Effect of traditional storage methods on post-harvest dormancy of Taewa Māori seed potato (*Solanum tuberosum* L.) in Aotearoa New Zealand

A thesis presented in partial fulfilment of the requirements for the degree

of

Doctor of Philosophy

in

Plant Science

School of Agriculture and Environment,

Massey University, Manawatu, New Zealand

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2024

Abstract

In the *Solanaceae* family, the potato (*Solanum tuberosum* L.) is one of the major tuber crops. In New Zealand there are potatoes called taewa. Māori growers who grow these potatoes generally store the harvested seeds in dark places, at the ambient temperature and a large proportion of those growers generally store with dry fern coverage for at least four months before planting. The objective of this study was to evaluate the Māori storage method on the preservation of the seed potatoes. This experiment chose conditions to represent traditional methods, the major difference being temperature control. The Māori Storage Method (ambient and dark environment) was contrasted with the Conventional Storage Method for potatoes, which consisted of placing the potato seeds in a dark room at continuous temperature of 5 ˚C. The potato seeds used in the experiment were randomly selected, weighed. And then put into storage. Tubers were evaluated at 30-day intervals from the beginning to 120 days of storage. A randomized complete block design was applied with 3 blocks of the treatments. In the first experiment (2022), analyses of respiration rate, weight loss and sugar content were performed. In 2023 the same experiment was repeated with some changes i.e., measuring sprouting (length, width and number of sprouts in taewa varieties), but not sugar content (SC), and doing respiration rate (RR) and weight loss (WL) again for comparison between the two trials.

Data on the evaluated parameters were analysed using a linear mixed model (Mixed Procedure) with year, variety, storage method and their interactions as the fixed factors and block as the random factor following by a Tukey-Kramer test for multiple comparisons. An exponential regression model (Nlin Procedure) was applied to fit the data on the change of parameters evaluated, and the coefficients of determination (R^2) for regressions were also calculated. The response variables (respiration rate, weight loss, and sugar content) presented characteristics of each variety, highlighting the Tutaekuri variety with the highest respiration rate and percentage of sugar content. The variety that showed the highest percentage of weight loss was Moemoe. The influence of environmental conditions during the storage period of the Māori method may have interfered with the dormancy period of taewa potatoes in the response variables (respiration rate, weight loss, sugar content, and sprout). The tuber dormancy duration is largely dependent on the genotype along with pre-and postharvest conditions. The factor that most determined this characteristic was the storage temperature. In this experiment, storage temperature is the main environmental factor affecting tuber dormancy on taewa potatoes. The tuber dormancy duration is largely dependent on the genotype along with pre-and postharvest

conditions. In general, there is a lot of common ground between both cultural and commercial approaches to seed selection and storage.

Acknowledgments

I thank God, almighty father, who from the height of his infinite kindness and love gave me life and chose me, among so many others, to write this thesis.

I would like to thank the supervisors, Professor Nick Roskruge, Dr. Margaret Carpenter and Dr. Samantha Baldwin, for their guidance. I would like to express my sincere gratitude to Professor Nick for inviting me to do this PhD during the COVID-19 pandemic period. It was quite a challenge, but it was worth it. Thank you, Professor Nick, for the patience, understanding and trust you placed in me.

I would like to thank Massey University for the study opportunity. This was an incredible experience. I would also like to thank Plant and Food Research - PFR, for the financial support received during my study.

I would like to thank all the Māori growers at Tahuri Whenua. There are so many good people out there that I had the opportunity to meet during my technical visits. I appreciate the kindness of all of you.

I would like to thank immensely Professors Xiong Zhao He and Ignacio Lopez Campbell for everything they helped me throughout my PhD journey. I would like to express my deep appreciation for your enormous contributions, in terms of time and efforts, to complete my research work (statistical analyses).

I would like to thank all the support staff at Massey University's School of Agriculture and Environment and the technicians in the Postharvest Laboratory of the School of Food and Advanced Technology. I would like to extend my sincere thanks to all PhD colleagues for the exchanges of ideas, conversations and laughs. I also would like to thank all my friends in my sport that I have practiced since I was a teenager, Brazilian Jiu-Jitsu (BJJ). Thank you everyone for the training in Fielding and all the moments of joy and fun we had. This was essential for my stress relief which helped me a lot in my PhD routine.

Dedication

To my family in Brazil,

My lovely mother Maria do Remédio, and my siblings Mara and Junior.

My dear aunt Maria do Socorro and my little nephew Miguel.

My father who has passed away (Francisco Mariano - in memoriam).

To my family in New Zealand,

My beautiful wife Rhonda Carvalho and my mother-in-law Jill Ralph.

I would like to express my deepest gratitude to my lovely wife Rhonda Carvalho for being the foundation of everything around me and for always being by my side. Thank you for your encouragement and support, which has been a constant source of motivation for me, and I could not have completed this without your unwavering support. Thank you so much my darling.

"PhD is about learning, sometimes learning can be fun, sometimes it can be hard work, and sometimes learning comes from "failure", and sometimes failure teaches more than success."

Anonymous

Candidate's Declaration

I, **Marcos Schleiden Sousa Carvalho**, declare that this thesis entitled *Effect of traditional storage methods on post-harvest dormancy of Taewa Māori seed potato (Solanum tuberosum L.) in Aotearoa New Zealand* submitted to Massey University for the degree of Doctor of Philosophy is the outcome of my own research work. Acknowledgment is given where material from other resources was used. I also certify that the thesis has not been presented, in whole or partly, for any degrees or diplomas.

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DATE:	July 25, 2024

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List of Abbreviations

a	Initial respiration rate
ABA	Abscisic acid
ADP	Adenine-5'-diphosphoglucose
AIA	Auxin - Indole-3-acetic acid
ANZAC	Australia and New Zealand Army Corps
ANZUS	Signed Australia, New Zealand, and US
atm	Atmosphere
b	Increase rate of respiration
BBC	British Broadcasting Corporation
c	Decrease rate of respiration
CA	Controlled atmosphere
CIA	Central Intelligence Agency
CK	Cytokinins
CLs	Confidence limits
CO_2	Carbon dioxide
CSM	Conventional Storage Method
FAO	Food and Agriculture Organization of the United
FCU	Fruit Crops Unit
g	Grams
Gas	Ethylene, gibberellins
HDI	Human development index
HPLC	High-performance liquid chromatography
IMF	International Monetary Fund
kg	kilogram
L	Liter
mL	Milliliter
mol	Mole. The molecule.
MSM	Māori Storage Method
n	Amount of substance
O_2	Oxygen
p	Pressure

PR-32 α	Refractometer
PGU	Plant and Growth Unit
R	Ideal gas constant
R^2	Coefficients of determination
RCBD	Randomized Complete Block Design
RH	Relative Humidity
RR	Respiration rate
RT	Room Temperature
s	Seconds
SAS	Statistical Analysis System
S1	The vegetative stage or tillering stage
S2	Tuber formation stage
S3	Tuber bulking stage
S4	Tuber maturation stage
SC	Sugar content
temp	Temperature
V	Volume
WL	Weight loss
Wt	Percent of weight loss
WVP	Water vapor pressure
WVPD	Water vapor pressure deficit
y	Data on the change of respiration rate, weight loss, and sugar content

Chapter 1

General Introduction and Research Objectives

1.1 Introduction

New Zealand is one of the countries that presents natural beauty and is based on the culture and traditions of the Māori together with the influences brought by European colonizers, in addition to the influence of people from other territories around the globe such as Asia, North and South America, among others, and New Zealand culture today reflects these many influences. In Figure 1 there is a map of the world where it is possible to see New Zealand in the South Pacific Ocean near Australia. New Zealand is a rugged country with high topography which gives varying exposures to weather systems (Garnier, 1950) and ocean currents (Brodie, 1960) as cited in Salinger (1979). These factors may influence the temperature behaviour locally to any regional trends (Salinger, 1979).

New Zealand consists of two main islands, the North Island and the South Island, along with several smaller islands, some of which are located hundreds of miles from the main group. This country is notably remote, being one of the last significant territories suitable for habitation to be populated and settled. It is situated more than 1,000 miles (1,600 km) southeast of its nearest neighbour, Australia. Wellington is the capital city, and the largest urban area is Auckland; both are on the North Island (CIA, 2023)[1]. New Zealand is a country divided into regions (Figure 2), while agriculture remains the backbone of the economy, manufacturing and tourism also play crucial roles. Tourists are attracted to the country's glacier-carved mountains, lakes, beaches, and thermal springs (CIA, 2023).

New Zealand takes an active part in Pacific affairs and maintains special constitutional relationships with the Pacific territories of Niue, the Cook Islands, and Tokelau (BBC, 2024)[2].

[1] CIA. Countries: New Zealand. The World Factbook. (2023). See in: https://www.cia.gov/the-world-factbook/countries/new-zealand/

[2] BBC. New Zealand: country profile. BBC News, 22 Feb. 2024. See in: https://www.bbc.com/news/world-asia-pacific-15357770

Figure 1. Word map. Source: Gisgeography (2024)[3]

The IMF (World Economic Outlook - February 2024)[4] discloses that the population of New Zealand in 2024 is 5.24 million people (Figure 3).

[3] https://gisgeography.com/high-resolution-world-map/
[4] IMF. Datasets: New Zealand. (2024).
See in: https://www.imf.org/external/datamapper/profile/NZL

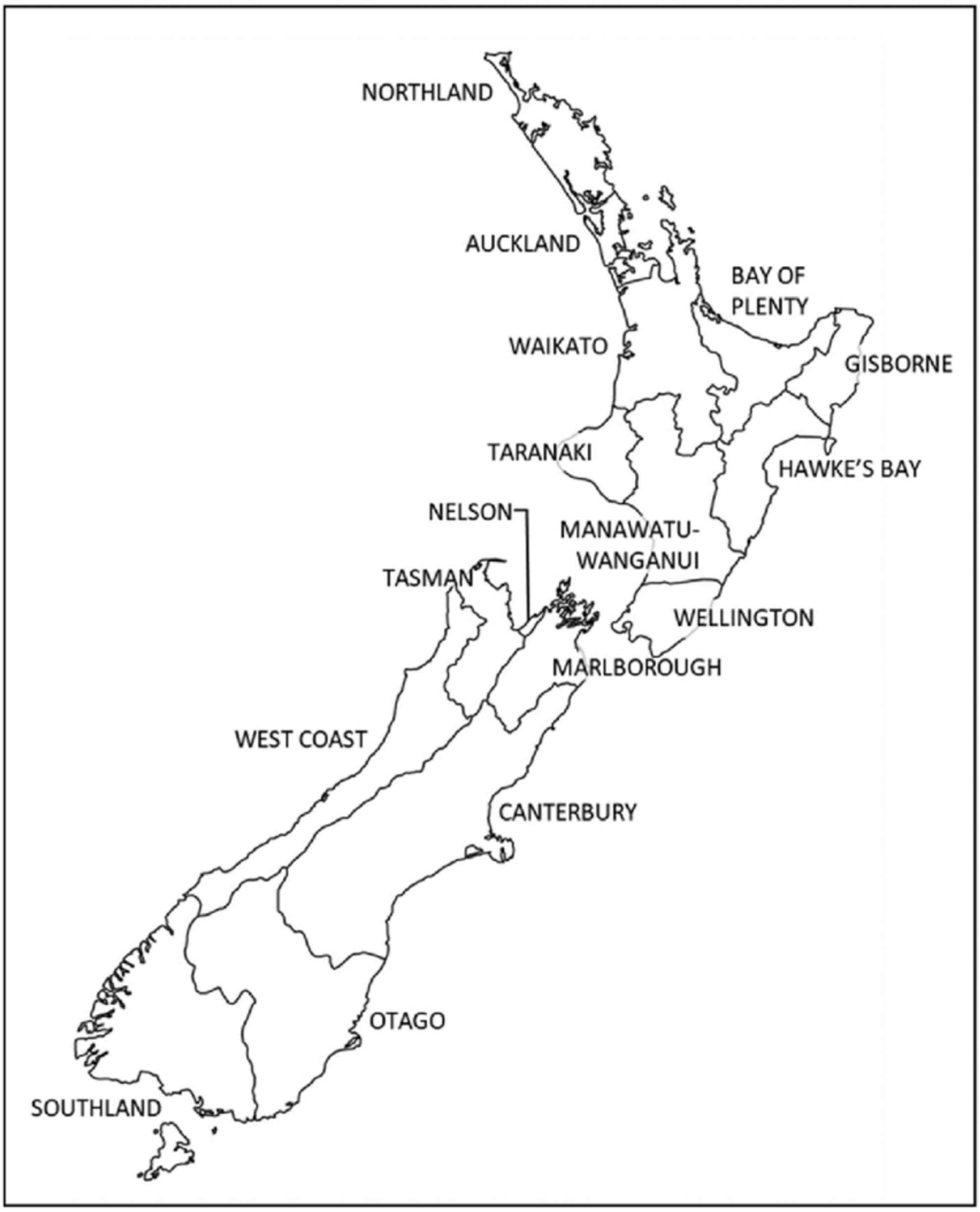

Figure 2. Map of New Zealand regions. Source: (Challies et al., 2022).

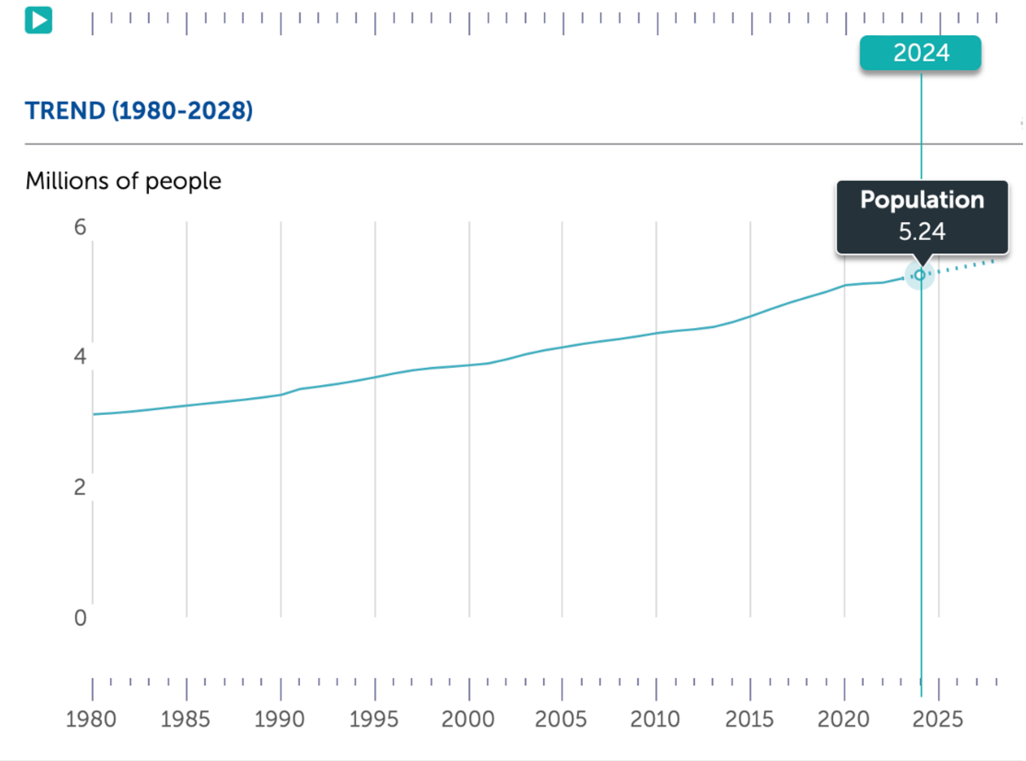

Figure 3. The population *of New* Zealand in 2024. Source: IMF. World Economic Outlook - February 2024.

