COMPARATIVE STUDY ON POST HARVEST LOSSES OF POTATO UNDER DIFFERENT STORAGE CONDITIONS

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Comparative Study on Post Harvest Losses of Potato under Different Storage Conditions

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

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Approval Letter

This *dissertation* entitled *Comparative study of Post Harvest Losses in Potato under Different Storage Conditions* presented by Shraddha Khanal has been accepted as the partial fulfillment of the requirements for the B.Tech. degree in Food Technology

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Abstract

The experimental work was carried out to make a comparative study on post harvest losses of potato under different conditions (in-house store, in-basket store and cold store). The effect of storage conditions on various kinds of storage losses and pattern of changes in respiratory and reducing sugar level throughout the storage period was studied. The total loss was 4.383%, 8.539% and 13.043% for cold storage, in-basket storage and in-house storage conditions respectively. In cold stores, reducing sugar increased with storage time with maximum of value of 1.04%. While, Sugar accumulation was almost constant throughout storage time with values of 0.65% and 0.673% in 60^{th} day of storage for in-house and in basket stored potatoes respectively. Respiration rate in cold stores decreased with storage time with minimum value of 3.17 mg CO_2/kg/hr. While, respiration rate increased with storage time with highest value of 6.025 mg CO_2/kg/hr and 6.55 mg CO_2/kg/hr for in-house and in-basket stored potatoes respectively.

Thus it is concluded that storage losses and respiratory rate are minimum for cold stored potatoes but high sugar accumulation is a problem. In-house storage does not suffer excessive sugar accumulation but storage loss is maximum. In case of in-basket storage, besides being cheap and feasible, there is no problem of sugar accumulation and other storage losses are significantly lower than in in-house storage. But, loss due to sprouting is higher leading to higher respiration rate. This problem can be easily solved with the use of appropriate sprout inhibitors. Thus, in Nepalese context, in-basket storage can be the best option.

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List of Abbreviations

Abbreviation	**Full form**
CA	Controlled atmosphere
masl	Meters above sea level
ha	Hectares
CO_2	Carbon dioxide
RH	Relative Humidity
NARC	Nepal Agricultural Research Council
PHL	Post Harvest Losses
R and D	Research and Development
R+U	Respiratory and unknown
LSD	Least Significant Difference
ANOVA	Analysis of Variance

Part I

Introduction

1.1 General introduction

Potato (*Solanum tuberosum*) are the fourth most important agricultural crop worldwide after wheat, corn and rice and play a major role in feeding the world population. Potato tuber develops as an underground stem (swollen part of a subterranean rhizome or stolon) bearing auxillary buds and scars of scale leaves and is rich in starch and storage proteins (Singh and Kaur, 2009). It is one of the important vegetables in human diet. Potato has been cultivated as a staple food in at least 40 countries of the world. It is an important food crop from the very beginning of human civilization both in respect of production and consumption. In Indian sub-continent the cultivation of potato was probably started during the 17th century (Hajong *et al.*, 2014). The history of potato production in Nepal is as long as that in Europe (Rhoades, 1985). Potatoes belong to the group of semi perishable goods, that is, product with high natural moisture content (Kibar, 2012).

Most of the harvested potatoes are put into storage for a while before being used or distributed in the market (Ghazabi and Houshmand, 2010). The main objectives of storage are future consumption, future processing, and maintenance of seed reserve. Also, it allows a better use of processing capacity, better tuning of production and consumption, and better quality of seed potatoes. To guarantee a top-quality product, storage conditions must be well controlled. Low temperature storage, CA storage, storage in diffused sunlight, in situ storage, traditional clamp storage, storage in pits, storage in bamboo baskets are the major storage techniques practiced all over the world.

In the context of Nepal, potatoes are generally planted in late September or early October. Harvesting of potatoes start as early as two months after planting(Rhoades, 1985). The growers have to sell major part of their produces immediately after harvesting at a very low price due to lack of storage facilities and cash need of the growers (Hajong *et al.*, 2014) while prices are higher in the months of September, October and November due to high demand and scarcity of seed potatoes in the market. The major types of storage practices that can be identified in Nepal are cold stores, in-house storage, pit storage, Netus (bamboo baskets lined with soil from inside and straw from outside with alternating layers of moist sand), separate storage buildings called kholma (better ventilated), hanging baskets, in ground (Rhoades, 1985).

While in storage, potatoes suffer losses due to weight loss, sprouting and rotting which are directly affected by storage conditions. Potatoes are more sensitive to quality loss than cereals because conservation using drying techniques cannot be applied and the risk of unacceptable moisture loss, disease spread, mold infections, and insect pests is obvious. In storage, potatoes undergo a gradual weight loss and quality loss which includes moisture loss, respiratory loss and changes in sugar. Potato tubers lose weight in the process of respiration, converting sugar and starches to carbon dioxide (CO_2 and water and losing moisture because of vapor pressure differences between the tubers and the surrounding air. Loss of moisture leads to quality loss and finally to nonmarketable produce (Butchbaker *et al.*, 1973). In addition to the overall health condition of the tuber, variety, growth condition in the field and maturity level of tubers and storehouse temperature is the major factor influencing respiration rate and weight loss of tuber during storage (Ghazabi and Houshmand, 2010).

1.2 Statement of the problems

According to the recent statistics, potato ranks fifth in area (185,342 ha), second in production (25,17,696 tons) and first in productivity (13.58 t/ha) among the major food crops grown in Nepal (ABPSD, 2010). Due to its potentiality and wider adaptability to grow year round in the country, its importance is ever increasing. As there is great diversity in agro-ecology and agricultural practices in Nepal, there are several methods used to store potatoes (Theisen and Campilan, 2010). Most of the Nepalese farmers still rely on the traditional storage methods, as there is lack of modern storage facilities for potatoes and they are quite unknown of the losses they are bearing. Due to lack of the knowledge about the losses in storage, improvement of traditional storage systems or introduction of modern potato storage system is greatly delayed or even neglected.

1.3 Objectives

1.3.1 General objective

The general objective of this work is to compare the post harvest losses of potato in different storage conditions

1.3.2 Specific objectives

The specific objectives are as follows:

1. To assess the respiratory activity of potatoes under different storage conditions.
2. To assess the changes in sugar concentration during storage.
3. To determine total losses of potatoes during storage.

1.4 Significance of the study

This study mainly analyses the losses occurring during potato storage in some common storage systems of Nepal. The findings of this study can be used to compare efficiency and reliability of various storage systems in Nepal. This information can be very helpful to assess whether the existing storage system for potatoes in Nepal are good enough in a long run for farmers or some modifications in traditional system will work for maintaining minimal losses or complete replacement of traditional storage systems needs to be done.

1.5 Limitations of the study

1. Alkali absorption was the only method used for analyzing respiratory rate of tubers.

2. All the causes for probable losses in potatoes could not be measured.

Part II

Literature review

2.1 Potato

While there are hundreds of species of *Solanum* around the world, only about 200 produce tubers. Eight of these are cultivated on some scale. The potato, *Solanum tuberosum* L., is by far the most commonly grown and its exploitation and movement around the world is well documented. Cultivated originally in Peru it was brought to Spain and Portugal, from where it dispersed to other parts of Europe in the late 1500s. Over the next two centuries it was exported to North America, Australia, China and latterly elsewhere (Pringle *et al.*, 2009). Yet, (Rhoades, 1985) states that potato has been grown as a food crop in Nepal almost as long as in Europe.

The potato is a tuber—a short, thick, underground stem with stored starches and sugars—of the potato plant. It was given its botanical name, *Solanum tuberosum,* in 1596 by the Swiss botanist Gaspard Bauhin, and belongs to the Solanaceae family, the nightshades, which includes eggplant, peppers, and the tomato (Murray, 2003).

Potato tuber develops as an underground stem (swollen part of a subterranean rhizome or stolon) bearing auxillary buds and scars of scale leaves and is rich in starch and storage proteins. Potatoes can be grown from the botanical seeds or propagated vegetatively by planting pieces of tubers. The eyes on the potato tuber surface, which are actually dormant buds, give rise to new shoots (sprouts) when grown under suitable conditions. A sprouted potato is not acceptable for consumption and processing. But optimum sprouting is a desired attribute when the tubers are used for propagation (Singh and Kaur, 2009).

The composition and amount of stored nutrients depend upon the growing season temperature and moisture, the soil and nutrient elements in the soil, and the genetic makeup of the cultivar or variety. The composition is of particular importance and concern to the potato manufacturers (Gould, 1999). Despite the potato's fundamental importance as a staple food, little is known about the nutrient composition of many of the world's potato varieties. The proximate composition is given in Table 2.1

Table 2.1 Proximate composition of potato

Constituents	Range	Average
Moisture	63.2% - 86.9%	77.5%
Carbohydrate	13.3% - 30.5%	19.4%
Protein	0.7% - 4.6%	2%
Fibre	0.14% - 3.48%	0.6%
Ash	0.4% - 1.9%	1%

Source : Gould (1999)

2.1.1 Potato varieties

While there are close to 4000 different varieties of potato (Roach, 2002), it has been bred into many standard or well-known varieties, each of which has particular agricultural or culinary attributes. In general, varieties are categorized into a few main groups (Anon.,2015b), such as

- Russet potatoes
- Red potatoes
- White potatoes
- Yellows (also called Yukons)
- Purple/Blue potatoes
- Fingerling potatoes
- Petite potatoes

Since the potato is of relatively recent origin to Asia, far fewer varieties are cultivated than in the potato's Andean homeland range. Formally or through less formal diffusion, Nepal has received several varieties developed by the Central Potato Research Institute (CPRI) of India, including Kufri Jyoti, introduced to Nepal in the mid 1960s and currently considered the oldest and most widely grown of "improved varieties". Varieties that have been present for several generations are likely to bear several local names. Sikha Local and Gumda Local are popular varieties in the mid to high hills, both grown under various local names. Several other varieties persist from their introduction via the British colonial presence in India several generations ago, while some were introduced via Mexico as a testing material in the late 1960s and has since been maintained by farmers in the high hills of the western region. All of these cultivars belong to *Solanum tuberosum* spp. *tuberosum*, except NPI/T-0012, which may belong to the subspecies *andigena*. (Theisen and Campilan, 2010)

The above mentioned varieties are not all. A section of the 1996-97 annual report posted by the NARC pertaining to varietal improvement efforts noted that sixteen local cultivars collected from different areas of Nepal were being used in trials, in addition to recently introduced varieties. Nonetheless, the introduction of new varieties is a recent effort in Nepal (Theisen and Campilan, 2010). The major potato varieties cultivated in Nepal are :

Released Varieties	Agro- climatic zones
• Kufri Jyoti	High and mid hills
• Kufri Sindhuri	Terai and inner Terai
• Desiree	Hills and Terai
• Janak Dev	High and mid hills
• Khumal Rato-2	Terai and inner Terai
• Khumal Seto-1	High and mid hills
• Khumal Laxmi	Terai to high hills
• IPY 8	Terai to mid hills

These are the eight released varieties while other TPS hybrids; HPS 2/67 and HPS 7/67 are soon going to be released while other pipeline clones like L235-4 and CIP 389746.2 are still under investigation to be released soon for the farmers (K.C., 2014). Among these varieties, Desiree variety is one of the most disease and damage resistant varieties showing resistance to dry rot, late blight, potato virus M and X, and other environmental stress factors leading to deterioration (Anon., 2015a).

2.1.2 Favorable climate and geography

The potato has long been classified as a short-day, cool-season crop, but does very well at high temperatures when water is supplied in uniform quantities sufficient to meet evapo-transpiration demands (Department of Agriculture, 2013). Tuber growth is sharply inhibited in temperatures below 10°C and above 30°C; while optimum yields are obtained where mean daily temperatures are in the 18 to 20°C range. For that reason, potato is planted in early spring in temperate zones and late winter in warmer regions, and grown during the coolest months of the year in hot tropical climates. In some sub-tropical highlands, mild temperatures and high solar radiation allow farmers to grow potatoes throughout the year, and to harvest tubers within 90 days of planting (in temperate climates, such as in northern Europe, that can take up to 150 days). The potato can be grown on almost any type of soil, except saline and alkaline. Naturally loose soils, which offer the least resistance to enlargement of the tubers, are preferred, and loamy and sandy loam soils that are rich in organic matter, with good drainage and aeration, are the most suitable. Soil with a pH range of 5.2 – 6.4 is considered ideal (FAO, 2008).

Potatoes are widely grown throughout Nepal, from the southern *terai* at altitudes below 100 masl, to the northern mountains as high as 4,000 masl. The potato crop becomes relatively more important in the high hills areas (from roughly 1,800 to 3,000 masl), as it becomes more productive relative to staples such as rice, maize and finger millet. This altitude range is also well suited to the production of potatoes to be used as seed tubers in lower altitude areas, since viral degeneration generally occurs more slowly at higher altitudes and storage is much less of a challenge. The harvest in the high hills area, from July to September, also complements the cropping calendar of the *terai* and low hills, where planting takes place from September through December (Theisen and Campilan, 2010).

The great agro-ecological diversity of Nepal allows for potato cultivation to occur somewhere at any time of year. Potato is a winter crop in the *terai* and low hills, a spring and autumn crop in the mid hills, and a summer crop in the high hills and mountains. The duration of a crop is variable by variety, but is longer at higher altitudes (Theisen and Campilan, 2010). The cropping calendar is shown in Table 2.2.

