0.74, 5.9±0.57, 6.2±0.63, 6.8±0.78 and 6.5±0.53 respectively. The statistical analysis shows that overall of different samples are significantly different (P<0.05). Among 9 samples, sample E was more preferable in terms of overall acceptability and was significantly different from the rest samples. The mean sensory score for overall of rehydrated sauerkraut is shown in Fig. 4.16.

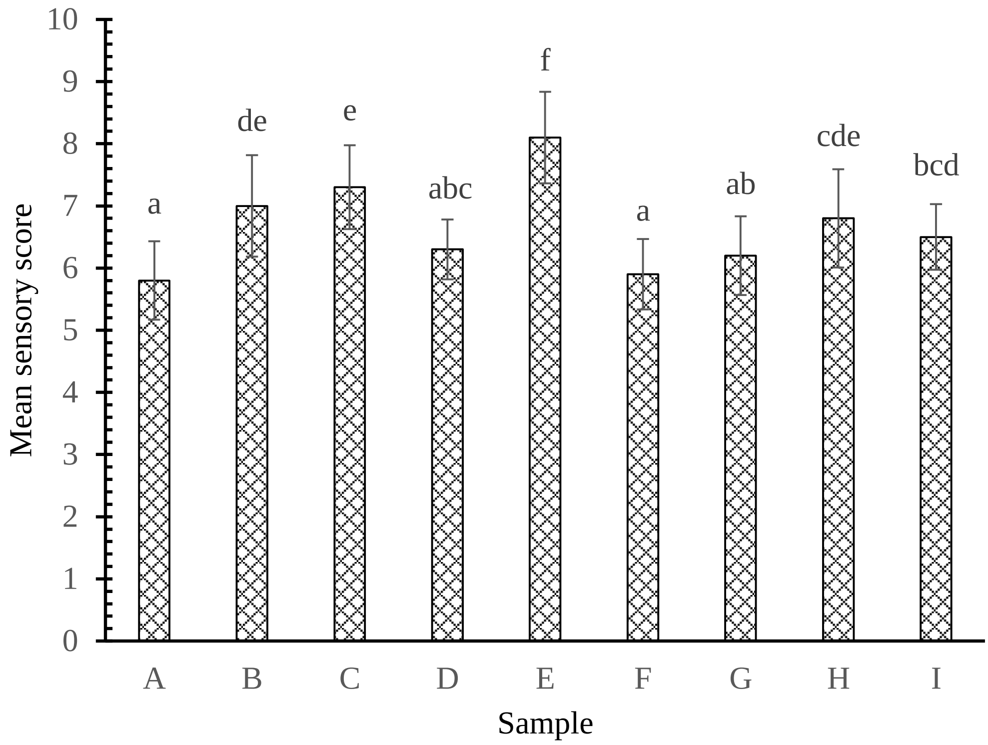


Fig. 4.16 Mean sensory score for overall acceptability of rehydrated sauerkraut

*Vertical error bars represent standard deviation of triplicate data.

In overall the sample E was found to be superior than others in both rehydrated and dehydrated samples. In case of colour of dehydrated sample E and B were found to be superior and E was found to be superior for rehydrated sauerkraut interms of colour. Similarly incase of flavour B, C and E were preferred more than other samples of rehydrated and dehydrated sauerkraut samples. E sample of both rehydrated and dehydrated samples were found to be superior interms of appearance. Incase of taste B and E samples were given the same mean sensory score and preffered more than other dehydrated and rehydrated sauerkraut samples. So, in overall E samples were preferred more than other sauerkraut samples of both rehydrated and dehydrated samples.

4.7 Rehydration properties

All the dehydrated samples of sauerkraut were rehydrated. Sample B was found to have higher rehydration coefficient. The rehydration coefficient of samples were given in Table 4.2.

Table 4.2 Rehydration coefficient of sauerkraut samples.