1.1.1 Background of New Zealand society

By the thirteenth century, East Polynesian people (Figure 4) had settled in New Zealand, and their descendants became the early Māori (King & Filer, 2007). The first European to see the islands was Dutch explorer Abel Tasman in 1642, but after an encounter with the local Māori, he departed. British Captain James Cook arrived in New Zealand in 1769, followed by whalers, sealers, and traders (CIA, 2023). During Captain Cook's visit in 1769, the Māori population was estimated to be around 100,000 people. European trade had various impacts on the Māori, including inter-racial sexual relationships, the introduction of diseases to which Māori had little or no immunity, and the acquisition of European goods such as alcohol, tobacco, and muskets (CIA, 2023).

Since the time when European people came to New Zealand and became part of the community of that country together with the indigenous Māori people who were already here, many episodes have occurred such as the Waitangui treaty in 1840 (Wyeth et al., 2010). This treaty basically reflected two streams of thinking (commercial and humanitarian interests) and thus embodied contradictory aims: provision for British settlement on one hand, and protection of Māori interests on the other (as outlined in the preamble of the Treaty) (Wyeth et al., 2010). Just as happened in the history of the discovery of several other countries in the world, New Zealand was no different, as there were conflicts, claims for land and rights.

In the Māori language there is a word that for them has a very important meaning when it comes to the genealogy of these people. This word is called Whakapapa. Roberts (2013) said that whakapapa as a philosophical construct implies that all things have an origin (in the form of a primal ancestor from which they are descended), and that ontologically things come into being through the process of descent from an ancestor or ancestors. The importance of whakapapa in the Māori world is paramount because it is considered crucial to assertions of Māori identity and tribal membership. Whakapapa has been integral to Māori history and knowledge, both before and after European arrival. Genealogical connections have shaped how tribes related to each other and identified themselves, with whakapapa being central to the organization of social and political units, from large tribes (iwi[5]) to subtribes (hapū) and families (whānau) (Mahuika, 2019).

[5] A collection of hapu, normally united through a common ancestor

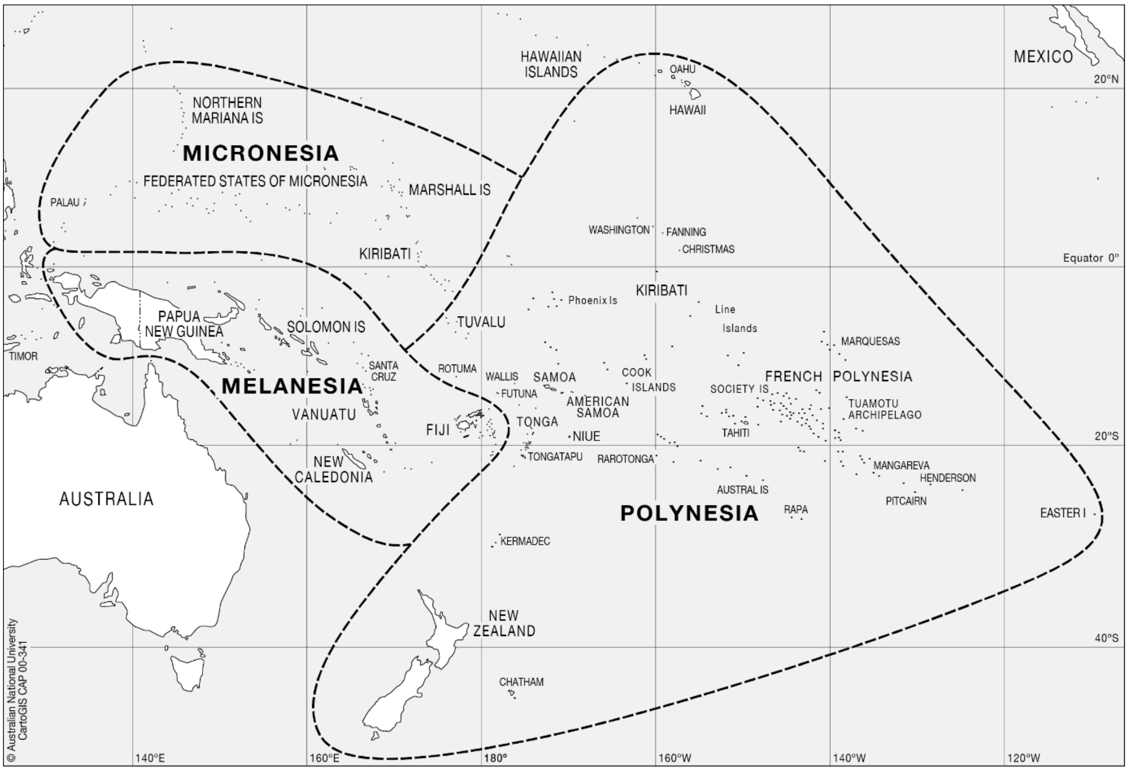

Figure 4. Polynesian territory and New Zealand. Source: Australia National University.

For Māori, identity was closely tied to place and land (Broughton, 1993[6]). The Māori's intimacy with the land, the places, was something that has always existed and that remains connected to them to this day, especially for those who make a living from agriculture. The Māori are agricultural producers who spend a large part of their time cultivating various agricultural crops and bring with them the teachings acquired by the ancients from land preparation, cultural treatments, harvesting, storage and marketing of products. Around the world, regarding food storage, since the beginning of humanity, ancient populations have looked for ways to store food to maintain their subsistence and the continuation of future generations.

Humans, like other animals, need a reliable food supply to meet their metabolic needs for maintenance, growth, and reproduction. Over evolutionary time, human civilizations searched for ways to successfully store and preserve food, often impacted by climate and the storage technology to be managed (Hammond et al., 2015). In addition to animals from hunting, humanity began to feed on other forms of food, including fruits and vegetables. Among the

[6] Broughton, J. (1993). Being Māori. New Zealand Medical Journal, 106(968), 506-508.

various vegetables in human diets, the potato stands out historically (Garn & Leonard, 1989). Potato tubers (*Solanum tuberosum* L.) have been cultivated for more than 6000 years (Alamar et al., 2017). Wang et al. (2023) stated that it has been used for food for over 10,000 years. The potato is a globally important food crop, rich in nutrients, including protein, fat, vitamins, and starch (King & Slavin, 2013). Alexopoulos A (2021) noted that in contrast to other staple food crops such as wheat, rice, maize, and various legumes (pulses), the edible portion of potato tubers contains high amounts of water (more than 70% of total fresh weight), a factor to be considered for setting proper storage conditions.

1.1.2 History of the potato in the world

Among all the plants that participate in the history of human evolution, the potato is one that has performed and contributed to evolutionary history.

Estrada de la Cerda (2015) reported that:

> "*A study by D. M. Spooner et al. (2005), a single centre of origin for the potato has identify in the surrounding areas of Lake Titicaca, on the border of present day Bolivia and Perú. Based on chloroplast DNA sequencing, all the cultivated and wild species of potatoes have a common maternal ancestry that also implies a single centre of origin (Hosaka, 2002). However, Spooner et al. (2014) suggests that the potato might have been first domesticated as early as 6000 BCE.*" (Page 75).

In a recently published study Rostain et al. (2024), archaeologists have discovered an extensive network of cities with highly structured pre-Hispanic settlements, featuring wide streets, long straight roads, plazas, and clusters of monumental platforms intertwined with agricultural and river drainages in the Upano Valley. This area stretches along the foothills of the Andes in southern Ecuador, enclosed between the Andes and the Cutucú range. These findings result from over two decades of interdisciplinary research, recently expanded by LIDAR mapping of a 300-km^2 area. Archaeological excavations date these occupations from around 500 BCE to between 300 and 600 CE. This extensive early development in the Upper Amazon is comparable to similar Maya urban systems recently highlighted in Mexico and Guatemala. These results and other future research will probably slightly modify the history of some plant food sources discovered in the history of South America.

The historic visit of Columbus in 1492 initiated contact between the Western and Eastern Hemispheres and an exchange of people, plants, animals, and cultures. The Spanish arrived in modern-day Peru in 1532, encountering a vast Inca Empire. This contact led to the decimation of the native civilization and the imposition of colonial structures. It is fascinating to consider that among the many discoveries made by the Spaniards was the potato, now a commonplace item in the world's diet (Brown, 1993). There is no specific record of when the potato was first introduced to Europe. However, the year 1570 seems likely, as there are accounts of a hospital in Seville, Spain, purchasing potatoes for food in 1573 (Hawkes, 1990) as cited in Brown (1993). The significance of the potato as a food in the Andes was not widely communicated throughout Europe (Figure 5). From Spain, the potato was taken to Italy, then to England in 1596, and subsequently to Germany in 1601 (Brown, 1993). Potatoes were introduced to England by Sir Francis Drake around 1586 (Salaman, 1949), to India by Portuguese sailors in the early seventeenth century, and around the same time to Sri Lanka by the British (Innes, 2002). The British brought potatoes to Bermuda around 1613, and from there, they were introduced to Virginia (United States) in 1621 (Innes, 2002). The potato reached Ireland in the late sixteenth century (Salaman, 1952).

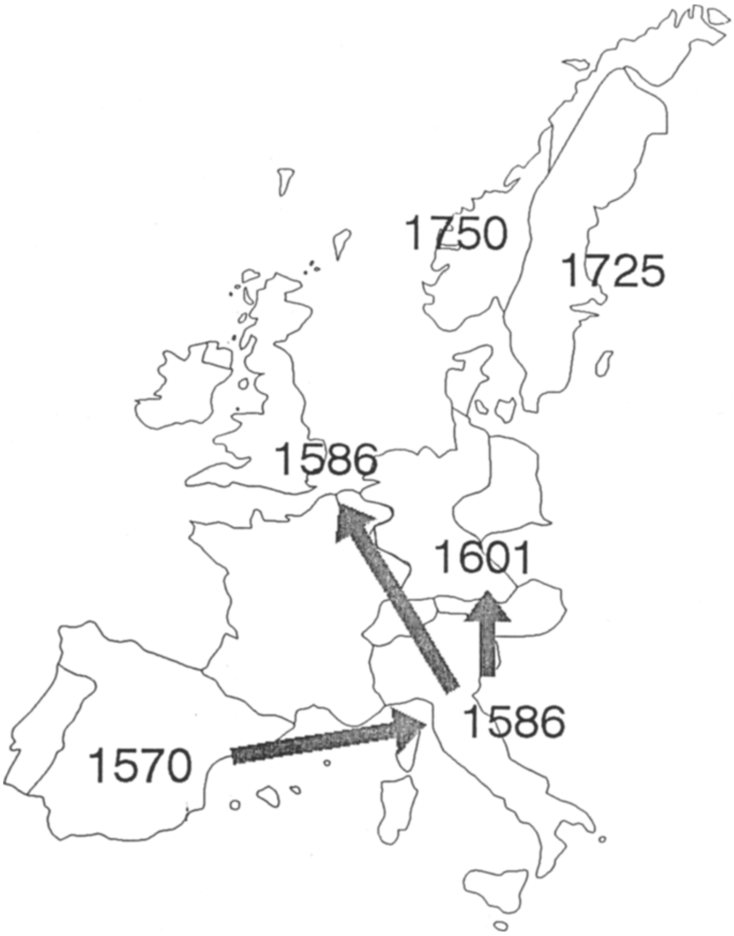

Figure 5. Dissemination of potato in Western Europe. Initial contacts occurred around 1600 before potato was recognized as a food crop. Introduction into Scandinavia was subsequent to widespread adoption as a food crop (Brown, 1993).

By the end of the 16th century, specimens of the tubers and berries of the plant were distributed among and grown by herbalists throughout Europe. One of them (Bauhin[7], 1596, as cited in Burton (1983) classified the plant is classified as Solanaceous and was given the Latin name *Solanum tuberosum*. Its vernacular names varied, including taratoufli and the corrupted Kartoffel. Due to some superficial similarity of the tubers to batatas, it also became known as batatas, patatas, and potatoes (Burton, 1983).

Botanists, historians, economists, anthropologists, and novelists have all shown interest in the intriguing story of the potato's spread from its centre of origin to the rest of the world (de Haan & Rodriguez, 2016). Historical records of the early introduction of potatoes to Europe are sparse at best (Glendinning, 1983); (Salaman & Burton, 1985). Early fourteenth-century

[7] Bauhin, G. (1596): Phytopinax. Basic.

introductions have been shown to be of Andean origin, while the introduction from Chile occurred as early as 1811, 34 years before the European late blight (*P. infestans*) epidemics (Ames & Spooner, 2008). In the mid-nineteenth century, a series of potato blight epidemics swept through Europe, devastating potato crops (Harris, 2006) because the potato cultivars grown at that time had a very narrow genetic base, they were all similarly affected. The consequences were particularly severe in Ireland, where the majority of the population depended on the potato as their primary food source (Harris, 2006).

The potato crops were destroyed by the potato late blight fungus *Phytophthora infestans* (Mont.) de Bary. At the time, knowledge of plant pathology was limited, and several theories were proposed regarding why the potato crops were destroyed. By the late eighteenth century, the potato was identified in France as a famine food, reliably feeding masses when other crops failed (Brown, 1993). Undoubtedly, the potato transformed European society by enabling farmers to produce more food in less time and on smaller plots of land. This increased population growth and facilitated the Industrial Revolution (Reader, 2008), as cited in de Haan and Rodriguez (2016).

1.1.3 Food store history in the world

Since human civilization began to work with agriculture, among all the activities related to this activity, the storage of the final product has always been a constant concern, because at many times of the year in some parts of the world, people did not have access to continue agricultural activities due to seasonal changes. History has shown that our ancestors (*Australopithecines*, from South Africa) were always concerned with food and how they should store these products, regardless of whether they were plant and animal sources (Garn & Leonard, 1989). Cheung (2021), when describing food storage in the Roman Empire, noted said that one of the most remarkable facets of the Roman Empire was its food supply system, because in many settlements across the Roman Empire, Roman builders constructed warehouses and cellars, and potters produced containers that not only protected goods but also helped stabilize temperatures and humidity levels for proper food storage over potentially long periods. Granaries throughout the Mediterranean, for example, were equipped with raised floors, small and secure windows, and thick walls to provide cool, ventilated rooms for grain coming into the capital. Farmers and merchants used large ceramic storage containers to stabilize temperatures year-round for goods such as wine, olive oil, and fish sauce (garum). Furthermore, the placement and installation of these vessels, whether in north- or south-facing rooms, mostly buried, or mostly exposed, could not only extend the shelf life of their contents but also help protect their quality (Cheung, 2021).