Table 2.2 Nepal: Cropping Calendars by Altitudinal Zone

Zone	Altitude (masl)	Planting Months	Harvesting Months
Terai	Up to 350	October - November	January - February
Low Hills	350 - 1,000	September - December	December - March
Mid Hills	1,000 - 1,800	January - February	April - June
		August - September	November - December
High Hills	1,800 - 2,200	February - March	July - August
	2,200 - 3,000	March - April	July - September
Mountains	3,000 - 4,000	Late April - Early May	September - October

Source: Theisen and Campilan (2010)

2.1.3 Production and consumption

Potato is the world's fourth most important food crop after wheat, maize and rice with 314 million tonnes fresh-weight produced in 2006 (Singh and Kaur, 2009) of which 2/3 were consumed by people as food. The other 1/3 is used as animal feed, and as potato starch in pharmaceuticals, textiles, adhesives, and in the wood & paper industries, etc (Ehler, 2015).

Potatoes have been grown in Nepal as food crop for more than two centuries. According to recent data collected, about 197,234 ha of land are under potato cultivation in Nepal and production is 2,690,420,000 kg while the total consumption according to 2013 data is 80.56 kg/capita/year (FAOSTAT, 2013). The potato supply and balance demand in 2007 is given in the Table 2.3.

Table 2.3: Nepal – Potato supply and demand balance 2007 ('000 tonnes)

	Potato (in cereal equivalent)
Total availability	388.6
Opening stocks	0.00
Production	388.6
Total utilization	388.6
Food use	319.8 (based on per capita food use requirement)
Seed use	29.9 (based on planting area)
Losses	38.9 (10% of production)

Source: Fang *et al.* (2007)

2.1.4 Potato storage system

2.1.4.1 Purpose and principle of storage

Storage mainly aims at holding a more or less perishable product in a salable and edible condition throughout as long a period as may be economically desirable. In the case of the potato, the storage is intended for consumption throughout the year or for seed purposes. The early or truck crop is usually sold as harvested, but there may be seasons when, owing to low prices, it might be found profitable to store the crop for a short period, or until such time as market conditions justify its disposal. Good storage not only serves to hold perishable crops in a salable condition but insures also a more uniform market supply throughout the season. It should provide the proper conditions for preserving the natural quality of the potato for table purposes, and also should preserve its vigor for seed purposes (Stuart, 1917).

Potato are semi perishable because they contain about 80% water and 20% dry matter (Anand and Chourasia, 1999) and harvested potato tubers being living organisms interact with the surrounding environment. To maintain potato quality during storage, the storage environment must be adjusted to minimize tuber deterioration (Mughrabi, 2002).

The storage temperature affects the curing and wound healing processes, disease spread and severity, the sugar-starch relationships, and respiration. Respiration, in turn, influences dormancy or sprouting, and weight loss (Voss *et al.*, 1996). At temperatures below 4°C most potato varieties will remain dormant during a normal storage season (up to 8 months) (Mughrabi, 2002). Tubers are often bruised and cut during harvesting and pre-storage handling. Healing proceeds most rapidly at temperatures of 15.556°C to 18.333°C. Most disease organisms logarithmically increase their population growth at temperatures ranging from 4.44°C to 26.667°C. Respiration increases with increasing temperatures and so does the tuber weight loss. Since lower temperatures also maintain dormancy, keep temperatures as low as possible without otherwise decreasing quality. Low temperatures (7.222°C or lower) enhance sugar formation. In general, the optimum, long-term storage temperature for processing potatoes is approximately 7.222°C. For fresh market potatoes, a temperature of 4.44°C is recommended. Seed potatoes may be stored at slightly lower temperatures (3.333°C to 4.44°C) for better weight loss and sprout control. (Voss *et al.*,1996)

Around 95 % relative humidity should be maintained at all times. High humidity is essential for optimum wound healing during the curing period. It is also essential during the entire storage period to minimize tuber weight loss; weight loss rapidly increases at relative humidity levels below 90 % (Voss *et al.*,1996).

Air movement includes both through-the-pile ventilation and over-the-pile ventilation (= recirculation). Through-the-pile ventilation is necessary to dry and cool the potatoes, supply fresh air, and remove carbon dioxide, volatiles and excess heat and moisture from the storage. Recirculation aids in maintaining uniform temperature conditions throughout the storage and sweeps moisture from the walls and ceiling (Mughrabi, 2002).

In addition to that, good storage monitoring is necessary for long term potato storage in any kind of potato storage structure (Mughrabi, 2002).

2.1.4.2 Goals of potato storage

It is important to make the distinction between ware potato storage and seed potato storage. The objective of ware potato storage main is to obtain the maximum quantity of tubers, of acceptable quality to the consumers, at a rate to meet consumer demand. This requires the lowest possible quantitative and qualitative losses, with no or little sprouting, kept in the dark to prevent greening and firm tubers, all at an economical cost. In seed potatoes storage the objective is to have optimum development of sprouts prior to planting. In both cases the farmer requires the maximum return from his investment in time, materials, equipment and buildings (Diop, 1998b) Thus, goal of potato storage is to maintain tubers in their most edible and marketable condition by preventing spoilage by pathogens, attack by insects and animals, and sprout growth. Prevention of tuber greening and glycoalkaloid accumulation is also important (Woolfe, 1987). To sum up, ideal potato storage method serves to retain the natural water in the tubers, to hold the respiration rate to a minimum, to hold reducing sugars to near zero and to maintain the external appearance of the tubers (Gould, 1999).

2.1.4.3 Types of storage systems

Many traditional and modern storage methods are practiced worldwide for potatoes. Though traditional methods of storage suffer considerable losses, the number of farmers relying upon traditional methods of potato storage is increasing. Over the period of 4 decades, the number has increased by eight folds. The main reason for continuing or increasing the use of indigenous methods of potato storage are cheap and easy handling of potatoes and better taste of traditionally stored potatoes than cold stored ones (Dahiya *et al.*, 1997). Some of the storage practices adopted worldwide are:

- Cold temperature storage at less than 5°C
- Controlled atmosphere storage (Gould, 1999)
- Traditional clamps
- Ventilated piles (Lisinska and Leszczynski, 1989)
- In-situ or in-farm storage
- Pit storage
- Wooden storage structures
- Storage in baskets
- Room storage
- Diffused light seed potato storage

As Nepal is a country with diverse climatic conditions and geography, potato production and storage methods also differ. In high hill reasons, because of the climate and short storage period, potato can be stored with other cereal grains. In mid hills, storage period is 4-5 months and that is not more than 3 months in Terai region. Following are the major storage methods practiced in Nepal.

A. Traditional methods of potato storage

- Storage in *bhakaris*
- In situ storage
- Pit storage/clamps dug in the ground
- Storage in heaps
- Storage with use of chemicals
- As layers in bamboo baskets
- In sack storage (Gautam, 2014)
- *Perungu* storage (Anon.,2004)
- In-house storage
- Kholma storage i.e. separate building storage (Rhoades, 1985)

B. Modern methods of storage

- Storage in cold stores (Theisen and Campilan, 2010)
- Storage in diffused sunlight (in wooden trays, improved perungus) (Anon., 2004)

Brief description of the major storage methods practiced in Nepal is given below.

2.1.4.3.1 In-house storage

In-house storage is practiced in all ecological regions of Nepal. Typically, potatoes are spread out to dry for 7-10 days after harvesting and then stored in the dark, especially under beds, corners or in the dark rooms of the house (Rhoades, 1985). This storage technique mainly aims at making potatoes devoid of sunlight during storage period as potatoes when exposed to strong or even modified light are soon materially injured for table purposes. The injury is due to the greening of the tubers and to the development of an alkaloid in the outer layer and chiefly around the eyes. This alkaloid is technically known as solanine and when present in sufficient amount it makes the consumption of such potatoes dangerous to the health. Also, as potatoes are not in large piles, the chances of violent sweating or curing process or development dangerously high temperature at the central portion of the pile is minimum (Stuart, 1917). The problems reported in this storage system is, this technique is space consuming. A large part of the floor area of the house is taken up by the seed potatoes which are kept in single or double layers. A disease or insect attack spreads to all seed stored. Seed stock vigor decreases and its uniformity declines due to excessive sprouting (Khatana *et al.*, 1997).

2.1.4.3.2 Storage in bamboo baskets

In this technique, potatoes are well mixed with dry wheat straw and kept in bamboo baskets, usually ware potatoes in dark room and seed potatoes in some light. Dry wheat straw is used to create dry and cool conditions within the storage area(Mutandwa and Gadzirayi, 2007). It prevents further loss of moisture from potatoes (Rhoades, 1985). This avoids the development of fungal diseases that normally thrive under humid and warm conditions (Mutandwa and Gadzirayi, 2007) and holes in the basket ensure proper ventilation and prevent overheating. The straw absorbs condensation produced by the tubers respiration, which might otherwise enhance the presence of microorganisms (Knutsson, 2012).

2.1.4.3.3 Low temperature storage

Cooling the harvested product control the rate of quality loss by slowing the rate of respiration. The warmer the temperature, faster is the deterioration and shorter the storage life; conversely, the cooler the temperature, the slower the deterioration and the longer the storage life. The more quickly the product is cooled, the longer it will remain marketable (Sakare, 2014). Fig 2.1 represents the storage of potato in sacks in the cold stores.

Fig. 2.1 Refrigerated storage system for potatoes

Desired storage temperature for seed potatoes after initial curing is 3.3°C to 4.4°C. Potato respiration is minimized at 2.8°C. Storage temperatures above 4.4°C results in physiological aging of tubers and promotes premature sprouting of seed potatoes, particularly of cultivars with a short dormancy. Seed tubers stored below 2.8°C have increased respiration and will increase in physiological age compared to tubers stored at 3.3°C to 4.4°C (Department of Agriculture, 2013). Also, there are chances of chilling injury (usually occurs below 0°C) and mahogany browning at such low temperatures. Tubers for fresh consumption are stored at 7°C to 10°C, to minimize conversion of non-reducing sugars such as starch to reducing sugars such as glucose, which darken during cooking. Tubers for frying are stored at 10°C to 15°C, depending on the cultivar and its respective sugar conversion characteristics. Many chipping cultivars accumulate excessive sugar if stored <15°C. Thus, chipping cultivars are stored at 15°C to 20°C; new cultivars are being developed that will not accumulate sugar at temperatures as low as 5°C to 10°C (Voss *et al.*,1996). Cold store employs vapor compression system for refrigeration and uses ammonia as refrigerant (Sakare, 2014).

Similarly, RH is another thing considered in cold stores. Current university of Idaho recommendations suggest that a plenum RH of at least 90%, and preferably greater than 95%, should be maintained throughout the duration of storage. This assumes that the crop is healthy, with a low presence of diseases. Ventilation with high RH air is specially critical immediately following harvests during curing. Monitoring the plenum RH of storage and actively working to achieve as high a RH as possible without excess condensation should is the major goal of successful storage. Cold stores may use cell type humidification systems, spinners, and high pressure nozzles for this purpose (Oberg *et al.*, 2010).

The cold storage industry, which has become very important to potato marketing in India, has yet to develop in Nepal (Theisen and Campilan, 2010). In Nepal, cold storage association has 23 members in their list and it has reported that there are 35 cold storages in the country with an average capacity of 3,000 MT each. The energy cost is with 38% of the turnover pretty high compared to other industrial sectors (Bodach, 2014).

The average loss in cold storage during nine months storage period was 3.82% of total potato stored. This loss included the weight loss (57%), spoilage loss (34%) and other loss (9%) caused due to sprouting, shrinkage, cold injury etc. Load shading, storing of unsorted potato, overload of storage bag are the main problems in cold storage operation (Hossain and Miah, 2009).

2.1.4.3.4 Other storage methods practiced in Nepal

In-situ storage is one of the common methods of potato storage in which farmers delay the harvesting of potato tubers and allow them to remain in soil. This is generally practiced in hill regions above 1800 meters above sea level (masl) (Theisen and Campilan, 2010). Rotting and lowering of quality are the major problems of this kind of storage.

Farmers also store potatoes in separate storage buildings call *kholma* the use of which is more common in hills than in terai. It is considered cooler and better ventilated than the warm, smoke filled typical Nepalese house. So this method is considered superior to in-house storage (Rhoades, 1985).

4.5 m (length) x 3.6 m (width) x 14 m (depth) dimensional pits are often used for potato storage which is then covered with 0.3 m thick available straw. This method is popular only in far north in Nepal which receives very low rainfall. Rodents and rotting are the major problems encountered in this (Gautam, 2014).

Another cheap and easy method of potato storage in northern parts of Nepal where temperature is around 5-10°C is storage in heaps. 1.5-3 ft tall potato heaps are made and covered with straw, mud or plastic. Pipes are inserted in between to ensure exchange of heat and gases.(Gautam, 2014).Use of chemicals is often practiced for storage in which 4 ml CIPC is mixed with 1 liter methanol and sprayed in 9-10 quintal potatoes. Potatoes can be stored for 3-4 months by regular spray of chemical in every 45 days (Gautam, 2014).

At higher altitudes within this range, seed potato storage in partial diffused light is an old established practice, as potatoes are often kept in different layers in bamboo baskets. Diffused light promotes the growth of sprouts which are short and stout, ideal for viable seed tubers (Theisen and Campilan, 2010).

2.2 Post harvest losses in potato

When food items are attached to the parent plant, losses due to respiration and transpiration are replaced by photosynthesis and nutrient uptake from root system. Even after the detachment from the plant, the produce continues to perform the metabolic reactions and maintain the physiological systems that were present when it was attached to the plant resulting in changes and losses postharvest (Kharel and Hashinaga, 2010).

Any change in availability, edibility, wholesomeness and quality of food stuff that reduces its quality to humans is called food loss (Grieig and Reeves, 1985). Food losses may be direct or indirect. A direct loss is disappearance of food by spillage, or consumption by insects, rodents, and birds. An indirect loss is the lowering of quality to the point where people refuse to eat it (Harris and Lindblad, 1978). The period between maturity of the crop and the time of its final consumption is called post harvest. The losses that occur during this post harvest period is called post harvest loss (Grieig and Reeves, 1985).