Samples	Coefficient of rehydration
A	0.4167^{e} (0.00067)
B	0.4482^{i} (0.00012)
C	0.4389^{g} (0.00047)
D	0.3913^{c} (0.00048)
E	0.3957^{d} (0.00088)
F	0.443^{h} (0.00072)
G	0.2814^{a} (0.00062)
H	0.3727^{b} (0.00039)
I	0.4281^{f} (0.00014)

Values in the column with the same superscript are not significantly different ($P<0.05$). Values in the parenthesis are standard deviation of triplicate data. According to Akonor and Tortoe (2014) the rehydration ratio of control sample (without brine) of chayote is greater than the salt treated samples. Rastogi *et al.* (2004) observed the decrease in the osmotic solution concentration from 10 to $0^{\circ}B_X$ (dipping in water) resulted an increase in moisture absorption and solid retention during rehydration of carrot. Similar type of results were obtained during our study. The coefficient of rehydration was higher for the sauerkraut sample fermented at lower salt concentration. This may be due to the impeded movement of water out of the tissues and hence lowered the effective moisture diffusivity due to salt treatment (Akonor and Tortoe, 2014). At the same time, solute loss during rehydration increased, possibly due to structural changes induced by osmotic pre-treatment, and interaction of the osmoactive substance with the cell components (Rastogi *et al.*, 2004). So that the water absorption is less for the sample treated with high salt concentration.

Part V

Conclusions and recommendations

5.1 Conclusions

Sauerkraut at different brine concentration were prepared and their rehydration property was studied. The conclusions of this study are:

- Acidity increases with fermentation time and decreases with salt concentration during fermentation.
- pH of sauerkraut decreases with fermentation time and decreasing rate declined as the salt concentration increased.
- Vitamin C degraded as the fermentation time increased and its degradation was less in sauerkraut fermented at high salt concentration.
- TSS was higher for sauerkraut fermented at high salt concentration and it increased as fermentation time increased.
- From the sensory analysis sauerkraut fermented in 2.25% brine concentration for 12 days was found to be superior than others where as interms of rehydration coefficient sample B was found to be superior.
- Coefficient of rehydration decreased as the brine concentration increased and increased as the fermentation time increases.

5.2 Recommendations

- Sauerkraut can be fermented in 2.25% brine concentratiom for 12 days to give an acceptable quality of dehydrated sauerkraut.
- Fermentation temperature may be controlled during sauerkraut fermentation.
- Different spices can be used during sauerkraut fermentation.

Summary

Sauerkraut is an acidic cabbage which results from natural fermentation by bacteria indigineous to cabbage in the presence of 2 to 3% salt. The addition of salt restricts the activities of Gram negative bacteria, while the growth of lactic acid bacteria is favoured. The dominant lactic acid bacteria involved in sauerkraut production are Leuconostoc mesenteriods, Leuconostoc fallax and Lactobacillus plantarum. Acidity and salt concentrations, as well as the volatile organic components, are important to overall sauerkraut flavor. Development and acceptance of sauerkraut-like products from cabbage by direct acidification could lead to an expanded use of cabbage in contemporary foods, especially if unique properties can be identified.

For this study the cabbage was bought from local market of dharan. Cabbage was sliced into thin strips. Salt was sprinkled over it and kneaded properly. Nine samples with 2%, 2.25% and 2.5% salt concentration were prepared for 9, 12 and 15 days fermentation. Then it was transferred into the fermentation jar. After the completion of fermentation time, sauerkraut were dried at 60°C temperatute for about 6 h. Then it was rehydrated by taking 10 g of each sample of dried sauerkraut in 150 ml water for about 30 min.

Acidity of sauerkraut was found to be increased as the fermentation time increased but it was found to be decreased as the salt concentration increased during fermentation. Here pH of sauerkraut was found to be decreased as the fermentation time increased. But as the salt concentration was increased, its pH was found to be decreased. Similarly,Vitamin C of sauerkraut was degraded as the fermentation time was increased and its degradation was less in sauerkraut fermented at high salt concentration. TSS was higher for sauerkraut fermented at high salt concentration and found to be increased with increase in fermentation time. From the sensory analysis sauerkraut fermented in 2.25% brine concentration for 12 days was found to be superior than others. Coefficient of rehydration decreased as the brine concentration increased and increased as the fermentation time increases.

