

पूसा फार्म सन फ्रिज में आलू (*सोलेनम ट्यूबरोसम एल.*) के
लंबे समय तक सुरक्षित भंडारण पर अध्ययन

**STUDIES ON PROLONGED SAFE STORAGE OF
POTATO (*SOLANUM TUBEROSUM L.*) IN PUSA
FARM SUN FRIDGE**

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**DIVISION OF AGRICULTURAL ENGINEERING
ICAR-INDIAN AGRICULTURAL RESEARCH INSTITUTE
NEW DELHI-110012**

2022

**STUDIES ON PROLONGED SAFE STORAGE OF
POTATO (*SOLANUM TUBEROSUM* L.) IN PUSA
FARM SUN FRIDGE**

A Thesis

By

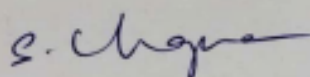
JUHI RANJAN

Submitted to the Faculty of the Post Graduate School,
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in partial fulfilment of the requirements
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**MASTER OF TECHNOLOGY
IN
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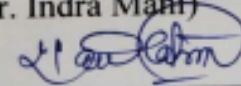


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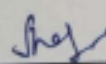
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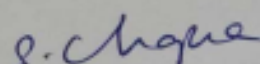
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CERTIFICATE

This is to certify that the thesis entitled “**Studies on prolonged safe storage of potato (*Solanum tuberosum* L.) in Pusa farm sun fridge**” submitted to the Faculty of the Post-Graduate School, Indian Agricultural Research Institute, New Delhi in partial fulfilment of **MASTER OF TECHNOLOGY IN AGRICULTURAL ENGINEERING (AGRICULTURAL PROCESSING AND STRUCTURES)**, embodies the results of research work carried out by **Ms. JUHI RANJAN** Roll No. 21392 under my guidance and supervision and that no part of this thesis has been submitted for any other degree or diploma.

It is further certified that all the assistance and help availed during the course of investigation as well as source of information have been duly acknowledged by her.

Date: 15/02/2023
Place: New Delhi


(Dr. Sangeeta Chopra)
Chairperson
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DEDICATED

To

My Beloved

Parents,

Teachers

&

My supporting

pillars

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'A thankful heart is not only the greatest virtue, but the parent of all the other virtues.

"The best and safest thing to keep a balance in your life, acknowledge the great powers around us and in us. So, it is essential that I acknowledge the great powers, who paved the way on which I have walked so far. Any accomplishment requires the effect of many people along with the sincere guidance of experienced persons and blessings of Almighty".

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Date: October, 2022
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Juhi Ranjan
(Juhi Ranjan)

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LIST OF ABBREVIATION

PFSF	Pusa Farm Sun Fridge
Fig.	Figure
TSS	Total soluble solid
PLW	Physiological loss in weight
<i>Wb</i>	Wet basis
<i>Db</i>	Dry basis
DBT	Dry bulb temperature
WBT	Wet bulb temperature
<i>i.e.</i>	That is
ANOVA	Analysis of variance
FAO	Food and Agricultural Organization
IARI	Indian Agricultural Research Institute
PV	Photo voltaic
AC	Alternating current
RH	Relative humidity
Eqn.	Equation
Lit	Litre
<i>Viz.</i>	Namely
FW	Fresh weight
SE	Standard error
CIPC	Isopropyl N-(3-chlorophenyl) carbamate
SREC	Solar refrigerated and evaporative cooled
REF	Refrigerator
RBD	Randomised Block Design
DF	Degree of freedom
D	Day
MoAFW	Ministry of Agriculture Cooperation and Farmers Welfare
MoFPI	Ministry of Food Processing Industries
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
AOAC	Association of Official Agricultural Chemists
NITI	National Institution for Transforming India
US	United State
INR	Indian Rupee
ASSOCHAM	Associated Chambers of Commerce and Industry of India

LIST OF SYMBOLS

\pm	Plus or Minus
$^{\circ}$	Degree
C	Celsius
a*	Redness and greenness
b*	Yellowness and blueness
L*	Lightness
R ²	Coefficient of determination
Rs	Rupees

LIST OF UNITS

Mm	Millimetre
Cm	Centimetre
M	Meter
G	Gram
Kg	Kilogram
H	Hour
N	Newton
kJ	Kilo Joules
J	Joule
W	Watt
S	Second
Min	Minute
A	Area
V	Volume
V	Volt
K	Kelvin
Lit	Litre
Mol	Mole

Agriculture is the primary source of livelihood for about 58% of India's population. Share of agriculture and allied sectors in GDP surged to 19.9% in 2020-2021, up from 17.8% in 2019-20 (Economic survey, 2021). Food grain production hit a new high of 296.65 million tonnes in 2019-20. As per third advance estimates for 2020-21, total food grain production in the country is estimated at a record 305.44 million tonnes (MoA & FW, 2021). India is the world's largest producer of fruits and world's second largest producer of vegetables. Horticulture production is reached around 326.58 million tonnes in 2020-21. Fruits and vegetables are perishable commodities. Total losses in fruits is about 20-30% and in vegetables it is about 30-35% due to their highly perishable nature (Chadha, 2001; Basediya *et al.*, 2013; Assocham, 2013). Due to their short life, it is estimated that around 30-35% of total fruits and vegetables production lost during different post-harvest operations in a year. The main reason of these losses is lack of post-harvest storage and processing facilities. If vegetables and fruits are maintained safely, they have a promising future in terms of export. Farmers will also be safeguarded from a great financial loss. This will also help to achieve the goal of doubling farmer's income.

Wastage of horticultural produce is a big concern for nation's economy. About 1/3rd of the food produce (about 1.4 billion tons), in the world every year, fit for human consumption, is wasted. An estimated sum of US\$ 1 trillion is lost annually during the post-harvest operations and post-harvest treatments (Food and Agriculture Organization 2016; Sawicka, 2019). In fact, the extent of loss of the perishables particularly fruits and vegetables have been alarming. These perishables are susceptible to damage and have a very short shelf life particularly in hot weather conditions prevailing in most part of the country. Huge post-harvest losses of fruits and vegetables are a matter of vital concern for India's agricultural sector too. The lack of an adequate and efficient cold chain infrastructure leads to massive post-harvest losses. It was estimated as INR 92,561 crore (US\$12.1 billion) annually; and many of the existing resources are inefficiently used exclusively to single commodities (NITI Aayog, 2018). According to the Central Institute of Post-harvest Engineering and Technology (CIPHET), Ludhiana, approximately 16 presents of the country's fruit and vegetables,

estimated worth INR 133 billion, gets waste annually because of the lack of cold storage facilities. The postharvest losses of fruit and vegetables is more than any other food product in India, is mostly due to inadequate cold storage and unproductive handling.

Proper storage facility plays a very important role in reducing post-harvest losses of fruits and vegetables by extending the shelf life. Proper storage means controlling abiotic factors by maintaining low temperature and high relative humidity of the storage area which reduces drastically the rate of decay of agricultural commodity during storage. In fact, the major abiotic factors affecting longevity of vegetables are temperature and relative humidity (Liberty *et al.*, 2013). Contaminations could initiate right from harvest and continues up to its consumption. At higher temperature, the rate of respiration increases which, in turn, results in release in moisture and weight loss of vegetables with resultant loss of quality and nutritive value. Liberty (2014) reported 2-3 times increase in the deterioration rate for every 10 °C rise in temperature above optimum temperature in fruits and vegetables. ASHRAE (1997) reported that vegetables of tropical and subtropical origin had optimum storage temperature between 5 °C and 10 °C. The vital activities of the tissue such as respiration, ripening continue even after harvest. The high moisture content of the horticulture commodity accelerates these reaction rate making them highly perishable. Storage structure with low temperature and high humidity maintain quality of fruits and vegetables by reduction reaction rate of tissues as compared to those exposes to ambient high temperature and low humidity condition. Therefore, in order to obtain the good quality of the produce, care should be taken right from the time of harvest by maintaining proper temperature and humidity. Thus, proper storage plays a critical role in maintenance of quality of fresh produce.

Storage of fruits and vegetables is a major challenge in India as we have scattered production catchments and highly varying climatic conditions both in time and space. The farmers in India faces difficulties in storage as options are very limited. The situation is more alarming for small holder farmers, as they do not have easy access to cold storage. Cold storages with good control of temperature and humidity are energy intensive and expensive, involve a large initial capital investment, and require uninterrupted electrical grid supply, which is not readily available in many parts of the country. Only a few states have cold storage facility that too for specific commodities and are controlled by business people, farmers do not have easy access.

Because of lack of on-farm cold storage facility farmer not able to store harvested farm produce on farmer's field. Thus, farmer sell their product at distress sale to middlemen who, procure and store material in cold store facility available in major cities and sell agriculture produce at higher price. So, benefits go to middlemen. As a result, if we implement on-farm cold storage facilities, the farmer will become a raw material provider in the supply chain, which in this study is referred to as backward integration. In such a backward integration arrangement, the processor company expands its role with the farmer who is a supplier in this case. Major success of part of efficient cold chain lies in having good backward integration but sadly it has been completely neglected so far in our country.

Due to a lack of capital and infrastructure to support traditional cold storage facilities, smallholder farmers can use low-cost, low-energy evaporative-cooled (EC) chambers as a viable alternative to cold storage for short-term, on-farm storage. (Ambuko *et al.* 2017; Chopra *et al.*, 2004b; Mogaji and Fapetu, 2011). Therefore, farmers need on-farm storage structure like evaporative cooled or refrigerated storage structure. These storages should be affordable, environment-friendly and could be built from locally available materials. The evaporative cooling principle is a gift of nature that occurs when air that is not already saturated with water vapour passes over a wet surface and water evaporates into the air, raising the humidity and cooling the enclosure at the same time. The technology of evaporative cooling is technically feasible for Indian climatic conditions that prevail in several part of the country. Another major challenge to adopt refrigerated system storage facility by smallholder farmers is the availability of electrical energy, throughout the year, for running cold storage effectively. India has great potential of solar energy estimated about 5×10^{15} kWh per year, which is far more than total energy consumption of country (Mitra *et al.*, 1997). Thus, a proper utilization of source of solar energy to develop solar refrigerated storage structure for storage of perishable agricultural commodities in the rural areas of the India where, power supply is still irregular have resulted in a strong push for the development of technologies that aimed at solar energy production and its use.

Efforts have been made to develop different designs of storage structures of different sizes for safe storage of perishable agricultural commodities. An evaporative cooled storage structure with solar refrigeration system was developed at the Indian Agricultural Research Institute (IARI) in New Delhi. Solar refrigerated and evaporative cooled (SREC) structure is an innovative, off grid, battery less, cold storage facility for

storage of perishable agriculture commodities. It is on -farm storage structure with combination of evaporative cooling system and solar refrigeration system to store harvested farm produce on farmer's field. This facility offers smallholder farmers inexpensive access to cold storage even without electrical connection and improves their control over the marketing of their crops. The SREC storage is having storage capacity of 2 tons of fruits and vegetables. Size (3 m x 3 m x 3 m). It incorporates several innovative features into its design. It includes wetted fabric over iron mesh walls for passive evaporative cooling, autoclaved aerated concrete blocks (AAC) and Styrofoam panels for insulation, a solar-powered, mini split inverter air-conditioning unit for refrigeration, water-based thermal storage in place of batteries for night time cooling, and a novel solar sensor that better balances refrigeration demand with available solar energy. The SREC was insulated with 5-cm thick panels of Styrofoam and refrigerated by an air conditioner modified to generate air temperatures as low as less than 5 °C. The SREC structure is unique among clean energy storage concepts in that it can be built all at once or in stages as time and funds allow. Farmers may construct the evaporative cooling (EC) chamber with locally available materials in the first stage, which provides modest cooling. Solar refrigeration is installed in stage two with minimal additional investment and no major structural changes.

Despite the benefits and ability to preserve the quality of harvested agricultural perishable commodities such as fruits and vegetables, smallholder farmers are still reluctant to adopt new storage technologies. The high cost and dependency on commercial energy sources became obstacle to move the technology in field especially for small scale farmer. As a result, raising awareness of new technologies is necessary. It needs proof and practical demonstration of their effectiveness in preserving the quality of agricultural perishable commodities. Therefore, efforts needed to study SREC structure for storage of agriculture commodity, provide proof and practical demonstration of their effectiveness and making awareness of such innovative, off grid, battery less, on farm storage structure to store harvested farm produce on farmer's field.

Some storage has limited control over their internal environment and undergoes daily and seasonal fluctuations in both temperature and humidity, which cause variation in the metabolic activity of stored products. EC structures have hourly, daily, and seasonal fluctuations in both temperature and humidity (Chopra and Beaudry, 2018a; Chopra *et al.*, 2004b). For these and other structures having fluctuating conditions, it is difficult to evaluate and compare performance and efficacy of the storage structures.

Therefore, efforts are needed for effective model plant for comparing the performance of storages differing dramatically in temperature control.

Potato (*Solanum tuberosum* L.) a semi-perishable commodity and the fourth most important food crop after wheat, rice and corn. It is a major world food crop and most important vegetable crop in terms of production and consumption worldwide. It is popularly known as “vegetable king”. In the fiscal year 2020- 2021, India produced 53.69 million metric tons of potatoes. It alone contributes about 21% of the total vegetable area and 26% of total vegetable production. Freshly harvested potato contains about 80% water and 20% dry matter. Potato contains complete range of nutrients which are necessary for growth and development of human beings.

In India 73% potatoes are consumed in different forms like cooked, roasted, French-fried, chipped etc. Good storage facilities provide tubers in their most edible, processing and marketable condition and it also ensure the uniform flow of potatoes to market and processing plant throughout the year. Also, it provides a better use of processing capacity, better combination of production and consumption, and better seed quality. To maintain a good quality product, storage conditions must be well controlled (Pringle *et al.*, 2009).

During storage, post-harvest losses of potatoes occur due to weight loss, sprouting and rotting which are directly affected by storage conditions. Potato tubers undergoes gradual weight loss and quality loss which include moisture loss, respiratory loss and changes in sugar during storage (Kuyu *et al.*, 2019). It loses weight in respiration, converting sugar and starches to CO₂ and water and losing moisture due to vapour pressure difference between tubers and surrounding air. This leads to overall quality losses and finally to non-marketable produces (Singh and Kaur, 2016).

The issue of these post-harvest losses of potato is of paramount importance in pursuit to combat hunger and improve food security, especially in poor and developing nations. In this scenario, we have to find the best possible storage conditions of potato storage which improve farmer’s income. Good storage prevents storage losses and maintain good quality product over long periods of storage. Thus, establishment and utilisation of cold storage is the need of hour, to reduce wastage of perishable commodities, also ensure economic benefit of both the farmers and consumers.

One of the major hindrances towards such initiative is the energy requirement by a cold storage for its powering and operation. This is a serious concern in the underdeveloped and developing countries, where a substantial fraction of rural population does not have access to the grid electricity. In developing nation like India, there are about 94,000 un-electrified villages and 25,000 of them are so remotely located that the extension of power grid there is not economically viable. Therefore, operation of cold storage powered through alternative energy like solar energy can be a perfect solution in this.

Pusa Farm Sun Fridge (Pusa-FSF) is a modern and innovative form of SREC structure developed at mela ground, IARI. It is fully solar powered cold storage for agricultural produce. It's a cutting-edge, off-grid, battery-free, cold-storage facility that can be constructed directly on the farm and operates without electricity. This cold storage is 10ft x 10ft x 10ft in size. It has rooftop solar panels that generate 5-kilowatt (KW) power, which helps in running air conditioner. The panels also power a 105-watt submersible pump circulating about 1,000 liters of water from a tank through overhead PVC pipes. At night, there is only passive evaporative cooling, with the water chilled during the day acting as a natural heat sink. All farmers with solar pumps are a potential market for the Pusa-FSF. The Pusa-FSF structure has less maintenance cost. In times of low prices, this can assist farmers to defer selling and boost pricing. It makes use of evaporative cooling and solar refrigeration. The temperature inside is 3-4° C during the day, and 8-10° C at night.

In order to evaluate the suitability of recently developed Pusa Farm Sun Fridge for storage as well as quality preservation of potato the study entitled “Studies on prolonged safe storage of potato (*Solanum tuberosum* L.) in Pusa Farm Sun Fridge” proposed the following objectives:

1. To study the spatio-temporal variation of temperature and RH in Pusa Farm Sun Fridge (under loaded and unloaded condition).
2. To study the effect of spatio-temporal variation of storage temperature and RH on physico-chemical properties of stored potatoes in Pusa Farm Sun Fridge.
3. Economic evaluation of Pusa Farm Sun Fridge for storage of potatoes.

Fruits and vegetables are of great economic importance. They form a valuable supplement to our food resources and improve the overall nutritional status of the country. Fruits and vegetables belong to the group of protective foods which supply a considerable number of vitamins and minerals apart from adequate quantities of carbohydrate and small number of proteins. The consumptions of these commodities are not up to the mark in our country. To maintain our nutritional standards and ensure more remunerative returns to growers and for the consumers, we must adopt some of the simple and low cost. Low energy consuming technologies for avoiding losses of fruits and vegetables. Storage of fruits and vegetables in cold storages has been an important area of research because at low temperature and relatively high humidity, these perishables can be preserved in their fresh form for extended shelf life. This safe storage is achieved through retardation of respiration rate, inhibiting the activities of microorganism and enzymes. However, the lack of cold storage facilities for storage of perishable agricultural commodities like fruits, vegetables and flowers leads to overall quality degradation and postharvest losses. Therefore, some of the literature related to the present investigation “Methods of storage of vegetables in the refrigerator at household level” are reviewed briefly in this chapter

2.1 Importance of fruits and vegetables

In the diet of humans, fruits and vegetables are significant sources of dietary fibre, minerals, and vitamins (C, A, B6, thiamine, niacin, and E). Fruits and vegetables also provide calories, magnesium, and iron. Fruits and vegetables include a number of crucial nutrients, including folic acid, riboflavin, zinc, calcium, potassium, and phosphorus. Climate factors, notably temperature and light intensity, have a significant impact on the nutritional value of fruits and vegetables. A lower risk of cancer, heart disease, stroke, and other chronic diseases has been associated with including fruits and vegetables in one's regular diet. Powerful antioxidants found in several fruits and vegetables can affect mechanisms that change the behaviour of tumour cells as well as the metabolic activation, detoxification, and disposal of carcinogens (Kader, 2001).

Dieticians suggested that adults consume 350 gram of vegetables per day (200 g green and 150 g root). Fresh vegetables, particularly leafy vegetables, must be included in one's daily diet. Adults should consume at least 2 servings of fruits and 3 servings of vegetables per day, according to most nutritional and global recommendations (WHO, 2002).

Rais and Sheoran (2015) reported that the largest producer of various fresh fruits and vegetables in the world is India. India currently ranks second in the world for fruit and vegetable production, after China. The projected 162,187 tonnes of vegetables produced in India represent 14.0 percent of the total amount produced worldwide. Tomatoes, cabbage, peas, eggplant, onions, carrots, broccoli, potatoes, onions, and several common green vegetables and gourds are the most widely farmed vegetables in the nation. Carrots, onions, and tomatoes are among them and are widely consumed and provided.

Wallace *et al.* (2020) emphasised that fruits and vegetables provide advantages beyond just helping people satisfy their basic dietary demands. Increased fruit and vegetable eating is strongly recommended by public health authorities as a means of illness prevention.

Horticultural products are an important source of agricultural income and contribute to the national economy. Despite the high yields and productivity, as the world's population grows, so does the demand for fruits and vegetables. Also, as people become more aware of the importance of vegetables in terms of nutritional value, the demand for vegetables is increasing both in terms of quality and quantity. To meet the needs of the growing population, we must extend the shelf life of harvested fruits and vegetables while reducing total post-harvest losses.

2.2 Post-harvest losses of horticultural crop production in India

Horticulture crops currently occupy a total area of 25.49 million hectares, according to the Department of Agriculture, Corporation and Farmer's Welfare, MoAFW, GOI, annual report 2019–20. Horticulture production, on the other hand, has increased by around 48.58 per cent from 2007–08 to 2018–19, reaching a production of over 313.85 million tonnes.

In the horticulture industry, vegetables are a significant crop, occupying 10.1 million hectares as of 2018–19, producing a total of 185.88 million tonnes with an average productivity of 18.4 Tonnes per hectare. In actuality, 59.2% of horticultural production was comprised of vegetables. India kept ranking after China as the world's top producer of vegetables. India is a global leader in the production of many vegetables, including okra. In addition, India is the second-largest producer of potatoes, tomatoes, onions, cabbage, cauliflower, and brinjal in the world. In the nation, a wide variety of vegetables are cultivated, including potatoes, tomatoes, okra, and cucurbits. The country's horticultural intervention has resulted in an increase per capita availability of vegetables has increased from 309 g/person/day in 2007-08 to 392 g/person/day in 2018-19.

The area under fruit crops during 2018- 19 is 6.65 million hectares, with a total production of 98.58 million tonnes. During the Period 2007- 08 to 2018-19 (3rd Adv. Est.), production of fruits increased by about 50%, while the area increased by about 14% (2007-08 to 2018-19). Interventions in Horticulture in the country have led to an increase per capita availability of fruits from 158 g/person/day in 2007- 08 to 208 g/person/day in 2018-19. India has retained its status as the second largest producer of fruits in the world. India is first in the production of fruits like mango, banana, guava, papaya, lemon and lime (ACFW Annual Report, 2019-20).

2.3 Major reasons of post-harvest losses of horticultural products

Huge post-harvest losses of fruits and vegetables are a matter of vital concern for India's agricultural sector. It is more sustainable to reduce post-harvest losses of food that has already been produced rather than increase output. Postharvest losses differ significantly between different commodities, production regions, and seasons. not offered as a service. The logical first step in determining an appropriate strategy for reducing postharvest losses is to conduct a systematic analysis of each commodity production and handling system. The horticultural crops, because of their high moisture content are inherently more liable to deteriorate especially under tropical conditions. They are biologically active; carry out respiration, transpiration and other biochemical activities, which further accelerate the rate of deterioration of the harvested produce.

Workneh (2007) claimed that postharvest losses could discourage farmers, reduction of postharvest losses, especially if it can economically be avoided, would be of great significance to farmers and consumers.

Inadequate infrastructure, strict quality control standards, high temperature and humidity, perishability of the produce, poor packing, inadequate transportation facilities, lack of processing units, lack of market demand, poor post-harvest handling practises, inappropriate harvesting time, mechanical injury during harvest, over-ripening, and a lack of market demand were the causes of post-harvest losses. The construction of cold storage infrastructure to manage temperature and humidity, increased attention to ripening procedures, and well-developed cold storage infrastructure were recommended as measures for reducing post-harvest losses. Evaporation of water from food is caused by physiological and biological processes, resulting in chemical and physical changes in fruits and vegetables (Brosnan and Sun, 2001; Pathare *et al.*, 2012).

Sawicka (2019) reported that around a third of the food produced for human use each year is lost. Food losses are predicted to cost \$680 billion in rich nations and only 310 billion in poor nations. Food is roughly wasted in industrialised and developing countries (670 and 630 million tons, respectively). Fruits and vegetables suffer the greatest losses when compared to all other food groups. The annual global quantitative losses and wastes of food are roughly 30% for cereals, 40%–50% for root crops, fruit, and vegetables, 20% for oilseeds, meat, and dairy products, and 35% for seafood.

Umbarkar (2019) stated that 65 percent of the population works in agriculture, and India generates 250 million tonnes of food annually. About 18% of the nation's fruits and vegetables, worth 133 billion rupees annually, are lost due to a shortage of cold storage facilities. India is a primarily agricultural economy, with agriculture contributing roughly 14% of the nation's GDP. The country is one of the major milk producers and the second largest producer of fruits and vegetables in the world. It also produces a large amount of meat and poultry. The annual expenditure of the Indian government on the food distribution system is 750 billion Indian rupees, which is roughly 1% of the 2011 GDP. Despite high production and an existing distribution network, India is struggling to feed your own people. This is due to a large amount of waste. According to the Central Institute of Postharvest Engineering and Technology

(CIPHET), about 16% of Ludhiana's fruits and vegetables worth Rs. 133 billion each year are wasted due to lack of cold storage facilities. India wastes more fruits and vegetables than any other food in India, mainly due to insufficient refrigeration and non-productive processing.

Rajapaksha *et al.* (2021) mentioned that lowering internal commodity temperature just after harvesting is critical in extending postharvest life. Fruit and vegetable post-harvest losses are significantly influenced by temperature and humidity. In actuality, the temperature is the single factor that has the greatest impact on how quickly freshly harvested goods deteriorate. To prevent weight loss and preserve freshness during storage, the proper relative humidity (RH) must be maintained. Cold storages are primarily designed to regulate the pace of transpiration, respiration, and microbial growth as well as to preserve produce in the most consumable state. While preventing chilling harm and slowing down the biological activities of fresh goods, cold storage facilities also exhibit microbial development. However, there are currently no services offered for suitably large-scale temperature- and humidity-controlled storage facilities.

2.4 Physiological changes in fruits and vegetables during storage

Ripening is a complex process of fruit development, which can be described as the result of biochemical and physiological changes leading to a stage of maturity that culminates in dramatic changes in color, texture and flavor (Javanmardi and Kubota, 2006). Most changes and deterioration of physiological changes and other biochemical activities of perishable agricultural products are highly dependent on storage temperature (Majidi *et al.*, 2014). Controlling fresh produce means controlling physical and chemical changes during storage.

Hardenburg *et al.* (1986) stated that storage at relatively low temperatures is the most efficient method of maintaining the quality of most fruits and vegetables due to its effects on reducing respiratory rate, sweat, ethylene production, ripening, of senescence and the development of rot. The changes that occur during the post-harvest operations of fruit and vegetables determine a decrease in their useful life which, in the long term, leads to a decrease in the quantity offered for consumption and for the export market. Common and noticeable post-harvest changes in vegetable quality include changes in color, weight loss and firmness changes, changes in total soluble solids, and

other biochemical changes such as loss of ascorbic acid (vitamin C), chlorophyll content, titratable acidity, total carotenoid content, and lycopene content.

Nyaura *et al.* (2014) stored amaranth in a local lump with low temperature packaging and modified atmosphere. Amaranth was tested for weight loss, ascorbic acid, beta-carotene, and respiration rates. The ascorbic acid content in the fresh amaranth leaf was 67 µg / g. The control sample lost 88% ascorbic acid in 4 days compared to 55% loss at 5 °C after 23 days. The beta-carotene content in fresh leaf amaranth was 61.4 mg / 100 g.

Ambuko *et al.* (2017) stored amaranth in a zero-energy brick chamber (ZEBC) and an evaporative cooling chamber (ECC). It noted that, at the end of storage (8 days), a higher PWL (47.6%) was recorded in ambient conditions compared to 10.5 and 6.7% in ZEBC and ECC, respectively. A rapid decrease in vitamin C (51%) was reported in vegetables stored under room conditions.

2.4.2 vegetables quality change parameters

Nourin *et al.* (2003) evaluated the quality changes in stored potatoes and quantify the associated parameters (rate constant) and activation energy to help model the changes in potato quality as function of storage temperature and time. Potatoes were stored at five temperatures (4,8,12,16 and 20°C) and at different storage time. The results revealed that potatoes became darker and softer by passage of time, and also shows that higher temperature resulted in more rapid changes in different quality parameters. Chemical parameters like ascorbic acid, p^H and starch were decreased and titratable acidity, reducing sugar, total sugar was increased. Respiration rate increased with temperature and duration of storage.

Singh *et al.* (2006) studied the physico-chemical, morphological, thermal, pasting, textural, and retrogradation properties of the starches isolated from four traditional Taewa (Maori potato) cultivars (Karuparera, Tutaekuri, Huakaroro, Moemoe) of New Zealand were studied and compared with starch properties of a modern potato cultivar (Nadine). The relationships between the different starch characteristics were quantified using Pearson correlation and principal component analysis. Significant differences were observed among physico-chemical properties such as phosphorus content, amylase content, swelling power, solubility and light

transmittance of starches from the different potato cultivars. The starch granule morphology (size and shape) for all the potato cultivars showed considerable variation when studied by scanning electron microscopy and particle size analysis. Starch granules from Nadine and Moemoe cultivars showed the presence of large and irregular or cuboid granules in fairly high number compared with the starches from the other cultivars. At 4 °C, all three cultivars had greater malondialdehyde concentration and catalase activity. The highest levels of malondialdehyde were found in Kufri Pukhraj, followed by Kufri Jyoti and Kufri Chipsona-1, while Kufri Chipsona-1 had the highest levels of catalase and peroxidase activity and Kufri Pukhraj had the lowest levels. Due to its high levels of catalase and peroxidase, Kufri Chipsona-1 outperformed the other two cultivars in terms of chip colour and malondialdehyde content while also having the highest resistance to activated oxygen. These characteristics make this cultivar more advantageous for processing.

Benetini *et al.* (2009) studied the effects of types of cultivar and storage time effects on potato physico-mechanical properties. Laboratory tests were conducted by using two potato varieties (*Solanum tuberosum* L. vs. Vivaldi and Primura) for two harvest years. Tubers were kept in controlled storage (temperature 4.5°C, humidity 80%) for a period of 240 days. Quasi-static compression tests were performed periodically, on whole tubers to determine mechanical properties at failure and on cylindrical specimens to evaluate young's modulus and Poisson's ratio. The two varieties showed different mechanical properties, but for both varieties, young's modulus decreases with the increasing number of days of storage.