Similarly, loss should not be confused with damage, which is the visible sign of deterioration, for example, chewed grain and can only be partial. Damage restricts the use of a product, whereas loss makes its use impossible (Kaiya, 2014). Damage is a clear deterioration in the product, e.g. broken or pitted grain, which affects more its quality than its quantity and can in the long-term result in a definite loss. Both damage and loss should be quantified in terms of weight and cost (Grolleaud, 2008).

PHL can occur due to food waste or inadvertent food losses along the way. Food waste refers to food appropriate for human consumption being discarded, whether or not after it is kept beyond its expiry date or left to spoil. Inadvertent food loss is the loss in food quantity because of the infrastructure and management limitations of a given food value chain. Food losses can be the result of a quantitative loss or a qualitative loss (Aulakh *et al.*, 2013).

Quality losses include those that affect the nutrient/caloric composition, the acceptability, and the edibility of a given product. These losses are generally more common in developed countries. Quantity losses refer to those that result in the loss of the amount of a product. Loss of quantity is more common in developing countries (Kaiya, 2014). Qualitative losses (such as loss of caloric and nutritive value, loss of acceptability by consumers, and loss of edibility) are more difficult to measure than quantitative losses of fresh fruits and vegetables. While reduction of quantitative losses is a higher priority than qualitative losses in developing countries, the opposite is true in developed countries where consumer dissatisfaction with produce quality results in a greater percentage of the total postharvest losses (Kader, 2005). The major types of food losses are given in fig. 2.2.

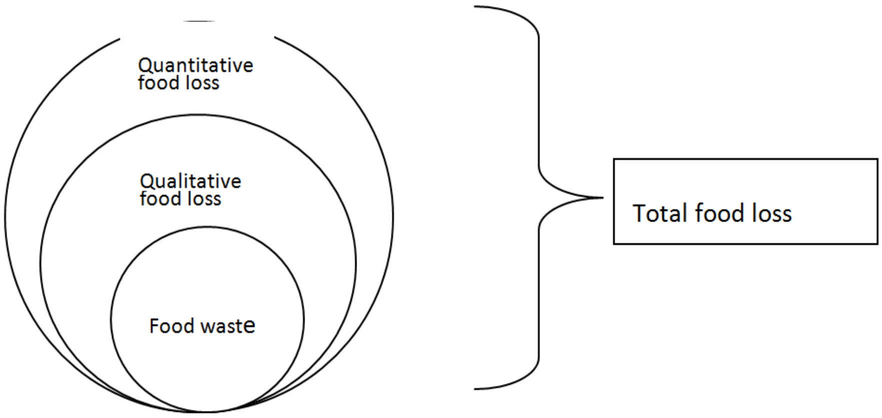

Fig. 2.2 Types of food loss

There are several causes of post harvest losses. Mechanical injury, pathological actions and environmental factors like temperature, RH and gas composition are the primary causes while inadequate harvesting, transportation, marketing facilities and legislation leads to favorable condition for secondary causes of losses (Sudheer and Indira, 2007).

2.2.1 Types of storage losses in potato

Loads of tubers of high storage potential eventually leave the store with minimum losses of weight and quality and retain a good appearance. In the absence of damage and disease, weight losses are the direct result of respiration, evaporative water loss and sprouting. Collectively, this has been described as 'natural wastage' or 'shrinkage'. Total weight loss is the sum of natural wastage, damage and disease. Deterioration proceeds in parallel with the shrinkage in the form of biochemical changes. This may not contribute to weight loss but can render tubers useless for a particular purpose. For example, senescent sweetening in long stored tubers make them unsuitable for crisp manufacture (Harrris, 1978). Thus, storage losses are mainly caused by the processes like respiration, sprouting, evaporation of water from the tubers, spread of diseases, changes in the chemical composition and physical properties of the tuber (Hossain and Miah, 2009).

2.2.1.1 Loss due to moisture change

The potato tuber is also roughly made up of 75% water and 25% starch, and therefore is capable of losing the internal water if subjected to low external vapor pressure or relative humidity. When potatoes lose excessive moisture they shrink and may become unmarketable. Sprouting will significantly increase water loss in stored and transported potatoes (Hossain and Miah, 2009). According to the study conducted by Mehta & Kaul, 1997, transpiration was found to be the major source of weight loss during storage (18-30°C, RH 80-90%) for a period of 4 months (Kaul and Mehta, 1999). Evaporation on the other hand is a physical process which can be managed by controlling the storage environment in terms of temperatures, air humidity and air flow rate. It should be taken into consideration that temperature change in storage should be made in gradual way. This gradual temperature reduction results in little changes in the sugar content of tubers and also avoids deterioration of quality of processed product quality. Most of the tuber shrinkage that occurs during the first month of storage results from water lost before the completion of the wound healing process. Maintaining high relative humidity in potato storage prevents some of the early season tuber dehydration and helps controlling the total shrinkage during the season. Shrinkage in storage is directly proportional to the length of the storage season and inversely proportional to the relative humidity conditions maintained within the store. The recommended RH in stores is 95% or above for minimizing early storage tuber losses due to dehydration (Singh *et al.*, 1994).

2.2.1.2 Loss due to respiration

Respiration is a key metabolic process that tubers undergo and this process allows the release of energy through the oxidative breakdown of stored carbon compounds, which in this case is starch.

$$C_6H_{12}O_6 + 6O_2 = 6\,CO_2 + 6H_2O + \text{energy}$$

During this process the tuber generates heat, which becomes an important consideration for storage and transportation of potatoes (Hossain and Miah, 2009).

Respiration rate varies with variety and response to storage temperature. In general, tuber respiration is relatively high at low storage temperatures, decreases as storage temperatures increase, and then increases again as storage temperatures are elevated. Respiration is a natural biochemical process under the physiological activity of the tuber tissue. It can be controlled by an appropriate temperature control to reach and keep low physiological activity of the tubers. Respiration consumes oxygen and as a result converts starches to sugar. The tuber cell, oxidize glucose into nutrient that is required by tuber to stay alive, produce water, carbon dioxide, heat and byproducts. The heat produced in the process reduces the relative humidity of the air within the cells, also increases water holding capacity and continues moisture loss through evaporation from tuber skin. Respiration also increases when tubers are mishandled, transported over rough tracks or subject to bruises or cuts. For most varieties, temperatures above 15^{o}C may cause dramatic increases in respiration (Singh *et al.*, 1994). Contribution of respiratory carbon loss to total weight loss was slight (3.56-6,07%) (Kaul and Mehta, 1999). Respiratory losses are usually minimal near 7°C. Tuber weight loss due to respiration alone can equal 1.5% of the total weight over an 8 to 10 months storage season (Kibar, 2012).

The terms "physiological loss" (Kaul and Mehta, 1999) or "natural wastage" or "shrinkage" or even just "weight loss (provided there is no loss due to damage, disease and sprouts)" collectively refers to loss due to transpiration and respiration (Harrris, 1978). Weight loss is greater during the early part of the storage season due to higher tuber respiration rates, higher storage temperatures for wound healing, and greater transpiration (Singh *et al.*, 1994). Weight loss is kept in check in the cold stores because the temperature is maintained at 2-4°C and relative humidity at 90% or higher. A weight loss of 0.5 to 1.0% per month is considered acceptable in refrigerated stores (Kaul and Mehta, 1999). According to the work by (Wager and Burton, 1952) at 2.8^{o}C temperature, and water vapor pressure deficit 1.5 mbar, potatoes lost 3.8% by respiration and evaporation over a period of 23 weeks. Of this, about 0.4 to 0.8% might have been due to respiration leaving evaporative loss of 3-3.4% (Harrris, 1978). Fig. 2.3 represents the general trend of weight loss per week of potatoes in ambient air cooled store for 14 weeks.

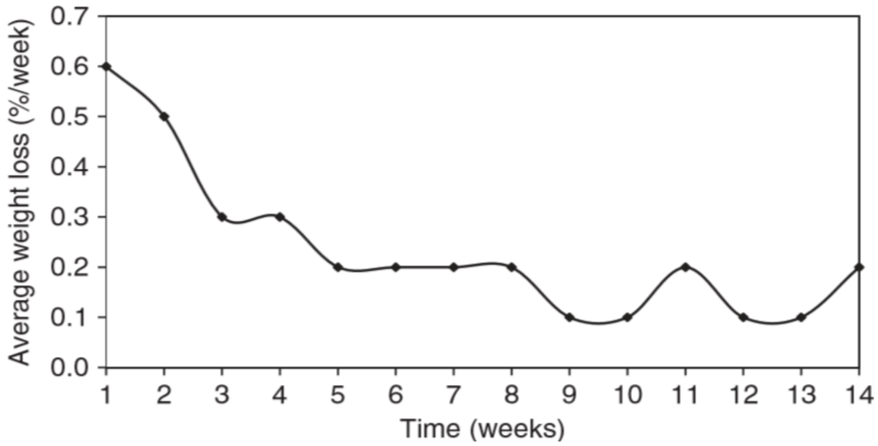

Fig. 1.3 Percentage weight loss per week over the first 14 weeks in an ambient-air cooled store.

Source: Pringle *et al.* (1997)

2.2.1.3 Loss due to sprouting

Sprouting of potatoes during storage, due to tuber dormancy release, is associated with weight loss and softening (Dudai *et al.*, 2010). Of all the physiological factors sprouting is the major cause of deterioration of market quality of potato and it is the obvious manifestation of the deterioration (Dris and Jain, 2004). Sprout development can impede airflow and affect temperature, thus reducing overall quality of the potato (Olsen and Kleinkopf, 2001). Though the estimates vary, losses due to sprouting may range between 5-15%. Sprouting doesn't start immediately after harvest. There is a time lag called the dormancy period (Dris and Jain, 2004).

Dormancy is a state in which tubers will not sprout even when placed under conditions ideal for sprout growth (18-20ºC, 90% RH and darkness). Duration of dormancy is normally counted from the date of harvest and is usually less than 71 days for short dormant varieties and more than 80 days for long dormant varieties (Singh, 2013). The dormancy period depends upon variety, climatic conditions, maturity at harvest, mechanical damage, microbial infections and the storage environment and temperature (Dris and Jain, 2004). The dormancy period can also be defined as the period of reduced endogenous metabolic activity during which the shows no intrinsic or bud growth, although it retains the potential for future growth (Diop, 1998a).

As soon as dormancy is broken and sprouting begins, the rate of dry matter loss increases dramatically since the formation of sprouts requires energy, which is drawn from the tubers' carbohydrate reserves. The rate of water loss also increases and if this becomes excessive the tubers dry out allowing pathogens to penetrate the tuber, potentially causing severe damage if not total loss, making continued storage quite impracticable (Diop, 1998a). Once sprouted, potatoes start losing weight, their appearance is affected by shriveling and they loose marketability for table and processing purposes. Besides, in seed as well sprouting before the required time is undesirable since the shriveled tubers loose vigor (Singh *et al.*, 1994). Sprouting may impede airflow through the potato pile. Reduced airflow often leads to increased pile temperatures and an increase in disease problems. Sprouting is also associated with the conversion of starch to sugars, which is undesirable in the processing industry due to darkening of fried products (Frazier *et al.*, 2004). The dry-stored potatoes develop only small sprouts but the humid and wet storage permitted very long sprouts to develop resulting more loss due to sprouting (Neubauer *et al.*, 1967).

As mentioned above, sprout growth, which involves mobilization and transfer of material from tuber to the sprout and its synthesis in to the sprout structure, is accompanied by increased respiration (Harrris, 1978). The respiration of a sprouting tuber includes both that of the tuber and the sprouts, and Burton *et al.* (1955) found that there is approx. 50% increase in respiration by the time sprout growth reaches about 1% by weight which increases with increasing growth.

Temperature has strong influence on sprout growth. Sprout growth does not take place when the storage temperature is less than 4ºC. Sprout growth is observed at 5ºC and increases with increasing temperature. It is optimum between 15 and 20ºC. Compared to the influence of temperature, humidity has only a slight effect on sprout growth. Light inhibits sprout growth and it has been shown that red light above 650 nm and blue light below 500 nm both contribute to the inhibition of sprout growth. Potato sprouts grown in the light develop chlorophyll and are shorter and sturdier than those grown in the dark (Singh *et al.*, 1994). Many sprout inhibitor chemicals like CIPC, mint essential oil, clove oil as well as gamma radiations can be used for sprout control (Frazier *et al.*, 2004).

Also, since the sprout depends on the tuber materials for growth, if there are several sprouts on the tuber, an inter-sprout competition for growth factors will be imposed by the size of the tuber. With fairly large tubers, no effect of size will be noticeable, but with decreasing size, a point can clearly be reached at which growth will be impaired (Carli *et* *al.*, 2012). Sprouting increases levels of toxic glycoalkaloids, accelerates starch breakdown with concomitant accumulation of undesirable reducing sugars (Singh and Kaur, 2009).

2.2.1.4 Loss due to deterioration

Losses in potatoes caused by pathogens are greater than the losses due to physiological causes. Physical damage to tubers during harvesting and careless handling immediately afterwards aggravates initiation and spread of the attack of bacteria and fungi leading to rotting and thus quantitative loss (Singh *et al.*,1994). Also, before harvest, through natural pores in the above and below ground parts of plants, which allow the movement of air, carbon dioxide and water vapour into and out of the plant. Pests like insects, birds, rodents and nematodes are also responsible for huge amount of losses (Diop, 1998a).

Rotting which is the result of attack by micro-organisms is a major cause of potato losses in non-refrigerated stores. Potato cultivars differ in their susceptibility to rotting under ambient storage conditions. Recent studies conducted with ten potato cultivars showed that rotting was maximum in Kufri Sherpa and Kufri Bahar (Kaul and Mehta, 1999).