References

Adams, J. and Pepping, J. (2005). Vitamin K in the treatment and prevention of osteoporosis and arterial calcification. *Am. J. Health System Pharm.* **62** (15).

Akonor, P. T. and Tortoe, C. (2014). Effect of blanching and osmotic pre-treatment on drying kinetics, shrinkage and rehydration of chayote (sechium edule) during convective drying. *British J. Appl. Sci. Technol.* **4** (8), 1215-1229.

Alden, L. (2005). Cabbages. The Cook's Thesaurus. Retrieved from http://www.foodsubs.com/. [Accessed 10 January, 2018].

Anonymous. Sauerkraut Fermentation. Wedliny Denowy. Retrieved from https://www.meatsandsausages.com/fermenting-pickling/sauerkraut/fermentation. [Accessed 25 January, 2018].

Anonymous. (1986). Solar drying-practical methods of food preservation. Retrieved from http://www.ilo.org/global/publications/ilo-bookstore/orderonline/ books/ WCMS_ PUBL_ 9221053571_EN/lang--en/index.htm. (Last update July 23, 1986). [Accessed 7 April, 2018].

Anonymous. (2015). Sauerkraut (canned drained). Retrieved from http://nutrition .healthgrove.com/l/16647/Sauerkraut. [Accessed 30, March, 2018].

Anonymous. (2017). Cabbage cultivation/cabbagre production technol. Kisan Suvida. Retrieved from https://www.kisansuvidha.com/cabbage. (Last update April 4, 2017). [Accessed 21 January, 2018].

Anonymous. (2018). Lactic acid fermentation, the process of culturing foods and drinks. superfoods-for-superhealth.com. Retrieved from https://www.superfoods-for-superhealth.com/fermentation.html. [Accessed 6 January, 2018].

Battcock, M. and Ali, S. A. (1998). Opportunity for ferment. food products in developing countries [Report]. Retrieved from http://practicalaction.org [Accessed 8 January, 2010].

Bhat, R., Dar, S. B. and Zahida, R. (2017). Yield performance and economic studies of cabbage as influenced by different sources and levels of sulphur. *Int. J. Curr. Microbiol. App. Sci.* . **6** (10), 322-328.

Bose, T. K. and Som, M. G. (1993). "Vegetable Crops in India" (1 ed.).Nayaprakash, Calcutta.

Breidt, F., McFeeters, R. F., Perez-Diaz, I. and Lee, C. H. (2013). Ferment. vegetables. *In:* "Food Microbiology: Fundamentals and Frontiers" (4th ed.). (M. P. Doyle and R. L. Buchanan, Eds.). pp. 841-855. Washington, D.C. ASM Press.

Burkill, H. I. (1930). The Chinese mustards in the Malaya Peninsula. *Gardners Bull*. **5**, 99-117.

Byers, B. (2013). Ferment dehydration: How to make sour cabbage crisps. The fermented food blog. Retrieved from http://fermup.com/blog/fermented-dehydration-how-to-make-sour-cabbage-chips/. [Accessed 4 March, 2018].

Carney, A. (2016). Sauerkraut: Nutrition facts and health benefits. *Wikihome Nutri.*

Chauhan, N., Chandra, S., Singh, J. and Samser. (2008). Effect of salt concentrations on sensory quality of sauerkraut *Environ. Ecol.* **26** (4), 2308-2310.

Desrosier, N. W. (1987). "The Technology of Food Preservation" (4 ed.). CBS publishers & distribution. New Delhi.

Desrosier, N. W. and Desrosier, J. N. (1998). "The Technology of Food Preservation". CBS publication and distribution. New Delhi, India.

Diamante, L. M. and Munro, P. A. (1993). Mathematical modelling of the thin layer solar drying of sweet potato slices. *Solar energy*. **51** (4), 271-276.

Encyclopedia.com. Cabbage. The Columbia Encyclopedia, 6th ed.

Enwa, F. O. (2014). A mini review on the microbiological properties of sauerkraut. *African J. Sci. Res.* **3** (1), 15-16.