In medieval England, the garden products were held locally in small volumes during most periods. The domestic trade of fruits grew slowly since the foundation of towns in the tenth and eleventh centuries (Qin, 2017). The same authors confirmed that, foreign import of garden products existed, but for the gardens of England themselves, the situation was paradoxical. Vegetables and fruits were common to every class in England, but their production and trading were on a small scale. They were highly valued and cherished by monks and nobles, while peasants and town households consumed even more vegetables than the higher class. Over the centuries, it was observed that most homes had a root cellar, where families stored food in a cool, dry environment (Finley[8], 2007). They stored apples and other foods in piles of sawdust or in containers filled with sawdust or similar loose material. Since the late 1800s, people have canned food and stored it in such places as the cellar (Finley, 2007). The storage of these foods is an option that basically presents an area control in the production system, to reduce risks. The storage of fruits, vegetables and seeds in general was a major milestone for the longevity of food and consequently the continued maintenance of plant diversity (Finley, 2007). Kumar (2019) noted that to secure global crop diversity, the world needs both ex-situ (off-site) storage and preservation of seeds in farmers' fields. Food preservation involves handling and treating food to control spoilage by preventing the growth of food-borne disease-causing microbes, avoiding oxidation of fats (rancidity), and maintaining the nutritional value, texture, and flavour of the food (Kumar, 2019). According to Kumar (2019), to store foodstuffs for a longer period without spoilage, proper preservation is essential. Care must be taken to preserve the nutritional value, texture, and flavour of foodstuffs. Traditional techniques for preservation, such as curing, freezing, canning, boiling, and pickling, as well as modern techniques such as pasteurization, freeze-drying, vacuum packing, irradiation, pascalization, biopreservation, hurdle technology, and modified atmosphere storage, are all possible means of storing and maintaining food.

Anderson et al. (2012) noted that the Svalbard Global Seed Vault, opened by the Norwegian government and its partners in 2008, stores backup agricultural seed collections, ensuring

[8] Finley, T. Food preservation. Put Up, Holed In, and Salted Down. Tar Heel Junior Historian, NC Museum of History. 2007. See in: https://www.ncpedia.org/culture/food/food-preservation

global food security and genetic diversity. The Arctic location keeps seeds frozen in conditions that allow for long-term storage, although not all seeds can be frozen (Anderson et al., 2012). Most of these are crops important to agricultural production and global food security, such as rice, wheat, barley, sorghum, maize, soybeans, and pearl millet (Anderson et al., 2012). The most substantial collections are kept in International Agricultural Research Centres under the Consultative Group on International Agricultural Research. These collections are held in trust by the United Nations system and are freely available to plant breeders, farmers, and scientists worldwide on the condition that no recipient seeks intellectual property rights to the material.

As previously mentioned, among the various foods consumed in the world, the potato is one of that has always stood out among vegetables. Potatoes represent an important staple food crop globally. However, maintaining tuber quality and extending availability requires long-term storage, often using industrial-scale facilities (Alamar et al., 2017). Wang et al. (2023) stated that storage of tubers is essential to ensure a year-round supply for the fresh market and processing potato (*Solanum tuberosum* L.) industries.

In a publication by Eltawil et al. (2006), potato tuber storage methods, which were in vogue in the warm plains of India until recently include:

> *"**i)** Storage in cool dry rooms with proper ventilation on the floor or on bamboo racks and **ii)** Storage in pits." The former was generally followed in the plains for seed potatoes during the period from Feb.- March to Sept.-Oct. Storage in pits was adopted in the erstwhile Bombay state from Feb.- March till the onset of monsoon season in June (Kishore, 1979 as cited in Eltawil et al. (2006). In Egypt, the bulk of potato storage takes place in traditional structures or Nawallas made of mud bricks. Nawallas are typically privately owned and are concentrated in the northern governorates with lower average temperatures. Walls are typically from 2.5 to 3.5 m high and 30 to 60 cm thick. Storage period is normally for 5 months, May to September. Roofs consist of bamboo matting, rice straw, and mud supported by wood or bamboo frames. Seed potatoes are dusted with SEVIN and CAPTAN (brand names) and arranged in piles 1.5 to 4 m across and 0.8 to 1.0 m high. The piles are sorted every two weeks and infested, diseased, or damaged tubers discarded. Rats and Tuber moth are major problems. Temperatures within the Nawallas are not much lower than the ambient temperatures in the shade outside, although within the heap's temperatures may as much as 10 °C lower. Losses from tuber moth infestation, dehydration, excessive sprouting, and other causes average about 20-30%, although losses of up to 70% have been reported. The need for improving storage facilities and practices for warehouse as well as seed potatoes has been noted by several authors* (Geddes & Monninkhof, 1984) (Page 3).

Eltawil et al. (2006), noted that major storage techniques practiced worldwide include low-temperature storage, controlled atmosphere (CA) storage, storage in diffused sunlight, in situ storage, traditional clamp storage, storage in pits, and storage in bamboo baskets.

Throughout the history of potato culture in the world, people tried to find ways to store potatoes for future consumption. A good example of the use of potato storage was the research conducted by Crook and Watson in the 1940s and 1950s (Crook & Watson, 1948); Crook and Watson (1950), during the war (1939-45) potatoes formed a very important part of the diet, and provision for increased production was made by greatly expanding the acreage grown. As it was no longer possible to import new potatoes in the spring and early summer, large stocks needed to be held in clamp storage until July or later, over a much longer period than was common in peacetime. Understanding the wastage expected during prolonged clamp underground storage was necessary to plan crop disposal and determine the amounts to be retained in storage as the season advanced, ensuring adequate supplies throughout the year.

Therefore, in the 1940s, specifically in the autumns of 1942 and 1943 in United Kingdom (Crook & Watson, 1948); Crook and Watson (1950), in an investigation of the amount and causes of wastage during prolonged clamp storage was carried out at Rothamsted and other centres. Several clamps were set up, each divided into several sections separated by vertical walls of stout wire mesh supported by stakes, covered with sisalkraft paper, and lined with a layer of straw. The potatoes in each section were weighed when the clamps were set up. From January onwards, at approximately monthly intervals, one section of each clamp was taken down, the contents were sorted, weighed, and examined to determine the proportion of sound tubers surviving, the extent of sprouting, and the loss in weight of the clamp contents, and to identify the causes of rotting of the discarded tubers. Variation in changes during storage related to their position in the clamp was too small to be of any practical significance. It is probable that the extent of variation with position, as well as the general storage conditions, depends on the clamp dimensions, the thickness of the coverings, the type of soil used for the earth cover, and seasonal weather conditions (Crook & Watson, 1948); (Crook & Watson, 1950). (Figure 6).

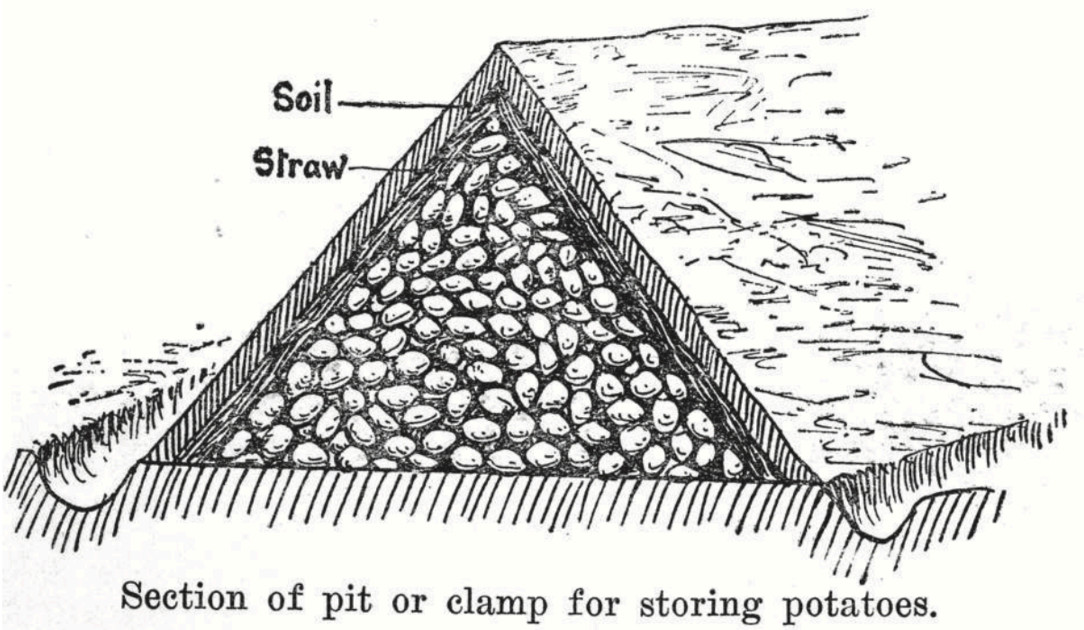

Figure 6. A potato clamp, commonly used by Europeans in New Zealand, described by Tannock (1934: 211). Source:Davidson et al. (2006).

Methods of clamp construction vary widely in different parts of the world, and an investigation of storage conditions in different types of clamps is highly desirable to put clamp-storage practice on a scientific basis rather than relying on farmer experience and prejudices. The clamps used for recent experiments were typical of good commercial practice, and the results show that in such clamps, the changes in the tubers during storage are uniform throughout the bulk of potatoes.

Gooding and Tucker (1958) compared the suitability of clamp-stored and barn-stored potatoes for processing. They studied the changes of sugars content in tubers stored and under different storage conditions and concluded that clamp storage had a higher success reducing sugar content than indoor storage of potatoes under conditions in which the ventilation was severely restricted for the minimum temperature. Potato storage in field clamps is a widely used method in Central and North Europe as well as in Spain and South America (Fabiani, 1967) as cited in Plaza et al. (1985). In the mountainous areas of Northern Greece some growers store potatoes in above ground clamps from October to April. No sprout inhibitors are applied. The tubers are kept in good condition regarding moisture retention, but some sprouting does occur. These potatoes are used mainly for fresh consumption, and they are sold at high prices because their quality is higher than of potatoes stored in non-refrigerated storehouses (Dogras et al., 1991). When it comes to the subject of potato storage, there is a vast amount of scientific research regarding storage temperature, storage time and the influence that these practices during the dormancy period can have on the final quality of the potatoes Krijthe (1962); Allen et al. (1978); Susnoschi (1981a); Hartmans and Van Loon (1987); Cottrell et al. (1993); Copp et al. (2000); Bianchi et al. (2014); Abbasi et al. (2016); Raigond et al. (2018); Johansen and Mølmann (2018); Cunnington (2023). Since the colonization of Aotearoa/New Zealand the taewa was a staple food crop of the Māori people. Commonly known as Māori potatoes, taewa (*Solanum* spp.) are also referred to by a few generic names which vary according to tribal dialect around the country (peruperu, parareka, mahetau and riwai). There are a few different beliefs regarding the origin of taewa in New Zealand and the route they took to get here. Many Māori believe that there were varieties of taewa here before European explorers; however, it is acknowledged that a number of varieties arrived with the first European explorers such as Cook in 1769 and subsequently with visiting whalers and sealers in the latter part of the eighteenth century (Roskruge, 1999). According to McFarlane (2007), with the introduction of preferred varieties from England and Australia during the latter part of the nineteenth century, many earlier taewa became relegated to the gardens of marae (formal Māori meeting venues) and have largely been grown in this typically non-commercial fashion until recent times.

Throughout New Zealand history, Māori growers stored taewa potatoes in shelters they called Pātaka (Williams, 1837) as cited in Richards (1993), describes that in Māori the term taewa can refer to a foreigner, a cold (a flu-like sickness), or the potato. Currently the most recognised and available varieties of taewa are: *huakaroro, pawhero, karuparera, raupi, tutaekuri* (also widely known as *urenika*), *wherowhero*, and *waiporoporo* Estrada de la Cerda (2015) (Figure 7). Among these taewa varieties, three of them were selected (Tutaekuri, Moemoe and Huakaroro) because they represented a range of phenotypical characteristics (Figure 8). Various growers associated to Tahuri Whenua, the National Māori Vegetable Growers Collective, have been propagating and perpetuating several of these varieties, as well as making them available for other growers. Usually, they cover the potatoes and kūmara with the use of dry fern inside the Pātaka. Fern (*Pteridium aquilinum* (L.), is primarily a woodland plant which flourishes and competes with other plant species following forest removal (Watt, 1976). Ferns are a diverse lineage of vascular plants that occupy a wide range of ecological niches and are an important part of the world's land flora (Smith et al., 2006). The fern can be used as medicine, controlling insect pests, as ornamentation, and conservation (Mannan et al., 2008). These are traditions used since the Māori ancestors when they started their practice of storing potatoes. The potato storage system practiced by Māori will be discussed in more detail. It is worth mentioning that before storage, all cultural practices are of fundamental importance for obtaining healthy potato tubers during the storage period, regardless of whether these seeds will be for consumption or for planting the next harvest. During storage, potato seeds are in the dormancy stage. Dormancy is the physiological state of the tuber in which tubers do not sprout even when placed in ideal germination conditions (Sonnewald & Sonnewald, 2014). Dormancy lasts during winter and serves to protect tubers as organs of vegetative reproduction under conditions unfavorable for growth (Aksenova et al., 2013).

1.1.4 The importance of potato production in New Zealand

New Zealand has 84,000 hectares of horticulture production, providing food for New Zealanders (Green and Schulze, 2020)[9]. While the horticulture industry already has a significant share of New Zealand's exports, the industry is set to grow substantially. The upcoming changes are expected to be even faster for Māori, with rapid growth in horticulture developments. New Zealand's export market has always been dominated by the primary industries, though the types of exports have been constantly changing (Green and Schulze, 2020). The New Zealand horticulture industry has been changing constantly, though the land used for all horticulture has been steady over the past 10 years. However, the value of horticultural exports is growing quickly with growth in high-value crops. The horticulture industry now brings almost $3.8 billion per year to New Zealand through exports. These same authors also confirm that despite New Zealand's significant population growth since 1998, the vegetable growing industry has reduced substantially, from 77,000 hectares to just over 45,000 hectares in 2018. In the Waikato region, with significant growth in dairy farming, the vegetable industry has reduced by 50 percent. The Manawatū-Whanganui Region has also had a similar reduction, from 7,800 hectares of vegetables to 3,600 hectares over the 20-year period from 1998 to 2018. In potato crops, for example, there was a reduction from 14,152 ha of potatoes in 1998 to 10,344 ha of potatoes in 2018 (Green and Schulze, 2020). The Māori share of the horticulture industry has emerged quickly and is expected to continue to grow quickly over the coming decade.