Generally, longer storage periods of raw roots prior to processing results in products with decreased firmness. Studies on the amylase activity in fresh and stored roots have shown marked differences in individual and total sugar concentrations among sweet potato cultivars as well as differences in alpha and beta amylase activity during storage (Adu-Kwarteng *et al.*, 2014).

Kandasamy *et al.* (2015) determined biochemical changes in the breaker stage of ripe tomatoes. In the breaker stage, stiffness, pH, TSS, acidity, sugars, ascorbic acid, lycopene 135.9664 N, 4.152, 4.571 ° Brix, 0.655%, 2.627 g 100g sample-1, 15.76 mg 100g sample-1 and 0.947 mg 100g Probe-1 respectively pointed out that the tomato was hard and ready. The L * a * and b * color values measured were 57.452, -1372 and

12.651, respectively. On the mature stage were hardness, pH, TSS, acidity, sugars, ascorbic acid, lycopene 54193 N, 4482, 6541 ° Brix, 0.422%, 4845 g 100g Probe-1, 34535 mg 100g Probe-1 and 5215 mg 100g Probe-1 respectively which proves that the tomatoes were completely cooked. The color values of L * a * and b * were determined to be 36,822, 26,843 and 21,781, respectively.

Ozturk and Polat (2016) studied the physical and chemical characteristics of potatoes in long-term storage. In this study, the physical characteristics of potato cultivars, such as weight loss, and the chemical characteristics, such as specific gravity, dry matter, starch, protein contents, and chips efficiency, were assessed at the end of the storage period. At the completion of storage, the weight loss was calculated for each cultivar. The changes at the rates of -2.03 percent in weight, 0.06 percent in specific gravity, -1.46 percent dry matter, 2.95 percent starch, 7.85 percent protein, and -5.43 percent were calculated. As a result, it was discovered that the chemical qualities of the potatoes that were stored under long-term (24 weeks) controlled settings changed depending on the cultivars, increasing and decreasing specific gravity, starch, protein, dry matter, and chips efficiency. The findings of the tests showed that the potato cultivars have an impact on the physical and chemical changes that take place on the tubers during long-term storage.

Kale and Nath (2018) studied the quality changes in tomatoes stored in three different storage condition in hot region of Punjab. Storage conditions was evaporative cold storage, cold store (CS) and room conditions (RC). Average temperature inside the room during study was fixed 26.5°C, 25-41°C and 10°C for EC, RC and CS respectively. The RH was 65-78%, 20-35% and 90% in EC, RC and CS respectively. It was found that the different storage conditions affect the quality parameters (TSS, weight loss, Color and texture) significantly ($p < 0.05$).

Raigond *et al.* (2018) Study the lipid peroxidation and starch hydrolysis during potato storage in three cultivars with varying degrees of storability. Popular potato cultivars in India, Kufri Chipsona-1, Kufri Jyoti, and Kufri Pukhraj, were assessed after storage at 4 and 12 °C for 180 days, with good, medium, and mediocre storability, respectively. The reducing sugar and sucrose content increased throughout both low-temperature and extended storage, and this increase was much greater at 4 °C than it was at 12 °C. Kufri Pukhraj had the maximum content, followed by Kufri Jyoti, while

Kufri Chipsona-1 had the lowest content. At 4 °C, all three cultivars had greater malondialdehyde concentration and catalase activity.

2.4.2 Potato quality change parameters

Erdogan Ozturk (2016) studied the quality changes of potato in the long-term storage and their variations are one of the significant specifications in terms of consumer preference and reaching high product quality. Knowing the potential changes to potato quality and physiological parameters during long-term storage is therefore important, just as it is to know about potato production and breeding. In this study, the physical characteristics of potato cultivars, such as weight loss, and the chemical characteristics, such as specific gravity, dry matter, starch, protein contents, and chips efficiency, were assessed at the conclusion of the storage period (Binella, Granola, Banba, Natascha, Toscana, Slaney and Marfona). In 2013 and 2014, the experiment was set up as a three-replicate, entirely randomised design. According to changes in the physical and chemical characteristics of potato tubers, considerable variances across potato cultivars were found towards the conclusion of the storage period. At the conclusion of storage, the weight loss was calculated for each cultivar. Some potato varieties' chemical characteristics improved, while others saw a decline. The changes at the rates of -2.03% in terms of weight, 0.06% in terms of specific gravity, -1.46% dry matter, 2.95% starch, 7.85% protein and -5.43% were determined in accordance with the general average of potato cultivars at the end of storage. As a result, it was discovered that the chemical properties of the potatoes that were held under long-term (24 weeks) controlled settings changed according to the cultivars, increasing and decreasing specific gravity, starch, protein, dry matter, and chips efficiency. The findings of the tests showed that the potato cultivars have an impact on the physical and chemical changes that take place on the tubers during long-term storage.

Nourin *et al.* (2003) conducted an experiment aimed at quantifying the extent of those changes under different storage minimizing the deleterious effect on product quality. The objective of this study was to evaluate the quality change in stored potatoes and quantify the associated kinetic parameters (rate constants) and activation energy to help model the changes in potato quality as function of storage temperature and time. Potatoes were stored at five temperatures (4°C, 8°C, 12°C, 16°C and 20°C) at different storage times (at least 5-time intervals) samples were removed and evaluated for

different quality parameters (physical: texture and color; chemical: ascorbic acid (AA), reducing sugars (RS), starch (S), total sugars (TS), total soluble solids, pH and titrable acidity (TA) and physiological: respiration rate). The results revealed that potatoes became softer and darker by passage of time, and higher temperature resulted in more rapid changes in the different quality parameters. Chemical changes during the storage were decreased AA, pH and S, and increased TA, RS and TS. Only small changes were observed with peroxidase and poly phenol oxidase activity. Respiration rate increased with temperature and duration of storage. In general, most changes were well described by some form of first-order rate. Temperature sensitivity of rate constants was adequately described by the Arrhenius model.

Liua *et al.* (2003) Studied development of new starch products depends on the physicochemical characterization of starch during potato growth. Without further physical or chemical alterations to the starch, desired functional qualities can be obtained by regulating the growth duration. Three different potato cultivars, Shepody, Snowden, and Superior, were harvested for their starch throughout this investigation. Different analytical techniques were used to categorize the physicochemical characteristics of starches. Differential scanning calorimetry was used to assess starch retrogradation and gelatinization. By using X-ray diffraction, the crystalline structure of starch was examined. The viscosity and pasting temperature of starch paste were measured using rapid viscosity analysis. Shorter growth times of potatoes resulted in starch with higher end viscosity, lower peak viscosity (half that of normal starch), higher gelatinization temperature, and higher pasting temperature (double the value of normal starch). The findings show that development time and the physicochemical characteristics of starches vary among potato varieties. Different starch granule sizes, phosphorous concentration, and amylose content may be the main determinants of how well a starch performs.

Mohamed *et al.* (2007) designed and fabricated a solar PV powered vapour compression refrigeration system to attain favourable conditions for potato storage, and to evaluate its shelf life under different operating conditions. The system is created and manufactured by the IARI, New Delhi, division of Agricultural Engineering. It included a PV panel, a lead-acid battery, an inverter, and a drier-cum-filter in addition to the compressor, condenser, expansion device, evaporator, exhaust, and evaporator fans that are the system's primary parts. The 2.50 m³ cold storage building was built and insulated

with the right supplies. The curing process was carried out in a storage structure (1.0 m³) that was cooled by evaporation. The Kufri Chandramukhi variety of dried potatoes was kept for five months. Two lots of the tubers that had been preserved were created; one was utilised as a control (free sprouting), and the other was manually disported. The shelf life of potatoes was determined by measuring moisture loss, dry matter, sprouting, rotting, sugar content, starch, and chipping quality. Under full load, the daily average solar photovoltaic (SPV) energy output and load energy consumption were 5.65 and 4.115 kWh, respectively. According to the data, the loaded and air-circulated cold storage structure's average daily actual COP was 3.25. The loaded and air-circulated storage structure maintained an average temperature and relative humidity of 283.13 K and 86%, respectively. An alternate energy source for running a cooling system is a solar panel.

Singh *et al.* (2007) revealed whether behaviour differs between various granule size classes of potato starches, small (SGF), medium (MGF) and large (LGF) granule fractions were separated from the native starches of three potato cultivars, and some of their physico-chemical and functional properties studied. When the native starches and their separated fractions were examined using particle size analysis and scanning electron microscopy, there was a significant variation in the granule size distribution. For LGF, MGF, and SGF, the granule size ranges were 40-65, 20-40, and 1-20 μm , respectively. Granule sizes in the fractions of the cultivar Kufri Ashoka that were isolated from the native starch were bigger than those in the comparable fractions of the other two cultivars (Kufri Kunden and Kufri Dewa). LGF had a higher amylose concentration and a lower swelling power than the matching MGF and SGF for all three cultivars. The three native starch fractions' solubility and light transmittance increased with granule size while their enzymatic digestibility declined. Peak and final viscosities were found to be lower for SGF among the three fractions, although peak viscosity temperatures were lower for LGF. For all three cultivars, the breakdown and setback in viscosity were found to be highest for LGF and lowest for SGF. During frequency sweep testing on a dynamic rheometer, gels of native Kufri Dewa starch and its fractions showed the lowest values of dynamic mechanical properties like G_0 , G_{00} , G^* , and g_0 . The textural characteristics of the gels made from native starches and their fractions had a correlation with how each type of pasted. The texture of the gels changed significantly and gradually over the course of seven days at 4°C.

Golmohammadi *et al.* (2013) determined physical properties of agricultural products, such as the potato, and their variations during long-term storage, is an important feature in achieving high product quality and consumer acceptance. In order to determine other characteristics, such as sphericity, roundness, geometric mean diameter, volume mean diameter, aspect ratio, effective diameter, and real density during storage time, physical characteristics of potatoes (Agria, Satina, and Caesar cultivars) such as surface area, volume, moisture content, weight, and three main diameters of tuber were measured. For a total of 22 weeks, measurements were taken every 15 days, and they were then evaluated using a completely randomized block design with 10 replications. Three potato cultivars were shown to have significant differences in terms of the tuber's primary diameter, form features, mass, volume, and surface area. In this comparison, Satina's size was greater than that of the other two cultivars. The Agria cultivar, on the other hand, was more spherical in shape. Additionally, it was discovered that a power law equation with a high coefficient of determination could be used to predict each potato's surface area based on its mass and volume. Based on the findings, actual tuber density increased with storage time as predicted by a polynomial equation with $R^2 = 0.99$. According to a linear model, the moisture content of the tubers dropped over the course of storage, which was presumably a key factor in the reduction in tuber size. Potato tubers' main physical qualities, which alter significantly over long-term preservation, are density, size, and moisture content. Considerable differences in physical properties of different cultivars persuade researchers to carry out further studies on other popular potato cultivars.

Mehta and Singh (2015) evaluated Sprout inhibition treatment with isopropyl 3-chlorophenyl carbamate (CIPC) under ambient conditions (20 to 35°C, 44 to 86% RH) in five potato varieties viz. Kufri Chipsona-1, Kufri Surya, Kufri Jyoti, Kufri Pukhraj and Kufri Bahar after harvest and after storage at 2-4°C for four months. Freshly harvested potatoes of all the kinds up to 60 days significantly decreased sprouting and total losses when treated with CIPC (15 and 20 mg a.i./kg tuber weight). In contrast, only two kinds of cold-stored potatoes responded well to CIPC treatment at higher doses (25 and 30 mg a.i./kg tuber weight). However, the treatments might be helpful in extending potatoes' shelf life by 30 to 45 days. The CIPC treatment increased chip colour and decreased sugar content. While other cultivars were only appropriate for table use, newly harvested Kufri Chipsona-1 potatoes can be sold as both table and

processing potatoes. Only table potatoes can be sold after being chilled. CIPC residues were below the permissible limits and potatoes were safe for human consumption. The information is of high practical utility to market/export potatoes to distant markets.

Gupta *et al.* (2015) assessed forty-four indigenous potato varieties for storage behaviour at room temperature, tuber dry matter content and cooking quality during 2010, 2011 and 2012. The maximum, minimum temperatures and relative humidity during storage period ranged between 26 to 40 °C, 17– 28 °C and 18 to 82 %, respectively. The lowest total weight loss was recorded in variety Kufri Pushkar (7.7%) followed by Kufri Lalima (7.9 %), Kufri Surya (8.3 %), Kufri Red (9.2 %), Kufri Dewa, Kufri Sheetman (9.3 %), Kufri Chandramukhi, Kufri Jyoti (9.5 %), Kufri Sindhuri (9.6%), Kufri Kuber (9.7 %), Kufri Chipsona-1 (9.8 %), Kufri Kundan (9.9 %) and Kufri Chamatkar (10.0 %). Highest tuber dry matter content (%) was observed in Variety Kufri Kundan (24.2) followed by Kufri Himsona (23.7), Kufri Frysona (23.6), Kufri Kuber (22.7), Kufri Chipsona-2 (22.3). Kufri Khasigaro (22.0), Kufri Sheetman (21.9), Kufri Chipsona-3 (21.7) and lowest in Variety Kufri Khyati and Kufri Pukhraj (16.1 %). Of the total varieties, 14 were adjudged as floury, 15 mealy, 14 waxy and one (Kufri Ashoka) as soggy. The total weight loss had highly significant and positive correlation with sprout weight/Kg tubers ($r= 0.76^{**}$), physiological weight loss ($r=0.97^{**}$). Based on the results potato varieties namely, Kufri Chamatkar, Kufri Chipsona-1, Kufri Chandramukhi, Kufri Dewa, Kufri Jyoti, Kufri Kuber, Kufri Kundan, Kufri Lalima, Kufri Lauvkar, Kufri Pushkar, Kufri Red, Kufri Safed, Kufri Sheetman, Kufri Sindhuri possessed excellent keeping quality with medium to long tuber dormancy, low storage losses, medium to high tuber dry matter and good flavour. The information generated in this study can be utilized in the breeding programme. This can also help the farmer to choose and cultivate the potato varieties as per demand of the consumers.

Kashif *et al.* (2016) identified the appropriate storage temperature for the premium potato variety Lady Rosetta with special reference to the changes in its quality attributes, Weight loss, total sugars, starch, ascorbic acids, total phenolic contents, radical scavenging activity, enzymatic activities, and potato chip colour are some of these factors. To determine the ideal storage temperature, the chosen potato variety was kept at various temperatures (5, 15 and 25°C). Our findings indicated that the assessed quality attributes responded significantly differently to various storage temperatures.

However, it was discovered that storage at 5° C was linked to increased sugar build up (2.32 g/100 g), quick starch depletion (13.25 g/100 g), and subpar post-processing results. Storage at 5°C maintained tuber dormancy for up to 126 days (L-value, 52.00). But until the end of storage, potatoes stored at 15° C had lower sugar contents (1.33 g/100g) and better chip colour (L-value, 59.33). In contrast to potatoes held at 5° C during the same storage duration, they were discovered to be linked to higher polyphenol oxidase (38.47 U/g f.w.) and peroxidase (15.25 U/100 g f.w.) activities. Due to the dormancy break on the 84th day and subsequent starch degradation (15.29 g/100 g), increased sugar accumulation (1.32 g/100 g), and increased polyphenol oxidase (79.89 U/g f.w) and peroxidase activities (40.69 U/100 g f.w) activities, the storage life of potato tubers at 25°C was significantly reduced. Our findings demonstrated that the Lady Rosetta variety of potatoes is cold sensitive and needs a particular temperature for extended storage and the optimal post-processing.

Sharma *et al.* (2016) estimated the variation in bio-chemical parameters among eight different parts viz. bud end cortex, bud end medulla, central cortex, central medulla, pith, stem end cortex, stem end medulla and peel of potato tuber of processing varieties. The cortical region of the stem end, bud end, and central section had larger concentrations of dry matter, reducing sugar, sucrose, and starch than the medullar region did. Variety The highest dry matter content in stem end cortex was found in Kufri Chipsona-1 (SEC 30.34%), followed by Kufri Frysona (SEC 27.71%). The bud end cortex had the highest mean reducing sugar values (BEC 111.3 mg/100 g FW) whereas the stem end medulla had the lowest (SEM 44.05 mg/100 g FW). Different genotypes and diverse sections of the tuber had significantly different biochemical compositions. The study's findings can assist processors in making the most use of potatoes for goods like chips and French fries, among others.

Raigond *et al.* (2017) studied potato storage behaviour in terms of lipid peroxidation and starch hydrolysis in three cultivars differing widely in storability. Popular potato cultivars in India, Kufri Chipsona-1, Kufri Jyoti, and Kufri Pukhraj, were assessed after storage at 4 and 12°C for 180 days, with good, medium, and mediocre storability, respectively. The reducing sugar and sucrose content increased throughout both low-temperature and extended storage, and this increase was much greater at 4°C than it was at 12°C. Kufri Pukhraj had the maximum content, followed by Kufri Jyoti, while Kufri Chipsona-1 had the lowest content. At 4°C, all three

cultivars had greater malondialdehyde concentration and catalase activity. The highest levels of malondialdehyde were found in Kufri Pukhraj, followed by Kufri Jyoti and Kufri Chipsona-1, while Kufri Chipsona-1 had the highest levels of catalase and peroxidase activity and Kufri Pukhraj had the lowest levels. Due to its high levels of catalase and peroxidase, Kufri Chipsona-1 outperformed the other two cultivars in terms of chip colour and malondialdehyde content while also having the highest resistance to activated oxygen. These characteristics make this cultivar more advantageous for processing.

Grubbena *et al.* (2019) presented 1-D mathematical model which includes relevant quality indicators for frying potatoes and climate-related variables. Temperature, moisture content, and the amount of reducing sugar in a potato are relevant quality indicators. Temperature, moisture content, and the amount of carbon dioxide in the air are climate-related parameters. With good results, parameter estimates and validation were carried out using information from two large-scale storage facilities during the 2016–2017 storage season. The improved cooling trajectory of stored frying potatoes was then examined using the validated model in a scenario analysis. Regarding the Ramos variety, quicker chilling results in less weight loss and an increase in sugar content, but still within acceptable levels for industrial application. In this paper, we have presented a 1-D spatially distributed convection-diffusion-reaction model for frying potato storage. The model contains dynamic interactions between relevant quality indicators (moisture content and sugar level) as well as interactions with the indoor climate. The model, with physical and physiological states (T_p , X_p , CO_2 and RS), was successfully calibrated and validated for a full storage season, on unique data sets of two large scale facilities in the Netherlands for the variety Ramos. In the scenario study, the hypothesis that slower cooling is beneficial for all quality indicators was rejected. Fast cooling lowers the respiration and ventilation cooling hours, and hence the dehydration of the potato. The sugar content is higher in the more rapidly cooled potato, but for the variety Ramos it is still within an acceptable range for the processing industry. However, as the model was calibrated and validated only for the variety Ramos, the result can differ for other varieties. Thus, further research is needed to evaluate the performance of the model on other varieties, and to come up with optimal storage strategies for each of these varieties. It would also be of interest to add other quality indicators to the model, like dormancy or pressure bruising.

Khanal and Bhattarai (2020) conducted a comparative study of three most common potato storage conditions (in-house store, in-basket store, and cold store) and to find the most suitable storage condition for farmers. Assessment of post-harvest losses and a study of the pattern of respiration and lowering sugar levels throughout a sixty-day storage period were part of the experimental effort. The total loss was lowest (4.38%) for potatoes kept in cold storage and greatest (13.04%) for potatoes kept in-house. For potatoes kept in-house for storage, the reduction in sugar build up was the least (0.65) and essentially consistent over the course of the trial. Reduced sugar accumulation gradually rose and peaked (1.04%) for potatoes kept in the refrigerator. Cold-stored potatoes had the lowest respiratory rate, which steadily dropped to 3.17mg CO₂/kg/hr after 60 days of storage. Potatoes housed in baskets had the highest respiratory rates, peaking at 6.55 mg CO₂/kg/hr at the end of storage. For potatoes kept in the cold, storage loss and respiration rate are at their lowest, but sugar accumulation is significant. Although excessive sugar accumulation does not occur in internal storage, storage loss is the worst of all. In addition to being affordable and practical, in-basket storage has much fewer storage losses than in-house storage and no issue with sugar accumulation.

Chopra *et al.* (2022) designed and fabricated relatively inexpensive evaporatively cooled (EC) storage, which was enable farmers to avert distress sale and get a fair price for produce. The Pusa EC room was constructed utilising unique building elements, such as fabric walls and insulative blocks, and it was assessed year-round for a period of five years (2017–2021) using the respiratory and senescence responses of amaranth (*Amaranthus* spp.) to storage temperatures. In the daytime, cooling of the interior of the structure was produced by wetting the fabric walls, but not at night. During the warm and dry spring and summer weeks, it was projected that store life would nearly double compare to storage at ambient temperatures. However, it did not significantly improve when the ambient temperature dropped and RH rose in the late summer, fall, and winter. Wet bulb depression of temperature in relation to ambient was employed to control a straightforward mathematical expression that determined the estimated daily reduction in respired CO₂ for the leafy amaranth, the model plant used in this study. The predictive equation allows for straightforward prediction of the advantages of evaporative cooling, potentially anywhere in the world, and may be used to any plant material for which the metabolic response to temperature is defined. Using

information gathered from the website <https://en.climate-data.org>, this relationship was utilised to forecast an improvement in storage-life for numerous cities in India's key climate zones. As would be expected, warmer, drier climates were predicted to profit from EC rooms the most; nevertheless, regional climate classifications were not always found to be a viable guide for situating EC rooms due to local and microclimate variability.

2.5 Evaporative cooled and solar energy assisted cooled storage structure and their performance evaluation for storage of different commodities

The essence of storage is of great importance, as all harvested leafy vegetables will generally not be used immediately after harvest. Therefore, measures to preserve vegetables before they expire are of great importance. Most farmers cannot afford the cost of purchasing high-tech equipment to store their harvested crops. Evaporation cooling has been found to be an effective and economical way to reduce the temperature and increase indoor humidity where the humidity is relatively low. Minimizing bad reactions in vegetables extends their shelf life, which means that the products will be available for a longer time; this would reduce fluctuations in delivery prices and the market. Evaporation cooling works on the principle of cooling, which is manifested by the evaporation of water from the surface of the structure.

Global environmental concerns and rising energy demand, combined with steady advancements in renewable energy technologies, are opening up new areas for renewable energy resource utilisation. Sunlight energy is the most widely available, inexhaustible, and environmentally friendly of all renewable energy sources. Sunlight energy is the most widely available, inexhaustible, and environmentally friendly of all renewable energy sources. The amount of energy intercepted by the earth from the sun is approximately 1.8×10^{11} MW, which is many times greater than the current rate of all energy consumption. One of the most effective ways to harness solar energy is through photovoltaic technology (Parida *et al.*, 2011).

Chopra *et al.* (2004) investigated the evaluation of the efficiency of the evaporation storage structure for cooling the Kinnow tangerine. The storage capacity of this refrigeration structure by evaporation is 2 tons. But the chosen structure was estimated at 1.5 tons of cinemas. The temperature and relative humidity in the EU room were determined during the storage period from 12.5 to 19 °C and 88 to 98%

respectively. A comparative study was also conducted with fruits stored under ambient conditions. The ambient temperature varies from 13.1 to 21.2°C, and during the storage period the relative humidity of the air is determined from 52 to 75%. It has been established that the shelf life has been extended by 13 days in the EC due to the state of the environment. The taste and appearance of the cinemas were also found in the EC storage structure. Data from a study based on weight loss, rot, vitamin C and TSS show that the storage structure of EC is good for maintaining the characteristics of quince fruit in relation to the state of the environment.

Mishra *et al.* (2009) performed an experiment to store the two most common vegetables, that is Potatoes (var. Kufri Ashoka) and tomatoes (var. Pusa Ruby). The tomato is stored in an evaporative cooling storage structure (ECSS) with a capacity of two tons. The microbial load in the form of a total viable number of bacteria and fungi is recorded at two-week intervals, taking into account 10% physiological weight loss according to ECSS as an acceptable level. Changes in sugar and soluble protein reductions were also assessed. The total number of viable bacteria on potatoes and tomatoes is lower in ECSS compared to storage in the environment. The reduction in sugar content and changes in soluble protein content were slower in ECSS than in environmental storage in both stored vegetables. Physiological weight loss (PLW) is about 6 and 11% lower in ECSS compared to the potato and tomato storage medium.

Anon (2014) has developed an evaporative refrigerated cart for mobile fruits and vegetables retail The Indian Institute for Agricultural Research, New Delhi. With the provision of additional storage space of 0.22 cubic meter, under the main platform of the stroller, an efficient and uniform evaporative cooling device with forced air circulation with the help of DC fans. The target light is powered by a DC LED light powered by a 100 W solar photovoltaic (SPV) panel, equipped with a 7Ah portable battery power with SPV through a charge controller. The storage chamber temperature of 5-8 °C and an increase in relative humidity of 15 to 30% were observed. Ultimately, this extends the shelf life of fresh fruits and vegetables to five days, bringing in a higher net income.

Jahun *et al.* (2016) developed and evaluated an evaporative cooler with locally available materials. The materials are outsourced and built locally within the research area. The performance of the refrigerant was evaluated in terms of temperature drop,

weight loss and increased relative humidity and evaporation efficiency. The results show that the evaporator cooler can reduce the effect of the daily maximum ambient temperature, the average temperature in the cooling chamber varies from 20 to 23.5 °C for tomatoes and 20.5 to 26.5 °C for hot peppers, while the outside air temperature varies from 25 to 28 °C and 28 to 30.5°C for these products. The average relative humidity in the closet during the experiment was 51 to 93%, respectively, while the average relative humidity was 47 to 58% for tomatoes. The average relative humidity in the closet during the experiment was 51 to 93%, while the average relative humidity was 47 to 58% for tomatoes, and the average relative humidity of hot peppers was 49 to 95% of the cabinet, and the average relative humidity was 47 to 57%. The efficiency of the evaporator cooler was higher during the day between 12-14 hours. Local time when observed. The evaporator cooler managed to keep freshly picked tomatoes and hot peppers for 8 days before the colors changed and mold appeared and the mass decreased dramatically.

Sundaram (2016) studied the storage of vegetables in a cold chamber without energy. A zero-energy cold chamber could be the best alternative for such farmers who have smaller farms, especially in the short term to store perishable products on the farm without recurring energy costs, as it works on the principle of evaporative cooling. This ZECC vegetable storage study showed its benefit in prolonging the storage of tropical vegetables, such as lowering the temperature to 9°C and increasing the relative humidity by 18% in the chamber compared to the environment. ZECC has been shown to be useful for storing vegetables with minimal weight loss and rot, and freshness is maintained for 3 days in the laboratory, 4 days in bhendi, five days in brinell, bitter gourd and radish.

Zakari *et al.* (2016) designed and constructed an evaporative cooling system that manually operated the tomato storage cart. Evaporative cooling system with solar power supply of 0.6 m³ is designed and built to increase the shelf life of stored vegetables. The developed evaporator cooler was evaluated and tested using tomato (rum). The principle of evaporative cooling is used and the relative humidity (RH) in the storage chamber is increased. The storage system is made of 1 mm thick aluminium sheets, while one side of the system is made of jute, moistened with water passing through a series of perforated pipes from a tank located at the top of the storage system. Water flows under the influence of gravity. The relative humidity and weight loss of

tomatoes were statistically analysed using a student t-test and the result showed that there was a significant difference in the use of an evaporative cooling system for tomato storage compared to environmental conditions. The average cooling efficiency is 83%. The temperature in the system dropped dramatically compared to the ambient state, which ranged from 6 to 10 °C, and the relative humidity in the cooling chamber increased significantly to 85%. However, testing of the evaporative cooling system showed that tomatoes can be stored for an average of five days with minor changes in weight, color, hardness, and rot compared to the state of the environment in which they began to rot after only three days.

Samuel *et al.* (2016) Automatic solar carts are designed and developed for storing fruits and vegetables. It has been tested for effectiveness during the summer season. The maximum and minimum temperature drops vary between 8.1 °C and 11.2 °C, and the relative humidity, increased by 15% and 25% in the chamber of the vending card, is observed in June. The need for water varies between 16.5 and 20.0 litres per day. They observed a significant effect on the physiological weight loss of various vegetables stored inside or outside the mobile camera. The shelf life of vegetables increases significantly after storage in the designed carts.

Ambuko *et al.* (2017) determined evaporative cooling efficiency using a zero-energy brick cooler (ZEBC) and a charcoal evaporator cooler (ECC) to maintain the quality of amaranth leafy vegetables after harvest. Freshly harvested vegetables are divided into bundles weighing 300 grams and stored at ZEBC, ECC and room conditions (control). Changes in real-time temperature and relative humidity (RH) as well as changes in quality properties (physiological weight loss (PWL), wilting index, staining angle, and vitamin C) were determined during the storage period. The temperature difference between ZEBC and ECC with respect to the outside air varies between 4 and 10 °C. Significantly higher relative humidity (80–100%) was recorded in both evaporative cooling chambers. At the end of storage, a higher PWL (47.6%) was recorded at room temperature compared to 10.5 and 6.7% in ZEBC and ECC, respectively. There was a rapid decline in vitamin C (51%) in vegetables stored indoors. In general, it was better to maintain the quality of vegetables according to ECC and ZEBC.