Faltmarsch, R., Osterholm, P. and Jacks, G. (2010). Chemical composition of cabbage (*Brassica oleracea* L. var. *capitata*) grown on acid sulfate soils. *J. plant nutri. social sci.* **173** (3), 423-433.

FAO. (1998). "Fermented Frutis and Vegetables: A Global Perspective". Food and Agriculture Organization of the United Nations. Rome.

Fellows, J. P. (2000). "Food Process. Technology: Principles and Practice" (2nd ed.). Woodhead Publishing Ltd. England.

Filippone, P. T. Cabbage varieties:Which is best for coleslaw? Or stuffed cabbage? Retrieved from https://www.thespruce.com/varieties-of-cabbage-1808038. (Last update December 17, 2017). [Accessed January 21, 2018].

Gould, S. E. (2014). The science of sauerkraut: Bacterial ferment, yum! *Scientific Am.*

Greensmith, M. (1998). "Practical Dehydration". Woodhead Publishing Ltd.

Hall, D. W. (1970). "Factors Affecting Food Values". Rome. Oxford and IBH publishing Co. Pvt. Ltd. Rome.

Han, X., Yi, H., Zhang, L., Huang, W., Zhang, Y., Zhang, L. and Du, M. (2014). Improvement of fermentation chinese cabbage characteristics by selected starter cultures. *J. Food Sci.* **79** (7), 1387-1392.

Harrison, J. A. and Andress, E. L. (2012). Preserving food: Dried foods and vegetables. University of Georgia Cooperative extention Service. USA. Retrieved from http://nchfp .uga.edu/ publications/uga/uga_dry_fruit.pdf. [Accessed 25 January, 2018].

Hiremath, V., Harshavardhan, P. G., Prashanth, S. J., Rokhade, A. K. and Madalageri, M. B. (2009). Effect of pre-treatments and drying methods on quality of dehydrated bitter gourd slices. *Asian J. Horticulture*. **4** (2), 351-354.

Holzapfel, W., Schillinger, U. and Buckenhuskes, H. J. (2003). Sauerkraut. *In:* "Handbook of Fermented Functional Foods". (E. R. Farnworth, Ed.). pp. 343-359. CRC Press.

Ingram, M. and Kitchell, A. G. (1976). Salt as a preservative for foods. *J. Food Technol.* **2**, 1-15.

Johanningsmeier, S., Mcfeeters, R. F., Fleming, H. P. and Thompson, R. L. (2007). Effects of leuconostoc mesenteroides starter culture on fermentation of cabbage with reduced salt concentrations. *J. Food Sci.* **72** (5), 166-172.

Jones, I. D. (1975). Nutritional evaluation of food process. *In:* "Effects of Processing on Fermentation on Nutrients" (2nd ed.). (R. S. Harris and F. Kannas, Eds.). West Port. The AVI Pub. Co. Inc.

Kannan, V. (2011). Extraction of bioactive compounds from whole red cabbage and beetroot using pulsed electric fields and evaluation of their functionality. Univ. of Nebraska-Lincoln,

Kent, D. (2009). Just add water cooking with dried foods. Retrieved from https:// www. scribd.com/document/177624916/Just-Add-Water-Cooking-With-Dried-Foods-Handout. [Accessed 26 January, 2018].

Kharel, G. P. (2004). Post-harvest operations: blanching. *Principle of Food Preservation*. **32**, 57-64.

Kim, H. Y., Min, J. H., Lee, J. H. and Ji, G. E. (2000). Growth of lactic acid bacteria and bifidobacteria in natural media using vegetables, seaweeds, grains and potatoes. *Food Sci. Biotechnol.* **9**, 322-324.

Konings, W. N., Kok, J., Kuiters, O. P. and Poolman, V. (2000). Lactic acid bacteria: The bugs of new millennium. *Curr. Opinions Microbiol.* **3**, 276-282.

Krokida, M. K. and Philippopoul, C. (2005). Rehydration of dehydrated foods. *Dairy Technol.* **23** (4), 799-830.

Lakshmana and Rajanna, K. M. (2001). Quality characteristics of sauerkraut prepared from cabbage hybrids. *Karnataka J. Agric. Sci.* **14**, 1149-1152.