[9] See in: https://www.tpk.govt.nz/en/o-matou-mohiotanga/whenua/maori-in-horticulture-2020-research-report

Among vegetables, potato is one of the most significant crops in terms of production and consumption worldwide, with potato (*Solanum tuberosum* L.) being the fourth most important food crop in the world after wheat, rice and corn (Singh et al., 2020). It is grown in temperate and sub-tropical regions. Around 1.3 billion people eat potatoes as a staple food (more than 50 kg per person per year) including regions of India and China (Devaux et al., 2020). According to FAO (2023)[10], in the year 2021 potato was grown on an estimated 18,132 million hectares of farmland globally, and the potato production worldwide stands at 376 million tonnes. In New Zealand, between 2000 and 2021, the potato crop decreased from a little over 11,816 ha to approximately 10,901 ha and production increased from approximately 500,000 tonnes to nearly 554,000 tonnes (FAO, 2023). This increased generated over a billion dollars in revenue (Tupu, 2023)[11]. The reasons for this productivity are based on the efficiency of production system in all its phases. This includes the advanced technology (a seed certification program) applied in the production of seed potatoes, thus obtaining excellent quality propagating material. Proper post-harvest management of seed tubers is of great interest, both for the seed potato grower and for the user of the product. In this management, attention should be paid to dormancy control (Tupu, 2023).

In New Zealand there are potato cultivars called taewa (J Singh et al., 2008). Taewa is a collective noun referring to the traditional cultivars of *Solanum tuberosum* that have been cultivated by the Māori – the indigenous people of New Zealand – for at least 200 years (J Singh et al., 2008). Settlement of this country came quickly and by the 1830's Māori were cultivating taewa as a commercial crop. With the introduction of preferred varieties from England and Australia during the latter part of the nineteenth century, the earlier taewa became relegated to the gardens of the marae[12] and have been grown in this typically non-commercial fashion ever since (Roskruge, 1999). Seed for potatoes is in fact the tuber, which is vegetative material. True seed, from the fruit of the plant, was known to Māori as *takuru* and from these, the plants produced were recognised as producing a smoother skinned potato, generically termed *monemone*. Some varieties of taewa are presumed to have come about by chance seedlings produced from true seed (Roskruge, 1999). The selection of tubers for the next seasons' crop was an important task, undertaken at the time of harvest. Harvesting of any

[10] See in: https://www.fao.org/faostat/en/#data/QCL/visualize

[11] See in: https://www.tupu.nz/en/fact-sheets/potatoes

[12] Carved meeting-house, dining-hall and cooking area, as well as the marae atea or sacred space in front of the meeting-house.

cultivated crop was a communal activity involving the entire village, from chiefs to children. Potatoes were treated in much the same way as Kūmara. Once harvested they were carefully graded, and the best tubers retained for seed. Any tubers which were ugly, had broken skin or were of an odd size were discarded from the seed selection. Essentially, the smaller tubers of good colour and shape, and with no blemishes, were kept for seed (Roskruge, 1999). The prolonged storage of theses potatoes at low temperature is required to ensure regular supplies throughout the year. Post-harvest cool storage provides a necessary environment to prevent loss of weight, spoilage and sprouting (Jaspreet Singh et al., 2008). It is noticeable that in the literature potato tubers are introduced as either potato cultivars or potato varieties Wiltshire and Cobb (1996); Pringle et al. (2009); Rees et al. (2012); Mani et al. (2014); Muthoni et al. (2014); Singh and Kaur (2016); Mustefa et al. (2017); Roskruge et al., (2019); Gong et al. (2021). A cultivar (cultivated variety) is a plant that is produced and maintained by horticulturists but does not produce true-to-seed. True to seed refers to plants whose seeds, when planted, produce plants with the same characteristics as the parent plant or true-to-seed simply means the offspring is genetically the same as the parent (Yard and Garden[13], 2016); Whereas a variety is a group of plants within a species that has one or more distinguishing characteristics and usually produces true-to-seed (Yard and Garden, 2016). For the taewa potatoes in this research, we will call them varieties following Roskruge[14] et al. (2019).

Understanding the specific dormancy characteristics of each potato crop is critical to the productivity of these species, and this is what will be seen in this research over the storage period of three Māori potato varieties.

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[13] Yard and Garden. Ted Griess/Extension Horticulture Assistant. 2016. See in: https://extension.unl.edu/statewide/buffalo/Yard/Cultivar%20vs%20Variety%2001-30-2016.pdf

[14] Roskruge, N., Puketapu, A., McFarlane, T. (2019). Pests and diseases of Taewa (Māori Potato) crops. ISBN 978-0-473-17613-6. 2nd ed). Rata Press. https://owll.massey.ac.nz/referencing/apa-interactive.php

Figure 7. Varieties of taewa potato seeds.

Figure 8. Varieties of taewa of the experiment – Moemoe, Huakaroro, and Tutaekuri.

1.1.4.1 Problems of potatoes storage

Explaining the problem of potato storage research involves addressing the common issues potatoes face when kept for extended periods, especially in commercial or large-scale storage environments.

For Māori growers who follow ancestral traditions in terms of storing taewa potato seeds, it becomes important to address the following points. This highlights the complexity of the storage problem and the research efforts to find practical, scalable solutions.

1. **Sprouting**: Potatoes naturally sprout over time in storage, which leads to quality loss and can make them unsuitable for sale or processing. A Research focus exists on finding ways to delay sprouting, either through temperature control, humidity adjustments, or chemical sprout inhibitors.

2. **Decay and Disease**: Potatoes in storage are susceptible to various diseases, including rot caused by fungi and bacteria. Research often investigates ways to prevent or minimize decay, such as through proper ventilation, disinfecting storage facilities, or exploring treatments to reduce microbial growth.

3. **Physiological Changes**: Potatoes undergo physiological changes during storage, such as changes in sugar content. Cold temperatures, for example, can lead to an increase in reducing sugars, which affects taste and frying quality. Research aims to determine optimal storage conditions to maintain quality and prevent undesirable changes.

4. **Temperature and Humidity Control**: Proper temperature and humidity levels are essential for preventing sprouting and decay, but the requirements vary depending on the potato variety and intended use. Research focusses on the ideal conditions for different storage durations and uses, whether for fresh consumption, processing, or seed use.

5. **Nutritional and Textural Quality**: Long storage periods can also impact the nutritional content and texture of potatoes. Research is focussed on how storage conditions affect these qualities and seek ways to preserve them over time.

6. **Economic Impact**: Potatoes that spoil in storage lead to financial losses for farmers, suppliers, and retailers. Research often looks at cost-effective methods to extend storage life and reduce waste, ultimately supporting a more sustainable supply chain.

1.1.5 Research Questions

- The present study hypothesises that the Māori storage method with ambient air temperature + relative humidity + darkness provided by dry fern fronds confers a storage condition that preserves quality of the taewa seed potatoes in comparable conditions to the conventional trial storage method.

The specific research questions central to this study are:

- How does fern coverage associated with environmental temperature and low light levels affect the taewa tuber quality during storage?
- To verify whether the two storage methods (Māori Storage Method – MSM and Conventional Storage Method - CSM) applied maintain the physiological quality of taewa potato seeds in the final storage period and, if so, which storage conditions were favourable to the final result.

1.1.6 Research Objectives

1.1.6.1 General objective

The general objective of this study is to determine the effects of storage inputs on graded for 'seed'. These seed are used to produce the next season's crop in New Zealand.

Specifically, the study aims to:

- Interact with Māori community and crop growers to identify traditional knowledge aligned to taewa.
- Compare the effects of two storage methods on the physiology of three taewa varieties.
- Determine the key characteristics (weight losses, sugar content, control of tuber respiration, and sprouting) which impact taewa tuber dormancy in storage.
- To contribute to the management of the accessions collection of taewa (*Solanum* spp.) by the Māori community in New Zealand.

Chapter 2

Literature Review

2.1 Introduction

The cultivated potato originated in the Andean mountains of South America (Dean, 2018). Today, it is grown in over 150 countries worldwide. However, potato production has increased less over the last six decades compared to other major food crops, except for sweet potato (Çalışkan et al., 2023). In 1961, when international statistics were first published by FAO, the potato was the most produced plant, with an annual production of 270.6 million tons. Today, it has fallen to fourth place, behind maize, wheat, and rice (Çalışkan et al., 2023). The evolutionary origin of the cultivated potato remains inconclusive, with geneticists, archaeobotanists, and taxonomists exploring various hypotheses for nearly nine decades (Spooner et al., 2014). Over 99% of European modern cultivars possess Chilean cytoplasm (Berg & Groendijk-Wilders, 2014). Potatoes are propagated vegetatively through tubers, which are greatly shortened and thickened stems bearing scale leaves with axillary buds (de Haan & Rodriguez, 2016).

The physiological properties of tubers change over time, reflected in their sprouting behaviour. This behaviour varies between cultivars and is influenced by storage conditions, commonly referred to as the 'physiological age' of tubers (Reust, 1986). Physiological age is the developmental stage of a potato seed tuber, influencing its production capacity. It determines the behaviour of each bud, affecting the number of sprouts per eye and their Vigor. It also impacts the physiological behaviour of the resulting stem, even after emergence (P. Struik, 2007). The physiological age of a planted tuber reflects its growth Vigor. While physiological age is primarily determined by the growing season (Van der Zaag & Van Loon, 1987). It progresses with chronological age and depends on the size of the tuber, the growth history of the seed crop, any treatments applied (e.g., hormonal sprays), the harvesting process, storage conditions, and treatments between storage and planting (P. Struik, 2007). Physiological age also affects the growth pattern of the plant. Plants grown from older seed tubers may senesce earlier than those from younger tubers (M. K. van Ittersum, 1992). Seed age influences various physiological processes, including dormancy length, time to emergence, stem number, leaf area index, total plant weight, Vigor, time of tuberization, yield, and quality (Iritani & Weller, 1987); (Marinus, 1993), (O'brien et al., 1983); (Walsh, 1995).

Regarding potato tuber storage, literature from Iritani (1968); O'brien et al. (1983), Jadhav et al. (1991), Kleinkopf et al. (2003), Pringle et al. (2009), Bhaskar et al. (2010), Liu et al. (2013), Bianchi et al. (2014), Paul et al. (2016), Gong et al. (2021), suggests maintaining chilling temperatures of 5.0–7.0 ˚C and relative humidity (RH) of 60–70% as ideal. Managing air circulation and light absence in the storage area is also crucial. Low storage temperatures (0–1.0 ˚C) inhibit sprouting (Kleinkopf et al., 2003), but can cause starch degradation (Matsuura-Endo et al., 2004), leading to a pulp sweetening defect. Potatoes are typically stored in refrigeration systems or room temperature storehouses without specific equipment (Bianchi et al., 2014).

2.1.1 Phenological growth stages of the potato crop

Phenology refers to the relationship between climate and plant life cycle events, such as bud burst and flower bloom (Eisavi et al., 2017). Temperature is the main factor controlling the phenological development of potatoes (Ahmadi et al., 2019). The growth and development of potato plants can be divided into several genetically and environmentally controlled stages, knowledge of which is crucial for scientists and farmers (Kolbe & Stephan-Beckmann, 1997). The four distinct stages of potato growth are the vegetative stage or tillering stage (S1), tuber formation stage (S2), tuber bulking stage (S3), and tuber maturation stage (S4) (Awgchew et al., 2016) and (Zotarelli et al., 2015) as cited in Liu et al. (2020). Figure 9 by Thomas (2016).

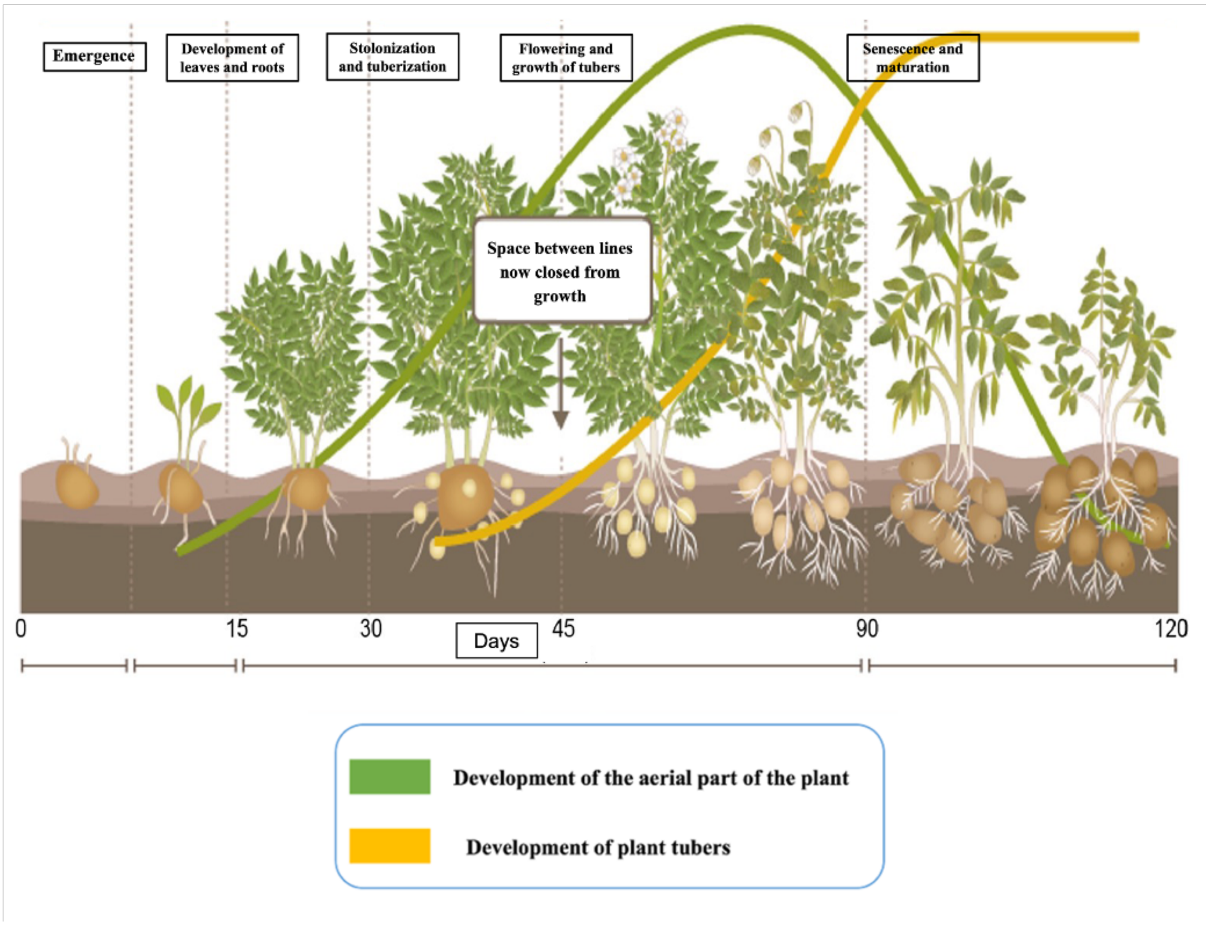

Figure 9. Phenological stages and potato plant development. Source: Thomas (2016).

During physiological development, the tuber passes through the stages of dormancy, apical dominance, full budburst, and senescence (Figure 10). According to Mani et al. (2014) Dormancy (A) is the temporary suspension of visible growth of any plant structure containing a meristem (Lang et al., 1987); Apical dominance (B) is a physiological phenomenon where a dominat bud suppresses the sprouting of the other buds (Pavlista, 2004); Full sprouting (C) when dormancy is broken, sprouting begins. This is a major visible milestone in determining tuber physiological age, starting with small white buds, often termed "pipping" or "peeping" (Sonnewald, 2001); (Daniels-Lake & Prange, 2007) and Senescence (D), this is the final development phase of the mother tuber, involving irreversible cell degeneration and sometimes programmed cell death (Zentgraf, 2007). After tuber initiation, while still attached to the plant, dormancy intensity gradually increases. Experiments show that tubers harvested early are often barely dormant, whereas later-harvested tubers have harder-to-break dormancy (Struik & Wiersema, 1999). After stem removal, dormancy intensity rapidly increases to a maximum.