Bruises during potato harvest and storage like black spot bruise, shatter bruise and white knot causes increased shrinking in storage, reduced returns from processing contracts, as well as the direct loss caused by bruising itself. Growers may lose up to 20% of their income through potato damage at harvest (Department of Agriculture, 2013). The most common and serious physiological disorders affecting potatoes include black spot, blackheart, freezing injury, greening, hollow heart, sugar end browning, and internal necrosis (Voss *et al.*,1996). The symptoms of chilling injury are not always obvious when the tubers are still in cold storage, they become noticeable as soon as the tubers are restored to ambient temperatures (Diop, 1998a)

Generally, the common storage diseases caused by fungi are late blight, dry rot and pink rot. When infection occurs in the field, rotting begins in the field and continues during storage. When infection occurs after harvesting, it is generally through mechanical injury as in the case of dry rot. High humidity and condensation of water on tuber surface can lead to infection by soft rot causing bacteria *Erwinia* spp which is the most severe bacterial infection. Qualitative losses are caused by diseases such as common scab, powdery scab, black scurf and wart, which affect the appearance of the tuber and thus reduce the market value of potatoes. Among the insect pests, tuber moth is common in potatoes stored under non-refrigerated storage. The larval damage results in direct weight loss and tuber moth infection greatly reduces market value of the tubers (Singh *et al.*, 1994).

Careful sorting before storage, management of air, RH, and temperature during storage and transit of potatoes with potential problems can be effective. Low RH, shortened curing time, and lower temperatures can minimize spread of rot diseases (Voss *et al.*, 1996).

Cramer (1967) estimated that excluding losses caused by virus diseases, insect pests directly cause a loss of about 3% of production in Britain, and about 5% in the rest of Europe, where other pests are present (Harrris, 1978). Loss due to rotting in traditional storage system is about 10-12 % (Singh *et al.*, 1994).

2.2.2 Changes in respiration rate

Respiration is a vital biochemical process for all living cells. It will continue after harvesting and during storage but at slower rates (Fennir *et al.*, 2005). Measurement of respiration affords an easy non-destructive means of monitoring the metabolic and physiological state of the tissues and thus acts as signal for events like senescence and ripening. Respiration rate can be measured by assessment of loss of substrate, production of carbon dioxide, consumption of oxygen or release of energy in a static or dynamic system (Saltveit,2003).

2.2.2.1 General trend of respiration rate change during storage

Respiration rate drops rapidly after harvesting and becomes relatively stable from senescence through to sprouting/dormancy break. It is less stable at high storage temperatures of 20°C, but in temperate climates (<10°C), respiration over the storage period are relatively constant. Respiration rate with respect to temperature 1 month after harvest shows higher rates at elevated storage temperatures and a minimum at 5–6°C; below which respiration increases as part of the tuber’s response to low temperatures (Pringle *et al.*, 2009). Kimbrough (1925) was the first to show that immediately after harvest potato tubers had a high rate of respiration which decreased rapidly from 20 mg CO_2/kg/hr to a constant level of 5 mg over a period of three weeks at 22°C. Smith (1929) stated that for harvested immature tubers, it took approximately six weeks to reach a constant level of respiration and about four weeks for mature (Schippers, 1976).

During dormancy, the endogenous metabolic rate of tubers is at its minimum and the dry matter losses are correspondingly reduced. For example, it has been shown that immediately after harvest yam tubers (*D. rotundata*) respire at a rate of 15 ml CO_2/kg fresh weight/hour at 25°C. The respiration rate will later drop as low as 3 ml CO_2/kg/hr and remain at that level until sprouting starts. During sprouting the respiration rate increases dramatically to over 30 ml CO_2/kg/hr (Diop, 1998a). Ziegenbein (1893) reported the respiration rate to be 4.6 mg CO_2/kg/hr at 30°C. The fig. 2.4 represents general trend of potato respiration after harvest.

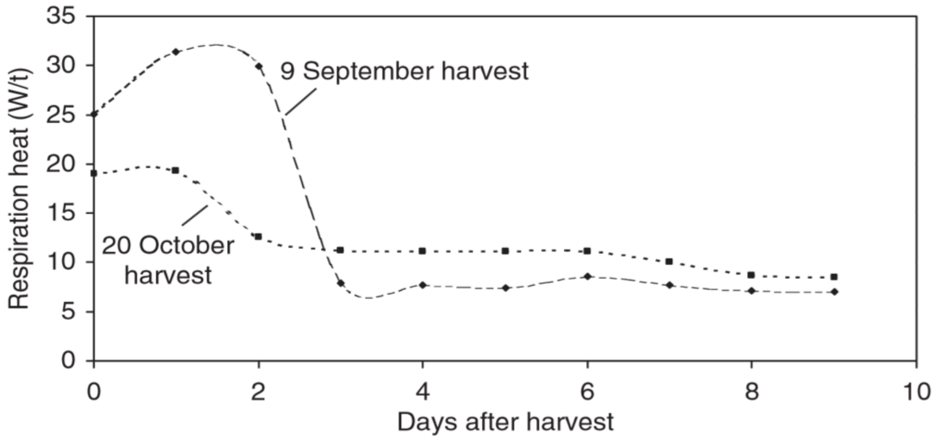

Fig. 2.4 Potato respiration in the days after harvest.

Source: Pringle *et al.* (2009)

2.2.2.2 Factors affecting respiration rate

While a produce is being stored, its respiration process is affected by several factors, generally classified into produce and storage environment related factors. The first group includes: variety, maturity, growing conditions, heat and water stresses, nutrient deficit, sprouting, injuries and diseases, while storage factors include: temperature, gas composition, ethylene and other storage conditions (Fennir *et al.*, 2005).

2.2.2.2.1 Maturity

Immature potato tubers usually have higher respiration rates than mature or cured tubers. Tubers lifted prior to senescence may still be increasing in size, with cell division proceeding at a rapid rate (Pringle *et al.*, 2009). Cooler temperatures and increased air movement are effective at controlling effects of a high rate of respiration. Increased air movement in the absence of high RH, however, will cause desiccation. Table 2.4 shows respiratory rate of matured and immature potatoes at different temperatures.

Table 2.4 Respiration rate of matured and immature potatoes at different temperatures

Temperature	Immature (mg CO_2/kg/h)	Mature (mg $CO_2 kg^{-1} h^{-1}$) (cured)
5 °C	24	6 to 18
10 °C	30 to 40	13 to 19
15 °C	25 to 57	11 to 22
20 °C	32 to 81	14 to 29

Source : Voss *et al.* (1996)

This phenomenon can also be explained by skin permeability. The permeability of the skin of the tuber is a function of its maturity and is a very significant factor in the rate of respiration. The periderm of freshly harvested immature tubers is most permeable and thus permits greater levels of respiration than similarly harvested mature tubers. Immature potatoes are reported to respire at a rate of about 17 ml O_2/kg/h immediately after harvest, compared to a rate of 5 ml O_2/kg/h when physiological mature (Diop, 1998a).

2.2.2.2.2 Composition

As suggested by Barker (1933)Barker (1936) there may be apparent correlation between sucrose content and rate of respiration. This is compatible with the high rates at low temp which cause tubers to sweeten; of immature tuber, which contain a high concentration of sucrose; and following gamma radiation which causes marked temp increase in sucrose. The cases just mentioned are all observed at times when rapid conversion of carbohydrate is occurring and it has been calculated that the increase in respiration is closely equivalent to the increased formation of ATP involved in the carbohydrate conversions (Schippers, 1976).

2.2.2.2.3 Sprout growth

Sprout growth, which involves mobilization and transfer of material from tuber to the sprout and its synthesis in to the sprout structure, is accompanied by increased respiration. The respiration of a sprouting tuber includes both that of the tuber and the sprouts, and

Burton *et al.* (1955) found an approx. 50% increase in respiration to have occurred by the time sprout growth had reached about 1% by weight which increases with increasing growth.

2.2.2.2.4 Handling

Baker found that turgid tubers could be handled without serious disturbance of their respiration, but that if the tubers were soft, gentle squeezing could increase the rate of respiration by about 30% the effect was temporary and disappeared in the course of day. Handling leads to a variable respiratory quotient, an effect which could last for several weeks (Harrris, 1978). This may be due to the subsequent wound healing process (Pringle *et al.*, 2009).

2.2.2.2.5 Temperature

It is the most important factor affecting the rate of respiration. $Q_{10} = 2$, i.e. the rate of respiration is doubled for every 10°C increase in temperature over the range 5°C to 25°C. Significant variations to this general rule will occur through interactions with other factors affecting the rate of respiration. For potatoes, the rate of respiration is at a minimum around 5°C. Below this temperature the respiration rate tends to increase (Diop, 1998a). Reducing the temperature to 3°C results in sharp increase in respiration due to the high concentration of reducing sugars formed by the breakdown of starch. At 0°C, the rate of respiration is same as that at 20°C. (Singh and Kaur, 2009). Table 2.5 shows the respiration rate of potatoes at different temperatures.

Table 2.5 Respiration rate of potatoes at different temperatures

Temperature °C	Temperature °F	ml CO_2/kg·hr
5	41	6-8
10	50	7-11
15	59	7-16
20	68	9-23

Source : Suslow and Voss (2015)

2.2.2.2.6 Size of tuber

Michaels (1932) found, as an average of three cultivars which behaved fairly consistently, that large, medium and small tubers had respiration rates of 22, 26 and 32 rag, respectively, at 22°C. He found that in smaller tubers the surface area was greater in relation to the volume of the tubers, and the number of lenticels per cm^2 surface was higher (Schippers, 1976).

2.2.2.2.7 Other factors

Herklots (1928) found continuous exposure to low concentrations of ethylene caused a mark temporary rise in the rate of co2 production by tubers (Harrris, 1978). Gamma radiation causes a marked temporary increase in respiration, rising to a peal in a week or so and then falling to about the control level. Mulder (1955) found that tubers which were deficient in potassium respired more intensely than those which had received a sufficient supply. There is influence of cultivar also on respiration rate. Smith (1929) found that the late-maturing White Rose had a higher rate of respiration at 25°C than the much earlier-maturing Irish Cobbler (Schippers, 1976). When tubers are harvested under warm conditions the respiration rate of the tubers increases (Singh and Kaur, 2009).

2.2.3 Changes in sugar level

The simple sugars that are formed in the plant are synthesized to form sucrose. Sucrose is then translocated from the above ground stem to the underground stem, that is, the rhizome or tuber. Here the sucrose is further synthesized to form starch in the tuber and will continue to accumulate until the plant stops manufacturing sugars. This process may be reversed during respiration (Gould, 1999). In the mature stored tuber, sugars and starch exist in a state of dynamic equilibrium (Woolfe, 1987).

Sugars are responsible for the production of dark colors during frying but not all sugars contribute equally. Most research indicates that only the reducing sugar content is related to the final degree of darkening in the finished product (Eduardo and Augusto, 1993). Sucrose or Chemical Maturity Monitoring (CMM) should be 1% or less if one wishes to store tubers for the chip market and below 1.5% for harvesting. If the glucose (reducing sugar) level is too high (>0.20%) these sugars will react with the naturally present amino acids (Maillard reaction) and cause dark colored chips. Thus, when manufacturing chips, the only sugar test that need be made is the reducing sugar test (Gould, 1999). Also, poor texture after cooking is associated with low-starch and high-sugar content (Singh and Kaur, 2009).

2.2.3.1 General trend of sugar change in storage

Storage at 1ºC stimulated reducing sugars accumulation, particularly in the first weeks. After 30 days of storage at this temperature a 5-fold increase was observed in the concentration of reducing sugars, thereafter their accumulation occurred at slower rate. Reducing sugars accumulation in tubers stored at 8ºC and 20ºC was almost nil having a non-significant increase only after 170 days of storage at 8ºC. Similar is the case for sucrose and after 30 days, the sucrose concentration increased more than seven times and then leveled off. Upon being transferred from 20ºC to 1ºC the sucrose accumulation exceeded that of reducing sugars after 30 days. From 40 to 180 days tubers held at 1ºC continued to show a slight accumulation of reducing sugars (Eduardo and Augusto, 1993).

Coffin *et al.* (1990) found that sucrose content increase within 2 days of 5°C storage for both mature and immature tubers of four cultivars, while fructose and glucose content increased more slowly. Pollack and Rees (1974) reported an increase in both sucrose and reducing sugar content within 5 days in tubers stored at 2°C and after 20 days storage, the sugar content was approximately six times greater than at day 0 (Eduardo and Augusto, 1993). Sugar formation at low temperatures differs from that resulting from senescence. Sugar formed during senescence cannot be decreased by reconditioning (Singh and Kaur, 2009)

2.2.3.2 Factors affecting reducing sugar accumulation in tubers

Factors affecting sweetening or breakdown of starch are drought, excess nitrogen during growth, high temperature during harvest, handling, physiological age (‘senescent sweetening’, cultivar, anaerobic conditions and temperature during storage (Shetty *et al.*, 2006).

2.2.3.2.1 Temperature

The transformation of starch into sugar is an enzymatic process which, although more rapid at high temperatures, occurs also at low temperatures. The respiratory activity which is almost at a standstill at 0°C rises with the temperature so that at higher temperatures an increasingly greater amount of sugar is consumed by respiration. The amount of sugar used in respiration at higher temperatures is, however, small compared with that utilized by another process i. e., the re-formation of starch from sugar, which increases in speed with the rise of temperature from 0°C (Hasselbring and Hawkins, 1915).