Lee, C. H. (1997). Lactic acid fermentation foods and their benefits in Asia. *Food Control*. **8** (5/6), 259-269.

Levi, A., Ben-Shalom, N., Plat, D. and Reid, D. S. (1988). Effect of blanching and drying on pectin constituents and related characteristics of dehydrated peaches. *J. Food Sci.* **53**, 1187-1190.

Lewicki, P. P. (2006). Design of hot air drying for better foods. *Trends Food Sci. Technol.* **17**, 153-163.

Lewicki, P. P. and Jakubczyk, E. (2004). Effect of hot air temperature on mechanical properties of dried apples. *J. Food Eng.* **64**, 307-314.

Li-Quan, Z., Liang-Mao, L. and Huang, Z. (2014). The effect of multivitamin/mineral supplements on age-related cataracts: A systematic review and meta-analysis. *Nutrients*. **6** (3), 931-949.

Lin, T. M., Durance, T. D. and Scaman, C. H. (1998). Characterization of vacuum microwave, air and freeze dried carrot slices. *Food Res. Int.* **31**, 111-117.

Lonergan, D. and Lindsay, R. C. (1979). Evaluation of sauerkraut-like products from direct-acidification of cabbage. *J. Food Protection*. **42** (1), 38-42.

Maggioni, L., Bothmer, R., Poulsen, G. and Branca, F. (2010). Origin and domestication of cole crops: Linguistic and literary considerations. *Econ. Bot.* **64** (2), 109-123.

Masley, S. (2009). Cabbage varieties. Retrieved from www.grow-it-organically.com/cabbage-varieties.html. [Accessed January 21,2018].

Matelijan, G. (2018). "The world's healthiest food" (2nd ed.). World's Healthiest Foods. US.

Mazza, G. and LeMague, M. (1980). Dehydration of onion: some theoretical and practical considerations. *J. Food Technol.* **15** (2), 81-194.

Mcallister, G. (2018). Dehydrating sauerkraut. Backpacking Chef.com. Retrieved from http://www.backpackingchef.com/dehydrating-vegetables.html#dehydratingsauerkraut. [Accessed 3 April, 2018].

McDougall, G. J., Fyffe, S., Dobson, P. and Stewart, D. (2007). Anthocyanins from red cabbage stability to simulated gastrointestinal digestion. *Phytochem.* **68** (9).

Montet, D., Ray, R. C. and Rozis, N. Z. (2014). Lactic acid fermentation of vegetables and fruits. Central Tuber Crops Research Institute. Retrieved from https:// www. researchgate. net/ publication /268740843. [Accessed 30 March, 2018].

Murison, J. and Napier, T. (2006). "Cabbage Growing". New South Wales. NSW Department of Primary Industries. pp. 1-7.

Narayanan, N., Roychoudhury, P. K. and Srivastava, A. (2004). L (+) lactic acid fermentation and its production polymerization. *Electron. J. Biotechnol.* **7** (2).

Nixon, S. (2017). The amazing health benefits of cabbage. *The Bayside Desk*

Oliveira, A. R. F. and Ilincanu, L. (1999). Rehydration of dried plant tissue: Basic concepts and mathematical modeling. *In:* "Processing foods, Quality, Optimization and Process Assessment". (A. R. F. Oliveira and J. C. Oliveira, Eds.). pp. 201-227. London. CRC Press.

Olivia, N. A. T. (2009). Effect of blanching and dehydration methods on the quality of moringa leaf powder used as herbal green tea. M. Tech Kwame Nkrumah Univ.,

Ostermann, T., Boehm, K. and Friedrich Molsberger, F. (2014). Regular consumption of sauerkraut and its effect on human health. *Glob Adv. Health Med.* **3** (6), 12-18.

Pandey, S. and Garg, F. C. (2015). Preparation of spiced sauerkraut by using lactic acid bacteria and by natural fermentation. *Int. J. Sci. Res.* **4** (6).