Detached tubers, no longer influenced by the stem, become more vulnerable to external factors (e.g., temperature, storage conditions, etc.), potentially leading to sudden biochemical and physiological changes (Struik & Wiersema, 1999).

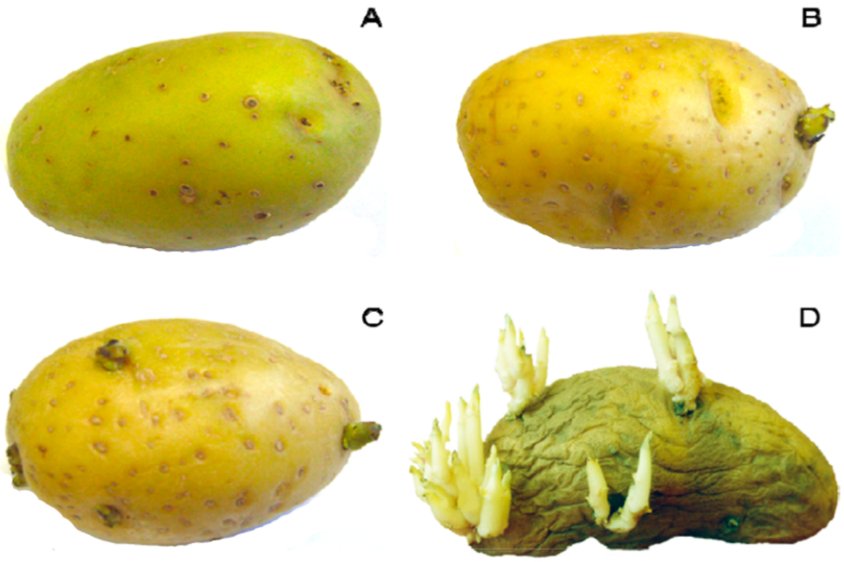

Figure 10. Physiological stages of potato tuber development. A – Dormancy; B – Apical dominance; C - Full Sprouting/ budding; D – Senescence. Source: Thomas (2016).

2.1.2 Potato dormancy

Various concepts about potato dormancy are discussed in the literature. Dormancy is generally defined as the physiological state in which a tuber does not undergo autonomous sprout growth, even under ideal conditions for sprouting (Reust, 1986). Dormancy is the temporary suspension of visible growth of any plant structure containing a meristem. This temporary suspension of visible growth occurs in any plant structure containing a meristem (Lang et al., 1987). Dormancy is a physiological condition where plants respond to stress by entering a state of growth suspension (Campbell et al., 2008). In potatoes, tuber dormancy is a state in which sprout growth does not occur for several weeks, even under conditions conducive to sprout initiation (Bryan, 1989). This growth arrest of meristematic tissue protects the tubers, serving as the organ of vegetative reproduction during winter (Aksenova et al., 2013). Sonnewald and Sonnewald (2014) said that dormancy is the physiological state of the tuber in which tubers do not sprout even when placed in ideal germination conditions. Dormancy represents a period when tubers do not sprout even in ideal germination conditions. This dormancy period is one of the five stages of the physiological age of tubers, based on visual changes related to the presence and development of sprouts (P. Struik, 2007). The length of the dormancy stage is highly dependent on genotype and storage conditions, which is crucial for post-harvest handling as it is the primary protective mechanism for plant survival against unfavourable vegetative growth conditions (P. Struik, 2007) as cited in Alexopoulos A (2021). The dormancy period, varying from 2 to 3 months, depends on genotype and pre- and post-harvest conditions (Mani et al., 2014). Before releasing any new variety, it is evaluated to ensure growers can store their produce under traditional or temperature-controlled conditions for the desired period. It is believed that five major plant hormones are involved in tuber dormancy: abscisic acid and ethylene in dormancy induction, cytokinin in dormancy break, and gibberellins and auxins in sprout development (Suttle, 2007).

Plant dormancy is further subdivided into three distinct types: endodormancy, paradormancy, and ecodormancy (Lang et al., 1987). In endodormancy, a meristem is arrested by physiological factors within the structure, preventing germination or sprouting even under favourable external conditions. In paradormancy, a meristem is arrested by external physiological factors, such as apical dominance, where a dominant bud suppresses the growth of lateral buds or tubers. Ecodormancy occurs when a meristem is arrested by external environmental factors like extreme temperatures or lack of water (Lang et al., 1987). Potato tubers can exhibit all three types of dormancies during their life cycle. After formation and for an indeterminate period post-harvest, tuber meristems (eyes) are in endodormancy and will not sprout. During extended storage, tubers exit endodormancy and begin to sprout, with typically one eye/sprout becoming dominant, inhibiting the growth of other eyes—this is paradormancy. Tubers stored at temperatures of 3.0 ˚C or lower will not sprout regardless of physiological dormancy status and are in a state of ecodormancy (Lang et al., 1987). Dormancy ends when sprouts form from buds on the tuber during storage. Both environmental and endogenous factors regulate dormancy and sprouting, involving comprehensive changes in many biochemical pathways, including carbohydrate and phytohormone metabolism (Hartmann et al., 2011).

2.1.3 Phase of Sprouting

The rate at which tuber samples progress from young to old is primarily affected by storage temperatures (Struik & Wiersema, 1999). In addition to these conditions, sprouting and growth Vigor of seed tubers depend on seed tuber size (Burton, 1978b). The number of sprouts on a tuber depends on the physiological stage when environmental conditions permit sprout growth. At low storage temperatures (e.g., 4.0 ˚C), sprout growth does not occur, but seed tubers continue to age. If a tuber starts sprout growth just after dormancy breaks, it remains in the stage of apical dominance (Struik & Wiersema, 1999). Struik and Wiersema (1999) noted that this will also be the case when seed tubers are stored at relatively high temperatures (e.g., 15.0 ˚C) which enhance sprouting before aging progresses. An apical sprout dominates other buds, keeping them dormant. When seed tubers at this stage are planted, they often show one main stem developing at a relatively low rate, which is typically undesirable for planting due to reduced yield potential. However, in short seasons with low optimal stem densities and premiums for large progeny tuber sizes, apical dominance may be beneficial (Struik & Wiersema, 1999). Sprouting is controlled by phytohormone levels (Mani et al., 2015). The same authors said that two phytohormones, ABA and ethylene, are believed to suppress tuber sprouting. Both cytokinins and gibberellins are necessary for bud break and sprout growth, respectively, while auxin plays a role in vascular development.

During dormancy, buds are symplastically isolated, a condition that changes during bud break. Vascular tissue develops below the growing bud to support the sprout with assimilates mobilized in parenchyma cells (Mani et al., 2015). In a review publication, Mani et al. (2015) proposed that sprouting period is a complex process influenced mainly by genetic background, tuber development stage, and environmental and management conditions during tuber growth and storage. They highlight the importance of temperature, humidity, water supply, and photoperiod during plant growth in regulating potato tuber sprouting. Storage temperature and gas composition control dormancy and sprouting. Various chemicals are used to inhibit or induce sprouting in potatoes. Additionally, hormonal regulation through endogenous and exogenous phytohormones is crucial in controlling potato sprouting.

2.1.4 Potato storage conditions

The primary goals of storage are to maintain the material in optimal condition and to prepare it appropriately for its intended use. The storage regime varies depending on the cultivar (as they respond differently to storage conditions) and on the time and method of using the seed tubers (Struik & Wiersema, 1999). Booth and Shaw (1981) noted that when it comes to storing potato seeds, two critical aspects must be considered: the storage climate (interior climate of the store) and the exterior climate of the store. The exterior climate refers to the natural climate at the storage building's location, including factors like wind, rain, humidity, hours of sunlight, maximum and minimum daily temperatures, and the number of hours per day the temperature falls below a certain level (typically 10.0 ˚C). This data is required for the months when the potatoes are to be stored. The interior climate is the desired environment for the potatoes during the storage period and for their intended use. The indoor climate is primarily controlled to ensure the quality of the potatoes, minimize sprouting, reduce weight loss, inhibit the spread of storage diseases, and dissipate the heat produced by potato respiration.

Four key factors determine storage losses: the potato variety, pre-storage conditions, storage conditions, and storage duration (Eltawil et al., 2006). Even with optimal storage, it must be recognized that storage losses are inevitable. Good storage practices can only limit these losses over extended periods. Storage losses are often measured as weight loss and quality degradation, although these two metrics are not always distinct. Losses are mainly due to respiration, sprouting, water evaporation from the tubers, disease spread, changes in chemical composition and physical properties, and damage from extreme temperatures. These processes are influenced by storage conditions (Eltawil et al., 2006). By maintaining favourable storage conditions, the aforementioned losses can be minimized. It may appear contradictory when Burton (1992) states that the storability of potatoes is predetermined by factors such as cultivar, growing techniques, soil type, weather during growth, pre-harvest diseases, maturity at harvest, and tuber damage during lifting, transport, and storage.

The four main uses for stored potatoes are: seed potatoes, household consumption, the processing industry, and as raw material for starch or alcohol production. The storage method should be chosen based on the requirements for each purpose, but wound healing is crucial immediately after harvest for all uses (Eltawil et al., 2006). Good storage should prevent excessive moisture loss, rot development, and excessive sprout growth. It should also prevent the accumulation of high sugar concentrations, which can result in dark-coloured processed products. During storage, temperature, humidity, CO_2 levels, and air movement are critical factors (Hardenburg et al., 1986) and (Maldegem, 1999) as cited in Eltawil et al. (2006). The optimal way to maintain tubers in good physiological and health conditions is to store them at about 2.0 – 4.0 ˚C (Eltawil et al., 2006). Some cultivars exhibit reduced sprouting capacity when stored at 2.0 ˚C and should therefore be kept at slightly higher temperatures. To promote the development of numerous vigorous sprouts per seed tuber, delaying sprout growth beyond the natural dormancy and apical dominance stages is effective. This can be achieved by storing tubers at low temperatures (4.0 ˚C) until the apical dominance stage is over. At 4.0 ˚C, no sprout growth occurs, but physiological aging continues through various phases (Eltawil et al., 2006). After the low-temperature storage phase, the temperature can be increased (above 15.0 ˚C) to promote sprout growth (optimal at about 18.0 ˚C), resulting in multiple sprouting (Eltawil et al., 2006). Regardless of the end users, they seek a quality product. For table markets, external appearance—size, shape, and defect freedom—is crucial. In contrast, the seed market prioritizes tuber health, Vigor, and physiological age over appearance (Walsh, 1995).

2.1.5 Temperature

When storing seed potatoes for planting the next crop, temperature is a critical factor. Controlling the temperature during storage is essential to reduce sprouting and, consequently, prolong dormancy. Some authors note that dormancy can be extended by keeping tubers at low temperatures (Struik & Wiersema, 1999) which inhibit budding, reduce microorganism infections, minimize fresh mass loss, increase shelf life, and extend the marketing period (Zommick et al., 2014). Optimal temperatures for prolonged storage are 2.0 – 4.0 ˚C (Struik & Wiersema, 1999), but low temperatures during refrigerated storage can increase reducing sugar content in the tuber, lowering processing quality (Zommick et al., 2014). Storage temperature also affects wound healing rate and low temperatures (<10.0 ˚C) result in slow healing, while high temperatures (>25.0 ˚C) do not affect cork development rate but cause increased weight loss due to higher respiration rates (Wang et al., 2020). Therefore, recommended temperatures for wound healing range between 12.0 and 15.0 ˚C to avoid pathogen infections (Alexopoulos A, 2021). Adequate temperature conditions are crucial in tuber storage to maintain quality and ideal physiological conditions (Khanal & Uprety, 2014).

2.1.6 Relative air humidity

When storing potato tubers, both humidity and temperature control are crucial (Struik & Wiersema, 1999). The ambient temperature influences how plants process energy in their environment. Changes in relative humidity and temperature directly impact photosynthesis, affecting plant growth and development. Maintaining these conditions within the desired range ensures that photosynthesis is not compromised (Thazin et al., 2019). Therefore, it is essential to regulate environmental parameters such as relative humidity and air temperature to enhance plant growth (Chia & Lim, 2022). According to Fanourakis et al. (2016), relative humidity

(RH) is the ratio of the water vapour pressure in the air to the water vapour pressure at saturation.

RH is closely linked to ambient temperature because vapour pressure at saturation increases as air temperature rises. These authors also note that vapor pressure deficit (VPD) is the difference between saturation vapor pressure and actual air vapor pressure, combining the effects of RH and temperature. Higher VPD signifies drier air. Consequently, tubers, which contain large quantities of water, require this water to function properly (Struik & Wiersema, 1999). After sprouting begins, water loss and respiration may increase. While low temperatures can suppress respiration, water loss must be controlled through low temperatures and high relative humidity (Struik & Wiersema, 1999). Early in the storage season, when surface drying, periderm formation, and wound healing are critical, air humidity should not be too high; optimal healing occurs at an RH of about 80-90%. Below this range, the air is too dry, inhibiting or even preventing healing (Lange et al., 1970) as cited in Struik and Wiersema (1999). High humidity is crucial for maximum wound recovery and during the storage period (dormancy) to reduce tuber weight loss. Relative humidity below 90% helps prevent significant tuber weight loss. Between 38% and 66% relative humidity, tubers start to sprout, leading to considerable weight loss over time (Ezekiel & Singh, 2003).

2.1.7 Effect of light

The effect of light on innate dormancy is likely minimal; however, light significantly contributes to enforced dormancy (Wiltshire & Cobb, 1996). Seed potatoes are grown across various latitudes and seasons, experiencing different levels of irradiance and photoperiods (M. Van Ittersum, 1992). These varying growth conditions may result in differences in tuber dormancy. Light, especially wavelengths longer than 500 nm (blue) or 650 nm (red and far-red), has a strong influence (McGee et al., 1987). At low northern latitudes tubers produced in autumn and winter have a longer dormancy period than those grown in spring. Besides temperature, light intensity and photoperiod may also play a role (Susnoschi, 1981b).

Although seed potatoes are often stored in darkness to prevent sprouting, light can also induce dormancy breaking to some extent. This effect is linked to the increased synthesis of chlorophyll (turning tubers green), chlorogenic acid, α-solanine, and α-chaconine (both harmful glycoalkaloids), total amino acids, and crude protein (Struik & Wiersema, 1999).

Percival et al. (1998) stated that tubers subjected to enforced dormancy are sensitive to light and photoperiod, which they can perceive through skin pigments, and are better protected against storage pathogens and pests as cited in Struik and Wiersema (1999).