2.7 Cost Economics

Dash and Chandra (2001) performed an analysis to assess the economic feasibility of refrigerated (EC) storage structures for the storage of horticultural products. For the analysis, two types of storage structures were considered, one with brick and sand brick walls and the other with wood wool walls. It was observed that in facilities of 0.25 m³ EC (capacity 100 kg) storage costs are Rs. 0.07 per kg of goods per day. Therefore, EU storage structures can be advantageously used to extend the shelf life of highly perishable products to approximately 6-7 days, which would otherwise deteriorate by 2-3 days under environmental storage conditions. However, for semi-perishable products such as potatoes, the storage cost for a period of 100-120 days will be around Rs. 7.001 kg. Therefore, in this situation, low-capacity EU structures do not offer any economic advantage over environmental storage conditions.

Storage costs would decrease with the size of the building, and the cost of storing potatoes for 100 days in 1 m³ of EU structures (capacity 400 kg) with pads and brick walls would amount to Rs. 1.22 and Rs. 2.38, respectively. The storage costs in an EC structure of 25 m³ (capacity 8 MT) equipped with an artificial ventilation system, which is Rs. 0.81 were also analysed for a storage period of 100 days. The break-even price of potatoes stored under EC conditions was Rs. 3.58 and Rs. 3.12 for EC wooden wool storage structures with a capacity of 1 m³ and 25 m³ respectively.

Therefore, EC structures can be adopted in places where cold stores are not available or transport costs to cold stores are very high to demonstrate the benefits of storing products in cold stores. Use of such EC storage structures for other operations such as mushroom growing, horticultural products, etc. and extending the number of working days per year would reduce the retention of unit costs and provide a better economic picture of EC storage structures.

Dash (1999) was reported the storage cost of one kg potato in 1m³ evaporative cooled structure made up of pad and brick for 100 to 120 days storage period. He reported that, Rs 1.14 kg⁻¹ ang Rs. 1.17 kg⁻¹ in the pad and brick structure, respectively.

From the review, it is evident that substantial work has been done on design and development of evaporative cooled storage structures and their performance evaluation. Numbers of researchers have reported cold storage structure advantages with respect to storage of produces and increase in self-life of produces. But there is no literature available which explain use of a model plant for performance evaluation of different cooled storage structures which undergo daily and seasonal fluctuation in both temperature and relative humidity.

2.5 Characteristics of Solar energy and solar potential of India

Energy plays a significant role in generation of wealth and economic development. Limited available of fossil resources and its associated problems to the environment make aware to focus on sustainable energy supplies that use renewable energies. Renewable energies include the energy source from sun, wind, water, tidal, wave, geothermal and biomass. All the sources of renewable energy are geographical dependent except sun. For example, wind and water source are mostly available in coastal and mountain regions. Solar energy can also produce both thermal and electrical power. Therefore, solar energy becomes an emerging renewable energy technology that can replace the shortage of conventional energy sources both in thermal and electrical power output. India is endowed with rich solar energy resource. The annual global radiation in India varies from 1600 to 2200 kWh/m² with about 300 clear sunny days in a year providing equivalent energy potential of about 6,000 million GWh of energy per year. The daily average solar energy incident over India varies from 4 to 7 kWh/m² with about 1500– 2000 sunshine hours per year (depending upon location).

Ramachandra (2011) noted that since about 58 percent of the total land region (1.89 million km²) gets annual average global insolation above 5 kWh / m²/day, India has a vast potential for solar power generation. Indeed, 1% of the land region is adequate to satisfy India's energy requirements by 2031 at current efficiency rates. The average solar radiation intensity received over India is 200 MW / km² (megawatt per kilometer square) with 250-300 sunny days per year. In India, solar energy intensity differs geographically, but in Rajasthan and northern Gujrat, the greatest annual worldwide radiation (about 2400 kWh/m²) is obtained.

Veeraboina and Ratnam (2012) explored solar potential in India and reported that India has excellent solar power potential and is estimated at around 5000 trillion kWh per year for so many times the energy requirement. The event of solar radiation over India is equivalent to 47 kWh/m² per day with an event of solar radiation over India is equivalent to 47 kWh/m² per day with an annual 1200-2300 kWh per square meter. It has an average of 250-300 clear sunny days and annual sunshine of 2300-3200 hours. India's electricity demands can be encountered on a 300 km² total land region equivalent to 0.1 percent of the country's total territory, the level of energy obtained by the Earth from solar energy is roughly 1,20,000TW. This is significantly high from both the present annual global energy consumption rate of roughly 15 TW and any future extra requirements. Solar power is a clean, environmentally friendly source of energy. There are no toxic by-products or emissions. Currently we are generating 4.59 % of solar energy of total produced renewable energy installed capacity in India. India has tremendous potential to generate solar power. This solar power can be effectively utilized for drying of grains in a solar dryer. The cost of energy generated is very low and free from emissions thus adding value to its usage in drying.

Raju *et al.* (2013) designed solar dryer for vegetables. The dryer works on the principle of greenhouse effect and thermosiphon principle. There is an air vent (inlet) where air enters and guides the air to solar collector and then heated up by greenhouse effect. The hot air then passes through the trays where foods are kept and dried the product. The moisture is removed through the air vent (outlet) near the top of the shadowed side. The food is dried under free convection and it is passive solar system. To collect the waste heat from the exhaust door, a heat exchanger consists of copper tubes for heating water is provided.

Vidyasagar *et al.* (2013) developed a vegetable solar dryer. The dryer operates on the greenhouse effect principle and the principle of thermosiphon. There is an air vent (inlet) in which air enters and guides the air to the solar collector and then the greenhouse effect heats up. Then the warm air passes through the trays where foodies stored and the item is dried. The moisture removed at the top of the shadowed side through the air vents (outlet). Under free convection, the food is dried and is passive

solar system. A heat exchanger consist copper pipes for heating water is supplied to retrieve waste heat from the exhaust gate.

The review of literature showed that substantial work has been done on design and development of evaporative cooled storage structures and their performance evaluation. Numbers of researchers have reported cold storage structure advantages with respect to storage of produces and increase in self-life of produces. But there is no literature available which explain storage of potatoes for performance evaluation of solar refrigerated evaporative cooled storage structure (Pusa Farm Sun Fridge) which undergo daily and seasonal fluctuation in both temperature and relative humidity.

This chapter deals with the materials and methods used for the Studies on prolonged safe storage of potato (*Solanum tuberosum* L.) in Pusa farm sun fridge. Pusa Farm Sun Fridge, is an innovative, off grid, battery less, on farm cold storage facility for storage of perishable and semi perishable agricultural commodities. This chapter includes plan of experiments, experimental procedures, and analytical methods to evaluate quality parameters. Quality parameters included product parameters and storage structure operational parameters. Product parameters such as weight loss, sprouting %, rotting %, colour change, TSS (total soluble solid), starch content, total sugar content, reducing sugar were studied. While storage structure operational parameters involved measurement of temperature and relative humidity. The cost economics of pusa farm sun fridge under potato was also estimated. The study was conducted at Division of Agricultural Engineering, Indian Agricultural Research Institute, New Delhi.

The study was completed in the following sequence

- Measurement of physical parameters (Temperature and RH) over time in selected storage structure (Pusa Farm Sun Fridge & Ambient) at no load condition.
- Measurement of physical parameters (Temperature and RH) over time in selected storage structure (Pusa Farm Sun Fridge & Ambient) at load condition
- Assessment of storage quality parameters changes of potato over time in selected storage structure.
- Evaluation of cost economics of Pusa Farm sun Fridge under potato storage. The detailed description of plan of experiments, materials and methods used for measurement of storage parameters (temperature and relative humidity) as well as quality parameters of potato over storage period in the present study are presented in the following sections:

3.1 Description of study area

3.1.1 Location

The study was conducted at Division of Agricultural Engineering, Indian Agricultural Research Institute, New Delhi. Which lies between Latitude of 28°37'22" to 28°39'05" N and Longitude of 77°08'45" to 77°10'24" E, at an average elevation of 230 m above the mean sea level (Figure 3.1).

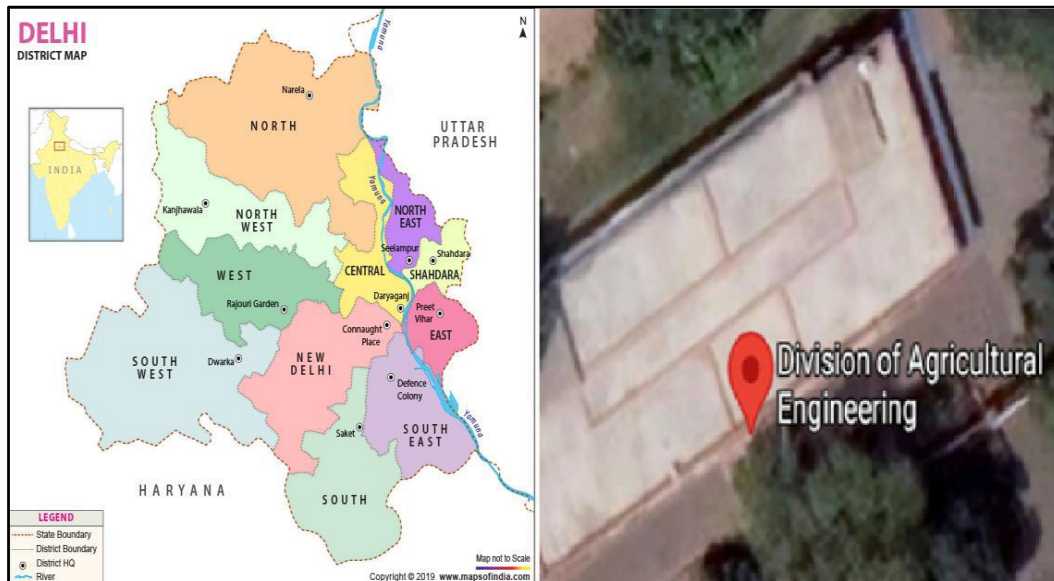


Plate 3.1. Location of the experimental site

3.1.2 Climate

The climatic condition of Delhi region is typical humid subtropical and semi-arid with severe summer and chilling winter temperatures. It comes under the agro-climatic zone of “Trans-Gangetic plains” in the agro-ecological region-IV (Ajadary *et al.*, 2007). The experiment was carried out during the period January to June 2022.

3.2 Measurement of storage parameters

3.2.1 Temperature measurement

Thermocouples were installed for ambient and inside temperature measurement in PFSF. A Thermocouple is a sensor used for temperature measurement. It consists of a junction of two different metals. An emf is generated at the other two ends and the temperature is detected. Basically, it works on the principle of the seebeck effect. Basically, 3 types of thermocouples are used, viz., J type, E type, K type and T type. In

this research, a T type thermocouple was used, consisting of copper and constantan. The temperature range that could be detected was -270 to 400°C.

3.2.2 Relative humidity measurement

Relative humidity calculated by using dry bulb temperature and wet bulb temperature.

3.3 Instrumentation

Temperature and relative humidity are of major concern in storage structures. Setup consisting of sensors and data acquisition elements was used for measurement temp and RH.

3.3.1 Thermocouples

Thermocouple is a sensor used for temperature measurement. It consists of a junction of two different metals, emf is generated at other two ends and using that temperature is detected. Basically, it works on the principle of seebeck effect. Mainly 3 types of thermocouples are used viz., J type, E type, K type and T type. In this research T type thermocouple was used consisting of copper and constantan. The temperature range that can be detected was -270 to 400°C.

3.3.2 Data Acquisition Setup

Data Loggers: Data logger is an electronic device that mainly records the data obtained from the sensors, in an appropriate format, after specific intervals. In this research, Campbell Scientific CR10 data logger was used. It was powered by 12 V battery. The battery was continuously charged using a solar photovoltaic cell and a charge controller.

The software used for programming of data logger and data collection was PC200W. This is software from Campbell Scientific capable of data collection, data monitoring and programming of new data loggers.



Plate 3.2. Data logger and multiplexer set-up for measuring temperature

3.4 Study of effects of storage parameters on shelf life of potato

Effect of storage parameters i.e., temperature and relative humidity on shelf life of potato was studied. For this, potatoes were stored in two storage conditions (PFSS, Ambient) at different temperatures and relative humidity. The effect of temperature and relative humidity on the dependent variables viz., physiological weight loss, sprouting, rotting, colour change, starch content, reducing sugar and TSS, of selected agricultural commodity was studied. Plan of experiments with factors considered and the levels of factors/variables are presented in Table 3.1.

Table 3.1. Plan of experiment to assess the effect of storage parameters on quality of potato during storage

S.No.	Variables	Levels	Parameters
1	Potato variety (kufri chandramukhi & Kufri bahar)	2	<ul style="list-style-type: none"> • Physiological loss of weight • Sprouting percentage • Colour • Rotting percentage • Total soluble solid • Starch • Reducing sugar
2	Storage condition	2	
Replication		3	
Total treatment		2x2x3=12	

3.4.1 Raw materials

Two cultivars of potato (*Solanum tuberosum* L.) were used: (i) kufri chandrimukhi (ii) kufri bahar. Seed potatoes harvested early in the morning from the

farm of the central potato research institute, Modipuram, Meerut, UP. Potatoes were transported early in the morning from the CPRI, Modipuram. The potatoes were collected, remove unhealthy one and stored in Pusa farm sun fridge. Healthy, uniform sized potato were selected for the present study.

3.4.2 Different Storage conditions

Two different variety of potato crop were stored in different storage condition with varying temperature and relative humidity and its effect on product quality during storage was studied. For this purpose, two different storage conditions were selected as:

- (i) Pusa Farm Sun Fridge (Solar refrigerated evaporative-cooled structure)
- (ii) Ambient room

3.4.2. i. Pusa Farm Sun Fridge (solar refrigerated evaporatively cooled structure)

The PFSF structure is a fully solar-operated cold storage for agricultural produce. The capacity of the PFSF structure is 10 x10 x 10 ft³. It is equipped with rooftop solar panels with a 5-kW capacity (kilowatts). An inverter, a 1.5-ton refrigeration system, a water battery, a water tank with a submersible pump and an evaporative cooling system (through wetted fabric) are also being used for natural cooling purposes. The structure is a hybrid system, in which evaporative cooling as well as forced cooling are used.



Plate 3.3. Pusa Farm Sun Fridge constructed at mela ground, IARI



Plate 3.4. storage of potatoes inside PFSF in crates as well as bags

Inside the structure, there is an indoor unit of refrigeration system, a water battery, and a water tank with a submersible pump. Solar panels convert solar energy into electrical energy, and an on-grid/hybrid inverter converts this direct current (DC) source of electricity into an alternating current (AC). Then this AC power is utilized to run the refrigeration system



Plate 3.5. Presentation of KB and KCM varieties of potato inside PFSF

3.4.2. ii. Ambient Room

Potatoes were also stored at ambient condition inside the room nearby PFSF at IARI.



Plate 3.6. Storage of potatoes inside ambient control room

3.5 Experimental Detail

3.5.1 Experimental Design

The experiment was conducted in Randomized Block Design with two storage conditions. The treatments were replicated thrice.

3.5.2 Selection of datalogger for measurement and recording the temperature and relative humidity

The air temperature in Pusa farm sun fridge was measured by T-type (copper-constantan) thermocouples and logged every 15 minutes in a datalogger (CR10X, Campbell Scientific, Logan, Utah, USA). In addition, a thermocouple was placed in a 1 cm wide, 10 cm long water-soaked cotton sock over which air could pass, to measure wet bulb temperature. The relative humidity (%) was calculated by the empirical relationship between wet and dry bulb temperatures (Vaisala, 2013). Temperature data was downloaded from the datalogger onto a computer with PC200W software (Campbell Scientific). Thermocouples were installed for ambient and inside temperature measurement in the PFSF structure. A Thermocouple is a sensor used for temperature measurement. It consists of a junction of two different metals. An emf is generated at the other two ends and the temperature is detected. Basically, it works on the principle of the seebeck effect. Basically, 3 types of thermocouples are used, viz., J type, E type, K type and T type. In this research, a T type thermocouple was used, consisting of copper and constantan. The temperature range that could be detected was -270 to 400°C. Temperature data is collected from a Campbell Scientific CR10 data

logger which is connected to the thermocouples. It was powered by a 12 V battery. The battery was continuously charged using a solar photovoltaic cell and a charge controller. Data is transferred from the data logger to the computer by data acquisition software PC200W.

3.5. Estimation of change in physicochemical parameters of potato with storage conditions

3.5.1. Physiological loss in weight (PLW)

Most of the fresh horticultural product contains around 65 to 95% of water at the time of harvest. As the harvested crop loses 10% of its fresh weight, it initiates to wilt and rapidly becomes unusable (FAO, 1989). Water is an important component of most fruits and vegetables and it adds up to the total weight. Losses of water lead to reduction in weight. The loss in weight includes both respiration and evaporation losses, which mainly depends on the temperature and relative humidity of the surrounding air.



Plate 3.7. measurement of weight of potato bag by using weighing balance

The PLW was calculated to find the percent weight loss of the test materials. Initial weight and weight of test material on the specified day of storage were measured by weighing balance with least count of 10 gram. Physiological loss in weight was calculated using the following formula

$$\text{Weight Loss(\%)} = \frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} \times 100$$

Cumulative weight loss was determined and expressed as weight loss as percentage of the initial weight.



Plate 3.8. Measurement of weight of potato crate by weighing balance

3.6.2 Sprouting

During storage, sprouting seriously affects potato quality since tubers need a large amount of water and nutrients to break bud dormancy. In general, potatoes remain dormant for a period after harvesting and generally the dormancy period ranges from 5–9 weeks. The length of dormancy in tubers is affected by cultivar, maturity of the tuber, soil, and weather conditions (Burton, 1978). Extreme cold wet weather increases dormancy whereas extreme dry warm weather shortens dormancy length. Under normal conditions, specific treatments are needed to break dormancy. Sprouting is known to break dormancy.

A major component of successfully managing potato quality in storage is effective sprout inhibition. Sprouting causes tuber dehydration and weight losses by increased respiration and transpiration, increases levels of toxic glycoalkaloids, accelerates starch breakdown with concomitant accumulation of undesirable reducing sugars and decreases vitamin content, increases physiological aging, and affects the appearance of the tuber which all affect the quality of the tuber. Sprouted tubers impede air movement through the potato pile. Various factors such as the physiological condition of the tubers, diseases, and storage conditions influence sprout growth during storage. Damaged and diseased tubers sprout earlier than healthy tubers. The tubers having at least one sprout longer than 5 mm was counted as sprouted tuber and sprouting percentage were calculated using the following formula:

$$\text{sprouting (\%)} = \frac{\text{weight of sprouted potato}}{\text{initial weight of sprouted potato}}$$



Plate 3.9. Measurement of weight of sprouted potatoes (KB variety)



Plate 3.10. Presentation of length of sprouting of potatoes



Plate 3.11. Measurement of weight of sprouted potato (KCM variety)

3.6.3 Rotting

During storage rotting seriously affect storage quality and quantity of stored product.

$$\text{Rotting (\%)} = \frac{\text{weight of rotted potato}}{\text{initial weight of potato}} * 100$$



Plate 3.12. measurement of weight of rotting potatoes

3.6.4 Colour Changes

The characteristic colour of vegetables is recognized as the essential quality indicator. Colour affects consumer acceptance of a product. The colour changes were based on the physical appearance of the fruits and vegetables. Surface colour of vegetables was measured by using AMTAST colorimeter colour difference meter 8mm digital precise colour analyser. Where a colour is expressed in CIE lab tristimulus values (L^* , a^* , b^*) values, (L^*) defines lightness, (a^*) denotes the red/green value and (b^*) the yellow/blue value. The colour was measured in three places of each sample and average values were recorded for the study. Before measuring, the colorimeter was standardized with white and black calibration tiles provided with the instrument. For colour determination of each sample, the reflectance spectrum was measured at 3 different points for three replications on the fruit surface and then the mean reflectance spectrum was obtained. These measurements were taken with colour difference meter (model: Mini Scan XE Plus, Hunter Lab, USA) and expressed as L, a, b Hunter colour values (Plate 3.13).

Colour difference values (ΔE) were calculated according to (Checmarev *et al.*, 2017) the following formula:

$$\text{Colour change } (\Delta E) = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}}$$



Plate 3.13. Measurement of L*, a*, b* values by colorimeter

3.6.5 Total soluble solids (TSS)

Change in total soluble solids occurs during storage of potatoes. Carbohydrates are broken down into a simpler unit i.e., the conversion of starch to sugar, giving the produce its characteristic sweet taste. The total soluble solid (TSS) was determined by following the procedures described by Seyoum *et al.*, (2009). The TSS was determined by hand refractometer (Model Misco) having a range of 0 to 32 °Brix and a resolution of 0.2 °Brix (Plate 3.9). The refractometer was standardized against distilled water (0 °Brix TSS). Potato juice was extracted using a pestle and mortar and by placing 1 to 2 drops of clear juice on the prism. Between samples the prism of the refractometer was washed with distilled water and dried before use. The observations were expressed as degree Brix (°B) at 20°C.



Plate 3.14. Sample preparation and measurement of TSS content by Refractometer

3.6.6 Starch content

Principle 80% alcohol was used for sample treatment that causes removal of sugars and then the starch is extracted with perchloric acid. Starch is hydrolysed to glucose in the hot acidic medium and dehydrated to hydroxymethyl furfural and this compound green colour product with anthrone.

Reagent which was used for starch estimation are:

1. Anthrone: dissolve 200 mg anthrone in 100 ml of ice-cold 95% sulphuric acid.
2. 80% ethanol
3. 52% perchloric acid
4. Standard glucose solution: 100 mg glucose in 100 ml distilled water.

Working solution: 10 ml from stock and diluted to 100 ml with distilled water.

Methodology

0.1g of potato sample was taken and wash homogenised by using 80% ethanol. Centrifuge and retain the residue. Wash the residue repeatedly with 80% ethanol till the washing do not give colour with anthrone reagent. Now added 5.0 ml of water and 6.5 ml of 52% perchloric acid into the residue. Placed it for centrifugation for 20 minutes and pool the supernatant and make up to 100 ml. pipette out 0.1 or 0.2 ml of the

supernatant and make up to volume of 1 ml with water. The standards were prepared by taking 0.2, 0.4,0.6,0.8 and 1 ml of working standard and make up volume to 1 ml with water. Now added 4 ml of anthrone reagent to each tube. The tubes were placed in water bath for heating purpose for 8 minutes now took the reading at 630 nm using spectrophotometer. The glucose content in the sample can be estimated by using standard graph. For calculating the starch content multiply the glucose content value by a factor 0.9.



Plate 3.15. Sample preparation and measurement of Starch content by Spectrophotometer

3.6.7 Total sugar

AOAC (1980) method was used to estimated total sugars content of potato tuber. 20-25g of sample was taken and crushed in pestle and mortar and volume was made up to 100 ml using distilled water. 45% lead acetate of 2ml was added and the samples was stored for 10 min. Later 22% potassium oxalate 2ml was added and volume was made up to 250 ml using distilled water and the samples was filtered using Whatman no. 1 filter paper. From the filtrate, 50 ml of aliquot was taken and to this 30% of 5 ml HCl added and was stored overnight for 24hrs. Phenolphthalein indicator 1-2 drops was added and was neutralized using concentrated 40% NaOH solution till color changes to light pink and the volume was made up to 100 ml with distilled water. Later fresh Fehling's solution was prepared by adding Fehling's A (2.5ml) + Fehling's B (2.5ml) + 50 ml of distilled water.

Meanwhile, aliquot was titrated against boiling Fehling's solution, which was standardized using methylene blue indicator. Titration was carried out until the color change to brick red color. After the color change, titrate value was noted and obtained total sugars content (%) was estimated using formula:

$$\text{Total sugar content} = \frac{\text{Fehling factor}(0.038) \times \text{Volume made up} \times 100}{\text{Titre value} \times \text{Weight of sample taken}}$$

3.6.8 Reducing sugar

AOAC (1980) method was used to estimate reducing sugars content of potato varieties. 20-25g of sample was taken and crushed in pestle and mortar and the volume made was up to 100ml using distilled water. 45% lead acetate of 2ml was added and the samples was stored for 10 min. Later 22% potassium acetate 2ml was added and volume was made up to 250ml using distilled water and the samples was filtered using Whatman no. 1 filter paper. From the filtrate 10 ml of aliquot is taken. Later fresh Fehling's solution is prepared by adding Fehling's A (2.5ml) + Fehling's B (2.5ml) + 50 ml of distilled water. Meanwhile, aliquot was titrated against boiling Fehling's solution, which was standardized using methylene blue indicator. Titration was carried out until the color change to brick red color. After the color change, titrate value is noted and total sugars content (%) was estimated using the formula:

$$\text{Reducing sugar content} = \frac{\text{Fehling factor} \times \text{volume made up} \times 100}{\text{titre value} \times \text{weight of sample taken}}$$



Plate 3.16. Sample preparation for measurement of total sugar and Reducing Sugar



Plate 3.17. Measurement of total sugar and reducing sugar content in gas flame

3.7 Cost economics of the Pusa Farm Sun Fridge (SREC storage system)

The cost economics of Pusa storage structure was done to evaluate the feasibility of developed SREC storage Structure in term of cost of storage ($\text{Rs kg}^{-1} \text{ day}^{-1}$)

3.7.1 Assumption

The Pusa Farm Sun Fridge (SREC structure) shall be constructed on farmers' land. Average storage capacity of the unit (75 % of the rated capacity) was 2000 kg. Annual repair and maintenance charges was 5 % of the cost of the structure.

Depreciation was 10 % p.a. Rate of interest was taken as 11% p.a. Total number of days for which the structure is expected to be used in year is 250 days.

3.7.2 Fixed cost

Fixed cost of PFSF includes all the material cost and labour cost.

3.7.3 Annual cost

- Depreciation (per annum)
- Interest on fixed investment
- Repair and maintenance cost
- Wages
- Miscellaneous contingencies

3.7.4 Cost of storage (Rs. kg⁻¹ day⁻¹)

$$\text{Cost of storage of commodities in the structure} = \frac{\text{Annual Cost (in Rs)}}{\text{Capacity (kgs) x No of days (pa)}}$$

This study was undertaken to study solar operated Pusa Farm Sun Fridge for storage of perishable and semi perishable agricultural commodities. Efficacy of Pusa Farm Sun Fridge (PFSF) for storage of perishable agriculture commodities was evaluated by using potato as a representative of root type vegetables. Effect of independent variables and their interactions on the storage parameters for potato was studied. The parameters included for assessment of storability study for potato were weight loss, colour change, sprouting, rotting and biochemical changes such as reducing sugar, total sugar, starch, and TSS. The experimental results were statistically analysed.

We used potato, king of vegetables for evaluating suitability of PFSF to store potato. Potato is a temperate crop grown under sub-tropical conditions in India and is recommended to be stored between 2 to 4 °C for seed purpose and 7 to 10°C at a relative humidity between 90-95 %. To study the changes in physico-chemical properties of potato for two storages having very different temperature profiles: Storages included: 1) Pusa Farm Sun Fridge (PFSF) structure; 2) ambient control room. Effect of structure type and variety on storability of potato were studied. The temperature and relative humidity variation inside PFSF was also studied. The cost economics of the PFSF was also estimated. The results of the study are presented in this chapter.

4.1 Temperature profile of Pusa Farm Sun Fridge in no load condition

The temperature profile in PFSF was studied in unloaded as well as in loaded conditions over the course of experiment. The circadian variation of temperature was recorded at different points in PFSF at no load condition. The outer ambient temperature was also recorded at various points simultaneously. The outer and inner temperature variation profile inside PFSF in no load condition is represented in (Figure 4.1). In no load condition the temperature variation was observed as is the maximum temperature during night was 13.5°C and the minimum temperature during day was 3°C.