Park, K. Y., Jeong, J. K., Lee, Y. E. and Daily, J. W. (2014). Health benefits of kimchi (korean fermented vegetables) as a probiotic food. *J. Med. Food*. **17** (1), 6-20.

Pederson, C. S. (1971). "Microbiology of Food Fermentation" (2nd ed.).AVI publishing Company Inc.

Penas, E., Frias, J., Sidro, B. and Vidal-Valverde, C. N. (2010). Chemical evaluation and sensory quality of sauerkrauts obtained by natural and induced fermentation at different nacl levels from *Brassica oleracea* var. *capitata cv. bronco* grown in eastern Spain. *J. Agric. Food Chem.* **58**, 3549–3557.

Penas, E., Frias, J. and Villaluenga, M. (2017). Sauerkraut: Production, composition, and health benefits. *Ferment. Foods Health Disease Prevention*. 557-576.

Pliszka, B., Huszcza-Ciokowska, G., Mieleszko, E. and Czaplicki, S. (2009). Stability and antioxidative properties of acylated anthocyanins in three cultivars of red cabbage (*Brassica oleracea L.* var. *capitata L. f. rubra*). *J. Sci. Food Agric.* **89** (7), 1154-1158.

Porro, D., Bianchi, M. M., Brambilla, L., Menghini, R., Bolzani, D., Carrera, V., Lievense, J., Liu, C., Ranzi, B. M., Frontali, L. and Alberghina, L. (1997). Replacement of a metabolic pathway for large scale production of lactic acid from engineered yeasts. *Appl. Environ. Microbiol.* **65**, 4211-4215.

Prakash, S. and Hinata, K. (1980). Taxonomy, cytogenetics and origin of crop Brassicas: a review. *Opera Botanica*. **55**, 1-57.

Prakasha, S., Jhab, S. K. and Datta, N. (2004). Performance evaluation of blanched carrots dried by three different dryers. *J. Food Eng.* **62**, 305-313.

Pundir, R. K. and Jain, P. (2010). Change in microfloral of sauerkraut during fermentation and storage. *World J. Dairy Food Sci.* **10** (5), 221-225.

Pundir, R. K. and Jam, F. (2010). Change in microflora of sauerkraut during fermentation and storage. *World J. Dairy Food Sci.* **5** (2), 221-225.

Quijada, P., Cao, J., Wang, X., Hirai, M. and Kole, C. (2007). *Brassica Rapa*. *Genome Mapping Mol. Breeding Plants*. **2**, 211-263.

Quintero-Ramos, A., Bourne, M. C. and Anzaldua Morales, A. (1992). Texture and rehydration of dehydrated carrots as affected by low temperature blanching. *J. Food Sci.* **57**, 1127-1128.

Rai, B. (2009). "Traditional fermentation foods and beverages" (1st ed.).Dharan.

Ranganna, S. (1986). Prod. *In:* "Handbook of Analysis and Quality Control for Fruits and Vegetable" (2nd ed.).). New Delhi. Tata McGraw Hill Publishing Company.

Rastogi, N. K., Nayak, C. A. and Raghavarao, K. S. M. S. (2004). Influence of osmotic pre-treatments on rehydration characteristics of carrots. *J. Food Eng.* **65**, 287–292.

Rawat, G. B. and Sapkota, K. S. (2012). Effect of low temperature and ice treatment on the post harvest quality of selected cultivars of cauliflower, cabbage and kohlrabi: an analysis of total antioxidant activity,total phenol and L ascorbic acid. M. Tech Norwegian Univ. of Life Sciences, Norway.

Rhee, S. J., Lee, J. E. and Lee, C. H. (2011). Importance of lactic acid bacteria in Asian fermented foods. *Microbial. Cell Factories*. **10** (1).

Robinson, J. and Smith, R. Sauerkraut: From garden to table. Food and Nutrition. Retrieved from https://www.ag.ndsu.edu/publications/food-nutrition/sauerkraut-from-garden-to-table. [Accessed 31 March, 2018].

Ronberg, G. (2017). Health benefits of a food dehydrator. Retrieved from https://www.livestrong.com/article/254798-health-benefits-of-a-food-dehydrator/. (Last update October 03, 2017). [Accessed 25 January, 2018].