2.1.8 Composition of the atmosphere

While the atmospheric composition has little effect on innate dormancy, it significantly influences sprout growth (Wiltshire & Cobb, 1996); (Mortimer & Bishop, 1998) as cited in Struik and Wiersema (1999). In potato storage, tubers consume O_2 and produce CO_2. Without proper ventilation, the O_2 content may drop, enhancing sprouting. In seed lots with severe internal or external damage, high respiration necessitates adequate ventilation, especially early in the storage season for long-term storage. Manipulating the O_2/CO_2 ratio or even the ethylene content can advance or delay dormancy breaking and control sprout number. Controlled atmosphere storage is commonly used for many vegetables. Extensive research has explored the feasibility of controlled atmosphere storage for seed potatoes. Although the effects are significant and consistent, this technique is not widely used in practice. Proper ventilation and temperature control are simpler methods to manage atmospheric composition (Struik & Wiersema, 1999).

2.1.9 Changes on potato resulting from storage

2.1.9.1 Respiration

Even in dormancy, potato tubers remain metabolically active. Respiration provides indirect information about intermediate production by plant tissues and direct information about energy production (Gude, 1989). Respiration is essential for cell maintenance and measurable throughout dormancy, resulting in slow carbon and weight loss. Respiration includes photorespiration, sensitive to light, and dark respiration, which is not light-sensitive and includes maintenance and growth respiration. Maintenance respiration accounts for 20-25% and growth respiration for 5-10%, with maintenance respiration being less temperature-sensitive than growth respiration (Beukema & van der Zaag, 1990). Temperature significantly influences respiration (Hopkins, 1924), which generally decreases from a high value at harvest to a lower basal level within weeks. Immediately after harvest, respiration rates drop rapidly from 20 mg CO_2 kg^{-1} h^{-1} to 5 mg CO_2 kg^{-1} h^{-1} over three weeks at 22.0 ˚C (Kimbrough, 1925); (Appleman & Miller, 1926) and (Smith, 1929) as cited in Schippers (1977). According to Burton (1992), depending on temperature, cultivar, tuber maturity, and previous field conditions.

Respiration rates are low in dormant potato tubers but increase at the end of dormancy as sprout growth requires more energy (Smith, 1977). The progressive rise in respiration rates during prolonged storage (at 4 ˚C) fuels age-dependent, energy-intensive metabolic changes, many due to oxidative stress (Kumar & Knowles, 1996). It remains unclear whether increased respiration results from intensified respiratory system functioning during dormancy or the initiation of new energy-producing systems during cell division and elongation (Smith, 1977). Exposure to higher temperatures (>4 ˚C) clearly increases tuber respiration rates (Rastovski & Es, 1987).

2.1.9.2 Weight Loss

During storage, potatoes experience gradual weight and quality loss, including moisture loss, respiratory loss, and changes in sugar levels (Kuyu et al., 2019) as cited in Khanal and Bhattarai (2020). Potato tubers lose weight through respiration, converting sugars and starches to carbon dioxide and water, and losing moisture due to vapor pressure differences between the tubers and the surrounding air. Moisture loss leads to quality degradation and eventually to non-marketable produce (Singh & Kaur, 2016) as cited in Khanal and Bhattarai (2020).

Weight loss determines the longevity and keeping quality of tubers. Variations in weight loss among cultivars are attributed to either their periderm characteristics or sprouting behaviour. Weight loss in unsprouted tubers occurs through the periderm and minimally through the lenticels (Mani et al., 2014). Hence, varieties with a thick periderm (many cell layers) and fewer lenticels lose less weight than others (Struik & Wiersema, 1999); (Ezekiel et al., 2004) as cited in Mani et al. (2014). Conversely, sprouted tubers lose significantly more weight than unsprouted ones. After sprouting begins, the rate and number of sprouts determine weight loss in potatoes. Greater water loss with sprout growth occurs due to the high permeability of the sprout wall to water vapor. Pandey et al. (2007) as cited in Mani et al. (2014) observed a significant correlation between weight loss and both the length of the longest sprout and the number of sprouts per tuber.

2.1.9.3 Sugar and starch content

Reducing sugar content is crucial for tuber quality, especially for table potatoes and potato processing potential. Reducing sugars (mainly glucose and fructose) are substrates for the non-enzymatic Maillard reaction, leading to undesirable browning and nutritional changes during processing. Sucrose, a non-reducing sugar, is less important but can cause an undesirable sweet taste at high concentrations. Generally, reducing and non-reducing sugar levels increase as storage temperature decreases below 10 ˚C, with rates rising rapidly below about 7 ˚C (Burton, 1992). Low-temperature-induced reducing sugar accumulation can be reversed by briefly increasing storage temperature to between 10 ˚C and 20 ˚C, a process known as reconditioning, where glucose and fructose are metabolized by glycolysis and respiration, with some reconverted to starch (Williams & Cobb, 1992). When sprouting begins, the reducing sugar pool increases as starch is hydrolysed for growth. It's long known that potato sugar content increases when stored at low temperatures (Smith, 1977). Sugars increase due to starch breakdown at low temperatures but decrease at high temperatures due to respiration and starch synthesis.

Sugar levels formed during low-temperature storage depend on variety, maturity, pre-storage conditions, and temperature. The extent of sugar loss on exposure to high temperatures also varies by variety and maturity (Smith, 1977). A large increase in total sugars, primarily reducing sugar, occurs in potatoes stored at approximately 1.1 ˚C to 5.5 ˚C, with less increase at approximately 10 ˚C and 15.5 ˚C where a slight reduction may occur. Most reducing sugars in tubers stored at 15.5 ˚C are in the sprouts. The dividing line between relatively high and low sugar content occurs between storage at approximately 10 ˚C and 4 ˚C. Sucrose, glucose, and fructose are the main sugars in potatoes, with fructose being most responsive to storage temperature changes. As temperature and sprouting increase, sucrose becomes more important in the accumulation process (Smith, 1977).

Starch is the main carbohydrate in potato tubers, and its phosphorylation during biosynthesis significantly affects the technological properties of potato starch (Lu et al., 2011). Starch biosynthesis involves converting G-1-P into adenosine-5'-diphosphoglucose (ADP-glucose), from which amylase and amylopectin are synthesized to form starch grains. Starch breakdown pathways differ between photosynthetic and non-photosynthetic tissues (Avigad & Dey, 1997). During dormant tuber storage and after dormancy breakage, there is a progressive reduction in starch concentration, correlating with changes in enzyme activities involved in starch synthesis and breakdown (Benkeblia et al., 2008). Starch content decreases during storage due to respiration, while dry matter changes depend on both respiration and evaporation (Burton, 1992). During sprouting, starch content decreases (Smith, 1977).

2.1.9.4 Plant Hormones

Tuber development is regulated by an interplay between endogenous and environmental signals, orchestrated by metabolic changes, and controlled by phytohormones including abscisic acid (ABA), ethylene, gibberellins (GAs), cytokinins (CK), and auxin (AIA) (Gude, 1989). Abscisic acid (ABA) is often cited as the crucial component of the inhibitor B-complex in potato tuber tissue, responsible for dormancy (Milborrow, 1967); (Bialek et al., 1973) as cited in Gude (1989). ABA is required for both initiation and maintaining tuber dormancy (Suttle & Hultstrand, 1994). It is viewed as an inhibitor of bud growth, overcoming the effects of promoters and disappearing when dormancy is broken (Cvikrová et al., 1994) as cited in Wiltshire and Cobb (1996). Ethylene is a key hormone in the development and physiology of potato tuber tissue, stimulating sugar breakdown via glycolysis (Solomos & Laties, 1975) as cited in Gude (1989). Increased ethylene production extends dormancy by promoting phenolic inhibitor biosynthesis (Cvikrová et al., 1994) as cited in Wiltshire and Cobb (1996). Since the mid-1950s, gibberellins (GA) have been known to trigger tuber sprouting (Brian et al., 1955); (Rappaport, 1956); (Rappaport et al., 1957). GA's dormancy-releasing capacity was confirmed through various methods, including injecting GA below the apical bud complex or bathing isolated tuber buds in GA_3 solution (Suttle, 2004); (Hartmann et al., 2011); (Rentzsch et al., 2012). These treatments with bioactive GA species terminate dormancy and stimulate bud outgrowth (Rentzsch et al., 2012).

Cytokinins (CK) play a vital role in bud break and tuber sprouting initiation. They indicate the importance of metabolic and hormonal balance in this process, suggesting that GA activity requires CK to stimulate meristematic activity and bud break (Sonnewald & Sonnewald, 2014), while ABA and ethylene are mainly linked with tuber dormancy onset and maintenance, GAs and CKs are associated with dormancy release and sprouting (Sonnewald & Sonnewald, 2014). Though auxin is crucial for plant growth and development, its role during tuber dormancy and sprouting is not well understood and has been poorly investigated. Research has shown that high concentrations of exogenous indole-3 acetic acid (IAA) inhibit sprout growth, while low doses stimulate growth in bud-containing tuber slices (Hemberg, 1949); (Suttle, 2007). Bioassay and HPLC-derived data suggest increased IAA levels after bud break (Hemberg, 1949); Sukhova et al. (1993), indicating no direct role for auxin in dormancy control. These results suggest that auxin biosynthesis, transport, and signalling may be required for cellular differentiation during bud break and outgrowth, but more investigation is needed (Sonnewald & Sonnewald, 2014).

2.1.9.5 Technology for potato storage and transport

Regarding the contemporary application, it is important to stress the care that must be taken from the moment of harvesting to the transport of the harvested potato to the proper storage location. An important point to remember is the exposure of the tubers to the sun throughout the post-harvest process, which should be avoided due to the greening and moisture loss of the product.

Potatoes are normally transported by truck, in various packages, such as big-bags, bags, boxes, or in bulk, always taking care not to cause mechanical injuries that could degrade the quality of the product, whether due to physiological changes or entry of pathogenic microorganisms, both resulting from the injuries caused. Transport and storage must be carried out in such a way as to provide aeration of the product, with transport in trucks with open bodies on the sides and storage must occur in cool and ventilated environments. If potatoes are to be used for consumption, care should be taken if storage is refrigerated, in cold chambers, and very low temperatures should be avoided, as temperatures below 10.0 ˚C favour the accumulation of reducing sugars, which cause browning of the product after frying.

There are several articles addressing the technology of potato management during the storage period Hanafi (1999); Eltawil et al. (2006); Olsen et al. (2006); Pinhero et al. (2009); Pringle et al. (2009); Gottschalk (2011); Bojanowski et al. (2013); Murigi et al. (2021); Cunnington (2023). In general, several factors are included in potato storage technology. A well-designed building, proper insulation, and adequate refrigeration machinery alone cannot ensure good storage business results. Effective storage management also requires vigilant management, careful operation, maintenance of the plant, and qualified, experienced managers. When potatoes are stored in a warehouse, the ventilation fan should run continuously during the equalization phase (immediately after placing the potatoes in storage) to allow the pile to achieve temperature equilibrium. Successful curing of potatoes is achieved by subjecting them to 8.0-20.0°C and 85% RH for 7 to 17 days. Temperature control is crucial to prevent additional respiratory losses and the development of fungal or bacterial diseases.

Chapter 3

3.1.1 The introduction of potato into New Zealand

There are different beliefs regarding the origin of taewa in New Zealand and the routes they took to get here. Many Māori believe that varieties of taewa existed before European explorers arrived (Roskruge, 1999). It is generally accepted that potatoes were first introduced to New Zealand in the late eighteenth century by Captain James Cook and the French explorer Marion du Fresne (Harris & Niha, 1999). The ancestors of Māori arrived on canoes from Pacific islands before 1300 CE. They lived in small tribal groups with rich culture of oral traditions and strong traditions of warfare. Their ancestors and the gods of the natural world were highly significant (Te Ara, 2023[15]). According to Furey (2006), the Polynesian ancestors of Māori, upon settling in Aotearoa New Zealand, brought well-established traditions and techniques for growing staple crops. Initially settling on the coast, they hunted seals and moas, large flightless birds (*Dinornis novaezealandiae*), native to New Zealand, which became extinct around 600 years ago due to human hunting and habitat changes (Worthy & Holdaway, 2002). Furey (2006) publication provides detailed explanations of this history. According to the author:

> "*The ancestors of Māori also began to grow food, and some moved to the forests. Within the New Zealand landscape, there is ample and varied evidence of the continuation of those gardening practices, and of the changes and adaptations that were made over time to accommodate local circumstances and environmental conditions (Walton, 2000). Stone rows were noted in the Warea area in the 19th century, but these no longer exist. They were probably removed by European farming activities. The distribution of storage pits in undefended sites and pa[16] mirrors the pattern for borrows pits. These amorphous, and sometimes large, depressions found in geographically restricted localities are the result of sand or gravel being removed from the ground and added to nearby soils. More appropriately, these features could be called 'quarry pits' (Buist[17] 1993), but the term 'borrow pit', adopted from an engineering term, is now entrenched in the literature. Borrow pits are found in the Hamilton Basin, at Aotea in the Waikato, in north and south Taranaki, Tasman Bay in the Nelson area, Clarence River on the east coast of Marlborough, and at Kaiapoi, Birdlings Flat and Taumutu in Canterbury (Figure 12). Borrow pits are the visible indicator that modified soils are present in the area; the material extracted from the*

[15] See in:

https://teara.govt.nz/en/maori#:~:text=The%20ancestors%20of%20Māori%20arrived,and%20strong%20traditions%20of%20warfare

[16] Pa in Māori language means small village.

[17] Buist, A. 1993. South Taranaki quarry sites. Archaeology in New Zealand. 36:66-74.

> *pits was rarely transported more than 100m (Cassels & Walton, 1992). The location of borrow pits is inextricably linked to expanses of modified soil used as gardens. They therefore contribute to the overall picture of focal points and the density of evidence in the archaeological landscape. Historically, Captain Cook, on the many visits he made to the Marlborough Sounds during his three voyages, did not report on gardening or evidence of recent gardening, but members of D'Urville's exploring party noted that potato and kūmara were being grown on the western side of Tasman Bay in 1827"* Law (1969). (Pages 22, 44, and 73).

Māori growers stored kūmara (*Ipomoea batatas*) and taewa (*Solanum* spp.) potatoes inside these storage pits (Davidson et al., 2006). The NgaRauru iwi of South Taranaki grew a potato called Tatairongo, named after their ancestor – te Reke Tatairongo – said to have obtained the first tuber from Te Ao Po (the netherworld) (Roskruge, 1999). Whatever the potato's origin in New Zealand, Māori quickly recognized the advantages of the introduced potatoes, which were easier to grow, yielded more heavily, and were easier to store. Potatoes soon became a staple crop, with various varieties receiving Māori names (Roskruge, 1999). Unlike kūmara, they could also be grown in colder regions of the country. Māori also saw the potato's potential as a commercial crop for trade. By the early 19th century, Māori agriculture was becoming commercialized, moving away from a wholly subsistence nature. During the Irish potato blight catastrophe, Māori agricultural production was at its peak. Māori-grown produce significantly fed the European population of Auckland Province and contributed to exports, mainly to Australia. At that time, Māori also produced other European-introduced crops on a commercial scale, including maize, wheat, cabbage, and turnips (Roskruge, 1999).