When stored at low temperatures (<10ºC), tubers undergo a phenomenon called low-temperature sweetening in which starch degradation occurs primarily through the action of starch phosphorylase and eventually reducing sugars accumulate through various enzymatic reactions (Abong *et al.*, 2009). The activity of the enzyme invertase, which hydrolyzes sucrose is high at lower storage temperature (Singh and Kaur, 2009). The activities of invertase was found to increase about 2 to 12 folds from harvesting to cold stored conditions. Similar trends were also reported by Geracimo and John (1990). Also, amylase activity was found to increase by 1.2 to 4 folds from harvesting to cold stored conditions. Thus resulting in reducing sugar increase of upto 4–11 folds from harvesting to cold stored (Karim *et al.*, 2008).

The accumulation of sugars during prolonged storage at higher temperatures (particularly 10 to 20 °C) is known as senescent sweetening and is irreversible, probably because of cell membrane breakdown (Woolfe, 1987). Higher temperatures combined with water stress can lead to premature changes from starch to sugars within tubers, providing nutrient source) for subsequent bacterial invasion (Pringle *et al.*, 2009). High night temperatures during the growing season causes high respiration rates and thus there is little accumulation of carbohydrates in the tuber (Gould, 1999).

2.2.3.2.2 Storage conditions

In all cultivars harvested 90 days and 120 days after planting, no significant change occurred in the reducing sugar content when tubers were stored at ambient air conditions (15-19°C/86-92 % RH) for up to 12 weeks. This outcome suggests that the ambient air conditions did not trigger any sugar accumulation or reduction in either of the two differently harvested batches, and could therefore be appropriate for long term storage. Such results were also reported by Kabira (1983) for varieties Kerr's Pink, Desiree and Kenya Baraka. (Abong *et al.*, 2009).

In cold storage (4°C), reducing sugars increased in all cultivars harvested at 90 and 120 days after planting. After one month of cold storage, the reducing sugar accumulation was slow but steady in all the cultivars examined (Abong *et al.*, 2009). It would also appear as if potatoes stored at 8-10°C not only do not accumulate sugar but do not reconvert it into starch as occurs at higher temperatures, or dispose of it through respiratory activity. The amount of sugar present in the potatoes when they are placed in storage at this temperature suffers little change. When potatoes containing sugar are stored at 20°C, the sugar gradually disappears due to increased respiration and reconversion to starch as the disappearance of the sugar could not be all accounted for by the amount of carbon dioxide exhaled. However, if the potatoes remain sufficiently long at 20ºC for germination to be initiated, an increase in the sugar content is liable to take place (Butler, 1913).

2.2.3.2.3 Cultivars

Varieties with low specific gravity tend to accumulate more sugar than varieties with high specific gravity (Singh and Kaur, 2009). However, at storage temperature of 12oC, the reducing sugars content remained low in several cultivars. But some cultivars like Kufri Sindhuri, Kufri Bahar, Kufri Anand and Kufri Pukhraj had higher sugars content even at 12^{o}C (Ezekiel *et al.*, 2008)

2.2.3.2.4 Tuber maturity/ harvesting time

Immature tubers have higher content of reducing sugars than fully matured tubers. Tubers harvested at 120 days after planting in all varieties and clones had significantly less reducing sugars (0.15-0.37 %) ($P \leq 0.05$) as compared to those harvested at 90 days (0.33-0.45 %) (Abong *et al.*, 2009) this is because passive resynthesis of sugar into starch occurs (Woolfe, 1987).

Immature tubers can be directly used by some manufacturers because the plant is respiring and the simple reducing sugars are being burned off rapidly and do not cause a discoloration problem in the manufacturing process. If the plant is stressed and/or if the tuber is harvested immature (immature tubers should not be stored butt can be directly used) the sugars never are all converted to starch and the result is that sucrose will break down to simple reducing sugars rather than be synthesized to starch. Depends on which rate is more (Gould, 1999).

Tubers prior to harvest, during harvest, and after harvesting must never be subjected to temperatures below 50°F (10°C) as temperatures below this will trigger high rates of conversion of sucrose to reducing sugars, particularly fructose. It should be fairly obvious that the reducing sugars have not been converted to sucrose and sucrose to starch fast enough (Gould, 1999).

2.2.3.2.5 Sprouting

Physiological changes in a potato upon initiation of sprouting will cause increases in reducing sugar (Olsen and Kleinkopf, 2001). Resting potatoes contain for the most part no sugar, its appearance indicating the initial stages of germination. The sugar first appears in the neighborhood of the eyes, more precisely in the parenchymatous tissue surrounding the bundles leading to them. At first present in small amounts, it soon increases in quantity, developing in all parts of the tubers (Butler, 1913).

2.2.3.2.6 Methods to prevent chips darkening due to sugar accumulation

Due to the need to prolong storage life by minimizing losses due to shrinkage, disease and sprouting, it has been proposed that tubers can be stored at as low as 4°C and then reconditioned at ≥15 °C prior to use (Abong *et al.*, 2009). The sugar contents of tubers stored at low temperature and reconditioned at higher temperatures gradually decrease over a period of 3–4 weeks, while the starch percentage increases during conditioning (Singh and Kaur, 2009). Blanching may, also, be used to reduce the sugars, that is, the leaching of the sugars from the cut and peeled potato (Gould, 1999). Also, growers need to select varieties which are resistant to LTS and ensure that tubers reach full physiological maturity prior to harvest. Tubers destined for processing are stored at temperatures of 10–12◦C and process then while the sugar level is low and they have not sprouted where accumulation of sugars is less and the resulting chips and fries are light in color (Singh and Kaur, 2009).

2.2.3.2.7 Other factors

Some of the disadvantages of irradiation are increased reducing sugars. Small tubers usually contain higher sugar percentages than large ones (Singh and Kaur, 2009). Carbon dioxide in store air percentage CO_2 level in store Risk of increasing sugar levels in crops (Pringle *et al.*, 2009).

Part III

Materials and methods

3.1 Materials

3.1.1 Procurement of potato tubers

Potato tubers harvested under similar conditions were procured and were sorted. There was time lag between harvesting and beginning of storage period which is unknown. Rotten, deteriorated or tubers with any other disorders were discarded and fresh, turgid tubers each weighting about 20 g were sorted out for the experimental purpose. The variety of potato was identified as *Desiree.*

3.1.2 Preparation of storage structures

Following the traditional practice, bamboo baskets locally known as *doko* (average sized) and wheat straw were procured for in-basket storage and arranged as shown in fig.3.1. The main use of wheat straw use is its humidity regulation properties and ease of availability.

Fig. 3.1 Potato storage in bamboo baskets with straw

To have easy accessibility for laboratory analysis and convenience during the whole work, storage environment of cold store was recreated in the laboratory refrigerator (Model: HSHD194, Capacity: 170 l - 190 l, Power supply: 220V.50Hz). Humidity of 85-90% was maintained using saturated potassium chloride solution (36 g of NaCl in 100 g of water at 20^{o}C) (Anon., 2003) and temperature of 2-5 °C was maintained. Maintenance of these conditions throughout the storage period was confirmed with the use of hygrometer (Model: J412CTH) and thermometer (range: 0ºC-100ºC) regularly.

3.1.3 Equipment and chemicals

General laboratory apparatus and equipment like glasswares, thermometer, hugrometer, hot air oven etc and chemicals like KOH solution, calcium bicarbonate solution etc were made available in laboratory of Central Campus of Technology, Dharan.

3.2 Methods

3.2.1 Experimental procedure

After variety identification and proper sorting of the similar sized fresh healthy tubers, each storage unit was loaded with 6 kg of the potato tubers. 2 kg of the 6 kg sample unit was segregated for easy assessment of weight loss at the end of storage period while 4 kg of the sample was kept for intermediate analysis purpose. For in-basket storage, tubers were arranged in layers in a bamboo basket with chopped wheat straw in between. Similarly, loading was done for in-house and cold storage units as well. Triplicate of such samples was arranged for obtaining accurate data.

The methodological approach used was pre- and post-test design. Within this context, the desired parameters shall be measured before commencement of the study and after the period of 2 months.

Before commencement of the experiment, analysis was carried out for moisture content, sugar content and respiratory rate. During the storage period, analysis was done for the assessment of sugar and respiratory rate in each 15 days and weight of sample in each storage conditions was taken for total loss assessment at the end of 60 days of storage period.

3.2.2 Analysis of potatoes

3.2.2.1 Analysis of moisture content

Moisture content of potato tubers were measured for the determination of total moisture loss by hot air oven method. The sample was fine ground and weighted sample was kept in hot air oven for 4 hr at 130°C (Ghadge *et al.*, 1989).

3.2.2.2 Analysis of reducing sugar content

Reducing sugar was determined by the Lane and Eynon method mentioned by (Ranganna, 2008). As the reducing sugar content in potato was less than 1% slight modification in the standard procedure was made in order to obtain the accurate value. 1g of dextrose was added initially in the 25 g sample and whole process of sample neutralization, clarification and titration with standardized Fehling's solution was done. Calculations were made to obtain the total % of reducing sugar after deducting the amount to dextrose added initially in the sample.

3.2.2.3 Analysis of respiratory rate

Initially, air was made free of CO_2 by passing the air through 40% potassium hydroxide solution. Then it was passed through the respiring potatoes where CO_2 respired by the produce was collected in calcium hydroxide solution. Thus collected CO_2 concentration was determined by by gravimetric method (i.e. by taking weight of calcium carbonate precipitated) which was finally related with the total CO_2 produced. (Schippers, 1976). The arrangement of apparatus for this determination is given in Appendix A.

3.2.2.4 Determination of moisture loss

Total moisture loss of sample was determined by subtracting final moisture content after storage period from initial moisture content.

Total loss due to moisture changes (%) = initial moisture content (%) - final moisture content (%)

3.2.2.5 Determination of loss due to sprouting

After the end of storage period, the sprouts were carefully taken out of the sample and were weighted.

Total loss due to sprouting (%) = (weight of sprouts ÷ total initial weight of tubers) × 100

3.2.2.6 Determination of loss due to deterioration

At the end of storage period, the deteriorated or inedible tubers were visually identified. The tubers with signs of fungal growth, softened texture, black patches in the surface, foul smell etc were separated and weighted.

Total loss due to deterioration (%) = (weight of deteriorated tubers ÷ total initial weight of tubers) × 100

3.2.2.7 Determination of total loss

At the end of storage period and after the segregation of sprouts and deteriorated sample, the undeteriorated tubers were finally weighted to obtain total loss.

Total loss = initial weight of tubers – final weight of tubers (final yield of tubers)

Final yield of tubers (%) = (final weight of undeteriorated tubers ÷ initial weight) × 100

Total loss (%) = 100 – final yield of tubers (%)

3.2.2.8 Determination of respiratory and unknown loss

After sprouts, deteriorated sample and edible undeteriorated tubers were weighted separately and loss due to moisture quantified, loss due to respiration was calculated.

Total loss = loss due to sprouts + loss due to deterioration+ loss due to moisture change + loss due to respiration + unknown losses

Also,

Initial weight of tubers= weight of sprouts + weight of deteriorated tubers + weight of moisture removed + respiratory+ unknown losses + weight of undeteriorated tubers

Or,

(Respiratory + Unknown) losses (%) = 100 - loss due to sprouts (%) – loss due to deterioration (%) - moisture loss (%) – final yield of tubers (%)

3.2.2.9 Determination of crude fibre

Crude fiber was determined by recovering the ash free residue after sequential treatment of ground potato with 1.25% sulphuric acid and 1.25% sodium hydroxide each under standard conditions. The ash that came along with the residue was removed by ashing in ashless filter paper as per (Ranganna, 2008).

3.2.2.10 Determination of Crude protein

It was determined by estimating nitrogen content in the sample by Kjeldahl method using the factor 6.25 as per (Ranganna, 2008).

3.3.2.11 Determination of Total Ash content

As per (Ranganna, 2008), dry ashing was done by incinerating all the organic matter of 10 g of the potato sample at 550ºC

3.3.2.12 Statistical analysis

Statistical calculations were performed in Microsoft Office Excel 2007. For the significance analysis, the data were analyzed by one-way ANOVA (no blocking) using GenStat Release 12.1 (2009) and means were compared using LSD at 5% level of significance. Fishner's protected LSD was used for the multiple comparison (Payne, 2007).

Part IV

Results and discussion

Losses in terms of moisture, respiration, deterioration and sprouting occurring in three major potato storage systems in Nepal i.e. in-basket storage, in-house storage and cold storage were measured and compared. Similarly, pattern of respiratory rate and reducing sugar content changes in the above three conditions was also studied.

4.1 Analysis of fresh tuber before storage

Peeled potato was analyzed for moisture, reducing sugar, ash content, fiber content, protein and respiratory rate and following results were obtained as shown in Table 4.1.

Table 4.1 Analysis of potato flesh

Parameter	**Values**
Moisture content (%)	77.1 (0.16)
Protein content (%)	2.1 (0.32)
Fiber content (%)	1 (0.47)
Ash content (%)	0.9 (0.305)
Reducing sugar (%)	0.645(0.0026)
Respiratory rate (mg CO_2/kg/hr)	5.42(0.01)

The values are the means of triplicate. Numbers in the parentheses are standard deviation of the values.

The chemical composition of potatoes is influenced by many factors, such as the production area, cultivar, soil and climate, agricultural practice, etc (Gould, 1999). Thus, chemical composition has a very wide range. The above obtained values were closer to those reported by (FAO, 2008) and also, these values fall within the range as per (Gould, 1999).

4.2 Comparison of losses during storage

4.2.1 Loss due to sprouting

Loss due to sprouting were (0.183 ±0.0015) %, (0.27±0.05) % and 0 % for in-house, in-basket and cold stored potatoes respectively. The results are significantly different with each other. As the sprouting phenomenon is dependent mainly on the temperature, the slightly high temperature of storage (i.e. by 3°C to 4°C) than ambient in in-basket storage has lead to somehow more sprouting loss in potatoes. While in cold store, temperature was between 2°C-5°C which didn't support any sprout growth. Fig. 4.1 is the bar diagram comparing the sprout loss in the three storage conditions.