Rose, A. H. (1982). Fermented Foods. *Econ. Microbiol.* **3**.

Sablani, S. S. (2006). Drying of fruits and vegetables: Retention of nutritional/functional quality. *Drying Technol.* **24**, 123-135.

SACN. (2010). "Iron and Health". TSO (The Stationery Office). Ireland.

Sagar, V. R. and Suresh, P. (2010). Recent advances in drying and dehydration of fruits and vegetables: a review. *J. Food Sci. Technol.* **47** (1), 15-26.

Shoemaker, S. W. (2009). Cabbage. *Small Farmer's J.* **33** (3).

Shrestha, R. (2002). Preparation and comparative study on sun and solar dried Gundruk. B. Tech Dissertation. Tribhuwan Univ., Nepal.

Shubrook, N. (2017). The health benefits of sauerkraut. BBC Worldwide. Retrieved from https://www.bbcgoodfood.com/howto/guide/health-benefits-sauerkraut. [Accessed 19 March, 2018].

Singh, N. (2003). Accomplishment and challenges in rapeseed mustard research. *Brassica*. **5**, 1-11.

Skory, C. D., Freer, S. N. and Bothast, V. (1998). Production of l-lactic acid by rhizopus oryzae under oxygen limiting conditions. *Biotechnol. Letters*. **20** (2), 191-194.

Smith, B. H. (2016). Cabbage & Chinese Cabbage. Retrieved from http://www.clemson.edu/extension/hgic. [Accessed 25 January, 2018].

Sokhansanj, S. and Jayas, D. S. (1995). Drying of foodstuffs. *In:* "Handbook of Industrial Drying". (A. S. Mujumdar, Ed.). pp. 589-625. New York. Marcel Dekker.

Somogyi, L. P. and Luh, B. S. (1988). "Vegetable Dehydration" (2nd ed.). Van Nostrand Reinhold. New York.

Steinkraus, K. (1996). "Handbook of Indigeneous Fermented Food".New York, USA.

Strohle, A. and Hahn, A. (2009). Vitamin C and immune function. *Med. Monatsschr Pharm.* **32** (2), 49-54.

Swain, M. R., Anandharaj, M., Ray, R. C. and Rani, R. P. (2014). Ferment. fruits and vegetables of asia: A potential source of probiotics. *Biotechnol. Res. Int.*, 1-19.

Tan, A. (2017). 7 varieties of cabbage and how to use. Retrieved from https://guide.michelin.com/us/chicago/dining-in/7-varieties-of-cabbage-and-how-to-use-them/news. (Last update October 17, 2017). [Accessed 20 January, 2018].

Terroir, S. (2016). History of sauerkraut. *Ferment. History*.

Thakur, P. K. and Kabir, J. (2015). Effect of salt concentration on the quality of sauerkraut. *J. Crop Weed*. **11** (1), 46-48.

Trail, A. C., Fleming, H. P., Young, C. T. and McFeeters, R. F. (1996). Chemical and sensory characterization of commercial sauerkraut. *J. Food Quality*. **19**, 15-30.

Upadhaya, A. (2002). Preparation and Quality evaluation of gundruk. B. Tech. (Food) Dissertation. Tribhauvan Univ, Nepal.

Weber, P. (2001). Vitamin k and bone health. Nutri. Retrieved from http://nutristart.com/vitamin-k2/. [Accessed 4 April, 2018].

Wellness, B. (2015). Types of Cabbage. Retrieved from www.berkeleywellness.com/healthy-eating/food/article/types-cabbage. (Last update September 28, 2015). [Accessed 10 January, 2018].

Wintergerst, E. S., Maggini, S. and Hornig, D. H. (2006). Immune-enhancing role of vitamin C and zinc and effect on clinical conditions. *Ann. Nutri. Metab.* **50** (2), 85-94.

Xiong, T., Li, X., Guan, Q., Peng, F. and Xie, M. (2014). Starter culture fermentation of chinese sauerkraut: Growth, acidification and metabolic analyses. *Food Control*. **41**, 122-127.