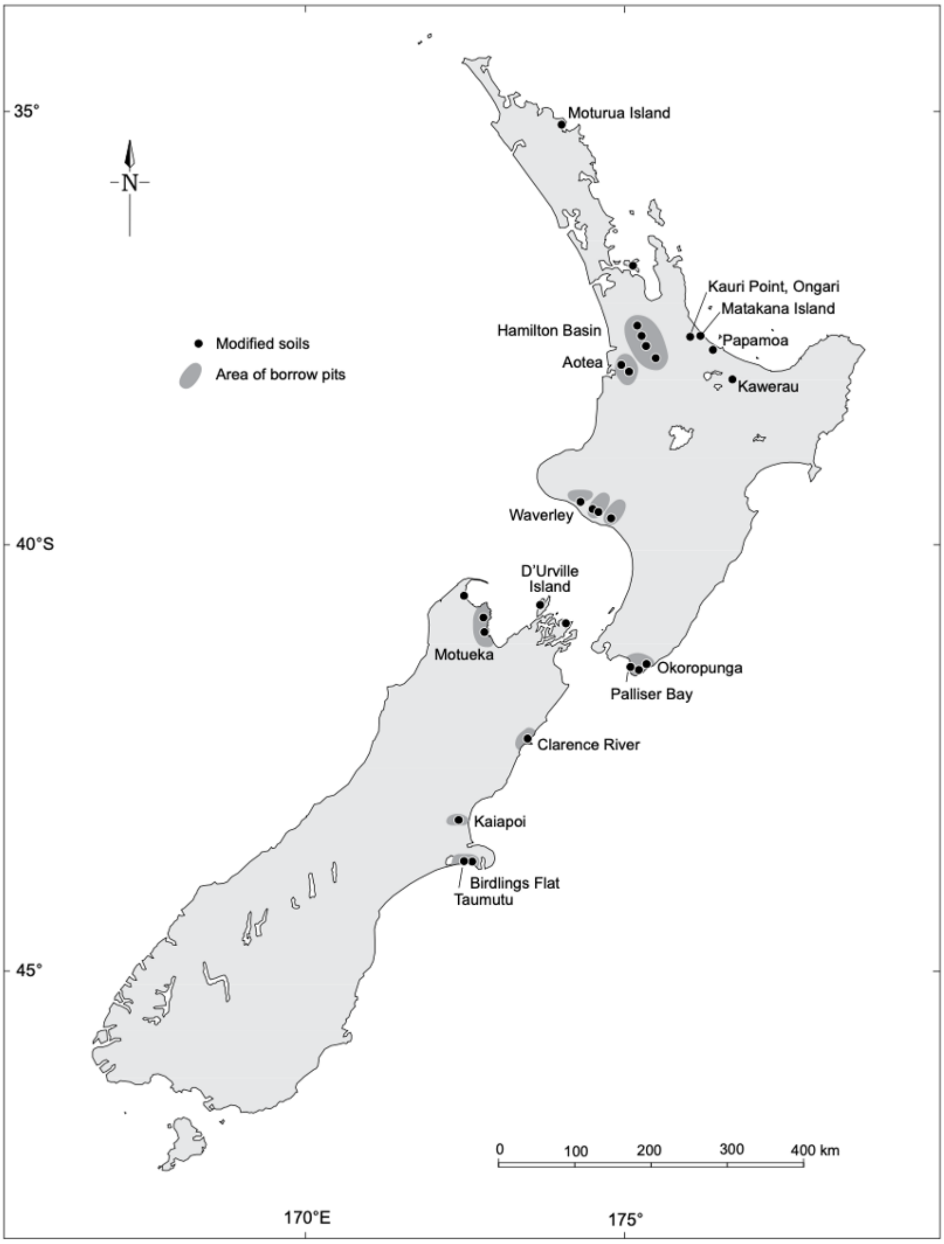

Figure 11. Distribution of recorded archaeological sites with modified soils and borrow pits. Coarse sand and small gravel were extracted from underlying deposits and added to soil before gardening. In other places, beach shells were added to the topsoil, or tephra layers were displaced. Map: C. Edkins, DOC, Source: Furey (2006).

The publication by Harris (2006) discusses relevant explanations about the causes and crises faced by Māori growers at that time. According to this author:

> "*Following the New Zealand land wars of the 1860s, Māori were dispossessed of most of their lands. As a result, there was a general deterioration in their health and well-being — a factor that contributed to a significant decline in the Māori population. European writers of the time described Māori as having become 'dispirited' and*

'fatalistic'. One result of this was that many Māori communities gave up growing traditional crops, as well as many of the European-introduced vegetable crops they had adopted earlier and became dependent on the potato as their main food source. Because of their reliance on the potato, when the crops in the North Island and most of the South Island were destroyed by a widespread potato blight epidemic in 1905 and 1906, Māori were particularly badly affected. The situation was further complicated by summer frosts, which damaged maize and those kūmara crops that were still being grown, as well as by flooding, which destroyed many remaining crops in the northern part of the North Island. The government of the time put in place a programme to supply Māori communities with 'seed' of modern 'blight-proof' potato varieties, and seeds and seedlings of a range of other common vegetable crops. They also planned to import high-yielding sweet potato 'seed' from California for distribution to Māori communities, to reduce their dependence on the potato and to replace or complement the traditional kūmara varieties. The programme was implemented by the Native Department, in co-operation with the Department of Agriculture and the Education Department". (Page 3).

Harris and Niha (1999) noted that, assuming such potatoes are relicts of varieties brought from Europe in the late eighteenth and nineteenth centuries, they have been maintained within whanau (Māori families) for possibly over 200 years – perhaps eight to nine generations. Harris and Niha (1999) also highlights the significant sentimental value and practical reasons for maintaining these old varieties. Passed down through generations, these tubers represent a taonga (something highly prized or treasured) left by their tipuna (ancestors). Roskruge et al. (2010) noted that varieties of Māori potatoes can be distinguished by their names, such as *peruperu*, *huakaroro*, *raupī*, or *moemoe*. Although potatoes and taewa are genetically the same plant, both being *Solanum Tuberosum*, there is a cultural and historical distinction. The history of taewa is more closely aligned with Māori, as Pākehā historically had limited interaction with these varieties since their introduction to the country. Another factor distinguishing taewa from potatoes is their resilience. Older varieties of taewa are noted for their disease resistance, particularly compared with modern potatoes (Webb Malone, 2023), pp.64).

Māori potatoes are identified by two major subspecies: ssp. *andigena* (Peruvian/Andean), and ssp. *tuberosum* (Chilean) (Roskruge[18] *et al.* 2019). They are collectively known by at least three primary names that vary according to tribe and dialect across Aotearoa/New Zealand – taewa,

[18] Roskruge, N., Puketapu, A., McFarlane, T. (2019). Pests and diseases of Taewa (Māori Potato) crops. ISBN 978-0-473-17613-6. 2nd ed). Rata Press. https://owll.massey.ac.nz/referencing/apa-interactive.php

parareka and peruperu, as well as sometimes being called rīwai, a generic term understood to identify the more recent "European" potato (Roskruge *et al.* 2019).

Roskruge *et al.* (2019) reiterate that the potato originates in the South American regions of Perú and Chile and there are several beliefs regarding the origin of the Māori potato in New Zealand and the route taken to get here. It is generally accepted that potatoes were not brought as cargo during the migrations of Māori to Aotearoa/New Zealand but how they arrived is an interesting point. Some believe chance visits by unrecorded trading vessels that may have earlier visited South America are responsible for the introduction of taewa, while some tribes believe taewa were sourced by their own people from the bush or through other obscure processes (Roskruge *et al.* 2019). Nowadays these potatoes are produced across all Aotearoa/New Zealand by Māori growers basically using the same process and technology as commercial crops, but it is important to inform that before European contact, Māori growers had no beasts of burden, no metal tools or implements, very few crop pest and disease issues, and no exposure to other cultures.

3.1.2 Characteristics of Māori potatoes

The Dictionary of New Zealand English Orsman (1997) described Māori potatoes as any of several varieties of mealy potatoes with reddish or purple skins and some interior colouration, grown originally and traditionally by the Māori. These present varieties possibly descended from stock introduced in the late 18th or early 19th centuries. Yen (1962) notes that 'In such characters as plant habit and vigour, flower colour, tuber shape, colour and texture, the Māori varieties exhibit a considerable range in variation'.

3.1.3 Description of varieties

For the development of this research, three distinct Māori varieties were used: Huakaroro, Moemoe, and Tutaekuri. Below are descriptions of these varieties based on Harris and Niha (1999).

3.1.3.1 Huakaroro

This taewa variety has a yellow skin which is often splashed with pink and covered in numerous small brown dots. It is sometimes called 'White Māori'. It has a very knobbly, slightly elongated shape and deeply set eyes. It yields more heavily than most other Māori varieties, and the tubers are often very large. When boiled, the hard waxy tubers, which have yellow flesh, remain firm (Harris & Niha, 1999) (Figure 13a).

3.1.3.2 Moemoe

One of the more commonly grown of the Māori potatoes. Tubers are round-to-slightly-elongated with yellow-and-reddish mottled flesh and deep-set eyes. The tubers' flesh is yellow, often with purple flecks around the vascular ring. They are a waxy potatoes that remains firm after boiling (Harris & Niha, 1999) (Figure 13b).

3.1.3.3 Urenika or Tutaekuri

By far the most widely known of the Māori potatoes, this variety is grown by Māori communities all over New Zealand. It is a potato that persists in the ground for long periods without cultivation and is sometimes found growing 'wild' on old Māori occupation sites and abandoned gardens (Harris & Niha, 1999) (Figure 13c).

Figure 12. Tubers of taewa potato. (a) Huakaroro; (b) Moemoe; (c) Tutaekuri.

3.1.4 Māori methods for storage of taewa and kūmara

When it comes to storing seeds from taewa potatoes or any other crop that has been used by Māori ancestors throughout New Zealand's history, some information on this type of subject has been found in the literature Walsh (1902); Leach et al. (1979); Lawlor et al. (1983); Challis (1991); Sutton (1993); (Best, 2005); Furey (2006); Davidson et al. (2006). In fact, archaeological research carried out in New Zealand has proven that Māori ancestors stored vegetables in pits for their subsistence. Basically, all the results of these studies proved that sweet potatoes (*Ipomoea batatas*) were the vegetable used in this storage method. Māori growers called the sweet potato Kūmara. The sweet potato, or kūmara, likely originated in or near northwestern South America. Common names for this plant in Latin America include *batata*, *camote*, *bonlato*, *batata doce*, *apichu*, and *kumara* (Huamari, 1992). The sweet potato (family *Convolvulaceae*, Genus *Ipomoea*, species *Ipomoea batatas*) is not botanically related to the potato (family *Solanaceae*, Genus *Solanum*, species *Solanum tuberosum*) (Huamari, 1992); (Ugent, 1970). The main similarity between these root crops is their similarly sized edible 'tubers', used for storing nutrients. However, the potato is a thickened modified stem (a botanical or true tuber), whereas the kūmara is a specialized swollen root (not a true tuber, though conventionally referred to as one) (CIP[19], 2014).

In New Zealand archaeological research was carried out with the aim of identifying the cultural traditions that were used by Māori growers to store food. Pits have been found in basically every region of the North Island of New Zealand (Furey, 2006). This research revealed that storage pits and archaeological garden sites indicate that gardening was viable at the northern end of the South Island and in favourable locations on the eastern coast as far south as Banks Peninsula. Radiocarbon dates show that gardens on the Marlborough coast were in use from the early settlement period through to the European period (Challis, 1991) as cited in Furey (2006). Kūmara tubers have been archaeologically recovered from two sites: Waioneke on the Kaipara Harbor (Leach et al., 1979) as cited in Furey (2006), and NZAA site number P05/288, known as Haratua's Pa, at Pouerua in Northland (Sutton, 1993) as cited in Furey (2006). In both cases, the kūmara excavated from storage pits were carbonized, or burned. Tubers from P05/288 were identified as varietal types Rekamaroa and Hutihuti/Taputini (Sutton, 1993) as cited in Furey (2006). The successful varieties of Kūmara grown in New Zealand may have been more adaptable to cooler conditions and faster maturing than modern tropical varieties grown experimentally in New Zealand (Furey, 2006). In the Wanganui region, as an example, pits dominate the archaeological evidence of gardening, accounting for 82% of the 78 recorded sites (Figure 14).

[19] Centro Internacional de la Papa [CIP]. (2014). Facts and figures about the potato [Fact Sheet]. Lima, Perú: Centro Internacional de la Papa.

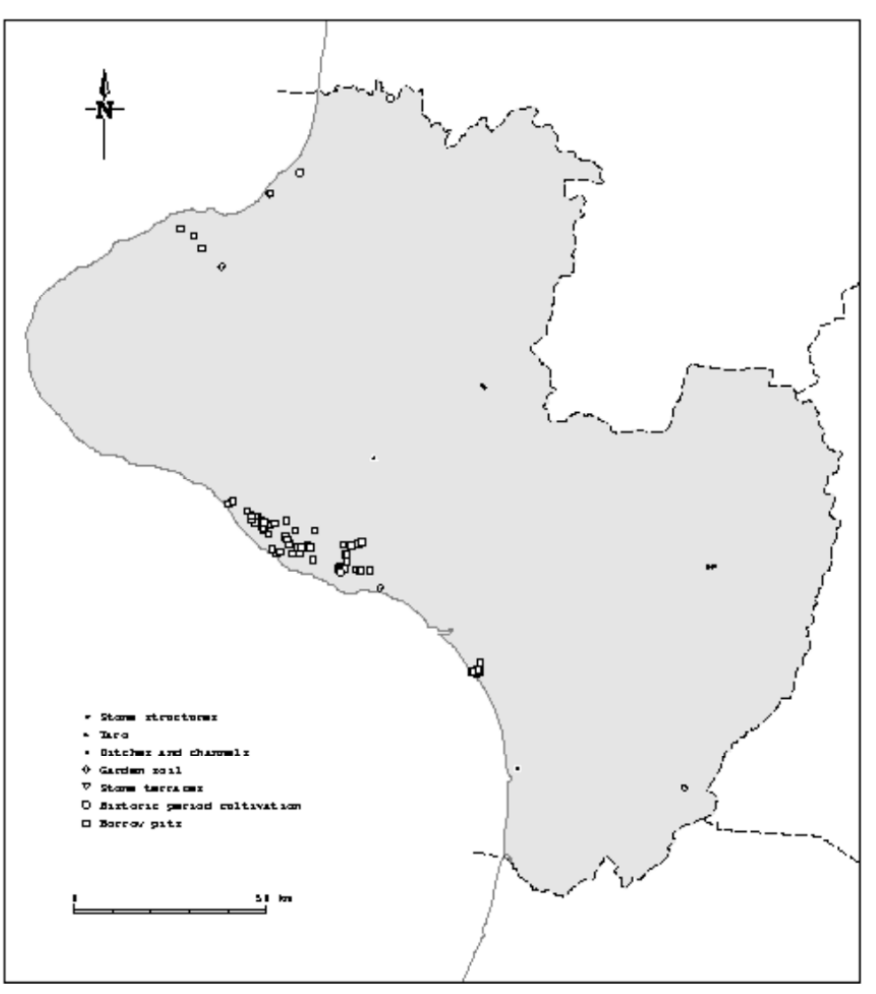

Figure 13. Distribution of recorded Māori horticulture-related archaeological sites, Wanganui Conservancy region, Department of Conservation. Map: C. Edkins, DOC. Source: Furey (2006).