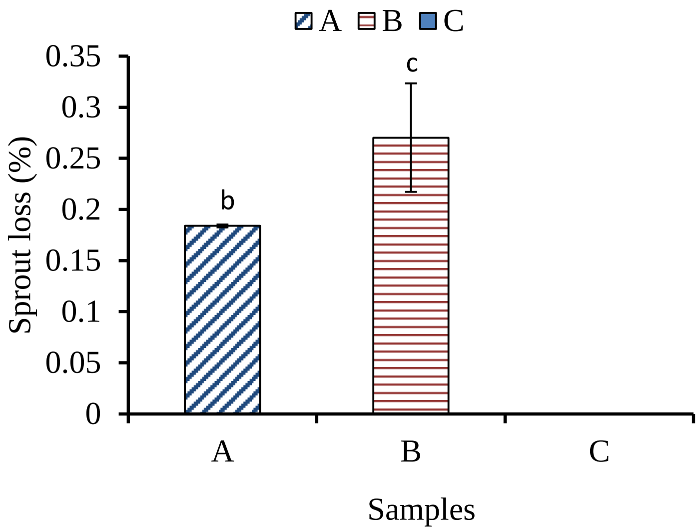

Fig. 4.1 Comparison of sprout loss in three storage conditions

Here, A, B, and C denotes in-house stored, in-basket stored and cold stored potatoes respectively. Vertical error bars represent standard deviation of values from mean. The same letters above the error bar signify no significant difference.

In the work carried out by Ezekiel *et al.* (2002), for room storage, sprout weight was 0.47g while for heap storage, that was 0.63 g per 100 g when stored for 127 days. Again, in the work done by (Kaul and Mehta, 1999) weight loss due to sprouting was 0.67% for kufri sinduri and 0.6% for kufri phulwa during 15 weeks of storage. The reported values were higher than that obtained for *Desiree* variety in this study. This is due to the fact that dormancy and extent of sprouting depends on variety. Also, since the sprout depends on the tuber materials for growth, if there are several sprouts on the tuber, an inter-sprout competition for growth factors will be imposed by the size of the tuber. With fairly large tubers, no effect of size will be noticeable, but with decreasing size, a point can clearly be reached at which growth will be impaired. Here, tuber sizes used form experimentation were very small i.e. around 20 g which might have resulted in lower growth of sprouts (Carli *et al.*, 2012).

4.2.2 Loss due to deterioration

Loss due to spoilage or deterioration of tubers after 60 days of storage was observed to be (5.733±0.22) %, (3.63±0.44) % and (1.53±0.15) % for in-house, in-basket and cold stored potatoes respectively. The amount of deterioration was significantly different in all three cases. Fig. 4.2 represents the comparison of the loss due to deterioration in the three storage conditions.

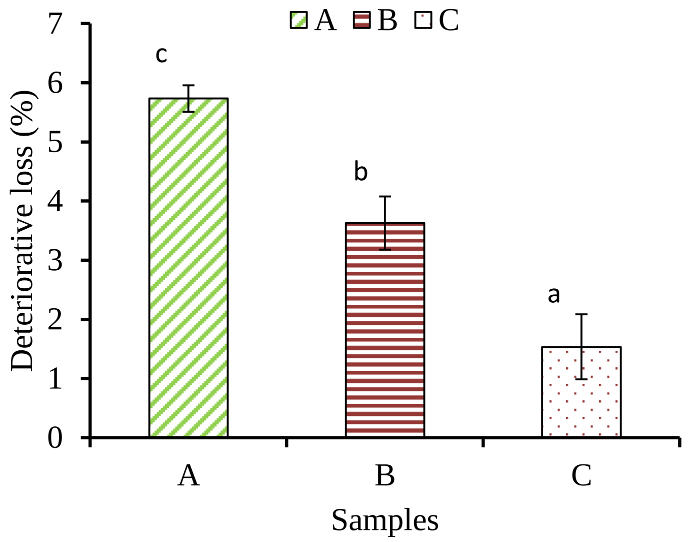

Fig. 4.2 Comparison of deteriorative loss in three storage conditions

Here, A, B, and C denotes in-house stored, in-basket stored and cold stored potatoes respectively. Vertical error bars represent standard deviation of values from mean. The same letters above the error bar signify no significant difference.

The deteriorative loss in traditional storage system was more than that of cold storage because in traditional storage systems, attacks by moth were also found. Among the insect pests, tuber moth is common in potatoes stored in non-refrigerated storage. The larval damage results in direct weight loss and tuber moth infection greatly reduces market value of the tubers (Singh *et al.,* 1994) which is unlikely in cold stored potatoes.

The percentage deterioration in in-basket storage was lesser than in in-house storage because dry wheat straw prevents condensation of transpired vapour on tuber surface. Thus prevents excessively wet condition within the storage area. This avoids the development of fungal diseases that normally thrive under humid and warm conditions (Mutandwa and Gadzirayi, 2007) and straw absorbs condensed water produced by the tubers respiration, which might otherwise enhance the presence of microorganisms (Knutsson, 2012).

Ezekiel *et al.* (2002) showed that for room storage, loss due to rotting was 4.7% while that for heap storage was 3.8%. This is similar to the result obtained here. But, (Singh *et al.,* 1994) reported that loss due to rotting in traditional storage system is about 10-12 %. Similarly (Hossain and Miah, 2009), reported that in cold stores, the weight loss due to rotting was 34% in nine months The variability of the results among various authors is because the extent of loss depends on various pre harvest factors, factors during harvest and the cultivar used for the experimentation itself. Here, Desiree variety was used for experiment which is one of the most disease and damage resistant varieties showing resistance to dry rot, late blight, potato virus M and X, and other environmental stress factors leading to deterioration. This fact might have resulted in somehow lower deteriorative loss results (Anon., 2015a).

4.2.3 Loss due to moisture changes

Loss in moisture content was (5.05±0.09) %, (3.4±0.1) % and (1.9±0.1) % for in-house, in-basket and cold stored potatoes respectively. The values are significantly different with each other. The moisture loss in cold storage was significantly lower than the traditional high temperature storage system which is because appropriate relative humidity is maintained in cold storage (85% - 90%) which helps in prevention of desiccation. Among the traditional storage structures as well, in-basket storage suffers lower loss in moisture than in-house storage which is because the straw prevents further loss of moisture from potatoes (Rhoades, 1985). Fig. 4.3 represents the comparison of loss of moisture in three storage conditions.

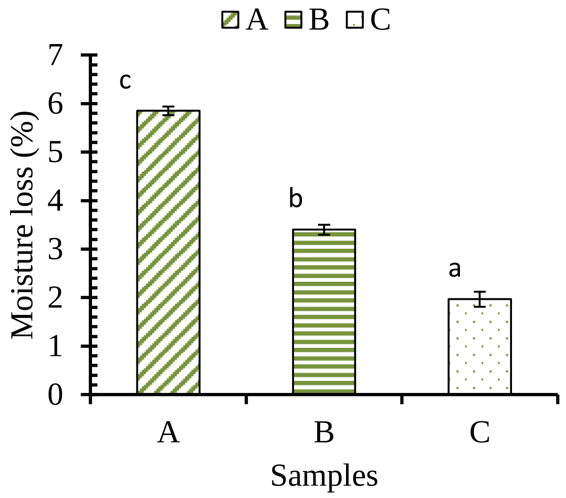

Fig. 4.3 Comparison of moisture loss in three storage conditions

Here, A, B, and C denotes in-house stored, in-basket stored and cold stored potatoes respectively. Vertical error bars represent standard deviation of values from mean. The same letters above the error bar signify no significant difference.

Similar results were also reported by (Kaul and Mehta, 1999) for room temperature storage for Kufri Chandramukhi and Kufri Jyoti varieties. Also, for cold storage, Ezekiel *et al.* (2002) observed that weight loss varied between 0.5 to 1.5% per month which is in agreement with the result obtained.

4.2.4 Loss due to respiration

Loss due to respiration was calculated through empirical method. All other known losses and final tuber yield was deducted from initially stored potatoes to obtain total respiratory loss. Thus, it is understood that the obtained value not only represents respiratory loss but may also include some other unknown loss which could not be quantified from this experiment. So, loss due to respiration is considered along with unknown losses.

Respiratory and unknown loss (R+U) loss was (1.27±0.085) %, (1.23±0.07) % and (0.882±0.027) % for in-house, in-basket and cold stored potatoes respectively. As the rate of respiration is lowest for cold stored potatoes, the respiratory loss is certainly lower. Fig. 4.4 represents the comparison of loss due to respiration in the three storage conditions.

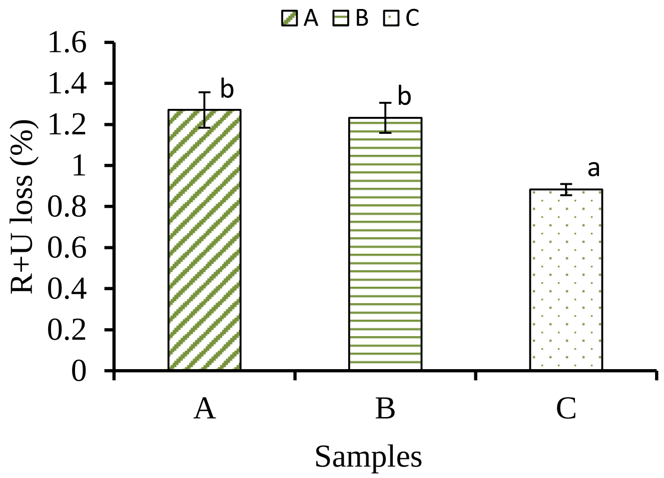

Fig. 4.4 Comparison of loss due to respiration in three storage conditions.

Here, A, B, and C denotes in-house stored, in-basket stored and cold stored potatoes respectively. Vertical error bars represent standard deviation of values from mean. The same letters above the error bar signify no significant difference.

Though the respiration rate of in-basket stored potatoes is higher, the resultant (R+U) value seems to be lower than in-house storage due to the contribution of unknown losses which is lower in case of in-basket storage.

4.2.5 Total loss during storage

Total loss during storage was found to be (13.043±0.3365) % for in-house storage. Similarly, total loss was (8.532±0.32) % for in-basket storage and for cold storage, total loss was (4.382±0.683) %. Thus, all the three values are significantly different with each other with loss in cold storage being minimum and that at in-house storage being maximum. Lesser efficiency of traditional storage systems is mainly because of loss due to rotting and moisture change rather than loss due to sprouting and respiration. While among the traditional storage systems, in-basket storage is found to be more efficient than in-house storage in terms of total loss at the end. Fig. 4.5 represents the total losses in the three storage conditions.

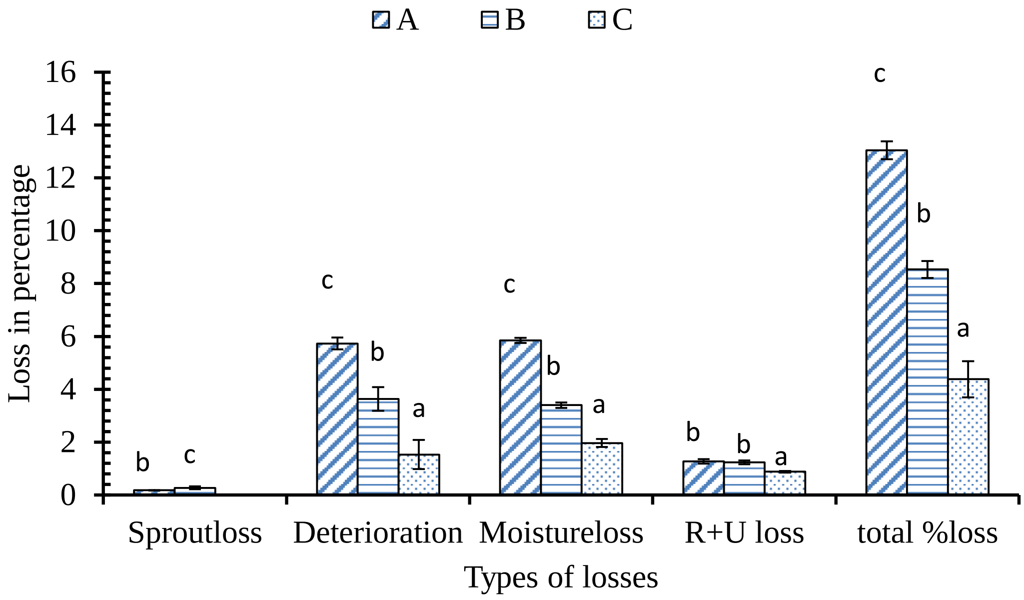

Fig. 4.5 Comparison of total (%) loss during storage

Here, A, B, and C denotes in-house stored, in-basket stored and cold stored potatoes respectively. Vertical error bars represent standard deviation of values from mean. The same letters above the error bar signify no significant difference.

The data obtained shows close resemblance with that observed by several other researchers. (Kaul and Mehta, 1999) observed that the storage loss in their experimental store was 11.64% for kufri chandramukhi and 11.22% for kufri lauvakar. (Anand and Chourasia, 1999) has also mentioned that In India, the storage losses in potato cold storages account for 3 % – 10 % of the stored product in the form of rotting, cold injury, weight loss, sprouting, etc which agrees with the result obtained.

4.3 Comparison of respiration rate

The changes in respiration rate were studied under various storage conditions, *viz*. in-house storage, in-basket storage and cold storage. The result of respiration rate in 0^{th} , 15^{th}, 30^{th} , 45^{th} and 60^{th} days in the above mentioned storage conditions is shown in appendix C.