Appendices

Appendix A

1. Sensory evaluation card

Sensory evaluation sheet of Sauerkraut

Prepared by: Samina Basnet

Purpose: Dissertation for the *partial fulfillment of the requirements for the degree* of Bachelor's Degree in Food Technology (B.Tech Food)

Name of panelist………………………..
Date……………………

Name of the product: *Sauerkraut*

Dear panelist, you are given 13 sample of *Sauerkraut* on each proportion with variation on *brine concentration and fermentation time* Please taste the sample and score how much you prefer the each one. Please give points for your degree of preference for each parameter as shown below using the scale given.

Parameter	A	B	C	D	E	F	G	H	I
Color									
Appearance									
Flavor									
Taste									
Overall acceptability									

Give points as follows:

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

Comments (if any)…………………………………………………………………………….

Signature………………………….

Appendix B

Table B.1 ANOVA (no blocking) for color of rehydrated sample

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	l.s.d
Sample	8	49.4	6.175	11.07	<.001	0.6658
Panelist	9	2.5444	0.2827	0.51	0.865	o.7018
Residual	72	40.1556	0.5577			

Table B.2 ANOVA (no blocking) for color of rehydrated sample

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	l.s.d
Sample	8	19.8222	2.4778	5.32	<.001	0.6082
Panelist	9	6.9889	0.7765	1.67	0.113	0.6411
Residual	72	33.5111	0.4654			
Total	89	60.3222				

Table B.3 ANOVA (no blocking) for appearance of dehydrated sample

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	l.s.d
Sample	8	27.6	3.45	4.49	<.001	0.7018
Panelist	9	2.7111	0.3012	0.39	0.935	0.8235
Residual	72	55.2889	0.7679			
Total	89	85.6				

Table B.4 ANOVA (no blocking) for appearance of rehydrated sample

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	l.s.d
Sample	8	8.8	1.1	2.49	0.019	0.5931
Panelist	9	6.2333	0.6926	1.56	0.142	0.6252
Residual	72	31.8667	0.4426			
Total	89	46.9				

Table B.3 ANOVA (no blocking) for flavour of dehydrated sample

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	l.s.d
Sample	8	25.6	3.2	5.67	<.001	0.6696
Panelist	9	2.6778	0.2975	0.53	0.85	0.7059
Residual	72	40.6222	0.5642			
Total	89	68.9				

Table B.3 ANOVA (no blocking) for flavour of rehydrated sample

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	l.s.d
Sample	8	24.6222	3.0778	5.53	<.001	0.6649
Panelist	9	3.5556	0.3951	0.71	0.698	0.7008
Residual	72	40.0444	0.5562			
Total	89	68.2222				

Table B.4 ANOVA (no blocking) for taste of dehydrated sample

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	l.s.d
Sample	8	38.7556	4.8444	8.89	<.001	0.6582
Panelist	9	7.1556	0.7951	1.46	0.18	0.6938
Residual	72	39.2444	0.5451			
Total	89	85.1556				

Table B.5 ANOVA (no blocking) for taste of rehydrated sample

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	l.s.d
Sample	8	14.0222	1.7528	3.6	0.001	0.6224
Panelist	9	7.2111	0.8012	1.64	0.119	0.656
Residual	72	35.0889	0.4873			
Total	89	56.3222				

Table B.6 ANOVA (no blocking) for overall acceptance of rehydrated sample

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	l.s.d
Sample	8	43.0222	5.3778	12.5	<.001	0.5848
Panelist	9	4.3222	0.4802	1.12	0.363	0.6164
Residual	72	30.9778	0.4302			

Table B.5 ANOVA (no blocking) for overall acceptance of rehydrated sample

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	l.s.d
Sample	8	13	1.625	6.02	<.001	0.4633
Panelist	9	2.4556	0.2728	1.01	0.44	0.4884
Residual	72	19.4444	0.2701			
Total	89	34.9				

Color Plates

P1 Stuffing cabbage into fermentation jar

P2 Reducing sugar determination

P3 Grinding sauerkraut

P4 Analysis of sauerkraut