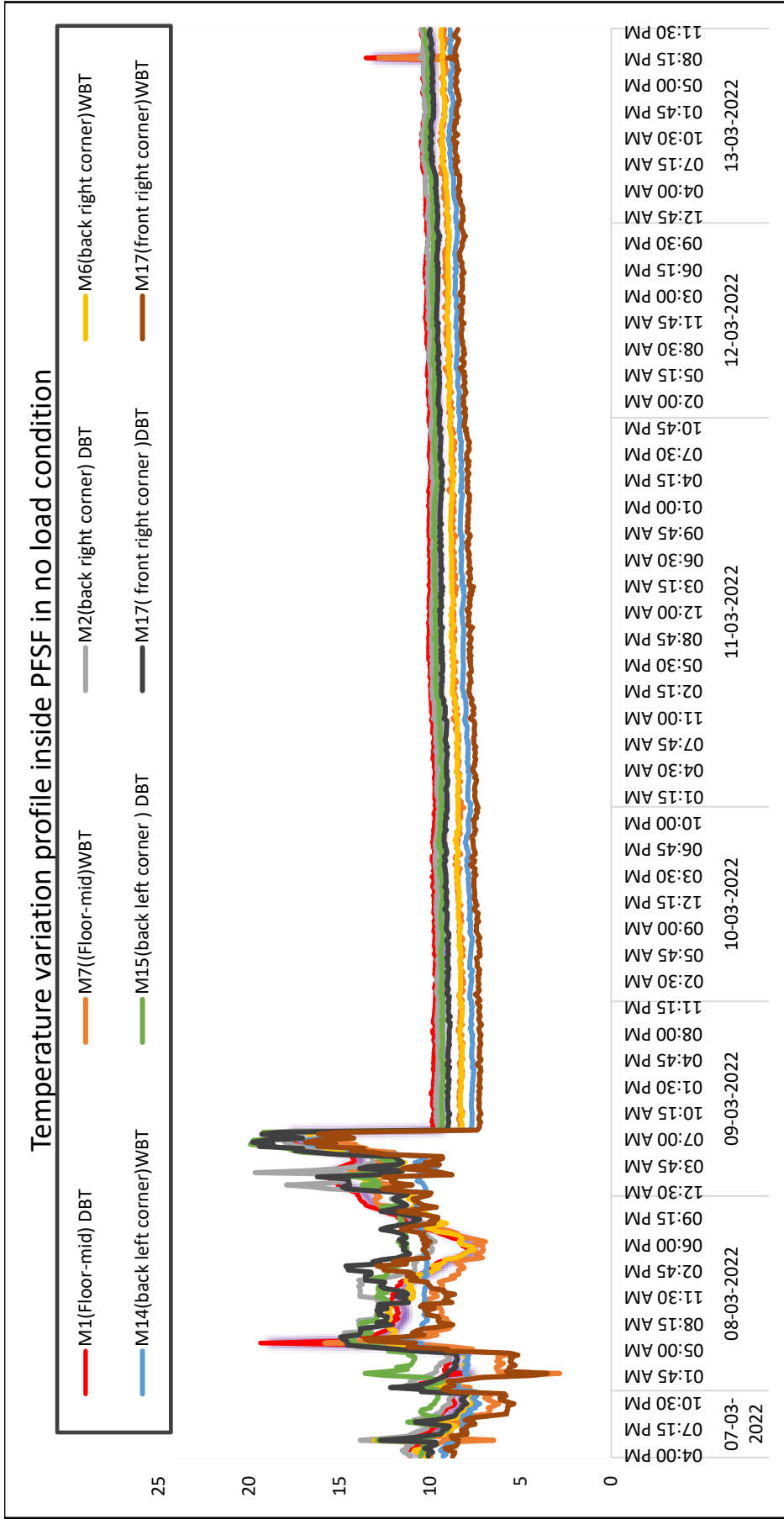
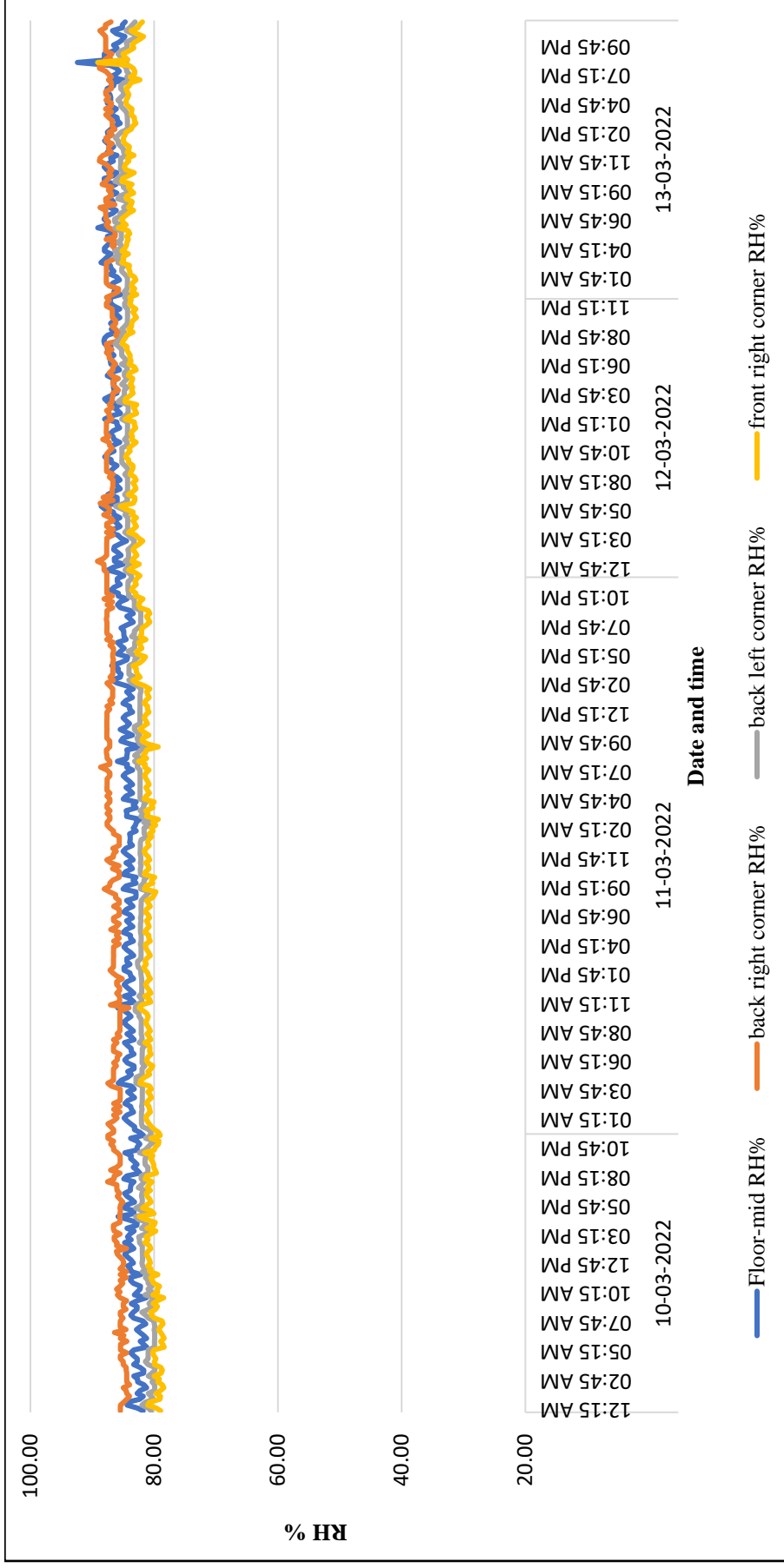


Figure 4.1. Temperature variation profile inside PFSF in no load condition during march month

4.2 RH profile of Pusa Farm Sun Fridge in no load condition

Relative humidity at different points calculated by measuring DBT and WBT at respected points. Due to circadian variation of temperature relative humidity varies accordingly. It was found that relative humidity inside PFSF in no load condition varies in between 80-90%.



4.3. Temperature profile of Pusa Farm Sun Fridge during loading condition

The spatio-temporal variations of temperatures during April-June month inside PFSF was recorded. It could be observed that temperature during 90 days storage period varied between 5 to 18 °C while outer ambient temperature varied from 25 to 49°C.

A relatively lower tuber temperature might have reduced respiration and transpiration of potatoes that ultimately might have reduced storage losses. It was observed that temperature measured at different points were differ in value. Temperature measured at the outer surface of potato also differ in value with respect to position and time. Temperature of different points inside PFSF as well as temperature of potatoes of both varieties stored in bag as well as tray presented in graph.

4.4. Relative Humidity Profile of Pusa farm sun fridge under load condition

Relative humidity trends at the time of potato storage study are represented in (Figure 4.16). This storage study was conducted in April- June 2022. The range of RH in the PFSF was between 60 and 90%.

Variation in the ambient temperature and relative humidity effect the working of PFSF. Evaporative cooling can occur until the relative humidity reaches 100% (saturated air). When the relative humidity is high, the rate of water evaporation is low, and therefore cooling is also low. Here in EC storage condition in month of June the temperature variation was 25 and 36 °C and relative humidity was 88 and 100%. Lower ambient relative humidity leads to better evaporative cooling because the wet-bulb temperature, is a measure of the potential for evaporative cooling. The greater the difference between the wet bulb and dry bulb temperatures, the greater the evaporative cooling effect.

Outer DBT vs inner DBT in PFSF april month in load condition

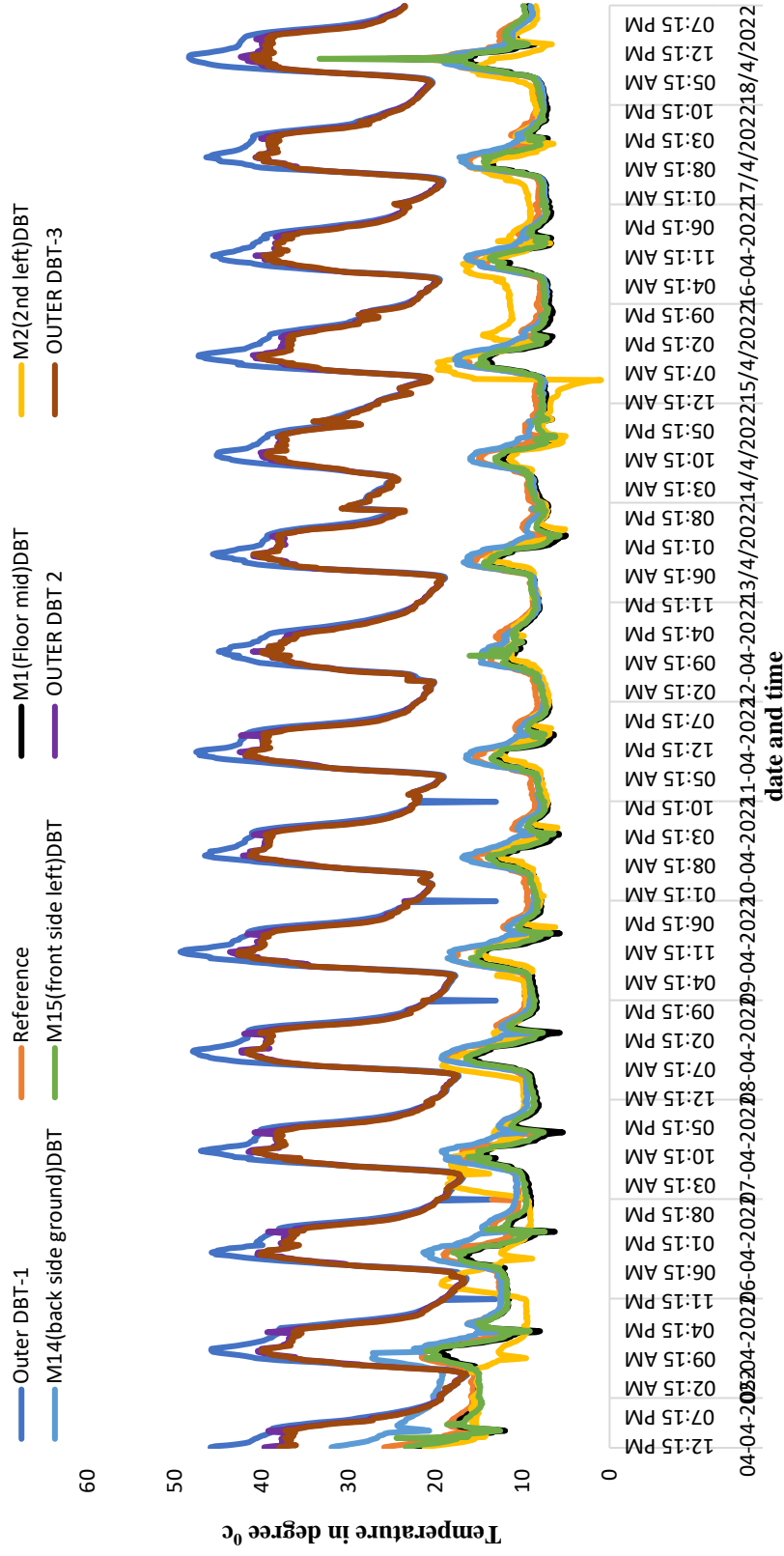


Figure 4.3. Temperature variation profile (outer vs inner DBT) at different points during April month in loading condition

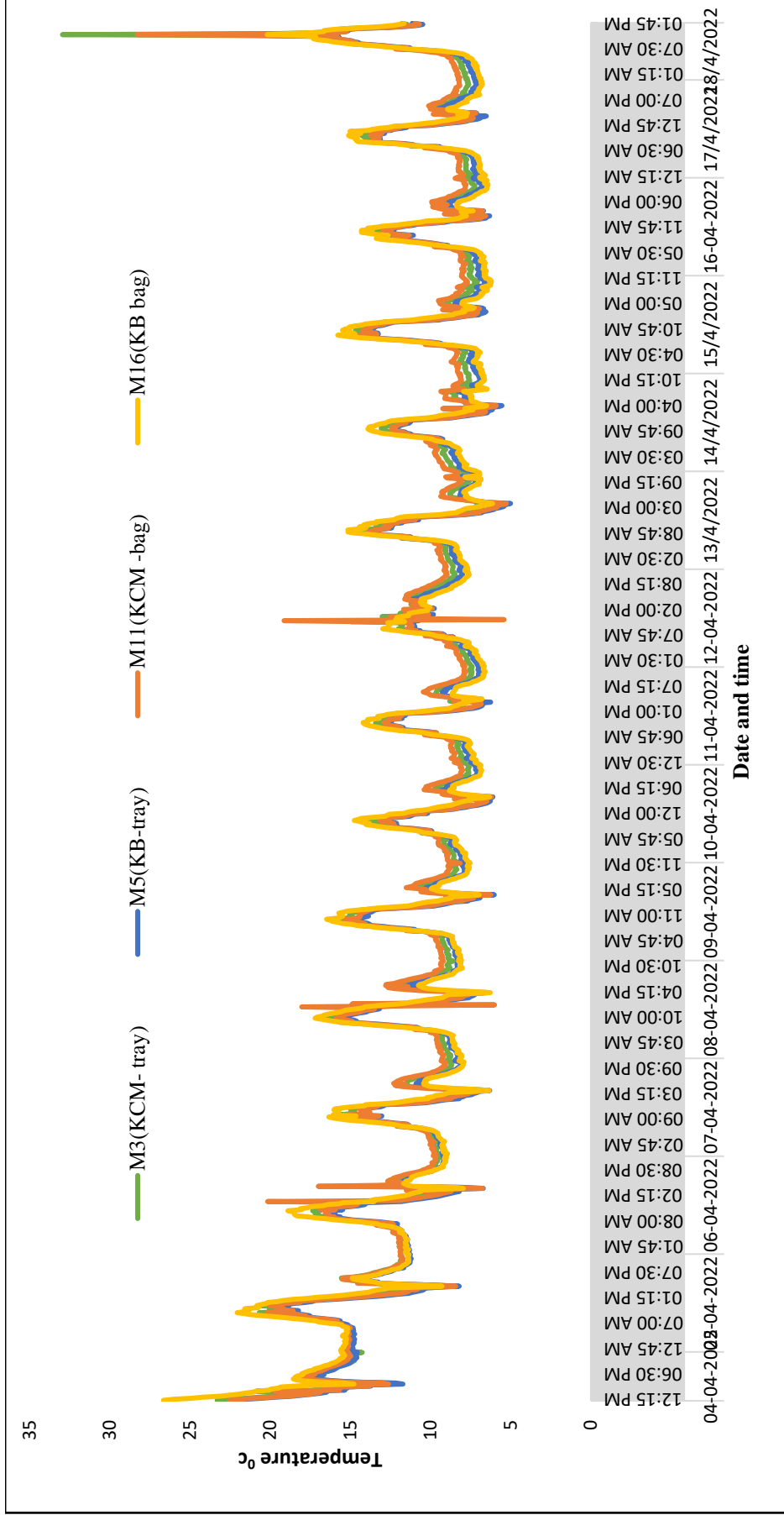


Figure 4.5. Temperature variation profile of stored potatoes of both varieties inside PFSF during April month

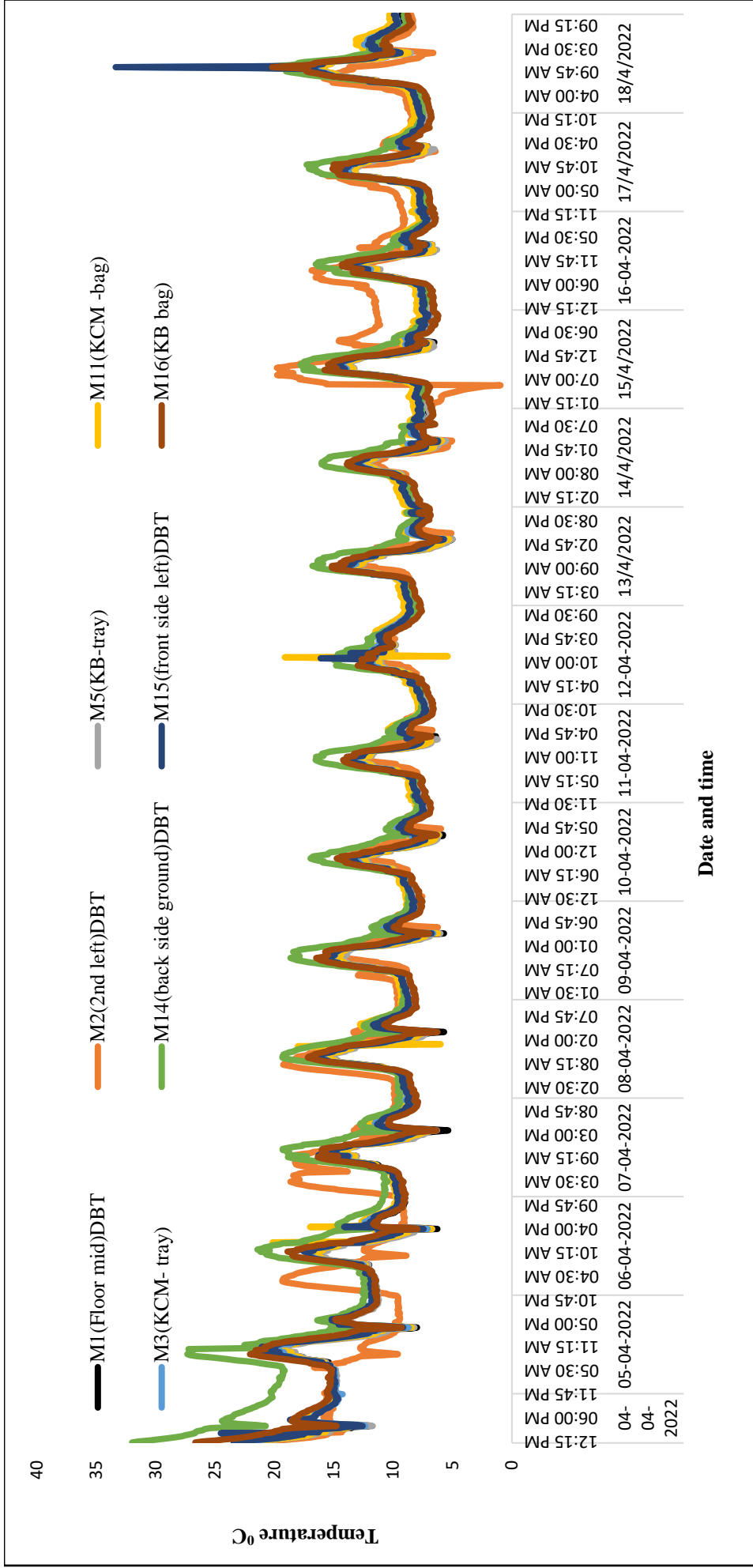


Figure 4.6. Temperature variation profile (inside DBT vs potato) during April month in loading condition

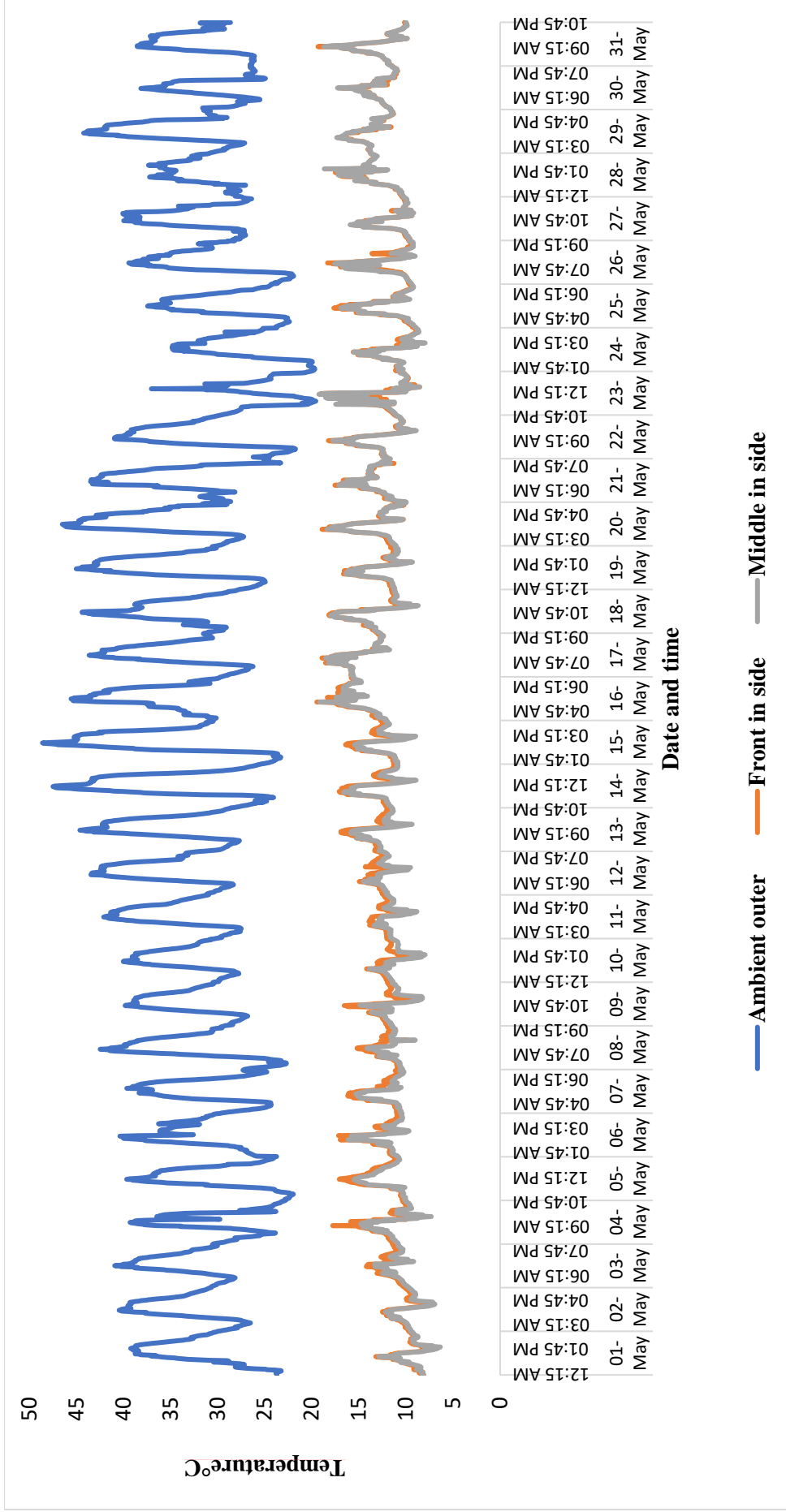


Figure 4.8. Temperature variation profile (ambient outer vs front inside vs middle inside) during may month in full load condition

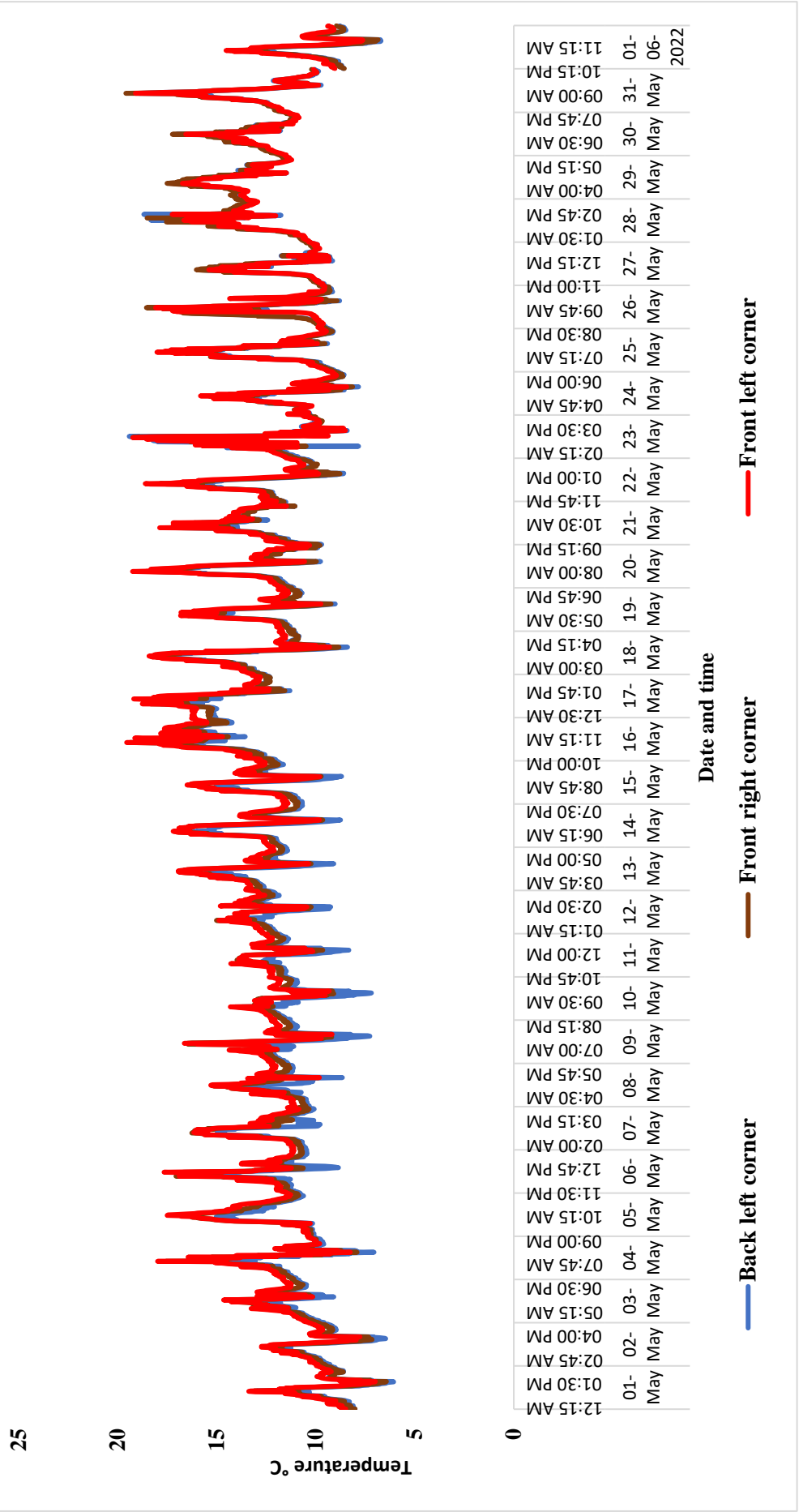


Figure 4.10. Temperature variation profile at different points inside PFSF in full load condition during may month