The one way analysis of variance (no blocking) showed that respiratory rate attained by in-house and in-basket stored potatoes were not significantly different with each other till 45^{th} day of storage. But at 60^{th} day of storage, they were significantly different. Respiration rate attained by cold stored potatoes were significantly different from the other two at 5% level of significance (Appendix C).

The initial rate of respiration rate was found to be 5.42 mg CO_2/kg/hr. While, during the course of storage, it ranged from 4.809 mg CO2/kg/hr to 6.025 mg CO2/kg/hr for in-house stored potatoes. The values were slightly higher for in-basket storage. Values ranged from 5.05 mg CO_2/kg/hr to 6.557 mg CO_2/kg/hr. This difference in respiration rate may be due to slightly higher temperature (3°C-4°C than ambient) attained in in-basket storage. While for low temperature storage, it is gradually declining to minimum of 3.177 mg CO_2/kg/hr at the final day of storage.

Mulder (1955) has accounted that the respiration rate of potatoes at 25°C is in the range of 5-7 mg CO_2/kg/hr and Ziegenbein (1893) reported the respiration rate to be 4.6 mg CO_2/kg/hr at 30°C (Schippers, 1976). These results closely resemble the results obtained in this dissertation work. While, (Voss *et al.*, 1996) have mentioned that rate varies between 14-29 mg CO_2/kg/hr at 20°C in non refrigerated storages. Thus, there is considerable variation between the results of various authors, dependent on cultivar, time of the year, degree of sprouting and possibly other factors. It is also possible that some experiments were carried out very shortly after harvest when rates of respiration are much higher than they are later during the storage season. At these non refrigerated storage conditions, differences in sprouting also may have been a cause. Variation in degree of sprouting and length of sprouts can be the cause for variation in respiration rate obtained by various authors (Schippers, 1976).

In case of low temperature storage, similar result was obtained by Barker (1933) who stated the respiration rate of stored potatoes to be 4-5 mg CO_2/kg/hr at 2°C and 3 mg CO_2/kg/hr at 5°C (Schippers, 1976).

4.4 Trend of respiration rate change

As shown in fig. 4.6, the initial rate of respiration is 5.42 mg CO_2/kg/hr. ANOVA test at 5% level of significance showed that for in-house storage, respiration rate significantly decreased for upto 30 days of storage while it significantly increased in 45^{th} and 60^{th} days of storage. For in-basket storage, there was slight but non significant decrease in respiration rate for upto 30^{th} day of storage which again significantly increased at 45^{th} and 60^{th} day of storage. For traditional storage systems i.e. in-house and in-basket storage, respiration rate has increased from 30th day of storage with very high and significant difference. This increase may be explained by the sprouting phenomenon. As sprouting starts, the resultant rate of respiration of sprouted tubers includes both that of the tuber and the sprouts (Harrris, 1978). But, during dormancy, the endogenous metabolic rate of tubers is at minimum and the dry matter losses are correspondingly reduced. This is the reason why respiration rate doesn't increase during dormant period but rather decreases or remains constant (Schippers, 1976).

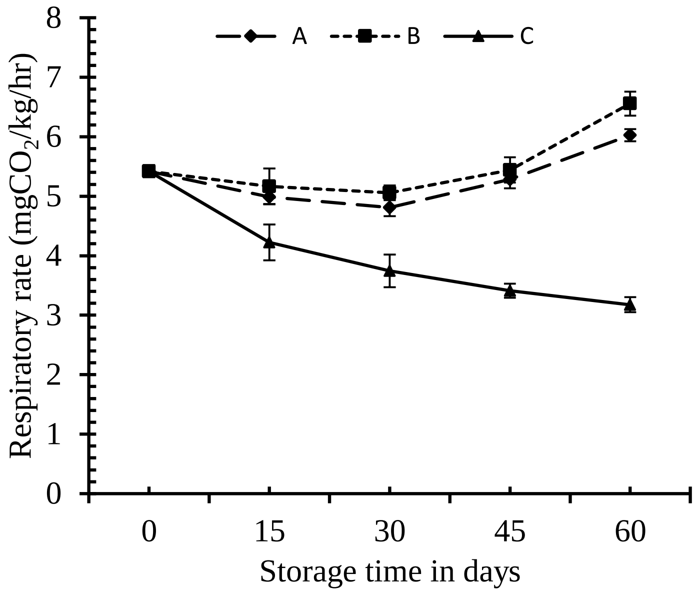

Fig. 4.6 Trend of respiration rate change with time during storage

Here, A, B, and C represents in-house stored, in-basket stored and cold stored potatoes respectively. The vertical error bars represents standard deviation of values from mean.

According to Kimbrough (1925), immediately after harvest, potato tubers had a high rate of respiration which decreased rapidly from 20 mg CO_2/kg/hr to a constant level of 5 mg over a period of three weeks at 22°C. Smith (1929) had similar results (Schippers, 1976). This rapidly high rate of decrease is not observed here in the study because the tubers here were stored only after certain time lag after harvest.

For cold storage, rate of respiration significantly decreased with storage time which is due to the decreasing metabolism in low temperature storage. Fennir in his similar study found similar results. He observed the respiration rate to be gradually declining from 4.5 mg CO_2/kg/hr to 3.1 mg CO_2/kg/hr in the period of 44 days at cold storage temperature

(Fennir *et al.*, 2005)

4.5 Comparison of reducing sugar content during storage

The changes in reducing sugar were studied under various storage conditions, *viz*. in-house storage, in-basket storage and cold storage. The resultant reducing sugar content in 0^{th}, 15^{th}, 30^{th} , 45^{th} and 60^{th} days in the above mentioned storage conditions is shown in appendix D.

The one way analysis of variance (no blocking) showed that the reducing sugar level attained by in-house and in-basket storage system was not significantly different from each other. But the reducing sugar level attained by cold stored potatoes was significantly higher than other storage structures ($p<0.05$) during the study period.

The reducing sugar content in tubers initially was 0.645%. For in-house storage, it ranged from minimum of 0.6223% on 15^{th} day of storage to maximum of 0.651% at 60^{th} day of storage. Similarly, values of reducing sugar for in-basket storage ranged from 0.616% at 30^{th} day of storage to 0.673% at 60^{th} day of storage.

In case of cold stored tubers, the initial reducing sugar content of 0.645% increased to 1.043% at the end of 60 days storage period. This result is significantly different from that obtained for higher temperatures as sugar accumulation occurs due to increased enzyme activity and minimal respiration at low temperature. Very Similar results were obtained in the work by Butler (1913) who reported the reducing sugar to change from 0.59% at the beginning of experiment to 0.97% at the end of 28 days with a daily increase of 0.013% for Triumph variety. But, in the similar work, 74-48-24 clone accumulated 0.68% and 74-4-9 clone accumulated 0.9% reducing sugar at the end of 60 days storage period. This variation has occurred because the reducing sugar content of the potato is affected not only by cultivar but several factors, including growing conditions, maturity at harvest, post harvest handling stress and the storage environment.

4.5 Trend of reducing sugar change

ANOVA at 5% level of significance showed that, for in-house storage and in-basket storage, there was no significant change in sugar level during the storage period. Still, very slight and non significant decrease in sugar level was observed upto 30 days of storage. After 30 days, again very slight increase in sugar level was seen. (Butler, 1913) explains that when potatoes containing sugar are placed at higher temperatures, the slow and slight disappearance of sugar is because sugar is partly used up in respiration, and partly reconverted to starch (the disappearance of the sugar can't be all accounted by the amount of carbon dioxide exhaled). And reducing sugar further accumulates in potatoes at the time of germination and that this accumulation is essential thereto. Physiological changes in a potato upon initiation of sprouting will cause increases in reducing sugar (Olsen and Kleinkopf, 2001). Here, the slight increase in sugar level after 30 days of storage is because of accumulation of sugar due to sprouting. Fig. 4.7 represents trend of reducing sugar change in all three storage conditions.

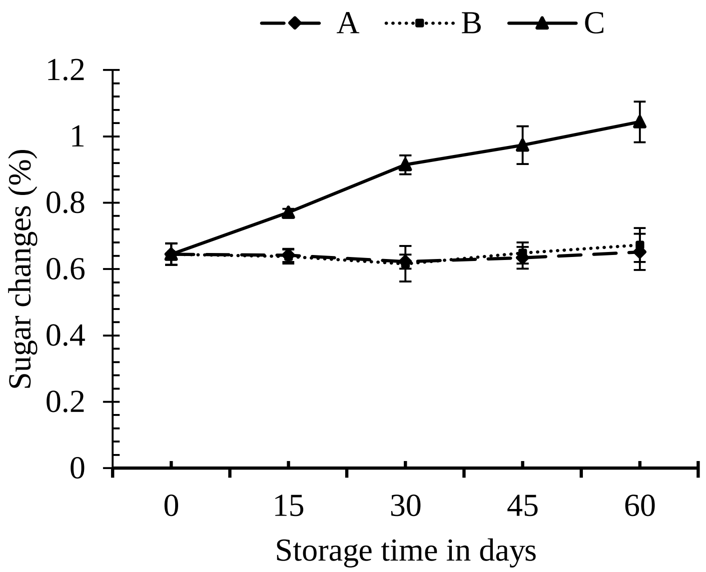

Fig. 4.7 Trend of reducing sugar change with time during storage

Here, A, B, and C represents in-house stored, in-basket stored and cold stored potatoes respectively. The vertical error bars represents standard deviation of data from mean.

Similar result was obtained by (Abong *et al.*, 2009). In all cultivars harvested 90 days and 120 days after harvesting, no significant change occurred in the reducing sugar content when tubers were stored at ambient air conditions for up to 12 weeks. This outcome suggests that the ambient air conditions did not trigger any sugar accumulation or reduction in either of the two differently harvested batches, and could therefore be appropriate for long term storage. Such results were also reported by Kabira (1983) for varieties Kerr’s Pink, Desiree and Kenya Baraka.

For cold stored potatoes, ANOVA at 5% level of significance showed that reducing sugar was found to increase with storage period. Similar pattern of sugar change was observed by Butler (1913) in his experiment. He found out the reducing sugar to increase from 0.53% to 1.22%. Also, Abong *et al.* (2009) found slow and steady accumulation of sugar in all the cultivars examined throughout the storage period.

The amount of reducing sugar increased is due to the enzymatic conversion of starch and sucrose to reducing sugar and decreased respiration rate. The activity of the enzyme invertase, which hydrolyzes sucrose is high at lower storage temperature (Singh and Kaur, 2009). The activity of invertase was found to increase about 2 to 12 folds from harvesting to cold stored conditions (Karim *et al.*, 2008).

Part V

Conclusions and recommendations

5.1 Conclusions

As per the objectives, methodologies stated in the methods were carried out for the results. Based on the obtained results , the following conclusions have been drawn:

- Cold storage of potatoes resulted in minimum storage loss while in-house storage suffered maximum storage loss.
- Cold stored potatoes were unsuitable for table purposes due to maximum sugar accumulation while minimum reducing sugar content was observed in traditional storage systems.
- Among the traditional storage systems, in-basket storage was found to be the best storage system.
- For seed potato storage, where sugar accumulation is not a problem, cold storage can be the most suitable.

5.2 Recommendations

- Farmers can be recommended to replace their in-house potato storage practices with in-basket storage with appropriate sprout inhibitors.
- Evaluation of reconditioning behavior of potatoes after cold storing can be made.
- The assessment of respiratory rate and loss can be made more reliable by application of modern gas analyzing systems.
- Experiments can be carried out to observe the resultant losses after use of sprout inhibitors in in-basket storage.

Part VI

Summary

Potato ranks fifth in area, second in production and first in productivity among the major food crops grown in Nepal. Various traditional and modern methods of its storage are being practiced by farmers each having its own pros and cons. In-house storage and in-house storage are the most popular traditional methods of potato storage, though very less is known about storage losses in these. So, it was felt that these storage methods should be investigated thoroughly under the farmers' field conditions so that an objective estimate of storage losses can be obtained in real situation. It is hoped that the findings of this research will help to either improvise the efficiency of traditional methods of potato storage or to adopt modern ones.

Potatoes were brought, sorted, variety was identified as 'Desiree' and weighted amount was stored in three storage conditions. In each 15 days, respiratory rate and reducing sugar was checked while after 2 months of storage period, resultant losses were assessed.

In cold stored potatoes, total storage loss was (4.383±0.68) % with no sprouting and minimum of other losses. Reducing sugar continued to increase with a maximum of (1.04±0.015) % and respiratory rate decreased over time and was least of all i.e. (3.17±0.025) mg CO_2/kg/hr on 60^{th} day of storage. In in-house storage, total loss was (13.043±0.33) % with maximum deteriorative, moisture and R+U loss. Also, respiration rate was (6.025±0.0081) mg CO_2/kg/hr attained on 60^{th} day. For in-basket storage, total loss was (8.539±0.32) % with highest loss due to sprouting. Respiration rate was highest of all i.e. (6.55±0.002) mg CO_2/kg/hr at the end of storage period which is contributed majorly by the sprout growth.

Though storage loss is least in cold stores, in the context of Nepal, cold stores are not accessible by all because of high expense in establishment and operation. Excessive sugar accumulation making it unsuitable for frying purpose is another problem for which even if provisions for reconditioning is made, it further adds to the expense. Thus, farmers have to rely on the traditional methods of storage. Among which, in-basket storage is cheapest, and suffer lesser loss in which the only considerable problem found out is loss due to sprouting which can be controlled by the use of sprout inhibitors.