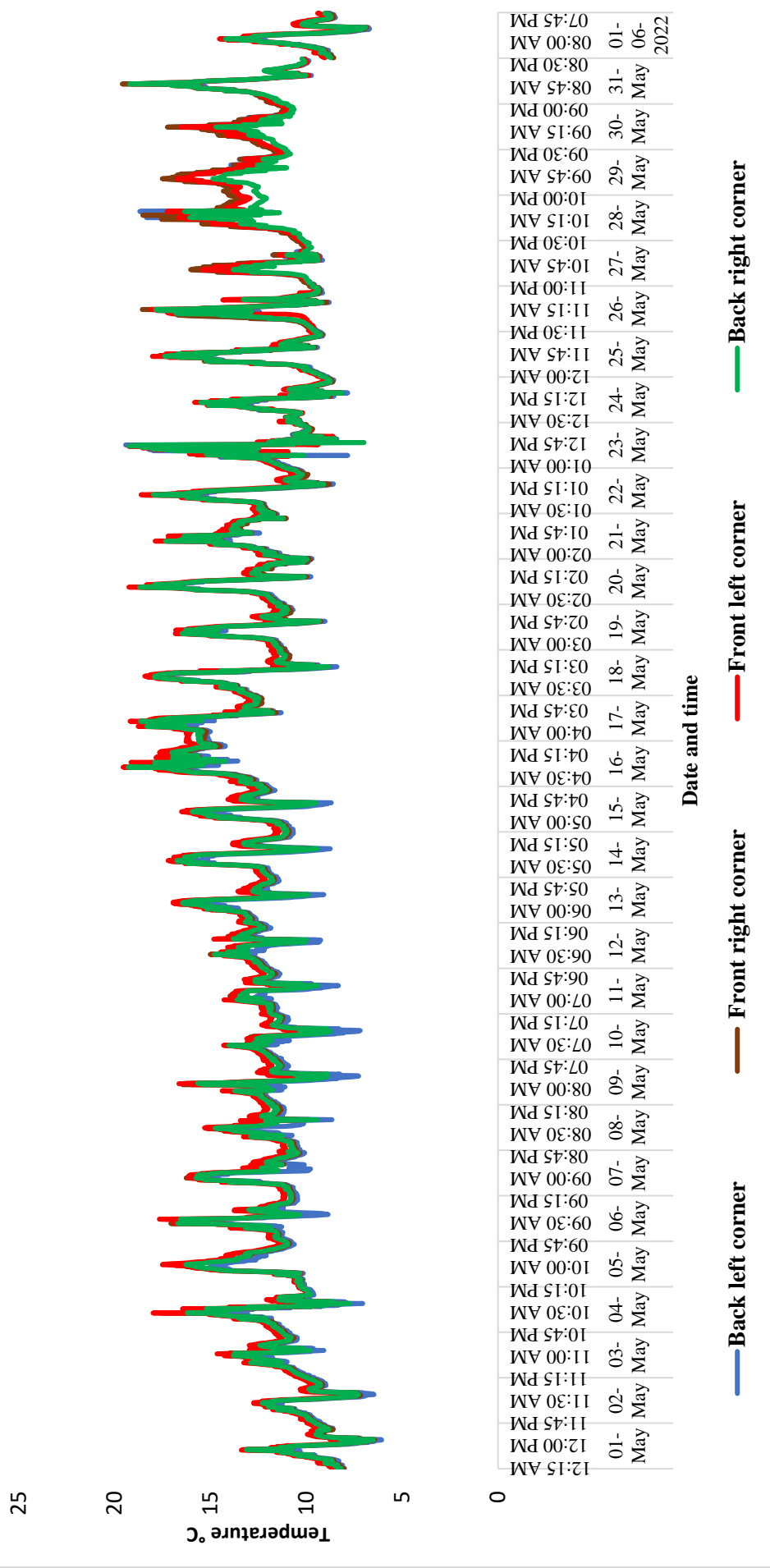
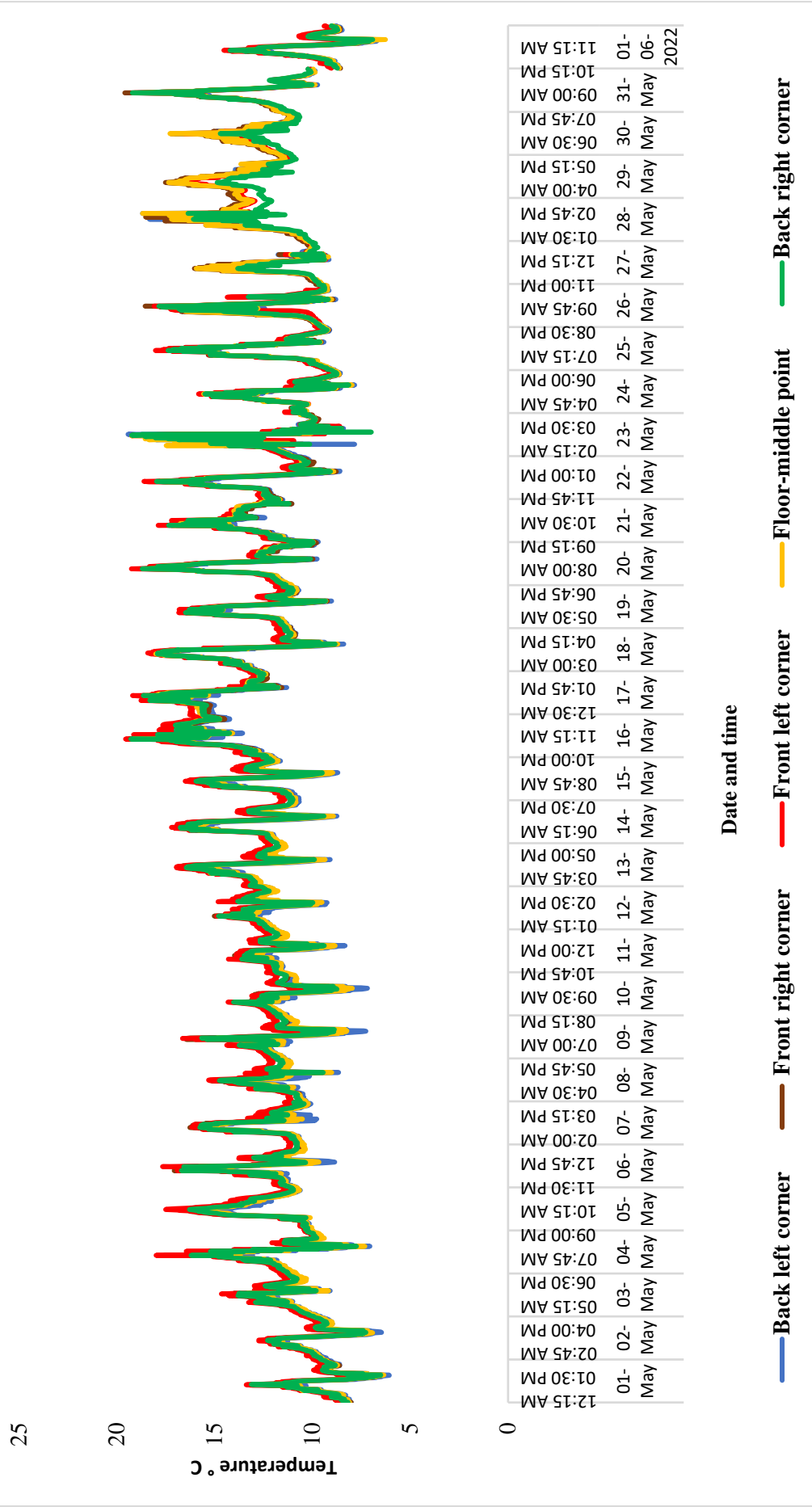


Figure 4.11. Temperature variation profile (front side vs back side) during may month in full load condition



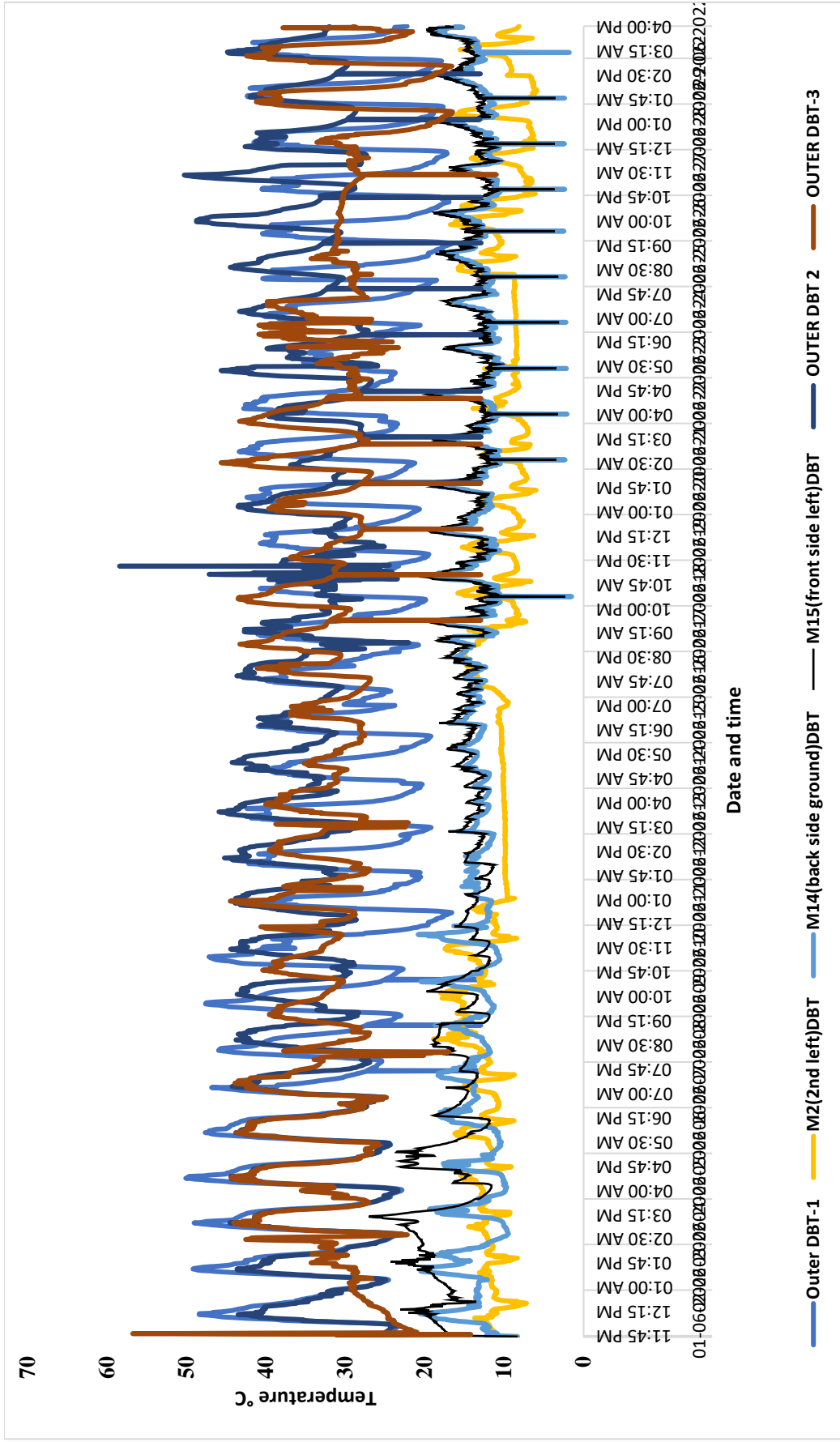


Figure 4.13. Temperature variation profile of outside vs inside PF5F during June month in full load condition

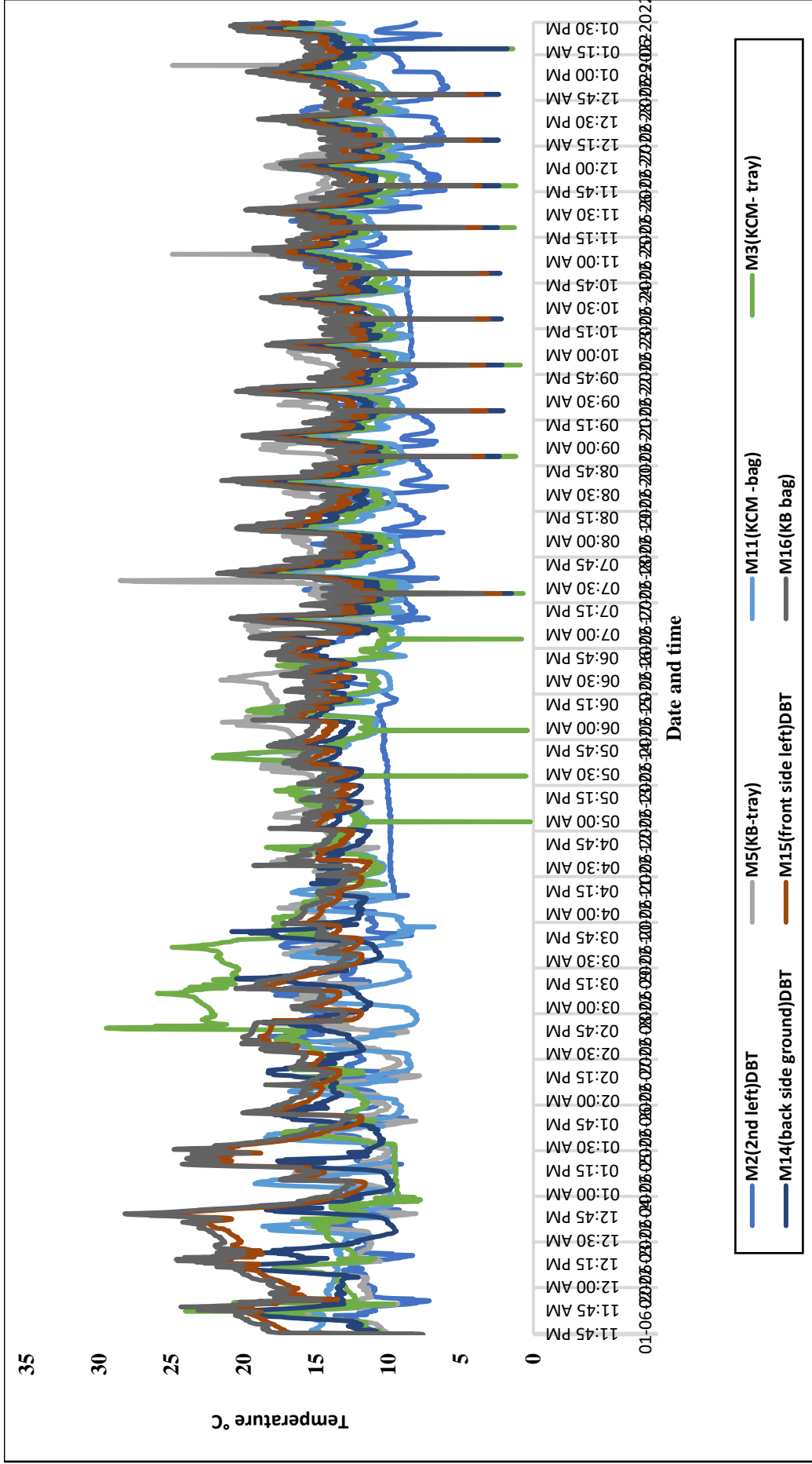


Figure 4.14. Temperature variation profile (inside DBT vs stored potato) in full load condition during June month

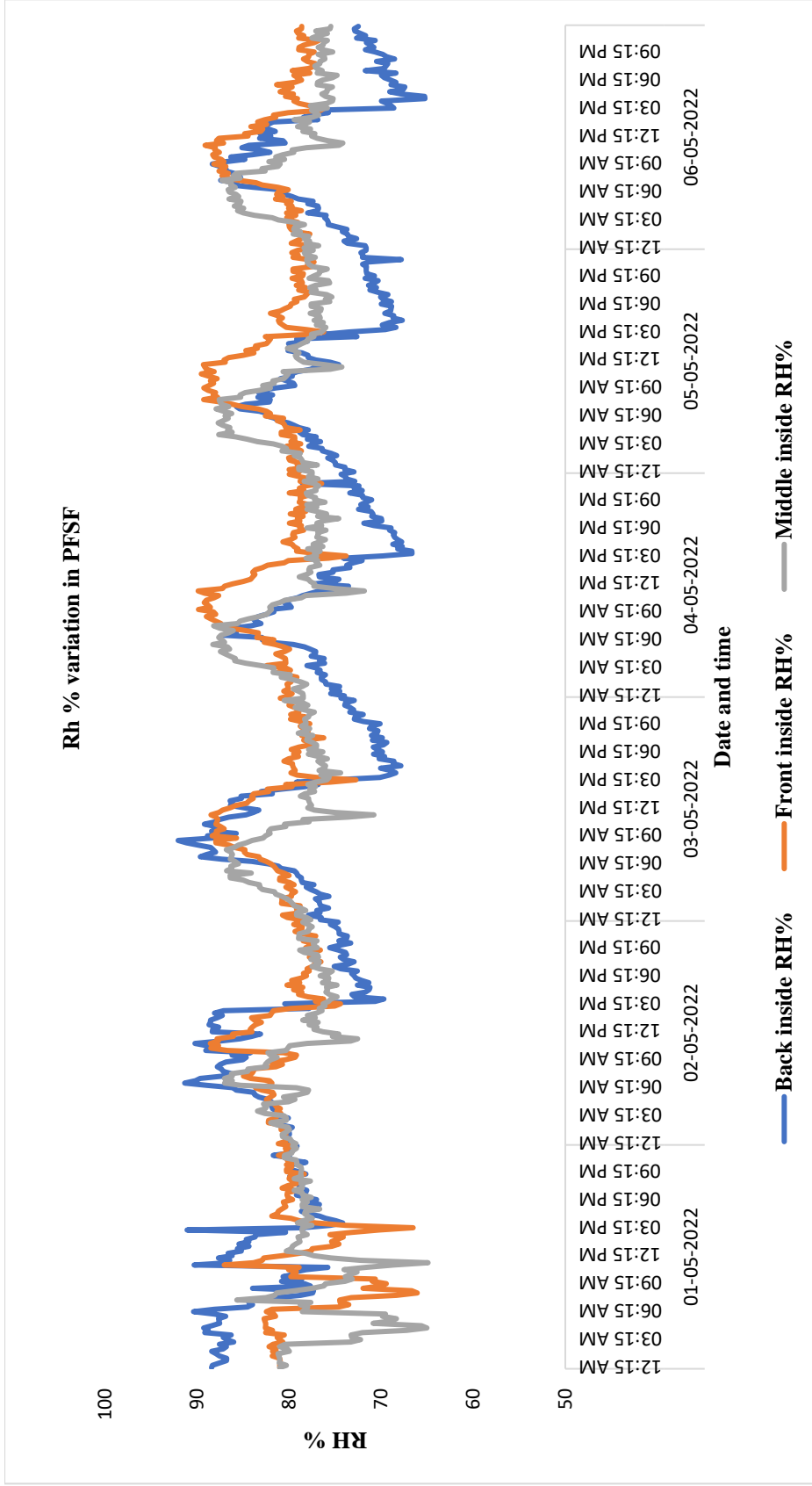


Figure 4.16. Relative humidity variation profile at different points in fully loaded condition inside PFSF during may month

Relative humidity trends at the time of potato storage study are represented in (Figure 4.16). It was observed that relative humidity inside Pusa farm sun fridge during fully loading condition was varies between 80 and 100 %.

4.2 Effects of storage parameters on potato storage

4.2.1 Physiological loss in Weight (PLW)

Potatoes stored in PFSF had lowest overall weight loss as compare to ambient storage condition. During storage, there was a gradual increase in cumulative PLW in both potato varieties. Graph was plotted to understand the variability in weight loss of stored potatoes with time during storage inside both PFSF and ambient storage conditions.

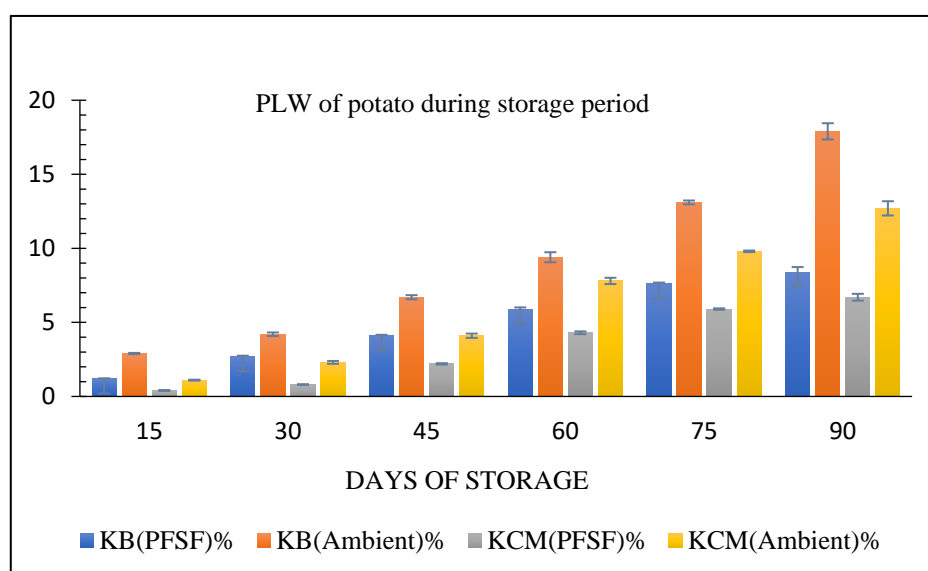


Figure 4.17. Weight loss of potato of both varieties stored in PFSF (Pusa Farm Sun Fridge) and ambient room during storage period.

Table 4.1 ANOVA of factorial two-way RBD model of weight loss of potato

Source	DF	Type III SS Sum of Squares	Mean Square	F Value	Pr > F
Replication	2	0.2631500	0.1315750	0.70	0.5327
Treatment	3	225.0825000	75.0275000	399.63	<.0001
Error	6	1.1264500	0.1877417		
Corrected total	11	226.4721000			

Table 4.2 Test of significance of effect of independent variables on weight loss of potato during storage Stored

t Grouping	Mean	N	Treatment
A	17.9000	3	2 (KB-ambient)
B	12.7000	3	4 (KCM-ambient)
C	8.4000	3	1(KB- PFSF)
D	6.7000	3	3(KCM-PFSF)

After 90 days of storage weight loss in KB and KCM variety were observed to be 17.9 and 12.7% stored in ambient conditions whereas 8.4 & 6.7% in PFSF respectively. If we compare PFSF and ambient storage conditions ambient storage conditions has higher weight loss then PFSF. It's because of lower RH and higher temperature in ambient storage conditions.

Higher relative humidity and low temperature reduces vapour pressure deficit which results in less weight loss for potatoes. High relative humidity is the best solution to avoid respiration and water loss during potato storage. Analysis of variance at 5% level of significance revealed a highly significance model for predicting weight loss. Results showed that storage conditions had significant effect at ($P < 0.05$) on weight loss.

4.2.2 Tuber loss due to rotting

Potato tuber loss due to rotting of potato during storage period occurs due to storage conditions. During storage, there was a gradual increase in cumulative rotting % in both potato varieties stored in ambient condition. Graph was plotted to understand the variability in rotting % of stored potatoes with time during storage inside both PFSF and ambient storage conditions.

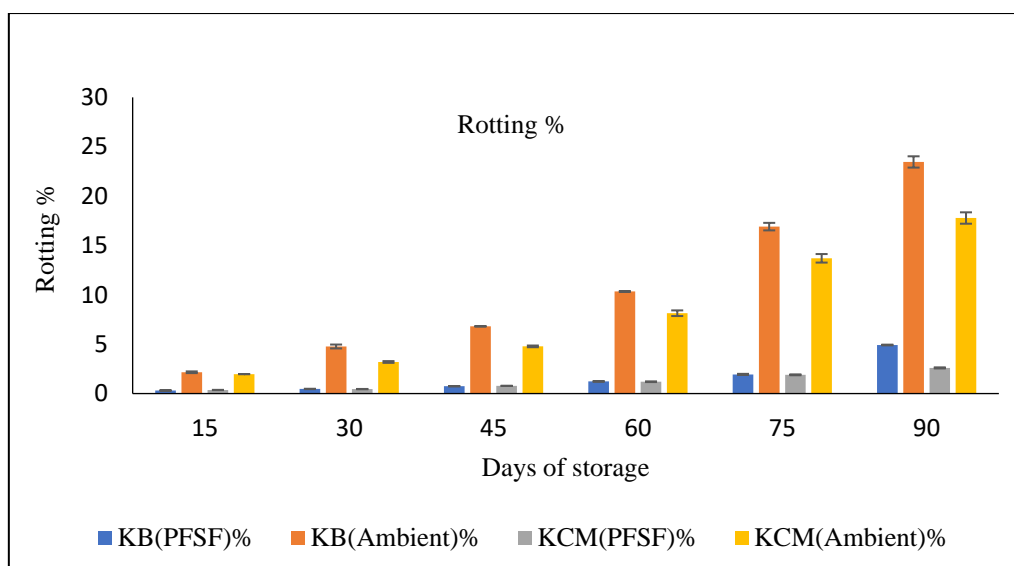


Figure 4.18. Rotting % of potato stored in PFSF and ambient storage condition during storage period

After 90 days of storage rotting % in KB and KCM variety were observed to be 23.46 and 17.78 % stored in ambient conditions whereas 4.92 & 2.6% in PFSF respectively. If we compare PFSF and ambient storage conditions then it was found that ambient storage conditions have higher rotting % than PFSF. It's because of lower RH and higher temperature in ambient storage conditions. Higher relative humidity and low temperature reduces vapour pressure deficit which results in less weight loss for potatoes. High relative humidity is the best solution to avoid respiration and water loss during potato storage. Analysis of variance at 5% level of significance revealed a highly significance model for predicting rotting %. Results showed that storage conditions had significant effect at ($P < 0.05$) on rotting %.

Table 4.3. ANOVA of factorial two-way RBD model of rotting % of potato stored

Source	DF	Type III SS Sum of Squares	Mean Square	F Value	Pr > F
Replication	2	0.4168500	0.2084250	1.38	0.3224
Treatment	3	908.8288667	302.9429556	1998.56	<.0001
Error	6	0.9094833	0.1515806		
Corrected total	11	910.1552000			

Table 4.4. Test of significance of effect of independent variables on rotting % of potato during storage

t Grouping	Mean	N	Treatment
A	23.4567	3	2 (KB- ambient)
B	17.7800	3	4 (KCM-ambient)
C	4.9200	3	1 (KB-PFSF)
D	2.6033	3	3 (KCM-PFSF)

4.2.3. sprouting percentage in varieties

The sprouting behaviour of potato for different storage conditions is different. Graph was plotted to understand the variability in sprouting % in two potato varieties Kufri chandramukhi and Kufri bahar stored in two different storage conditions (Fig.4.19). sprouting in potatoes was directly affected by storage temperature and relative humidity inside both storage conditions.

At the end of 90 days of storage sprouting% in KB and KCM variety were observed to be 72.95% and 45.64 % stored in ambient conditions whereas 32.65% & 23.56% in PFSF respectively.

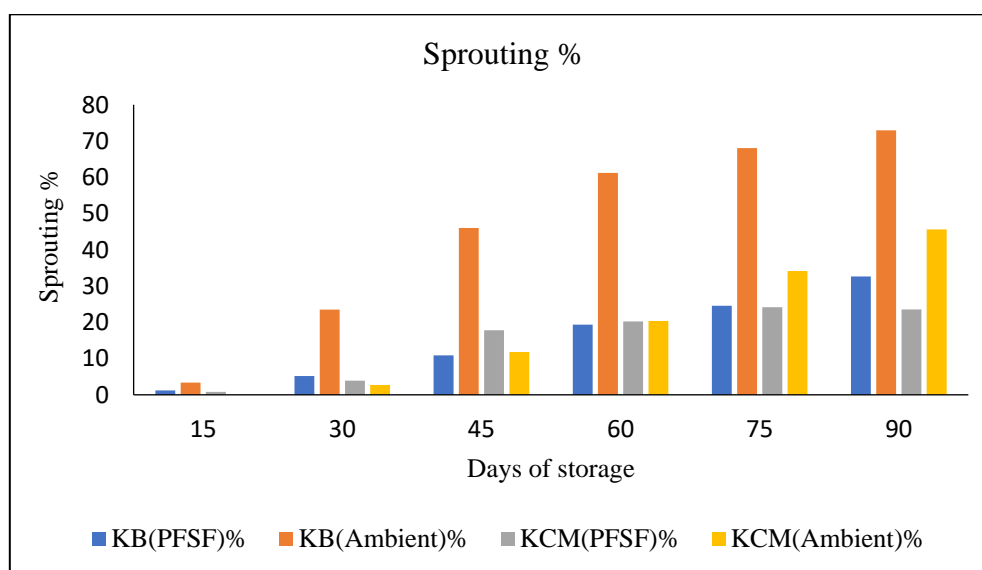


Figure 4.19. Sprouting % of potato stored in PFSF and ambient storage condition during storage period

If we compare PFSF and ambient storage conditions then it was found that ambient storage conditions have higher sprouting% than PFSF. It's because of lower RH and higher temperature in ambient storage conditions. High relative humidity and lower temperature is the best solution to avoid sprouting during potato storage. Analysis of variance at 5% level of significance revealed a highly significance model for predicting rotting %. Results showed that storage conditions had significant effect at ($P < 0.05$) on rotting %.

Table 4.5. ANOVA of factorial two-way RBD model of sprouting % of potato stored

t Grouping	Mean	N	Treatment
A	72.95	3	2 (KB- ambient)
B	32.65	3	1(KB-PFSF)
C	45.64	3	4(KCM-ambient)
D	23.56	3	3 (KCM-PFSF)

Table 4.6 Test of significance of effect of independent variables on sprouting % of potato during storage

Source	DF	Type III SS Sum of Squares	Mean Square	F Value	Pr > F
Replication	2	4.7	2.3	0.71	0.52
Treatment	3	2038	679	204.94	<.0001
Error	6	19.8	19.8		
Corrected total	11	2062	2062		

4.2.4. Colour Changes

Colour of fruits and vegetable is one of the main factors which is related to consumer attraction. It is critical external characteristic for determining quality and post-harvest life in potatoes, which is a major factor in the consumer's purchasing decision. Graphs were plotted to understand the variability in different colour parameters such as lightness, redness, yellowness and total colour change of stored potato in PFSF and ambient storage room (Figures 4.20, 4.21, 4.22 and 4.23).

The brightness of stored potatoes L value decreased with time in both storage conditions. The rate of decreased was small in PFSF as compare to ambient. As we know that L value is a measure of colour in light-dark axis. Here L value decreased with tie showed that loss of brightness of potato when storage temperature and duration increased. Due to this potato became darker in colour. The magnitude of decreased was higher for potato stored in ambient storage condition. At the end of 90 days of storage L value decreased from 71 to 29.1 for KB and 71 to 43.2 for KCM stored in ambient condition. But even after 90 days of storage L value remained higher for potato stored in PFSF. It was found that at the end of 90 days of storage L value decreased from 71 to 50.7 for KB and 71 to 64.8 for KCM stored in PFSF. A similar trend of decrease was observed in b value or yellowness of potato. It was observed that potato stored in ambient storage condition exhibit the most and those stored in PFSF exhibited the least change in b values. The change in a value was small and largely variable as compare to L and b values. The combine change in L- a – b value has been taken as change in colour difference(ΔE). The total colour difference (ΔE) which combines the changes of the three colour attributes (L^* , a^* , and b^*) was observed to increase with time under all storage conditions. It was observed that larger change in ΔE was ambient storage condition or higher storage temperature. It can be clearly seen from the results that during the storage period, the colour of the stored potatoes was significantly affected ($p < 0.05$).

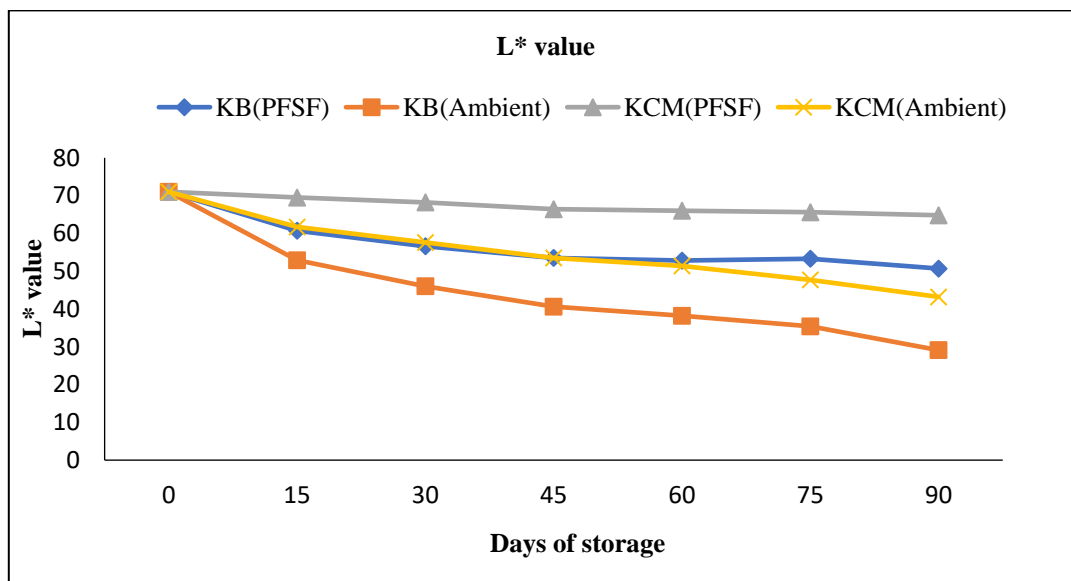


Figure 4.20. Trends of L* value of potatoes stored in, PFSF (solar-refrigerated evaporative-cooled) structure and ambient storage during storage period.

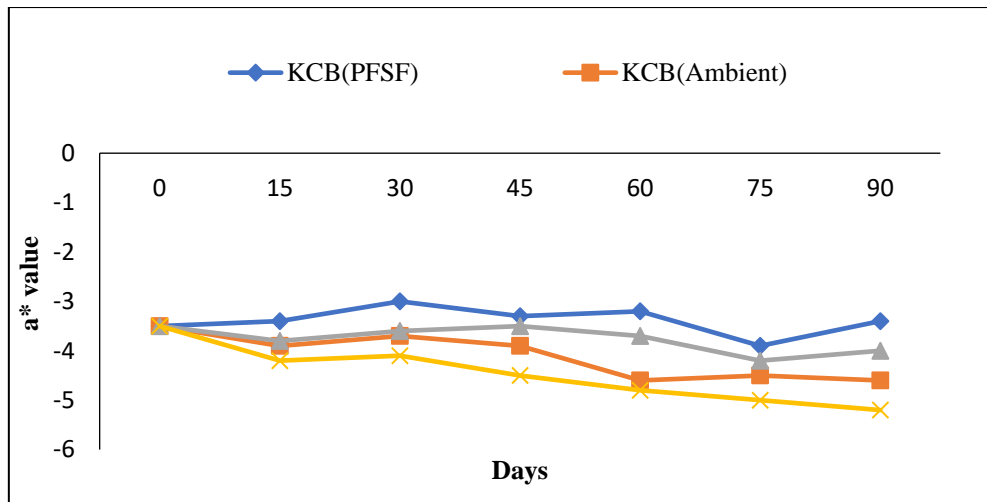


Figure 4.21. Trends of a* value of tomatoes stored in, PFSF (solar-refrigerated evaporative-cooled) structure and ambient storage during storage period

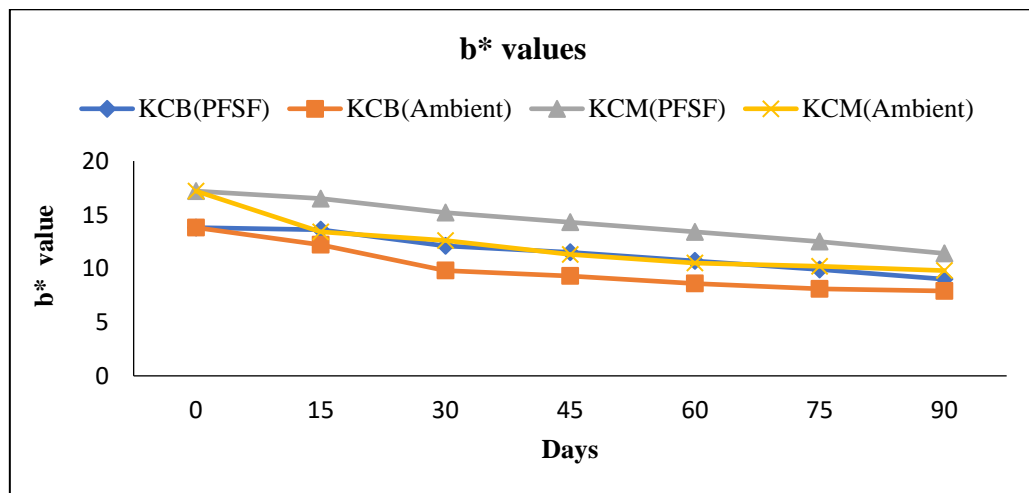


Figure 4.22. Trends of b* values of potatoes stored in, PFSF (solar-refrigerated evaporative-cooled) structure and ambient storage during storage period

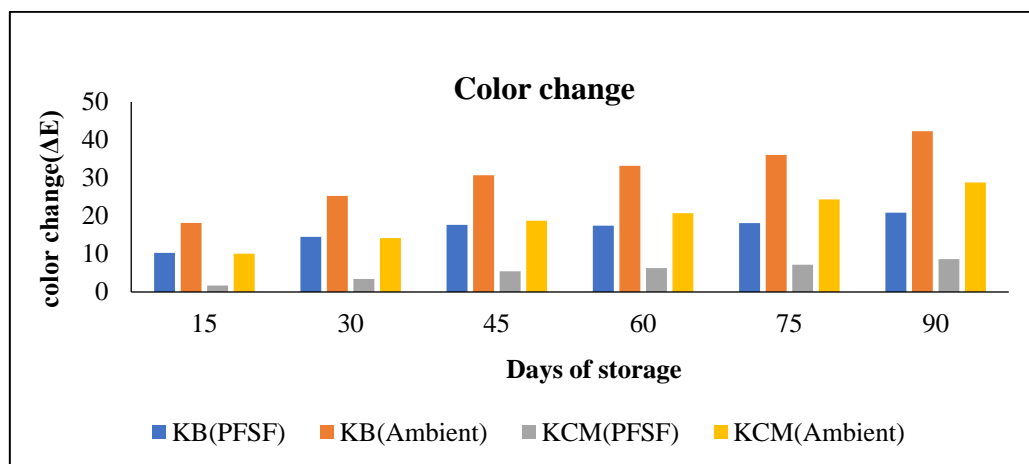


Figure 4.23. Colour change of potatoes stored in, PFSF structure and ambient storage condition during storage period

Analysis of variance at 5% level of significance showed that there was significant difference on the colour change of stored potatoes under different storage conditions. Analysis of variances indicated that storage conditions had significant effect on the colour change of stored potatoes (Table 4.13). It is also observed that effect of interaction of storage condition with storage days had significant effect on the colour change of stored potatoes (Table 4.14).

Table 4.7. ANOVA of factorial two-way RBD model of change in L value of stored potato

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Replication	2	1.930950	0.965475	0.33	0.7345
Treatment	3	1996.392067	665.464022	224.02	<.0001
Error	6	17.823183	2.970531		
Corrected Total	11	2016.146200			

Table 4.8. Test of significance of effect of independent variables on change in L value of potato during storage

t Grouping	Mean	N	Treatment
A	64.800	3	3(KCM-PFSF)
B	50.700	3	1(KB-PFSF)
C	43.203	3	4(KCM-ambient)
D	29.097	3	2(KB-ambient)

Table 4.9. ANOVA of factorial two-way RBD model of change in a value of stored potato

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Replication	2	0.06486667	0.03243333	3.88	0.0830
Treatment	3	5.40602500	1.80200833	215.38	<.0001
Error	6	0.05020000	0.00836667		
Corrected Total	11	5.52109167			

Table 4.10. Test of significance of effect of independent variables on change in a value of potato during storage

t Grouping	Mean	N	Treatment
A	-3.40000	3	1(KB-PFSF)
B	-4.00000	3	3(KCM-PFSF)
C	-4.60333	3	2(KB-ambient)
D	-5.20000	3	4(KCM-ambient)

Table 4.11. ANOVA of factorial two-way RBD model of change in b value of stored potato

Source	DF	Type III SS	Mean Square	F Value	Pr > F
replication	2	0.11765000	0.05882500	1.01	0.4188
Treatment	3	19.59256667	6.53085556	112.12	<.0001
Error	6	0.34948333	0.05824722		
Corrected Total	11	20.05970000			

Table 4.12. Test of significance of effect of independent variables on change in a value of potato during storage

t Grouping	Mean	N	treatment
A	11.4033	3	3(KCM-PFSF)
B	9.8000	3	4(KCM-ambient)
C	9.0000	3	1(KB-PFSF)
D	7.8967	3	2(KB-ambient)

Table 4.13. ANOVA of factorial two-way RBD model of change in E value of stored potato

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Replication	2	1.544117	0.772058	0.19	0.8321
Treatment	3	1798.874967	599.624989	147.17	<.0001
Error	6	24.445683	4.074281		
Corrected Total	11	1824.864767			

Table 4.14. Test of significance of effect of independent variables on change in E value of potato

t Grouping	Mean	N	Treatment
A	42.323	3	2(KB-ambient)
B	28.820	3	4(KCM-ambient)
C	20.857	3	1(KB-PFSF)
D	8.633	3	3(KCM-PFSF)

4.2.5 Change in starch content of potato during storage

Change in temperature and relative humidity has significant effect on starch content of potatoes. It was found that starch decreased more rapidly in potatoes of both varieties stored in PFSF. It was found that starch decreased more rapidly in both varieties of potatoes stored in PFSF. The starch content was decreased from 13.4 to 7.04% in KB and from 13.1 to 6.89% in KCM variety stored in PFSF. Whereas starch content was decreased from 13.36 to 8.23% in KB and from 13.3 to 7.8% in KCM variety stored in ambient storage condition.

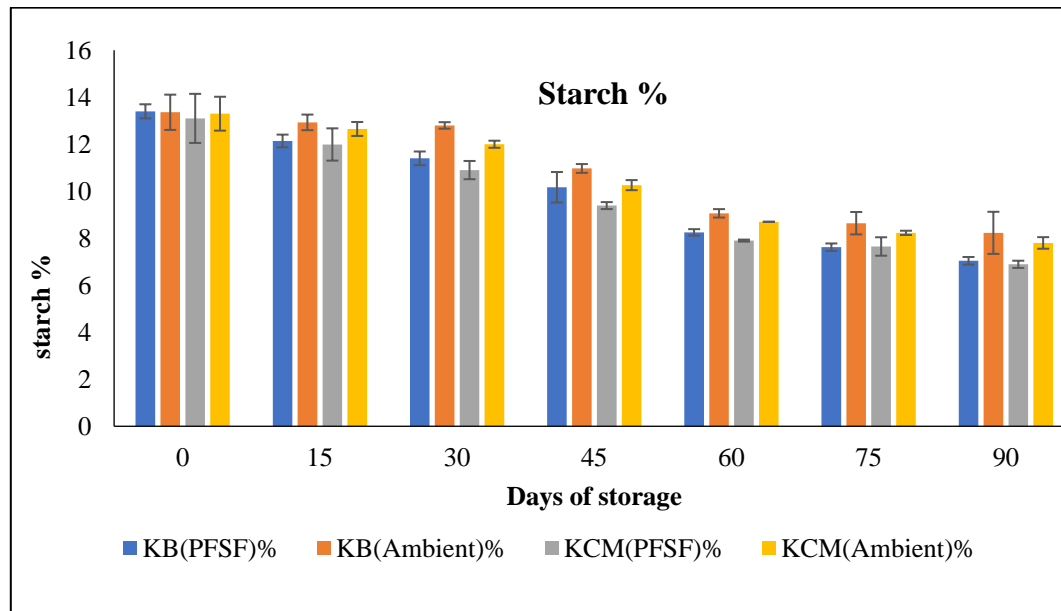


Figure 4.24. change in starch content of potato stored in PFSF and ambient storage condition during storage period

From analysis of variance, it was observed that starch content of potato stored at two storage condition (PFSF and ambient) were significantly different at 5% level of

significance (Table 4.15). The difference in total sugar content between KB and KCM varieties was not significant, but there was a significant difference between PFSF and ambient storage condition for both varieties.

Table 4.15. ANOVA of factorial two-way RBD model of change in starch content of stored potato

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Replication	2	0.53761667	0.26880833	1.26	0.3505
Treatment	3	3.58855833	1.19618611	5.58	0.0359
Error	6	1.28511667	0.21418611		
Corrected Total	11	5.41129167			

Table 4.16. Test of significance of effect of independent variables on change in starch content of potato during storage

t Grouping	Mean	N	Treatment
A	8.2333	3	2(KB-ambient)
A	7.8000	3	4(KCM-ambient)
B	7.0433	3	1(KB-PFSF)
B	6.9000	3	3(KCM-PFSF)

4.2.6 Change in total sugar content of potato during storage

Total sugar content of potato was directly related to storage days and it varies inversely with storage temperature. The variability of total sugar content of potato with storage conditions plotted in graph (Figure 4.25). At zero day of storage total sugar measured and it was found that 94.17 and 79.98 mg/100g for KB & KCM varieties. At the end of 90 days of storage total sugar accumulation were 425.69 & 408.60 mg/100g for KB & KCM varieties stored in PFSF whereas total sugar accumulation was lower in ambient storage. It was found as 259.72 & 226.80 mg/100g for KB & KCM varieties stored in ambient storage condition.

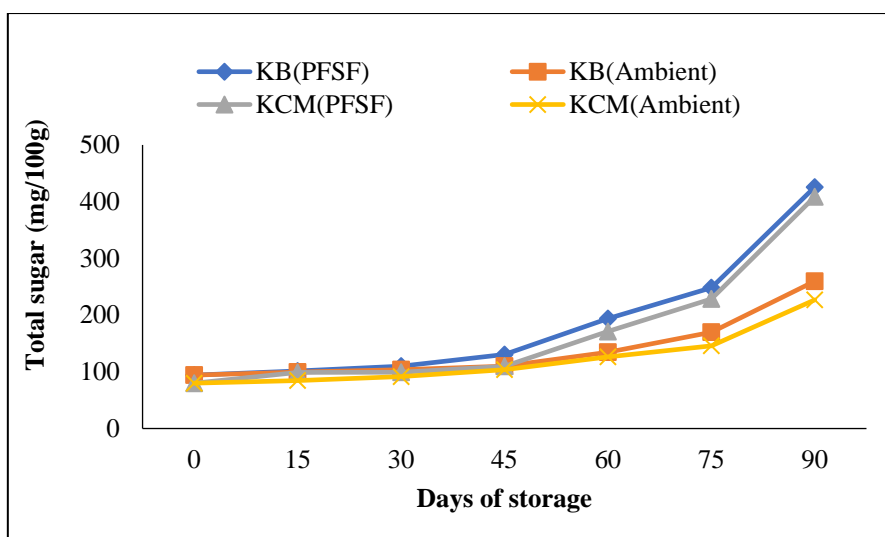


Fig 4.25. Change in total sugar content of potatoes stored in PFSF and ambient storage conditions

From analysis of variance, it was observed that total sugar content of potato stored at two storage condition (PFSF and ambient) were significantly different at 5% level of significance (Table 4.17). The difference in total sugar content between KB and KCM varieties was not significant, but there was a significant difference between PFSF and ambient storage condition with only KB variety.

Table 4.17. ANOVA of factorial two-way RBD model of change in total sugar content of stored potato

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Replication	2	2391.1243	1195.5622	1.57	0.2820
Treatment	3	941283.4638	313761.1546	413.25	<.0001
Error	6	4555.5389	759.2565		
Corrected Total	11	948230.1270			

Table 4.18. Test of significance of effect of independent variables on change in total sugar content of potato during storage

t Grouping	Mean	N	Treatment
A	1059.58	3	3(KCM-PFSF)
B	984.90	3	1(KB-PFSF)
C	474.07	3	4(KCM-ambient)
C	455.42	3	2(KB-ambient)

4.2.7 Change in total soluble solids (TSS) of potato during storage in PFSF and ambient storage condition

Change in total soluble solids occurs during ripening. Carbohydrates are broken down into a simpler unit i.e., the conversion of starch to sugar, giving the produce its characteristics sweet taste on passage of time. The variability in total soluble solid of stored potato of both varieties with change in independent variables both storage structure and days was plotted in graph (Figure 4.14). TSS of potato increases slowly during storage period from the initial value 6.01 (°brix) to 7.4 (°brix) and 6 (°brix) to 7.31 (°brix) for KB & KCM varieties of potato stored in PFSF at the end of storage period of 90 days whereas it was 6.0 (°brix) to 7.18 (°brix) and 6 (°brix) to 6.9 (°brix) for KB & KCM varieties of potato stored in ambient storage condition, respectively (Figure 4.26). The increment in TSS was highest in potatoes stored in PFSF.

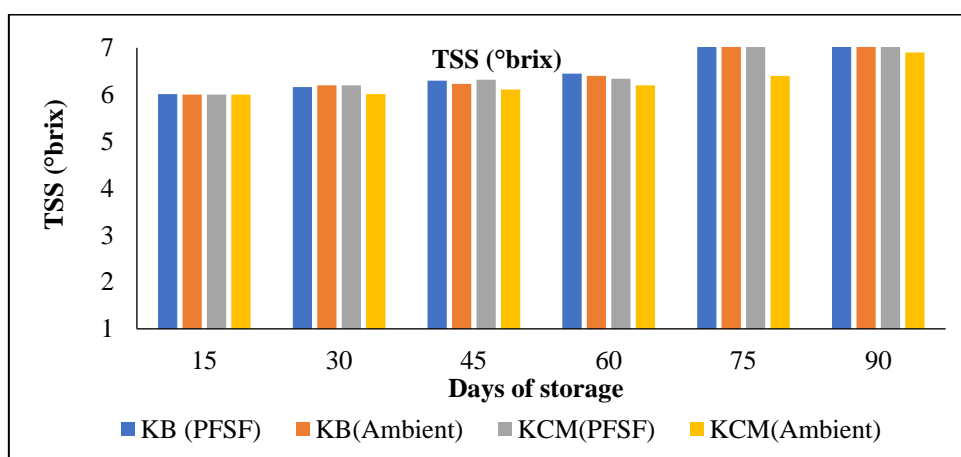


Figure 4.26. TSS of potatoes stored in in, PFSF (solar-refrigerated evaporative-cooled) structure and ambient storage condition during storage period

Analysis of variances showed that storage condition had significant effect on TSS of stored potatoes (Table 4.19). Change in TSS was not substantially different between both varieties of potatoes.

Table 4.19. ANOVA of factorial two-way RBD model of change in total soluble solid content of stored potato

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Replication	2	0.04500000	0.02250000	2.79	0.1389
Treatment	3	32.60666667	10.86888889	1349.24	<.0001
Error	6	0.04833333	0.00805556		
Corrected Total	11	32.70000000			

Table 4.20. Test of significance of effect of independent variables on change in total soluble solid content of potato during storage

t Grouping	Mean	N	Treatment
A	7.4	3	2(KB-ambient)
B	7.18	3	4(KCM-ambient)4
C	7.31	3	1(KB-PFSF)
C	6.9	3	3(KCM-PFSF)

4.2.8 Change in reducing sugar content of stored potatoes

Low temperatures (45° F. or lower) enhance sugar formation. If the storage temperature is maintained below 45° F. for a long time, accumulated sugars in the tuber do not readily reconvert to starch (recondition). High-reducing sugar concentrations result in undesirably darkened potato chips and fries. Some varieties recondition better from low temperatures than others

Reducing sugar content of potato increases directly with time and inversely with storage temperature. At low temperature carbohydrates in potato breaks in reducing sugar. Reducing sugar accumulation was more when potato stored in less than 4°C with passage of time.

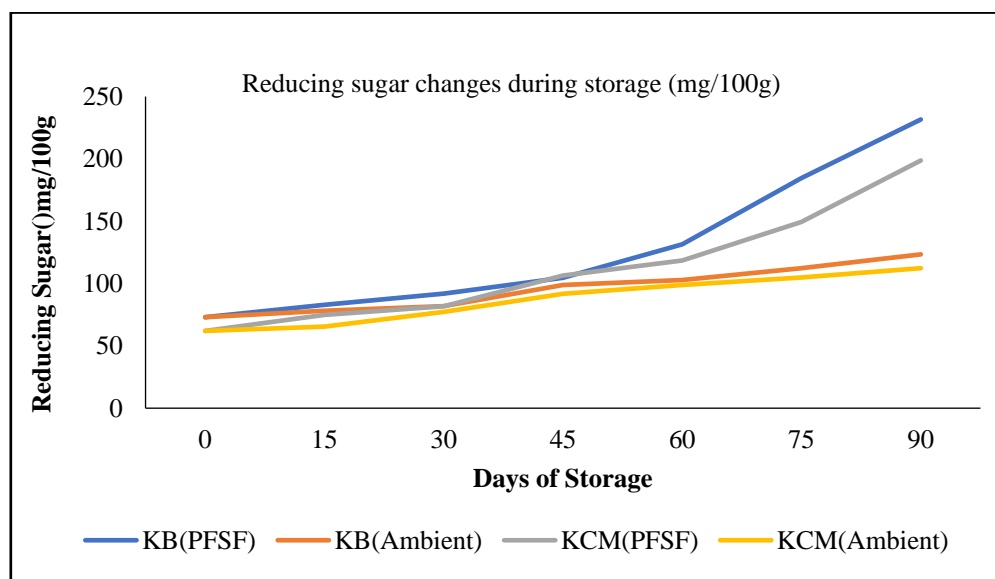


Figure 4.27. change in starch content of potato stored in PFSF and ambient storage condition during storage period

Table 4.21. ANOVA of factorial two-way RBD model of change in Reducing Sugar content of stored potato

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Replication	2	100.3186	50.1593	2.19	0.1936
Treatment	3	435604.3286	145201.4429	6327.94	<.0001
Error	6	137.6765	22.9461		
Corrected Total	11	435842.3237			

Table 4.22. Test of significance of effect of independent variables on change in Reducing Sugar Content of potato during storage

t Grouping	Mean	N	Treatment
A	720.800	3	3(KCM-PFSF)
B	670.000	3	1(KB-PFSF)
C	322.497	3	4(KCM-ambient)
D	309.803	3	2(KB-ambient)

4.3 Analysis of Cost of Storage of potatoes inside Pusa Farm Sun Fridge

The size of the PFSF storage structure is 10 ft x 10 ft x 10 ft and it has a storage capacity of 2 metric tons of fruits and vegetables.

Assumptions

The assumptions for calculations are as under:

- The structure PFSF shall be constructed on farmers' land.
- Average storage capacity of the unit (75 % of the rated capacity): 1500 kg
- Annual repair and maintenance charges: 5 % of the cost of the structure.
- Depreciation: 10 % p.a.
- Rate of interest: 11% p.a.
- Total number of days for which the structure is expected to be used in year: 300

4.3.1 Fixed Capital/Cost

Table 4.23. Item-wise cost of storage structure

S.No.	Item	Cost (in Rs)
1.	Autoclaved aerated concrete block (surface floor)	20000
2.	Structural steel	20000
3.	Metro sheet	20000
4.	Refrigeration System (18000 BTU GREE air conditioner)	80000
5.	Solar panels 14 panels of 350 watt	130000
6.	Inverter (MPP)	60000
7.	Water tank (200 lit)	10000
8.	Water battery (75m pipe)	25000
9.	PVC pipes and fittings	20000
10.	Square pipes and Iron	80000
11.	Thermocole and PU foam	120000
12.	Wiremesh	35000
13.	Cement, sand, stone and bricks	25000
14.	Auxiliary materials	20000
15.	Labor charge	35000
	Total (Rs)	7,00,000.00

Table 4.24. Annual Cost of PFSF under potto storage

S.No.	Item	Cost (in Rs)
a.	Depreciation (per annum)	Rs 70,000.00
b.	Interest on fixed investment (per year)	Rs 77,000.00
c.	Repair and maintenance cost (5% of fixed capital pa)	Rs 35,000.00
d.	Wages (Rs 635 /day for 90 days in a year)	Rs 57150.00
e.	Miscellaneous contingencies (per year)	Rs 5,000.00
	Total annual operating cost	Rs 2,44,150.00

$$\text{Cost of storage of commodities in the structure} = \frac{\text{Annual Cost (in Rs)}}{\text{Capacity (kgs) x No of days (pa)}}$$

Hence, cost of storage of potatoes in Pusa Farm Sun Fridge = Rs 0.41 kg⁻¹ day⁻¹

In order to make comparison with cost of storage in commercial storage structures, rates were collected on phone from few operators and these are as under:

Table 4.25. Cost of storage – existing commercial cold storages in Delhi

S.No.	Cold Storage	Cost of Storage (Rs. kg ⁻¹ day ⁻¹)
1.	Cold Store A	Rs 0.50
2.	Cold Store B	Rs 0.35
3.	Cold Store C	Rs. 0.30
	Average cost	Rs 0.38

The average cost of storing agriculture commodity in cold storage service on rent basis was observed to be approximately Rs.0.38 kg⁻¹ day⁻¹.

The cost of storage of agricultural commodities in PFSF structure obtained is Rs 0.41 kg⁻¹ day⁻¹. The average cost of storing agriculture commodity in cold storage service on rent basis was observed to be approximately Rs.0.38 kg⁻¹ day⁻¹.

Agricultural is the primary source of livelihood for about 58% of India's population. Share of agriculture and allied sectors in GDP surged to 19.9% in 2020-2021, up from 17.8% in 2019-20 (Economic survey, 2021). Food grain production hit a new high of 296.65 million tons in 2019-20. As per third advance estimates for 2020-21, total food grain production in the country is estimated at a record 305.44 million tons (MoA & FW, 2021). India is the second largest producer of vegetables and fruits. Our demand of fruits and vegetable will be 350 MT by 2030 (Vision 2030- Indian Institute of Vegetable Research). However, vegetables and fruits are essential for nutritional safety and storage due to its high perishable nature. 30 to 35% of India's total fruits and vegetables production is lost in a year which reduces the growers share. Vegetables and fruits get shrivel or rot quickly, particularly under hot conditions, if not preserve after harvesting. Small-scale farmers and sellers require cost effective storage solutions that can provide them with a basic storage structure to store their product immediately after harvesting and bring their produce from the farm to the market in an acceptable form, it will help them to get a better price. The grower barely gets 25–35 paise out of the consumer's one rupee. A huge budget of all over the world, land and high percentage of fresh water consumed for growing food, a third of all those the resources are also wasted. This spoilage in our country is because of lack of proper storage facilities. We need more storage facilities, but only constructing storage structure is not enough because each and every food commodity have different characteristics. So, accurate storage condition in storage structure of food is a prerequisite for optimum storage life and minimizing the food losses. Potato (*Solanum tuberosum* L.) is a semi-perishable commodity and the fourth most important food crop after wheat, rice, and corn. It is a major world food crop and most important vegetable crop in terms of production and consumption worldwide. It is popularly known as “vegetable king.” In the fiscal year 2020- 2021, India produced 53.69 million metric tons of potatoes. It alone contributes about 21% of the total vegetable area and 26% of total vegetable production. Freshly harvested potato contains about 80% water and 20% dry matter. Potato contains complete range of nutrients which are necessary for growth

and development of human beings. In India 73% potatoes are consumed in different forms like cooked, roasted, French-fried, chipped etc. Good storage facilities provide tubers in their most edible, processing, and marketable condition and it also ensure the uniform flow of potatoes to market and processing plant throughout the year. Also, it provides a better use of processing capacity, better combination of production and consumption, and better seed quality. To maintain a good quality product, storage conditions must be well controlled (Pringle *et al.*, 2009). During storage, post-harvest losses of potatoes occur due to weight loss, sprouting and rotting which are directly affected by storage conditions. Potato tubers undergoes gradual weight loss and quality loss which include moisture loss, respiratory loss, and changes in sugar during storage (Kuyu *et al.*, 2019). It loses weight in respiration, converting sugar and starches to CO₂ and water and losing moisture due to vapour pressure difference between tubers and surrounding air. This leads to overall quality losses and finally to non-marketable produces (Singh and Kaur, 2016). The issue of these post-harvest losses of potato is of paramount importance in pursuit to combat hunger and improve food security, especially in poor and developing nations. In this scenario, we have to find the best possible storage conditions of potato which improve farmer's income. Good storage prevents storage losses in good product over long periods of storage. Thus, establishment and utilization of cold storage is the need of hour, to reduce wastage of perishable commodities, also ensure economic benefit of both the farmers and consumers. One of the major hindrances towards such initiative is the energy requirement by a cold storage for its powering and operation. This is a serious concern in the underdeveloped and developing countries, where a substantial fraction of rural population does not have access to the grid electricity. In developing nation like India, there are about 94,000 un-electrified villages and 25,000 of them are so remotely located that the extension of power grid there is not economically viable. Therefore, operation of cold storage powered through alternative energy like solar energy can be a perfect solution in this.