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Appendices

Appendix A

Fig. 1 Apparatus for respiratory rate measurement

Appendix B

Table 1 Percentage loss in three storage conditions

Storage type	Loss due to sprouts(%)	Loss due to deterioration(%)	Moisture loss(%)	R+U loss (%)	Total loss (%)
In-house storage (A)	0.183^{b} (0.0015)	5.733^{c} (0.22)	5.85^{c} (0.091)	1.276^{b} (0.08)	13.043^{c} (0.33)
In-basket storage (B)	0.27^{c} (0.05)	3.63^{b} (0.44)	3.4^{b} (0.1)	1.239^{b} (0.07)	8.539^{b} (0.32)
Cold storage (C)	0	1.55^{a} (0.55)	1.96^{a} (0.15)	0.883^{a} (0.02)	4.383^{a} (0.68)
LSD	0.0612	0.860	0.2356	0.03726	0.929

The values are the means of triplicate. Numbers in the parentheses are standard deviation of the data. The same letters in the superscript in a column signify no significant difference between the samples.

Appendix C

Table 2 Comparison in respiration rate of in-house, in-basket and cold stored potatoes

Storage Condition	Respiration rate (mg CO_2/kg/hr)			
	In-house storage (A)	In-basket storage (B)	Cold storage (C)	LSD values
Day 0	5.42^{a}	5.42^{a}	5.42^{a}	0.1998
	(0.1)	(0.1)	(0.1)	
Day 15	4.98^{b}	5.164^{b}	4.222^{a}	0.5094
	(0.11)	(0.301)	(0.300)	
Day 30	4.809^{b}	5.05^{b}	3.743^{a}	0.3866
	(0.14)	(0.12)	(0.274)	
Day 45	5.286^{b}	5.44^{b}	3.41^{a}	0.3343
	(0.155)	(0.212)	(0.125)	
Day 60	6.025^{b}	6.557^{c}	3.177^{a}	0.2990
	(0.1)	(0.2)	(0.12)	

Figures in parentheses are standard deviations. Values are the means of triplicates and values followed by the different superscripts in a row differ significantly by LSD ($p \leq 0.05$).

Appendix D

Table 3 Comparison of reducing sugar in in-house, in-basket and cold stored potatoes

Storage Condition	Reducing sugar (%)			
	In-house store (A)	In-basket store (B)	Cold store (C)	LSD values
Day 0	0.645^{a} (0.032)	0.645^{a} (0.032)	0.645^{a} (0.032)	0.065
Day 15	0.6413^{a} (0.0195)	0.638^{a} (0.021)	0.771^{b} (0.011)	0.0354
Day 30	0.6223^{a} (0.0215)	0.616^{a} (0.0535)	0.9147^{b} (0.028)	0.0742
Day 45	0.634^{a} (0.0325)	0.648^{a} (0.032)	0.9733^{b} (0.0568)	0.0841
Day 60	0.651^{a} (0.0544)	0.673^{a} (0.051)	1.043^{b} (0.061)	0.1112

[*]Figures in parentheses are standard deviations. Values are the means of triplicates and values followed by the different superscripts in a row differ significantly by LSD ($p \leq 0.05$).

Appendix E

Analysis of Variance (ANOVA) for losses

Table E.1 ANOVA for R+U loss

Variate: R_U_loss

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Sample	2	0.2827669	0.1413834	406.40	<.001
Residual	6	0.0020873	0.0003479		
Total	8	0.2848542			

Since F pr.<0.05, R+U loss is significantly different in all storage conditions and LSD testing is necessary.

l.s.d. at 5%= 0.03726

Table E.2 LSD for R_U_loss

Sample code	Mean score	Mean difference
A	1.276	A-B<LSD
B	1.239	B-C<LSD
C	0.883	A-C>LSD*

* = significantly different

Table E.3 ANOVA for deterioration

Variate: deteriorat

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Sample	2	26.4600	13.2300	71.40	<.001
Residual	6	1.1117	0.1853		
Total	8	27.5718			

Since F pr.<0.05, loss due to deterioration is significantly different and LSD testing is necessary.

Table E.4 LSD for deterioration

LSD at 0.05 = 0.860

Sample code	Mean score	Mean difference
A	5.733	A-B>LSD*
B	3.630	B-C>LSD*
C	1.533	A-C>LSD*

* = significantly different

Table E.5 ANOVA for moisture loss

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Sample	2	23.13722	11.56861	831.61	<.001
Residual	6	0.08347	0.01391		
Total	8	23.22069			

Since F pr.<0.05, moisture loss is significantly different in all storage conditions and LSD testing is necessary.

Table E.6 LSD for moisture loss

LSD at 0.05 = 0.2356

Sample code	Mean score	Mean difference
A	5.850	A-B>LSD*
B	3.400	B-C>LSD*
C	1.967	A-C>LSD*

* = significantly different

Table E.7 ANOVA for total % loss

Variate: total_%loss

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Sample	2	112.5614	56.2807	260.58	<.001
Residual	6	1.2959	0.2160		
Total	8	113.8573			

Since F pr.<0.05, total % loss is significantly different and LSD testing is necessary.

Table E.8 LSD for total loss

LSD at 0.05 = 0.929

Sample code	Mean score	Mean difference
A	13.043	A-B>LSD*
B	8.539	B-C>LSD*
C	4.383	A-C>LSD*

* = significantly different

Table E.9 ANOVA for sprout loss

Variate: sproutlos

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Sample	2	0.1143830	0.0571915	60.92	<.001
Residual	6	0.0056332	0.0009389		
Total	8	0.1200162			

Since F pr.<0.05, loss due to sprouting is significantly different and LSD testing is necessary.

Table E.10 LSD for sprout loss

LSD at 0.05 = 0.0612

Sample code	Mean score	Mean difference
A	0.1840	A-B>LSD*
B	0.2703	B-C>LSD*
C	0	A-C>LSD*

* = significantly different

Appendix F

Analysis of Variance (ANOVA) for respiration rate

Table F.1 ANOVA for respiration rate in 0th day

Variate: zero

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Sample	2	0.00000	0.00000	0.00	1.000
Residual	6	0.06000	0.01000		
Total	8	0.06000			

Since F pr.>0.05, respiration rate in all storage conditions is not significantly different and LSD testing is not necessary.

Table F.2 ANOVA for respiration rate in 15th day

Variate: fifteen

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Sample	2	1.50623	0.75312	11.58	0.009
Residual	6	0.39012	0.06502		
Total	8	1.89636			

Since F pr.<0.05, respiratory rate in fifteen days in different storage conditions is significantly different and LSD testing is necessary.

Table F.3 LSD for fifteen

LSD at 0.05 = 0.5094

Sample code	Mean score	Mean difference
A	5.164	A-B<LSD
B	4.980	B-C<LSD
C	4.22	A-C>LSD*

* = significantly different

Table F.4 ANOVA for respiration rate in 30th day of storage

Variate: thirty

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Sample	2	2.92287	1.46143	39.04	<.001
Residual	6	0.22462	0.03744		
Total	8	3.14748			

Since F pr.<0.05, the respiration rate in 30th day in all storage conditions is significantly different and LSD testing is necessary.

Table F.5 LSD for thirty

LSD 0.05= 0.3866

Sample code	Mean score	Mean difference
A	4.809	A-B<LSD
B	5.050	B-C<LSD
C	3.743	A-C>LSD*

* = significantly different

Table F.6 ANOVA for respiration rate in 45th day

Variate: fortyfive

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
sample	2	7.66399	3.83200	136.86	<.001
Residual	6	0.16800	0.02800		
Total	8	7.83199			

Since F pr. <0.05, respiration rate at 45th day for all storage conditions is significantly different and LSD testing is necessary.

Table F.7 LSD for forty five

LSD at 0.005=0.3343

Sample code	Mean score	Mean difference
A	5.286	A-B<LSD
B	5.440	B-C<LSD
C	3.410	A-C>LSD*

* = significantly different

Table F.8 ANOVA for respiration rate in 60th day

Variate: sixty

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Sample	2	19.82007	9.91004	442.37	<.001
Residual	6	0.13441	0.02240		
Total	8	19.95449			

Since F pr. <0.05, respiration rate at 60th day for all storage conditions is significantly different and LSD testing is necessary.

Table F.9 LSD for sixty

LSD at 0.005=0.2990

Sample code	Mean score	Mean difference
A	6.025	A-B>LSD*
B	6.557	B-C>LSD*
C	3.177	A-C>LSD*

* = significantly different

Appendix G

Analysis of Variance (ANOVA) for reducing sugar

Table G.1 ANOVA for reducing sugar in 0^{th} day

Variate: zero

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
C1	2	0.000000	0.000000	0.00	1.000
Residual	6	0.006342	0.001057		
Total	8	0.006342			

Since F pr.>0.05, respiration rate in all storage conditions is not significantly different and LSD testing is not necessary.

Table G.2 ANOVA for reducing sugar in 15^{th} day

Variate: fifteen

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
C1	2	0.0345136	0.0172568	54.82	<.001
Residual	6	0.0018887	0.0003148		
Total	8	0.0364022			

Since F pr.<0.05, respiratory rate in fifteen days in different storage conditions is significantly different and LSD testing is necessary.

Table G.3 LSD for fifteen

LSD at 0.05 = 0.03545

Sample code	Mean score	Mean difference
A	0.6413	A-B<LSD
B	0.6380	B-C<LSD
C	0.7710	A-C>LSD*

* = significantly different

Table G.4 ANOVA for reducing sugar in 30th day of storage

Variate: thirty

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
C1	2	0.174701	0.087350	63.30	<.001
Residual	6	0.008279	0.001380		
Total	8	0.182980			

Since F pr.<0.05, the respiration rate in 30th day in all storage conditions is significantly different and LSD testing is necessary.

Table G.5 LSD for thirty

LSD 0.05= 0.0742

Sample code	Mean score	Mean difference
A	0.6223	A-B<LSD
B	0.6160	B-C<LSD
C	0.9147	A-C>LSD*

* = significantly different

Table G.6 ANOVA for reducing sugar in 45th day

Variate: fortyfive

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
C1	2	0.220771	0.110385	62.31	<.001
Residual	6	0.010629	0.001772		
Total	8	0.231400			

Since F pr. <0.05, respiration rate at 45th day for all storage conditions is significantly different and LSD testing is necessary.

Table G.7 LSD for forty five

LSD at 0.005=0.0841

Sample code	Mean score	Mean difference
A	0.6340	A-B<LSD*
B	0.6487	B-C>LSD*
C	0.9733	A-C>LSD

* = significantly different

Table G.8 ANOVA for reducing sugar in 60th day

Variate: sixty

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
C1	2	0.291513	0.145756	47.06	<.001
Residual	6	0.018585	0.003098		
Total	8	0.310098			

Since F pr. <0.05, respiration rate at 60th day for all storage conditions is significantly different and LSD testing is necessary.

Table G.9 LSD for sixty

LSD at 0.005=0.1112

Sample code	Mean score	Mean difference
A	0.6517	A-B>LSD
B	0.6730	B-C>LSD
C	1.0433	A-C>LSD*

* = significantly different

Appendix H

Analysis of Variance (ANOVA) in between storage days for respiration rate

Table H.1 ANOVA for sample A

Variate: A

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Days	4	2.63295	0.65824	41.16	<.001
Residual	10	0.15994	0.01599		
Total	14	2.79288			

Since F pr.<0.05, respiratory rate for sample A in different days of storage is significantly different and LSD testing is necessary.

Table H.2 LSD for sample A

LSD at 0.05 = 0.2301

Days of storage	Mean	
zero	5.420	B
fifteen	4.988	A
thirty	4.810	A
fortyfive	5.286	B
sixty	6.025	C

Different alphabets refers to significantly different

Table H.3 ANOVA for sample B

Variate: B

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Days	4	4.29591	1.07398	26.47	<.001
Residual	10	0.40568	0.04057		
Total	14	4.70160			

Since F pr.<0.05, respiratory rate for sample A in different days of storage is significantly different and LSD testing is necessary.

Table H.4 LSD for sample B

LSD at 0.05 = 0.3664

	Mean	
Zero	5.050	Ab
Fifteen	5.164	Ab
Thirty	5.420	A
Fortyfive	5.440	B
Sixty	6.557	C

Different alphabets refers to significantly different

Table H.5 ANOVA for sample C

Variate: C

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Days	4	9.47215	2.36804	57.54	<.001
Residual	10	0.41154	0.04115		
Total	14	9.88368			

Since F pr.<0.05, respiratory rate for sample A in different days of storage is significantly different and LSD testing is necessary.

Table H.6 LSD for sample C

LSD at 0.05 = 0.3691

	Mean	
Zero	5.420	D
Fifteen	4.222	C
Thirty	3.743	B
Fortyfive	3.410	Ab
Sixty	3.177	A

Different alphabets refers to significantly different

Appendix I

Analysis of Variance (ANOVA) in between storage days for reducing sugar level

Table I.1 ANOVA for sample A

Variate: A

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Days	4	0.001514	0.000378	0.32	0.859
Residual	10	0.011842	0.001184		
Total	14	0.013356			

Since F pr.>0.05, reducing sugar level for sample A in different days of storage is not significantly different and LSD testing is not necessary.

Table E.3 ANOVA for sample B

Table I.2 LSD for sample B

Variate: B

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Days	4	0.005051	0.001263	0.79	0.557
Residual	10	0.015979	0.001598		
Total	14	0.021030			

Since F pr.>0.05, reducing sugar for sample A in different days of storage is not significantly different and LSD testing is not necessary.

Table I.3 ANOVA for sample C

Variate: C

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Days	4	0.309774	0.077443	43.25	<.001
Residual	10	0.017904	0.001790		
Total	14	0.327678			

Since F pr. <0.05, reducing sugar level for sample A in different days of storage is significantly different and LSD testing is necessary.

Table I.5 LSD for sample C

LSD at 0.05 = 0.0770

	Mean	
Zero	0.6450	A
Fifteen	0.7710	B
Thirty	0.9147	C
Fortyfive	0.9733	CD
Sixty	1.0433	D

Different alphabets refers to significantly different