Pusa Farm Sun Fridge is a fully solar operated cold storage for agricultural produce. It is a cutting-edge, off-grid, battery-free, cold-storage facility that can be constructed directly on the farm and operates without electricity. The PFSF structure has no maintenance cost. In times of low prices, this can assist farmers to defer selling and boost pricing. It makes use of evaporative cooling and solar refrigeration. The

temperature inside is 3-4° C during the day, and 8-10° C at night. In order to evaluate the suitability of recently developed Pusa farm sun fridge for storage quality preservation in potato. In this context, a study was undertaken for prolonged safe storage of potatoes inside Pusa farm sun fridge.

The aim of this study was to evaluate the suitability of recently developed Pusa Farm Sun Fridge for storage as well as quality preservation of potato cost economics of the PFSF under potato storage. This chapter presented the detailed discussion regarding the results obtained in the study.

5.1 Temperature and Relative humidity profiles of storages

The temperature and RH profile inside PFSF was studied over the period of experiment. The temperatures for EC room were significantly higher than those obtained by Ambuko *et al.*, (2017), for the zero-energy brick cooler (18.0 to 20 °C) and the evaporative charcoal cooler (15.5 to 20.5 °C). This was likely because the ambient temperatures (15.3 - 29 °C) and relative humidity (46% to 97%) in Kenya were lower than those in India.

Elevated humidity in the interior of EC storages is well established (Basediya *et al.*, 2013; Liberty *et al.*, 2014); however, the humidity (>85% RH) of SREC storages has not been documented. Unlike the EC room, the SREC room does not have wetted interior walls and yet achieved similar high humidity. Since the temperatures achieved in the SREC were considerably lower than ambient, they were near or below the dew point for the air (10 to 27 °C), which would have assured an elevated humidity.

5.2 Effect of storage conditions on physico-chemical parameters of stored potatoes

The change in the physicochemical properties of stored potatoes was mainly as a result of varying temperature and relative humidity in both storage structures (PFSF & ambient storage). The temperature in the PFSF was very much lower compared to ambient storage as a result of evaporative cooling in the structures and the value of relative humidity was highest. The physiological loss in weight (PLW %) was least for the PFSF and highest for the ambient storage condition. Weight loss of fresh potatoes is primarily due to transpiration and respiration. The higher temperature and intermediate relative humidity in the ambient storage creates higher difference in the vapor pressure between the stored potatoes and the surrounding which ultimately leads

to more loss of weight in the potato. Similar results were observed by Mangal *et al.* (1999). Potato tubers were examined for sprouting over entire storage period. It was observed that at higher temperature (ambient storage condition) sprouting was more in both varieties of potatoes. Similar results were found by Nourian *et al.* (2002). Rotting loss occurred in potatoes due to physiological processes like respiration and transpiration of potato tubers. It was found that rotting loss was highest in ambient storage condition. The result of present study is in agreement with the results obtained by Jaiswaal *et al.* (2003). Lower temperature favours the degradation of starch into sugar. Starch content of tubers decreased with time at low temperature. More starch degradation occurred in potatoes stored in PFSF than ambient storage condition. Same result was found by Nourian *et al.* (2002). Reducing sugar accumulation is mainly attributed to starch breakdown into glucose and fructose. Study showed that reducing sugar content increased in potatoes with passage of time in PFSF as well as in ambient storage condition. It was also found that reducing sugar accumulation rate was more in PFSF. Nourian *et al.* (2002) reported same results. Identical results were reported by Uppal *et al.* (2001). L-a-b has been considered as change in total colour difference. Larger change in color was observed in ambient stored condition. Same results were found by Nourian *et al.* (2002).

5.3 Cost economics of SREC storage

The fixed cost needed to build PFSF storage in size (10 ft x 10 ft x 10 ft) and having a storage capacity for up to 2 metric tons of fruits and vegetables storage structure included following major items: First step to construct storage room needed cement, sand, stone brick, structure steel, metro sheet, autoclaved aerated concrete block to build surface floor, PVC pipes and fittings, square pipes, iron, thermocole, lightening rod, PU foam, and wire mesh cost around Rs. 3,40,000.00. The refrigeration System used was 18000 BTU GREE air conditioner cost Rs. 80000.00. To run the refrigeration system with photovoltaic array fourteen 330-W panels (CS6U-330P, Canadian Solar Inc., CA, USA) were used it cost around Rs. 130000.00. In order to convert DC power to AC power 5-kW inverter (MPP 5048, MPP Solar Inc., Taiwan) was used it cost around Rs. 60000.00. In order to keep the storage structure cool at night used water battery (75 cm length PVC pipe) and water tank to store and submersible pump which circulate cold water total cost around Rs. 35000.00. Labor Charges

required to construct PFSF structure cost around Rs 35000.00. And Auxiliary material cost Rs. 20000.00.

Thus, the total fixed cost of PFSF structure cost around Rs. 7,00,000.00. Variable cost of PFSF included repair and maintenance cost (5% of fixed capital pa), Wages of labor. As per the annual cost analysis the total annual operating cost of storage structure was Rs 2, 44,150.00.

Cost of storage of commodities in the PFSF obtained Rs 0.41 kg⁻¹ day⁻¹. The average cost of storing agriculture commodity in cold storage service on rent basis was observed to be approximately Rs.0.38 kg⁻¹ day⁻¹. It is slightly lower than the cost of storage of perishables in the newly developed PFSF. Most of the commercial cold storages have been built in India after availing subsidy from the government. However, in places where cold storage facilities are not available or are far off, the additional cost of transportation to the cold storages may be quite high. If the product quality lost then market value loss is much higher than storage cost. PFSF storage structure can recommended for on farm storage of agriculture commodities. If we consider subsidies provided by government to farmers storage cost would reduce further. And if storage structure used for high value products, then cost of storage would very much affordable and improves profitability. Another advantage of PFSF is that it extends the period of on farm storage. Longer storage time means higher market price. The PFSF storage structure can store vegetables, fruits, and flowers for shorter duration for which a small and marginal farmer can store products for shorter period and sell it without deterioration of the product. Farmers will also get appropriate value of the product. It will reduce the distress sale.

The cost of storage in case of PFSF structure is quite competitive and is thus recommended for farmers/retailers in rural and semi-urban and in also urban areas.

SUMMARY AND CONCLUSIONS

Seed India is the world's second-largest producer of horticultural crops, and it is known as the "basket of fruits and vegetables". However huge post-harvest losses of fruits and vegetables are a matter of vital concern for India's agricultural sector, as these perishables are susceptible to damage and have a very short shelf life particularly in hot weather conditions prevailing in most part of the country. Proper storage facility plays a very important role in reducing post-harvest losses of fruits and vegetables by extending the shelf life. The farmers in India faces difficulties in storage as options are very limited. The situation is more alarming for small holder farmers, as they do not have easy access to cold storage. Cold storages with good control of temperature and humidity are energy intensive and cost expensive, involve a large initial capital investment, and require uninterrupted electrical grid supply, which is not readily available in many parts of the country. Thus, farmers need on - farm, solar powered operated evaporative cooled or refrigerated storage structure storage. Pusa Farm sun Fridge is a Solar refrigerated and evaporative cooled (SREC) structure. It is on -farm storage structure with combination of evaporative cooling system and solar refrigeration system to store harvested farm produce on farmer's field. This facility offers smallholder farmers inexpensive access to cold storage even without electrical connection and improves their control over the marketing of their crops. Therefore, efficacy studies of Pusa Farm sun Fridge (solar refrigerated and evaporative cooled structure) for storage of semi perishable commodity potato (*Solanum tuberosum* L.) were performed.

During cold storage, at uniformly maintained low ($\leq 4^{\circ}\text{C}$) temperature throughout inside the structure promotes potato tubers undergo cold-induced sweetening (CIS), also enhance rapid degradation of starch and sucrose hydrolysis leads to the accumulation of reducing sugars (RS) – such as glucose and fructose. During processing (as frying) of these potatoes the RS react with free amino acids in a Maillard reaction to generate dark-pigmented products that are bitter and unsightly to consumers. In addition to this, one of the products of the Maillard reaction is acrylamide – a potential neurotoxin and carcinogenic to human health. In PFSF circadian variation of

temperature (3-4°C during the day, and 8-10°C at night.) happens. Storage of potatoes in Pusa farm sun fridge enhance shelf life of selected potatoes will enable the farmers, processors, and retailers to optimize their storage and selling duration and hence reduce risk of loss due to spoilage of produce also acrylamide production during processing.

In the present study the variation of temperature and relative humidity in no load as well as in full load condition was studied.

Also in the present study, the effect of abiotic parameters on semi-perishable commodity potato was studied. Storability study of two varieties of potatoes namely kufri bahar and kufri chandramukhi was conducted in two storage structures with different temperature and relative humidity. Their effects on physico-chemical parameters such as physiological loss in weight (PLW %), rotting%, Sprouting %, color change, total soluble solid (TSS), starch content, reducing sugar content and total sugar content were studied. The effect of abiotic parameter i.e., temperature and relative humidity of selected storage structures (PFSF and ambient storage condition) on storability parameters was found significantly different at 1% level of significance ($P < 0.05$). The cost economics of storage of semi perishable agricultural commodity potato in PFSF structure was also estimated.

Based on the analysis of results, the following conclusions were drawn from the present study:

- 1) Pusa farm Sun Fridge maintained a constant high relative humidity of more than 85% up to 100% and low temperature as low as 3-12°C with average value of 7°C in no load condition.
- 2) In fully load condition Pusa Farm Sun Fridge maintained low temperature 0-18°C with average 9°C whereas, maximum outside ambient temperature was recorded as 50°C with average value of 32°C during loading condition.
- 3) Pusa farm sun fridge maintained high relative humidity as in between 60 to 90%.
- 4) Physiological loss in weight (PLW%) of potato of both varieties as kufri bahar and kufri chandramukhi showed increasing trend with increase in temperature and decrease in relative humidity for both selected storage conditions as PFSF

and ambient storage condition. PLW was more in ambient storage condition. PLW for KB was below 9.5% in PFSF as compared to ambient storage. Similarly, for KCM, the PLW was lower (6%) in PFSF compared to ambient.

- 5) Rotting % of potato of both varieties showed increasing trend with increase in temperature and decrease in relative humidity. Rotting % was more in potatoes stored in ambient storage condition. Rotting loss was 15.18 to 18.54% lesser in PFSF stored potatoes (KB & KCM variety) than those stored in ambient condition.
- 6) Sprouting % of potato of both varieties showed increasing trend with increase in temperature and decrease in relative humidity. sprouting % was more in potatoes stored in ambient storage condition. Sprouting in PSFS was lesser than ambient by upto 40.3% in KB and 21.08% lower in KCM during 90 days storage.
- 7) Color change of potato showed increasing trend with increasing in temperature and decreasing in relative humidity. Maximum colour change was observed in KB (ambient) minimum change in KCM(PFSF)
- 8) Starch content of potato showed decreasing trend with decrease in temperature and increase in relative humidity. At the end of storage starch content was less in both varieties of potato stored in PFSF. Starch content of potato tubers recorded at the beginning of storage was 13.4% for KB and 13.36% for KCM respectively. It reduced to 7.04% & 6.89% for KB and KCM variety stored in PFSF. Whereas, 8.23% & 7.8% for KB and KCM variety stored in ambient condition
- 9) Reducing sugar content of potato showed increasing trend with decreasing temperature and increase in relative humidity. At the end of storage reducing sugar content was more in both varieties of potato stored in PFSF. The highest reducing sugars concentration in PFSF potatoes was 231.6 mg/100g which is much below the acceptable limit of 500 mg/100g for processing purpose
- 10) Total sugar content of potato showed increasing trend with decrease in temperature and increase in relative humidity for both storage condition. Total sugar accumulation was least (259.72 mg/100g) in KB (ambient) and it was

highest (425.69 mg/100 g) for KB(PFSF). Upto 45 days, 5.6 and 18.7% higher total sugars were recorded for KCM and KB varieties stored in PFSF than ambient stored potatoes. However, beyond 45 days, the difference became higher (35-60%).

- 11) Total soluble solid content of potato showed increasing trend with decrease in temperature and increase in relative humidity for both storage conditions.
- 12) The cost of storage of potatoes in PFSF was $0.41 \text{ kg}^{-1} \text{ day}^{-1}$. The average cost of storing agriculture commodity in cold storage service on rent basis was observed to be approximately $\text{Rs.}0.38 \text{ kg}^{-1} \text{ day}^{-1}$. It is slightly lower than the cost of storage of perishables in the newly developed PFSF structure. Most of the commercial cold storages have been built in India after availing subsidy from the government. The cost of storage in case of PFSF is quite competitive and recommended for farmers/retailers in rural and semi-urban areas.

STUDIES ON PROLONGED SAFE STORAGE OF POTATO (*Solanum tuberosum* L.) IN PUSA FARM SUN FRIDGE

ABSTRACT

The environmental factors like temperature and relative humidity play key role that affect storage of vegetables and fruits. Smallholder farmers in India do not have easy access to cold storage for safe storage of fruits and vegetables. Undesirable storage conditions lead to physical and chemical quality loss in stored potatoes, which affect their consumer acceptability. Some storages have limited control over their internal environment and undergo daily and seasonal fluctuations in both temperature and humidity, which cause variation in the metabolic activity of stored products. Pusa Farm Sun Fridge (evaporative cooled storage structure) with solar refrigeration system is an on farm, cold storage facility for smallholder farmers developed at IARI New Delhi, of size (10 ft x 10 ft x 10 ft) and having a storage capacity for up to 2 metric tons of fruits and vegetables. Pusa farm Sun Fridge maintained a constant high relative humidity of more than 85% up to 100% and low temperature as low as 3-12°C with average value of 7°C in no load condition. In load condition Pusa Farm Sun Fridge maintained low temperature 0-18°C with average 9°C whereas, maximum outside ambient temperature was recorded as 50°C with average value of 32°C during loading condition. Pusa farm sun fridge maintained high relative humidity as in between 60 to 90%. The objective of this study was to evaluate the quality change in stored potatoes and cost economics. The physical properties of potato such as weight loss, tuber loss due to rotting, sprouting percentage, color changes and the chemical properties such as starch content, dry matter, reducing sugar, total soluble solids (TSS) and total sugar were evaluated during the storage period of potato cultivars (Kufri Chandra mukhi, and kufribahar). The results revealed that potatoes became softer and darker by passage of time, and higher temperature resulted in more rapid changes in the different quality parameters. Physiological loss in weight (PLW%) of potato of both varieties as kufri bahar and kufri chandramukhi showed increasing trend with increase in temperature and decrease in relative humidity for both selected storage conditions as PFSF and ambient storage condition. PLW was more in ambient storage condition. Rotting % of potato of both varieties showed increasing trend with increase in temperature and decrease in relative humidity. Rotting % was more in potatoes stored in ambient storage condition.

Sprouting % of potato of both varieties showed increasing trend with increase in temperature and decrease in relative humidity. sprouting % was more in potatoes stored in ambient storage condition. Colour change of potato showed increasing trend with increasing in temperature and decreasing in relative humidity. Starch content of potato showed decreasing trend with decrease in temperature and increase in relative humidity. At the end of storage starch content was less in both varieties of potato stored in PFSS. Reducing sugar content of potato showed increasing trend with decreasing temperature and increase in relative humidity. At the end of storage reducing sugar content was more in both varieties of potato stored in PFSS. Total sugar content of potato showed increasing trend with decrease in temperature and increase in relative humidity for both storage condition. Total soluble solid content of potato showed increasing trend with decrease in temperature and increase in relative humidity for both storage conditions. The cost of storage of potatoes in PFSS was $0.41 \text{ kg}^{-1} \text{ day}^{-1}$. The average cost of storing agriculture commodity in cold storage service on rent basis was observed to be approximately $\text{Rs.}0.38 \text{ kg}^{-1} \text{ day}^{-1}$. It is slightly lower than the cost of storage of perishables in the newly developed PFSS structure. Most of the commercial cold storages have been built in India after availing subsidy from the government. The cost of storage in case of PFSS is quite competitive and recommended for farmers/retailers in rural and semi-urban areas. The effect of abiotic parameter i.e., temperature and relative humidity of selected storage structures (PFSS and ambient storage condition) on storability parameters was found significantly different at 5% level of significance ($P < 0.05$).

पूसा फार्म सन फ्रिज में आलू (सोलेनम ट्यूबरोसम एल.) के लंबे समय तक सुरक्षित भंडारण पर अध्ययन

सारांश

तापमान और सापेक्ष आर्द्रता जैसे पर्यावरणीय कारक महत्वपूर्ण भूमिका निभाते हैं जो सब्जियों और फलों के भंडारण को प्रभावित करते हैं। भारत में छोटे किसानों के पास फलों और सब्जियों के सुरक्षित भंडारण के लिए कोल्ड स्टोरेज तक आसान पहुंच नहीं है। भंडारण की अवांछनीय दशाओं के कारण भण्डारित आलू में भौतिक और रासायनिक गुणवत्ता का नुकसान होता है, जो उनकी उपभोक्ता स्वीकार्यता को प्रभावित करता है। कुछ भंडारणों का अपने आंतरिक वातावरण पर सीमित नियंत्रण होता है और तापमान और आर्द्रता दोनों में दैनिक और मौसमी उतार-चढ़ाव से गुजरते हैं, जो संग्रहीत उत्पादों की चयापचय गतिविधि में भिन्नता का कारण बनते हैं। पूसा फार्म सन फ्रिज (सौर प्रशीतन प्रणाली के साथ एक बाष्पीकरणीय ठंडा भंडारण संरचना) आईएआरआई नई दिल्ली में विकसित छोटे किसानों के लिए एक फार्म, कोल्ड स्टोरेज सुविधा है, आकार (10 फीट x 10 फीट x 10 फीट) और भंडारण क्षमता के लिए 2 मीट्रिक टन तक फल और सब्जियां। पूसा फार्म सन फ्रिज ने 85% से 100% तक लगातार उच्च सापेक्षिक आर्द्रता बनाए रखा और बिना लोड की स्थिति में 7 डिग्री सेल्सियस के औसत मूल्य के साथ न्यूनतम तापमान 3-12 डिग्री सेल्सियस तक बना रहा। लोड की स्थिति में पूसा फार्म सन फ्रिज ने औसत 9 डिग्री सेल्सियस के साथ 0-18 डिग्री सेल्सियस कम तापमान बनाए रखा, जबकि लोडिंग की स्थिति के दौरान अधिकतम बाहरी परिवेश का तापमान 32 डिग्री सेल्सियस के औसत मूल्य के साथ 50 डिग्री सेल्सियस दर्ज किया गया था। पूसा फार्म सन फ्रिज 60 से 90% के बीच उच्च सापेक्ष आर्द्रता बनाए रखता है। इस अध्ययन का उद्देश्य संग्रहीत आलू में गुणवत्ता परिवर्तन और लागत अर्थशास्त्र का मूल्यांकन करना था। आलू के भौतिक गुणों जैसे वजन में कमी, सड़ने के कारण कंद की हानि, अंकुरण प्रतिशत, रंग परिवर्तन और रासायनिक गुण जैसे स्टार्च सामग्री, शुष्क पदार्थ, चीनी को कम करना, कुल घुलनशील ठोस (टीएसएस) और कुल चीनी का भंडारण के दौरान मूल्यांकन किया गया था। आलू की खेती की अवधि (कुफरी चंद्र मुखी, और कुफरीबहार)। परिणामों से पता चला कि समय बीतने के साथ आलू नरम और गहरे रंग के हो गए, और उच्च तापमान के परिणामस्वरूप विभिन्न गुणवत्ता मापदंडों में अधिक तेजी से बदलाव आया। कुफरी बहार और कुफरी चंद्रमुखी दोनों किस्मों के आलू के वजन में शारीरिक कमी (पीएलडब्ल्यू%) ने पीएफएसएफ और परिवेश भंडारण स्थिति के रूप में चयनित भंडारण

स्थितियों दोनों के लिए तापमान में वृद्धि और सापेक्ष आर्द्रता में कमी के साथ बढ़ती प्रवृत्ति दिखाई। पीएलडब्ल्यू परिवेशी भंडारण की स्थिति में अधिक था। दोनों किस्मों के आलू के सड़ने का प्रतिशत तापमान में वृद्धि और सापेक्षिक आर्द्रता में कमी के साथ बढ़ती प्रवृत्ति को दर्शाता है। परिवेशी भंडारण की स्थिति में संग्रहीत आलू में सड़न प्रतिशत अधिक था। दोनों किस्मों के आलू के अंकुरण% ने तापमान में वृद्धि और सापेक्ष आर्द्रता में कमी के साथ बढ़ती प्रवृत्ति दिखाई। एंबियंट स्टोरेज कंडीशन में रखे आलू में स्प्राउटिंग % अधिक था। तापमान में वृद्धि और सापेक्षिक आर्द्रता में कमी के साथ आलू के रंग परिवर्तन में वृद्धि की प्रवृत्ति दिखाई दी। आलू में स्टार्च की मात्रा तापमान में कमी और सापेक्षिक आर्द्रता में वृद्धि के साथ घटती प्रवृत्ति को दर्शाती है। भंडारण के अंत में पीएफएसएफ में भंडारित आलू की दोनों किस्मों में स्टार्च की मात्रा कम थी। आलू में चीनी की मात्रा कम होने से तापमान में कमी और सापेक्षिक आर्द्रता में वृद्धि के साथ बढ़ती प्रवृत्ति दिखाई दी। भंडारण के अंत में पीएफएसएफ में संग्रहीत आलू की दोनों किस्मों में चीनी की मात्रा कम थी। आलू की कुल चीनी सामग्री ने तापमान में कमी और भंडारण की स्थिति दोनों के लिए सापेक्ष आर्द्रता में वृद्धि के साथ बढ़ती प्रवृत्ति दिखाई। आलू की कुल घुलनशील ठोस सामग्री ने तापमान में कमी और दोनों भंडारण स्थितियों के लिए सापेक्ष आर्द्रता में वृद्धि के साथ बढ़ती प्रवृत्ति दिखाई। पीएफएसएफ में आलू के भंडारण की लागत रु 0.40 प्रति किलो प्रति दिन थी। कृषि जिंसों को कोल्ड स्टोरेज सेवा में किराये के आधार पर रखने की औसत लागत लगभग रु. 0.38 प्रति किलो प्रति दिन देखी गई। यह नव विकसित पीएफएसएफ संरचना में खराब होने वाली वस्तुओं के भंडारण की लागत से थोड़ा कम है। भारत में अधिकांश वाणिज्यिक कोल्ड स्टोरेज सरकार से सब्सिडी प्राप्त करने के बाद बनाए गए हैं। पीएफएसएफ के मामले में भंडारण की लागत काफी प्रतिस्पर्धी है और ग्रामीण और अर्ध-शहरी क्षेत्रों में किसानों/खुदरा विक्रेताओं के लिए अनुशंसित है। अजैविक पैरामीटर अर्थात्, चयनित भंडारण संरचनाओं (पीएफएसएफ और परिवेश भंडारण स्थिति) के तापमान और सापेक्ष आर्द्रता का प्रभाव भंडारण क्षमता मापदंडों पर 5% महत्व के स्तर (पी <0.05) पर काफी भिन्न पाया गया।

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APPENDIX-I

Table 1. Physiological weight loss of KB & KCM varieties of potatoes stored in PFSF & ambient storage condition

Potato varieties with storage condition (PLW%)	Storage Period in days						
	D0	D15	D30	D45	D60	D75	D90
KB(PFSF)%	0	1.2	2.7	4.1	5.9	7.6	8.4
KB(Ambient)%	0	2.9	4.2	6.7	9.4	13.1	17.9
KCM(PFSF)%	0	0.4	0.8	2.2	4.3	5.9	6.7
KCM(Ambient)%	0	1.1	2.3	4.1	7.8	9.8	12.7

Table 2. Sprouting % of KB & KCM varieties of potatoes stored in PFSF & ambient storage condition

Potato varieties with storage condition (Sprouting%)	Storage Period in days					
	D0	D15	D30	D45	D60	D75
KB(PFSF)%	0	1.2	5.2	10.88	19.36	24.58
KB(Ambient)%	0	3.38	23.49	46	61.18	68.04
KCM(PFSF)%	0	0.8	3.9	17.8	20.23	24.15
KCM(Ambient)%	0	0	2.7	11.8	20.35	34.15

Table 3. Rotting % of KB & KCM varieties of potatoes stored in PFSF & ambient storage condition

Potato varieties with storage condition (Rotting%)	Storage Period in days					
	D0	D15	D30	D45	D60	D75
KB(PFSF)%	0	0.313	0.468	0.743	1.23	1.94
KB(Ambient)%	0	2.16	4.77	6.81	10.34	16.91
KCM(PFSF)%	0	0.363	0.453	0.782	1.2	1.9
KCM(Ambient)%	0	1.97	3.2	4.78	8.14	13.7

Table 4. Changes in L*, a* and b* values of potatoes stored in PFSF and ambient storage condition during storage period

Potato varieties with storage condition (L value)	Storage Period in days					
	D0	D15	D30	D45	D60	D75
KB(PFSF)%	71	60.7	56.6	53.5	52.8	53.3
KB(Ambient)%	71	52.9	46	40.6	38.2	35.4
KCM(PFSF)%	71	69.5	68.2	66.4	66	65.6
KCM(Ambient)%	71	61.7	57.6	53.5	51.4	47.7

Table 5. Changes in L*, a* and b* values of potatoes stored in PFSF and ambient storage condition during storage period

Potato varieties with storage condition (a value)	Storage Period in days					
	D0	D15	D30	D45	D60	D75
KB(PFSF)%	-3.5	-3.4	-3	-3.3	-3.2	-3.9
KB(Ambient)%	-3.5	-3.9	-3.7	-3.9	-4.6	-4.5
KCM(PFSF)%	-3.5	-3.8	-3.6	-3.5	-3.7	-4.2
KCM(Ambient)%	-3.5	-4.2	-4.1	-4.5	-4.8	-5

Table 6. Changes in L*, a* and b* values of potatoes stored in PFSF and ambient storage condition during storage period

Potato varieties with storage condition (b value)	Storage Period in days					
	D0	D15	D30	D45	D60	D75
KB(PFSF)%	13.8	13.6	12.1	11.5	10.7	9.9
KB(Ambient)%	13.8	12.2	9.8	9.3	8.6	8.1
KCM(PFSF)%	17.2	16.5	15.2	14.3	13.4	12.5
KCM(Ambient)%	17.2	13.4	12.6	11.3	10.5	10.2

Table 7. Color change of potatoes stored in PFSF and ambient storage during storage period

Potato varieties with storage condition (E value)	Storage Period in days					
	D0	D15	D30	D45	D60	D75
KB(PFSF)%	10.3	14.51	17.65	17.47	18.12	20.85
KB(Ambient)%	18.15	25.31	30.73	33.22	36.06	42.32
KCM(PFSF)%	1.68	3.44	5.43	6.28	7.19	8.63
KCM(Ambient)%	10.07	14.18	18.76	20.75	24.37	28.82

Table 8. Change in starch content of potato stored in PFSF & ambient storage conditions

Potato varieties with storage condition (Starch content)	Storage Period in days					
	D0	D15	D30	D45	D60	D75
KB(PFSF)%	13.4	12.14	11.4	10.17	8.25	7.62
KB(Ambient)%	13.36	12.93	12.8	10.97	9.06	8.64
KCM(PFSF)%	13.1	11.99	10.9	9.39	7.9	7.65
KCM(Ambient)%	13.3	12.65	12	10.26	8.7	8.23

Table 9. Change in reducing sugar content of potatoes stored in PFSF and ambient storage during storage period

Potato varieties with storage condition (Reducing sugar content)	Storage Period in days					
	D0	D15	D30	D45	D60	D75
KB(PFSF)%	73	82.87	91.9	104.58	131.5	184.6
KB(Ambient)%	73	78.2	81.9	98.8	102.8	112.3
KCM(PFSF)%	62	74.78	81.69	106.34	118.5	149.4
KCM(Ambient)%	62	65.4	77.3	91.7	98.8	104.8

Table 10. Change in total sugar content of potato stored in PFSF & ambient storage conditions

Potato varieties with storage condition (Total sugar content)	Storage Period in days					
	D0	D15	D30	D45	D60	D75
KB(PFSF)%	94.17	101.40	110.05	130.50	193.89	248.33
KB(Ambient)%	94.17	99.60	103.85	109.99	134.57	169.85
KCM(PFSF)%	79.98	98.90	99.31	109.71	171.16	228.60
KCM(Ambient)%	79.98	84.60	91.54	103.81	126.40	145.80

Table 11. Change in total sugar content of potato stored in PFSF & ambient storage conditions

Potato varieties with storage condition (TSS)	Storage Period in days					
	D0	D15	D30	D45	D60	D75
KB(PFSF)%	6.01	6.16	6.3	6.45	7.18	7.4
KB(Ambient)%	6	6.2	6.23	6.4	7.02	7.18
KCM(PFSF)%	6	6.2	6.32	6.34	7.23	7.31
KCM(Ambient)%	6	6.01	6.11	6.2	6.4	6.9

APPENDIX-II

Table 1. One day temperature data inside PFSF as well as outside ambient of various points at an interval of fifteen minute in loading condition during April month

Time	Outer 1	Outer 2	Outer 3	M14 (back side ground)	M16 (back left corner)	M17 (front right corner)	M18 (front left corner)	M1 (floor- mid)
12:15PM	45.9	39.72	37.99	15.36	16.85	14.87	15.34	15.91
12:30 PM	45.32	38.69	37.4	15.95	19.73	14.74	15.24	15.86
12:45 PM	43.83	37.11	36.06	15.86	15.68	14.77	15.05	15.83
01:00 PM	42.79	37.58	37.1	15.78	16.66	14.68	14.9	15.76
01:15 PM	41.91	37.33	36.69	15.63	15.71	14.6	14.83	15.78
01:30 PM	41.46	37.68	37	15.89	15.49	14.66	14.7	15.79
01:45 PM	41.25	37.64	36.99	15.74	13.82	14.67	14.57	15.68
02:00 PM	41.02	37.4	36.6	15.36	14.24	14.61	14.56	15.26
02:15 PM	40.82	37.76	37.2	15.78	12.61	14.71	14.51	15.78
02:30 PM	40.49	37.67	37.35	16.38	12.95	14.26	14.43	15.95
02:45 PM	40.26	37.01	36.48	16.84	15.28	14.85	14.49	15.91
03:00 PM	39.96	36.9	36.34	17.53	16.44	15.02	14.46	15.77
03:15 PM	39.57	37.08	36.43	17.52	17.2	14.98	14.44	15.66
03:30 PM	39.37	37	36.87	17.23	17.59	14.84	14.5	15.7
03:45 PM	38.99	36.97	36.16	17.62	17.61	14.9	14.58	15.72
04:00 PM	38.86	39.15	36.69	18.26	17.93	14.93	14.68	15.75
04:15 PM	38.85	39.25	37.32	18.36	17.59	14.87	14.76	15.7
04:30 PM	38.89	37.52	36.23	18.63	17.3	14.82	14.77	15.74
04:45 PM	38.77	36.92	35.7	18.64	17.2	14.77	14.67	15.67
05:00 PM	38.26	35.84	35.11	18.63	17.25	14.8	14.73	15.61
05:15 PM	37.54	35.04	34.55	18.91	17.07	14.86	14.76	15.67
05:30 PM	36.63	33.79	33.14	18.6	16.8	14.85	14.79	15.79
05:45 PM	35.6	33.08	32.59	19.6	16.66	14.82	14.73	15.75
06:00 PM	34.61	32.09	31.43	16.36	16.5	14.86	14.6	15.97
06:15 PM	33.4	30.54	29.72	16.38	16.43	14.9	14.76	15.89
06:30 PM	31.97	28.78	28.12	18.36	16.18	15.08	14.74	15.66
06:45 PM	30.57	27.69	27.2	23.47	16	15	14.68	16
07:00 PM	29.6	27.62	27.21	23.4	15.81	14.9	14.73	16.54
07:15 PM	28.97	27.45	27.08	23.18	15.66	14.88	14.86	15.67
07:30 PM	28.21	26.56	26.06	22.91	15.51	14.93	14.82	16.11
07:45 PM	27.34	25.6	25.43	22.61	15.38	14.92	14.95	16.74
08:00 PM	26.56	24.99	24.45	22.49	15.25	14.91	14.95	17.32
08:15 PM	25.79	24.46	24.05	22.22	15.15	14.92	14.81	17.92
08:30 PM	25.05	23.81	23.48	21.98	15.14	14.99	14.84	17.75
08:45 PM	24.38	23.22	22.97	21.8	15.11	15.17	14.84	18.22
09:00 PM	23.78	22.82	22.53	21.53	14.99	15.33	14.87	18.56
09:15 PM	23.17	22.34	22	21.42	15.01	15.27	14.91	19.77
09:30 PM	22.65	21.98	21.73	21.15	15.12	15.54	14.83	18.82
09:45 PM	22.19	21.69	21.35	20.93	15.09	16.3	14.91	18.4
10:00 PM	21.73	21.39	21.06	20.72	15.12	16.66	15.17	19.56
10:15 PM	21.3	20.96	20.71	20.63	15.19	15.97	15.16	18.95
10:30 PM	20.95	20.78	20.49	20.53	15.36	16.45	15.23	19.18

10:45 PM	20.58	20.58	20.25	20.42	15.32	17.33	15.29	19.18
11:00 PM	20.31	20.31	19.97	20.31	15.18	17.87	16	19.79
11:15 PM	19.99	19.99	19.82	20.16	15.15	18.42	16.54	19.07
11:30 PM	19.75	19.75	19.59	20.22	15.1	18.38	15.67	18.74
11:45 PM	19.56	19.56	19.39	20.23	15.13	16.66	16.11	17.87
12:00 AM	19.36	19.53	19.35	20.24	15.16	15.97	16.74	16.38
12:15PM	45.9	39.72	37.99	15.36	16.85	14.87	15.34	15.91
12:30 PM	45.32	38.69	37.4	15.95	19.73	14.74	15.24	15.86
12:45 PM	43.83	37.11	36.06	15.86	15.68	14.77	15.05	15.83
01:00 PM	42.79	37.58	37.1	15.78	16.66	14.68	14.9	15.76
01:15 PM	41.91	37.33	36.69	15.63	15.71	14.6	14.83	15.78
01:30 PM	41.46	37.68	37	15.89	15.49	14.66	14.7	15.79
01:45 PM	41.25	37.64	36.99	15.74	13.82	14.67	14.57	15.68
02:00 PM	41.02	37.4	36.6	15.36	14.24	14.61	14.56	15.26
02:15 PM	40.82	37.76	37.2	15.78	12.61	14.71	14.51	15.78
02:30 PM	40.49	37.67	37.35	16.38	12.95	14.26	14.43	15.95
02:45 PM	40.26	37.01	36.48	16.84	15.28	14.85	14.49	15.91
03:00 PM	39.96	36.9	36.34	17.53	16.44	15.02	14.46	15.77
03:15 PM	39.57	37.08	36.43	17.52	17.2	14.98	14.44	15.66
03:30 PM	39.37	37	36.87	17.23	17.59	14.84	14.5	15.7
03:45 PM	38.99	36.97	36.16	17.62	17.61	14.9	14.58	15.72
04:00 PM	38.86	39.15	36.69	18.26	17.93	14.93	14.68	15.75
04:15 PM	38.85	39.25	37.32	18.36	17.59	14.87	14.76	15.7
04:30 PM	38.89	37.52	36.23	18.63	17.3	14.82	14.77	15.74
04:45 PM	38.77	36.92	35.7	18.64	17.2	14.77	14.67	15.67
05:00 PM	38.26	35.84	35.11	18.63	17.25	14.8	14.73	15.61
05:15 PM	37.54	35.04	34.55	18.91	17.07	14.86	14.76	15.67
05:30 PM	36.63	33.79	33.14	18.6	16.8	14.85	14.79	15.79
05:45 PM	35.6	33.08	32.59	19.6	16.66	14.82	14.73	15.75
06:00 PM	34.61	32.09	31.43	16.36	16.5	14.86	14.6	15.97
06:15 PM	33.4	30.54	29.72	16.38	16.43	14.9	14.76	15.89
06:30 PM	31.97	28.78	28.12	18.36	16.18	15.08	14.74	15.66
06:45 PM	30.57	27.69	27.2	23.47	16	15	14.68	16
07:00 PM	29.6	27.62	27.21	23.4	15.81	14.9	14.73	16.54
07:15 PM	28.97	27.45	27.08	23.18	15.66	14.88	14.86	15.67
07:30 PM	28.21	26.56	26.06	22.91	15.51	14.93	14.82	16.11
07:45 PM	27.34	25.6	25.43	22.61	15.38	14.92	14.95	16.74
08:00 PM	26.56	24.99	24.45	22.49	15.25	14.91	14.95	17.32
08:15 PM	25.79	24.46	24.05	22.22	15.15	14.92	14.81	17.92
08:30 PM	25.05	23.81	23.48	21.98	15.14	14.99	14.84	17.75
08:45 PM	24.38	23.22	22.97	21.8	15.11	15.17	14.84	18.22
09:00 PM	23.78	22.82	22.53	21.53	14.99	15.33	14.87	18.56
09:15 PM	23.17	22.34	22	21.42	15.01	15.27	14.91	19.77
09:30 PM	22.65	21.98	21.73	21.15	15.12	15.54	14.83	18.82
09:45 PM	22.19	21.69	21.35	20.93	15.09	16.3	14.91	18.4
10:00 PM	21.73	21.39	21.06	20.72	15.12	16.66	15.17	19.56
10:15 PM	21.3	20.96	20.71	20.63	15.19	15.97	15.16	18.95
10:30 PM	20.95	20.78	20.49	20.53	15.36	16.45	15.23	19.18
10:45 PM	20.58	20.58	20.25	20.42	15.32	17.33	15.29	19.18
11:00 PM	20.31	20.31	19.97	20.31	15.18	17.87	16	19.79
11:15 PM	19.99	19.99	19.82	20.16	15.15	18.42	16.54	19.07
11:30 PM	19.75	19.75	19.59	20.22	15.1	18.38	15.67	18.74

11:45 PM	19.56	19.56	19.39	20.23	15.13	16.66	16.11	17.87
12:00 AM	19.36	19.53	19.35	20.24	15.16	15.97	16.74	16.38
12:15PM	45.9	39.72	37.99	15.36	16.85	14.87	15.34	15.91
12:30 PM	45.32	38.69	37.4	15.95	19.73	14.74	15.24	15.86
12:45 PM	43.83	37.11	36.06	15.86	15.68	14.77	15.05	15.83
01:00 PM	42.79	37.58	37.1	15.78	16.66	14.68	14.9	15.76
01:15 PM	41.91	37.33	36.69	15.63	15.71	14.6	14.83	15.78
01:30 PM	41.46	37.68	37	15.89	15.49	14.66	14.7	15.79
01:45 PM	41.25	37.64	36.99	15.74	13.82	14.67	14.57	15.68
02:00 PM	41.02	37.4	36.6	15.36	14.24	14.61	14.56	15.26
02:15 PM	40.82	37.76	37.2	15.78	12.61	14.71	14.51	15.78
02:30 PM	40.49	37.67	37.35	16.38	12.95	14.26	14.43	15.95
02:45 PM	40.26	37.01	36.48	16.84	15.28	14.85	14.49	15.91
03:00 PM	39.96	36.9	36.34	17.53	16.44	15.02	14.46	15.77
03:15 PM	39.57	37.08	36.43	17.52	17.2	14.98	14.44	15.66
03:30 PM	39.37	37	36.87	17.23	17.59	14.84	14.5	15.7
03:45 PM	38.99	36.97	36.16	17.62	17.61	14.9	14.58	15.72
04:00 PM	38.86	39.15	36.69	18.26	17.93	14.93	14.68	15.75
04:15 PM	38.85	39.25	37.32	18.36	17.59	14.87	14.76	15.7
04:30 PM	38.89	37.52	36.23	18.63	17.3	14.82	14.77	15.74
04:45 PM	38.77	36.92	35.7	18.64	17.2	14.77	14.67	15.67
05:00 PM	38.26	35.84	35.11	18.63	17.25	14.8	14.73	15.61
05:15 PM	37.54	35.04	34.55	18.91	17.07	14.86	14.76	15.67
05:30 PM	36.63	33.79	33.14	18.6	16.8	14.85	14.79	15.79
05:45 PM	35.6	33.08	32.59	19.6	16.66	14.82	14.73	15.75
06:00 PM	34.61	32.09	31.43	16.36	16.5	14.86	14.6	15.97
06:15 PM	33.4	30.54	29.72	16.38	16.43	14.9	14.76	15.89
06:30 PM	31.97	28.78	28.12	18.36	16.18	15.08	14.74	15.66
06:45 PM	30.57	27.69	27.2	23.47	16	15	14.68	16
07:00 PM	29.6	27.62	27.21	23.4	15.81	14.9	14.73	16.54
07:15 PM	28.97	27.45	27.08	23.18	15.66	14.88	14.86	15.67
07:30 PM	28.21	26.56	26.06	22.91	15.51	14.93	14.82	16.11
07:45 PM	27.34	25.6	25.43	22.61	15.38	14.92	14.95	16.74
08:00 PM	26.56	24.99	24.45	22.49	15.25	14.91	14.95	17.32
08:15 PM	25.79	24.46	24.05	22.22	15.15	14.92	14.81	17.92
08:30 PM	25.05	23.81	23.48	21.98	15.14	14.99	14.84	17.75
08:45 PM	24.38	23.22	22.97	21.8	15.11	15.17	14.84	18.22
09:00 PM	23.78	22.82	22.53	21.53	14.99	15.33	14.87	18.56
09:15 PM	23.17	22.34	22	21.42	15.01	15.27	14.91	19.77
09:30 PM	22.65	21.98	21.73	21.15	15.12	15.54	14.83	18.82
09:45 PM	22.19	21.69	21.35	20.93	15.09	16.3	14.91	18.4
10:00 PM	21.73	21.39	21.06	20.72	15.12	16.66	15.17	19.56
10:15 PM	21.3	20.96	20.71	20.63	15.19	15.97	15.16	18.95
10:30 PM	20.95	20.78	20.49	20.53	15.36	16.45	15.23	19.18
10:45 PM	20.58	20.58	20.25	20.42	15.32	17.33	15.29	19.18
11:00 PM	20.31	20.31	19.97	20.31	15.18	17.87	16	19.79
11:15 PM	19.99	19.99	19.82	20.16	15.15	18.42	16.54	19.07
11:30 PM	19.75	19.75	19.59	20.22	15.1	18.38	15.67	18.74
11:45 PM	19.56	19.56	19.39	20.23	15.13	16.66	16.11	17.87
12:00 AM	19.36	19.53	19.35	20.24	15.16	15.97	16.74	16.38
12:15PM	45.9	39.72	37.99	15.36	16.85	14.87	15.34	15.91

Table 2. One day temperature data inside PFSF as well as outside ambient of various points at an interval of fifteen minute in loading condition during May month

Time	Outer 1	Outer 2	Outer 3	M14 (back side ground)	M16 (back left corner)	M17 (front right corner)	M18 (front left corner)	M1 (floor- mid)
12:15 AM	23.82	23.82	23.57	9.3	7.07	7.67	6.47	8.62
12:30 AM	23.71	23.88	23.71	9.32	7.13	7.73	6.53	8.8
12:45 AM	23.65	23.82	23.65	9.47	7.24	7.84	6.64	8.82
01:00 AM	23.7	24.03	23.7	9.52	7.29	7.89	6.69	8.92
01:15 AM	23.61	23.86	23.78	9.43	7.37	7.97	6.77	8.91
01:30 AM	23.71	24.04	23.88	9.49	7.43	8.03	6.83	9.02
01:45 AM	23.57	23.9	23.57	9.21	7.24	7.84	6.64	8.82
02:00 AM	23.42	23.59	23.42	9.23	7.21	7.81	6.61	8.89
02:15 AM	23.23	23.4	23.23	9.21	7.32	7.92	6.72	8.87
02:30 AM	23.1	23.27	23.18	9.25	7.36	7.96	6.76	8.99
02:45 AM	23.36	23.69	23.69	9.47	7.62	8.22	7.02	9.25
03:00 AM	24.06	24.81	25.22	9.55	7.96	8.56	7.36	9.55
03:15 AM	24.27	24.77	24.94	9.42	7.71	8.31	7.11	9.42
03:30 AM	25.03	26.03	26.28	9.52	7.81	8.41	7.21	9.52
03:45 AM	25.85	27	27.38	9.33	7.66	8.26	7.06	9.33
04:00 AM	26.4	27.56	27.64	9.05	7.51	8.11	6.91	9.23
04:15 AM	27	28.15	28.24	8.99	7.45	8.05	6.85	9.16
04:30 AM	27.48	28.39	28.47	8.98	7.35	7.95	6.75	9.15
04:45 AM	27.58	28.24	28.2	9.08	7.37	7.97	6.77	9.25
05:00 AM	27.47	27.88	27.72	9.31	7.42	8.02	6.82	9.4
05:15 AM	27.3	27.46	27.3	9.31	7.59	8.19	6.99	9.56
05:30 AM	27.2	27.37	27.24	9.64	7.84	8.44	7.24	9.81
05:45 AM	27.13	27.29	27.13	9.69	8.02	8.62	7.42	9.99
06:00 AM	27.09	27.26	27.18	9.82	8.15	8.75	7.55	10.12
06:15 AM	27.27	27.6	27.6	9.96	8.42	9.02	7.82	10.39
06:30 AM	27.81	28.18	28.22	10.23	8.69	9.29	8.09	10.44
06:45 AM	28.41	28.58	28.74	10.47	8.97	9.57	8.37	10.6
07:00 AM	29.2	29.2	29.36	9.23	9.49	10.09	8.89	10.98
07:15 AM	30.4	30.23	30.32	7.78	9.71	10.31	9.11	10.31
07:30 AM	30.81	29.74	29.74	11.42	9.79	10.39	9.19	10.74
07:45 AM	29.85	28.7	28.54	11.41	9.49	10.09	8.89	11.07
08:00 AM	29.25	28.14	28.06	11.51	9.55	10.15	8.95	11.26
08:15 AM	30.82	30.33	30.33	11.91	10.5	11.1	9.9	11.4
08:30 AM	32.24	31.42	31.58	12.66	11	11.6	10.4	11.56
08:45 AM	33.63	32.4	32.49	12.66	11.26	11.86	10.66	11.9
09:00 AM	34.6	33.06	32.9	12.54	11.3	11.9	10.7	11.61
09:15 AM	35.38	33.52	33.19	11.15	11.36	11.96	10.76	11.45
09:30 AM	36.01	33.66	33.45	12.41	11.34	11.94	10.74	11.43
09:45 AM	36.66	34.31	34.14	13.6	11.77	12.37	11.17	12.71
10:00 AM	37.55	35.04	34.92	14.15	12.15	12.75	11.55	13.39
10:15 AM	37.9	35.23	34.74	12.32	12.27	12.87	11.67	13.72
10:30 AM	38.74	36.4	36.28	13.51	12.19	12.79	11.59	12.41
10:45 AM	38.58	35.56	35.19	13.51	11.6	12.2	11	11.69
11:00 AM	38.85	35.87	35.71	13.12	11.72	12.32	11.12	11.77

11:15 AM	39.8	37.22	37.14	12.89	11.95	12.55	11.35	12.09
11:30 AM	40.17	37.19	36.79	12.56	11.5	12.1	10.9	11.55
11:45 AM	40.7	38.05	37.44	12.74	11.46	12.06	10.86	11.56
12:00 PM	40.85	37.71	37.07	12.73	11.28	11.88	10.68	11.46
12:15 PM	41.03	38.06	37.66	12.42	10.89	11.49	10.29	11.11
12:30 PM	40.51	37.7	37.21	11.41	10.04	10.64	9.44	10.17
12:45 PM	40.22	37.88	37.72	10.76	9.43	10.03	8.83	9.69
01:00 PM	39.97	38.12	37.64	10.11	8.75	9.35	8.15	8.79
01:15 PM	39.75	37.9	37.58	9.8	8.47	9.07	7.87	8.6
01:30 PM	39.77	37.84	37.44	9.52	8.36	8.96	7.76	8.36
01:45 PM	39.95	38.58	38.58	9.44	8.2	8.8	7.6	8.12
02:00 PM	39.77	38.08	37.8	8.95	7.58	8.18	6.98	7.71
02:15 PM	39.88	38.51	37.87	8.73	7.53	8.13	6.93	7.486
02:30 PM	40.02	38.81	38.49	8.71	7.34	7.94	6.74	7.423
02:45 PM	40.28	38.92	38.51	8.73	7.28	7.88	6.68	7.361
03:00 PM	40.32	38.95	38.15	8.94	7.06	7.66	6.46	7.142
03:15 PM	40.07	38.55	38.23	8.39	6.89	7.49	6.29	7.057
03:30 PM	39.85	38.33	37.84	8.32	6.82	7.42	6.22	7.035
03:45 PM	39.69	38.32	38	9.6	7.25	7.85	6.65	8.62
04:00 PM	39.53	38.33	38.16	9.39	7.16	7.76	6.56	7.85
04:15 PM	39.63	38.43	38.35	9.41	7.18	7.78	6.58	7.87
04:30 PM	39.41	38.21	37.72	10.03	7.46	8.06	6.86	8.92
04:45 PM	39.3	38.05	37.69	10.33	7.68	8.28	7.08	9.22
05:00 PM	38.96	37.59	37.23	10.61	7.75	8.35	7.15	9.59
05:15 PM	38.53	37.24	36.87	10.7	7.84	8.44	7.24	9.68
05:30 PM	38.13	36.84	36.43	10.79	7.97	8.57	7.37	9.77
05:45 PM	37.67	36.46	36.01	10.82	8.08	8.68	7.48	9.8
06:00 PM	37.12	35.91	35.43	10.75	8.02	8.62	7.42	9.82
06:15 PM	36.61	35.4	35.23	10.8	7.98	8.58	7.38	9.87
06:30 PM	36.1	34.97	34.76	10.77	8	8.6	7.4	9.8
06:45 PM	35.58	34.53	34.36	10.65	7.96	8.56	7.36	9.72
07:00 PM	35.18	34.16	33.88	10.57	8	8.6	7.4	9.8
07:15 PM	34.55	33.58	33.41	10.5	7.85	8.45	7.25	9.65
07:30 PM	34.15	33.33	33.25	10.5	8.11	8.71	7.51	9.82
07:45 PM	33.69	32.84	32.72	10.49	7.97	8.57	7.37	9.68
08:00 PM	33.37	32.63	32.71	10.62	8.14	8.74	7.54	9.85
08:15 PM	32.97	32.56	32.31	10.46	7.89	8.49	7.29	9.6
08:30 PM	32.89	32.89	32.56	10.11	7.63	8.23	7.03	9.35
08:45 PM	32.92	32.92	32.88	9.89	7.49	8.09	6.89	9.21
09:00 PM	32.77	32.69	32.61	9.86	7.51	8.11	6.91	9.23
09:15 PM	32.6	32.52	32.27	9.89	7.5	8.1	6.9	9.34
09:30 PM	32.43	32.35	32.11	9.89	7.58	8.18	6.98	9.38
09:45 PM	32.26	32.1	31.93	9.88	7.65	8.25	7.05	9.54
10:00 PM	32.01	31.76	31.43	9.95	7.68	8.28	7.08	9.53
10:15 PM	31.64	31.23	30.9	9.91	7.69	8.29	7.09	9.61
10:30 PM	31.25	31.09	30.76	9.94	7.88	8.48	7.28	9.64
10:45 PM	31.09	31.05	30.88	9.85	7.96	8.56	7.36	9.76
11:00 PM	30.9	30.82	30.58	9.83	7.94	8.54	7.34	9.83
11:15 PM	30.72	30.64	30.47	9.89	7.92	8.52	7.32	9.8
11:30 PM	30.6	30.6	30.43	9.93	7.96	8.56	7.36	9.85
11:45 PM	30.36	30.28	30.11	9.85	8.05	8.65	7.45	9.94

12:00 AM	30.2	30.2	30.04	9.99	8.15	8.75	7.55	10.12
12:15 AM	23.82	23.82	23.57	9.3	7.07	7.67	6.47	8.62
12:30 AM	23.71	23.88	23.71	9.32	7.13	7.73	6.53	8.8
12:45 AM	23.65	23.82	23.65	9.47	7.24	7.84	6.64	8.82
01:00 AM	23.7	24.03	23.7	9.52	7.29	7.89	6.69	8.92
01:15 AM	23.61	23.86	23.78	9.43	7.37	7.97	6.77	8.91
01:30 AM	23.71	24.04	23.88	9.49	7.43	8.03	6.83	9.02
01:45 AM	23.57	23.9	23.57	9.21	7.24	7.84	6.64	8.82
02:00 AM	23.42	23.59	23.42	9.23	7.21	7.81	6.61	8.89
02:15 AM	23.23	23.4	23.23	9.21	7.32	7.92	6.72	8.87
02:30 AM	23.1	23.27	23.18	9.25	7.36	7.96	6.76	8.99
02:45 AM	23.36	23.69	23.69	9.47	7.62	8.22	7.02	9.25
03:00 AM	24.06	24.81	25.22	9.55	7.96	8.56	7.36	9.55
03:15 AM	24.27	24.77	24.94	9.42	7.71	8.31	7.11	9.42
03:30 AM	25.03	26.03	26.28	9.52	7.81	8.41	7.21	9.52
03:45 AM	25.85	27	27.38	9.33	7.66	8.26	7.06	9.33
04:00 AM	26.4	27.56	27.64	9.05	7.51	8.11	6.91	9.23
04:15 AM	27	28.15	28.24	8.99	7.45	8.05	6.85	9.16
04:30 AM	27.48	28.39	28.47	8.98	7.35	7.95	6.75	9.15
04:45 AM	27.58	28.24	28.2	9.08	7.37	7.97	6.77	9.25
05:00 AM	27.47	27.88	27.72	9.31	7.42	8.02	6.82	9.4
05:15 AM	27.3	27.46	27.3	9.31	7.59	8.19	6.99	9.56
05:30 AM	27.2	27.37	27.24	9.64	7.84	8.44	7.24	9.81
05:45 AM	27.13	27.29	27.13	9.69	8.02	8.62	7.42	9.99
06:00 AM	27.09	27.26	27.18	9.82	8.15	8.75	7.55	10.12
06:15 AM	27.27	27.6	27.6	9.96	8.42	9.02	7.82	10.39
06:30 AM	27.81	28.18	28.22	10.23	8.69	9.29	8.09	10.44
06:45 AM	28.41	28.58	28.74	10.47	8.97	9.57	8.37	10.6
07:00 AM	29.2	29.2	29.36	9.23	9.49	10.09	8.89	10.98
07:15 AM	30.4	30.23	30.32	7.78	9.71	10.31	9.11	10.31
07:30 AM	30.81	29.74	29.74	11.42	9.79	10.39	9.19	10.74
07:45 AM	29.85	28.7	28.54	11.41	9.49	10.09	8.89	11.07
08:00 AM	29.25	28.14	28.06	11.51	9.55	10.15	8.95	11.26
08:15 AM	30.82	30.33	30.33	11.91	10.5	11.1	9.9	11.4
08:30 AM	32.24	31.42	31.58	12.66	11	11.6	10.4	11.56
08:45 AM	33.63	32.4	32.49	12.66	11.26	11.86	10.66	11.9
09:00 AM	34.6	33.06	32.9	12.54	11.3	11.9	10.7	11.61
09:15 AM	35.38	33.52	33.19	11.15	11.36	11.96	10.76	11.45
09:30 AM	36.01	33.66	33.45	12.41	11.34	11.94	10.74	11.43
09:45 AM	36.66	34.31	34.14	13.6	11.77	12.37	11.17	12.71
10:00 AM	37.55	35.04	34.92	14.15	12.15	12.75	11.55	13.39
10:15 AM	37.9	35.23	34.74	12.32	12.27	12.87	11.67	13.72
10:30 AM	38.74	36.4	36.28	13.51	12.19	12.79	11.59	12.41
10:45 AM	38.58	35.56	35.19	13.51	11.6	12.2	11	11.69
11:00 AM	38.85	35.87	35.71	13.12	11.72	12.32	11.12	11.77
11:15 AM	39.8	37.22	37.14	12.89	11.95	12.55	11.35	12.09
11:30 AM	40.17	37.19	36.79	12.56	11.5	12.1	10.9	11.55
11:45 AM	40.7	38.05	37.44	12.74	11.46	12.06	10.86	11.56
12:00 PM	40.85	37.71	37.07	12.73	11.28	11.88	10.68	11.46
12:15 PM	41.03	38.06	37.66	12.42	10.89	11.49	10.29	11.11