In other archaeological research conducted in Marlborough (region of New Zealand, at the northeastern tip of the South Island), Davidson et al. (2006) evidenced the storage of kūmara (sweet potato) tubers in pits (dating mainly from the end of the 19th century and early 20th century). In this research, archaeologists argue that this storage method was an essential part of the pre-European Māori horticultural cycle throughout New Zealand's history.

The pits showed enormous variation in size, length-width-depth proportions, presence or absence of buttresses, and fire features. Bell-shaped and cave pits could only be dug in certain places, and variations in roofed rectangular pits (e.g., presence or absence of drains and stone retaining walls) were attributed to the nature of the material in which they were dug (Figure 15 and 16) (Davidson et al., 2006). The results of this research showed that the storage method adopted by Māori growers, all activities relating to the storage period were closely monitored by the growers. It was shown that in this area, regular human intervention would be required to ensure survival of seed tubers until the next planting season. People would have to inspect each tuber, remove rotting ones, light fires in cold weather, and regularly exchange air in the pit. This methodology adopted by Māori growers with Kūmara was probably the same method used to store taewa, because as mentioned by the researchers of this work, Māori growers used dry fern in the wells in which they stored Kūmara and the same way was carried out with the varieties of taewa, however these are not stored in pits but in Pātakas. The term Pātaka mean raised storehouses or Whata, supported on one, four, or more posts (Best[20], 2005). The term Pātaka could not rightly be applied to an open platform - i.e., uncovered and without walls as it implies something "enclosed." The term Whata, however, simply means "to elevate, to support, or elevate on supports," hence it would appear that this term might be applied to both Pātaka and open platforms (Best, 2005).

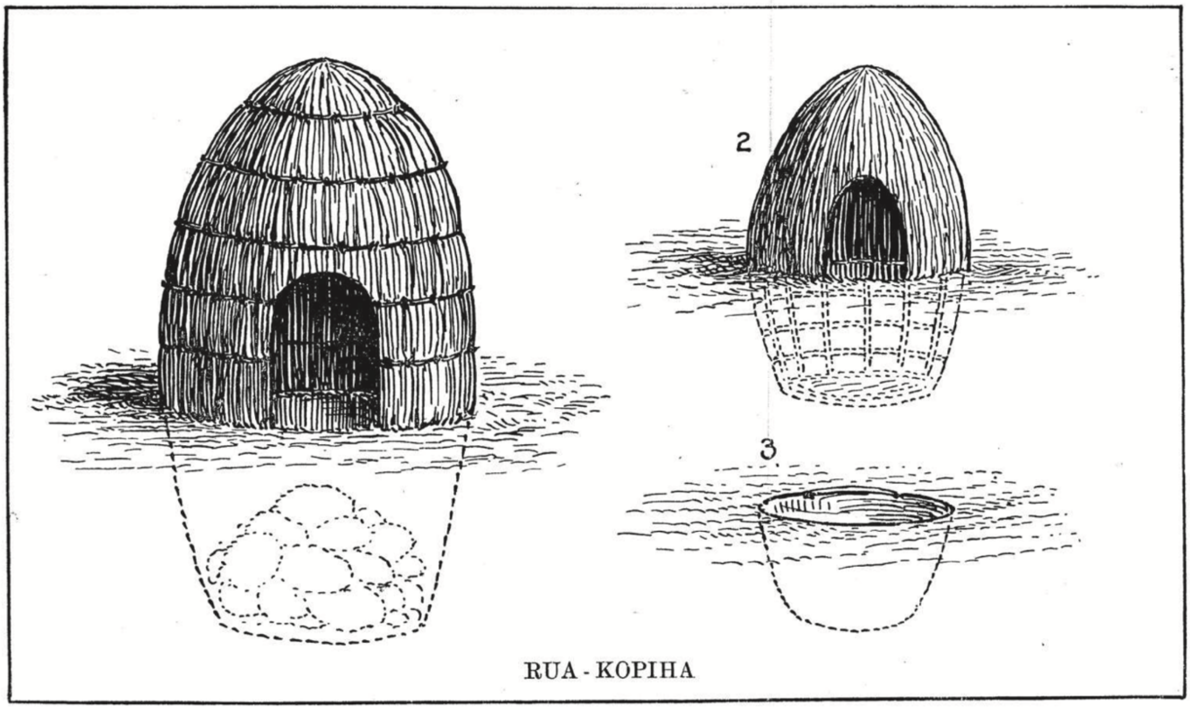

Figure 14. "Rua-kopiha" northwest of Auckland described by Graham (1922: 22). Source: Davidson et al. (2006).

[20] Best, Elsdon, Māori storehouses and kindred structures. 2005. Museum of New Zealand Te Papa Tongarewa. Dominion Museum Bulletin Number 5. PO Box 467, Wellington, New Zealand. ISBN 1-877385-07-7.

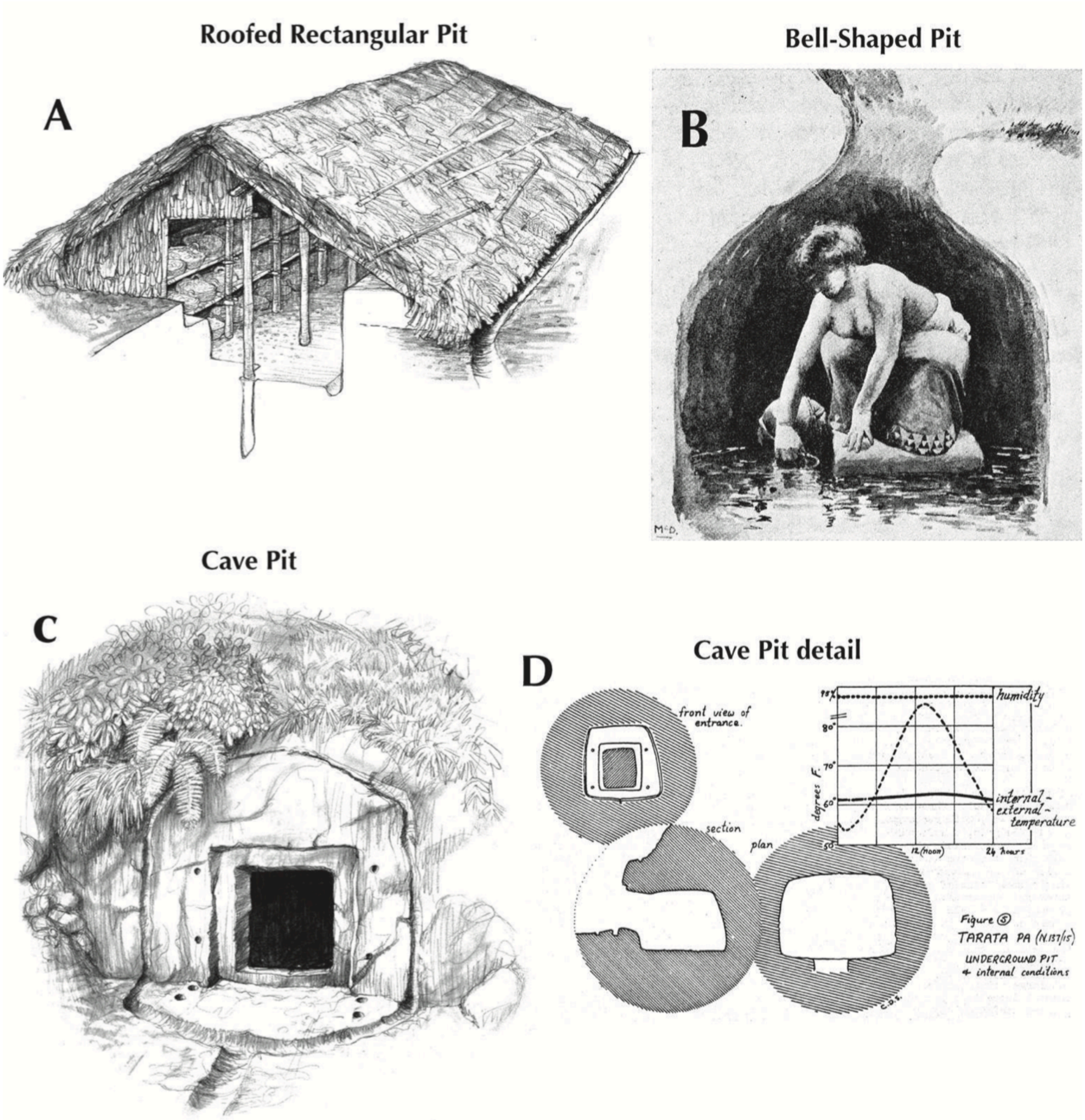

Figure 15. Types of storage pit. A: A roofed rectangular pit with Kūmara stored in baskets on racks. B: A bell-shaped pit at Tunuhaere Pa in the Whanganui district. Best interpreted this pit as for water storage, but in form it is typical of bell-shaped pits used for Kūmara storage. Note the upstand above the floor. C: The entrance to a cave pit. D: Details of a cave pit at Tarata Pa, Waitotara Valley, on which C is based. A and C: By Nancy Tichbourne (from Leach 1984: 36, courtesy H.M. Leach). B: By James McDonald (from Best 1974: 89, courtesy of Te Papa). D: By Colin Smart from Smart 1962: 181). Source: Davidson et al. (2006).

Best (2005) classified the construction and uses of the elaborately adorned elevated storehouses as follows:

> *"I. Raised storehouses, termed Pātaka, Whata, etc., supported on one, four, or more posts (Figure 17).*
>
> *II. Storehouses resembling ordinary huts.*

III. Platforms and stages elevated on posts or trees, but not supporting any house, and also racks.

IV. Semi-subterranean stores- pits and caves used as storage- places for food.

The first of these series is by far the most important, from the native and European point of view, as it includes the carefully constructed and elaborately carved structures with which most of us are familiar, and which often displayed evidence of the highest form of artistic skill attained by the woodcarvers of Maoriland. The second series includes the communal storehouses found in some native hamlets in former times, as well as others of a more private nature. The third series embraces many different forms of elevated platforms, and racks, used as storage-places for food. The fourth division includes the various forms of pits and semi- subterranean storage-places that were so largely used by the Māori of former times. The Raised storehouses, the two native terms Pātaka and Whata appear to be used in a somewhat loose manner and are both applied to the elevated store- house and the simple platform, stage, or scaffold with no erection thereon". (Pages 1, 2, and 3).

Similar storage methods developed for kūmara were used for overwinter potato storage (Harris & Niha, 1999). Leach et al. (1979) described a circular raised-rim storage pit on a bank of the Mākotukutuku stream in Palliser Bay. This was interpreted as a potato store that was probably in use in 1840 when it was recorded that potatoes were grown in the area. A layer of fern stalks was found on the floor of the pit. The use of fern as a floor covering suggests a continuation of an earlier practice designed to keep tubers off the damp floor of storage pits (Leach et al., 1979). These potatoes were stored for consumption, while seed potatoes were placed in baskets covered with fern (Marshall, 1836) as cited by Harris and Niha (1999). Marshall (1836) observed 'several Whata or stages, supporting baskets of seed potatoes carefully sewn up with dried grass and covered with fern leaf. The practice of covering stored seed potatoes with fern is still undertaken by Māori in Northland today (Figure 18).

Storehouses in Canterbury (South Island of New Zealand) were sometimes built on four legs and sometimes on two (Whata) at various heights off the ground (Beattie, 1994). A storehouse in the earth to store Kūmara, pora, pohata and potatoes was known as Koropu (Beattie, 1994). According to this author, an old Māori said that there was only one way to make whata, and that was to put them on posts. A whata was usually put on two posts (pou), the floor being called Kaupapa and the rafters kauwhata. A small house was built of wood or totara bark and roofed with raupo or bark, where food was stored. Some are quite large. They are put up high so that if anyone goes to them the person could be seen – this is a protection against robbery. A ladder or arawhata runs up to the high ones. It is a pole in which holes have been gouged out for footholds. It could be set up right to whata or on a slant as required. He had never heard of earth storehouses but a hole to pit "spuds" was called rua (Beattie, 1994). All the examples cited with Kūmara, they are examples of Māori innovation in storage and crop behavior. Taewa are different and require unique system. Kūmara and taewa were never stored together as Kūmara was a sacred crop for the ancestors and too tapu[21]. Taewa were in purpose-built storage separate to Kūmara (Nick Roskruge - personal information).

Figure 16. Examples of traditional storage/ Pātaka (photos courtesy Roskruge, 2024).

Many of the old-time customs of the Māori of New Zealand have passed into oblivion, but traces of ancient habits remain in certain aspects of native life. As regards the storage of food and other property (Firth, 1925). Taewa are grown annually during the summer months and stored for use in the winter or off-season (Roskruge et al., 2019). Māori lived in permanent settlements and their cultivations were distributed around a district claimed by the residents. They practiced a form of rotational land use, generally used only wood ash as fertilizer, and cropped for no more than three annual seasons on a piece of land. Food storage was as crucial as crop production. Without knowledge of storage, they were likely to be without good nutrition

[21] Tapu is the strongest force in Māori life. It has numerous meaning and references. It can be interpreted as "sacred" or defined as "spiritual restriction".

during winter months. The whole production system was based on the annual seasons, with planting in spring, crop husbandry in summer through to harvest in late autumn. The winter was always a period of rest for both the people and the land resource (Roskruge et al., 2019).

Figure 17. Dry fern covering potatoes in storage.

3.1.5 Interview with Māori growers

Several Māori taewa growers were interviewed about traditional storage methods. The way some Māori growers continue to store taewa potatoes nowadays is very similar to the methods that were practiced throughout Aotearoa New Zealand's history by their ancestors.

There is more than one Māori methods and more than one conventional method. This experiment chose conditions to represent these, the major difference being temperature control. According to readings and interviews with some Māori growers, little has changed when it comes to the storage of taewa potatoes for either seed production or consumption. In interviews with Māori growers from different parts of the North Island of New Zealand, such as Hawkes Bay, King Country, Taranaki, and Manawatū, it was possible to get some information about the way they conduct the storage of taewa.

The Māori growers who participated in the survey that they all follow the Maramataka (Māori Calendar) guidelines (Appendix 1). Although New Zealand is a long narrow country which straddles the mid-latitudes from 35˚ to 47˚ south with a range of climatic conditions (Salinger,

1979) and, consequently, in some regions there are different times for planting and harvesting taewa. So, in the spring period warmer regions like Hawkes Bay, Māori growers prefer to plant taewa at the end of August or in the first week of September, as they believe the risk of planting before that time could be compromised by frost (personal communication, Hanui Lawrrence – Waipatu). In the small inland town of Taumarunui (central north Island), Māori growers start planting they taewa seeds between August and September and in the Manawatū region, planting is carried out in October or November. All Māori growers gave the same answer when asked about what they do to maintain crops in the field. All the growers interviewed follow organize production principles to limited or no chemical inputs. They usually use natural products (organic products) such as sheep manure, chicken manure, coffee granules, eggshells, compost, and worm juice (from their worm farm) (personal communication, Pal Toroa, Joy Meihana – Taumarunui).

Growers generally harvest taewa between 120 days to 180 days after planting. This difference in growing time adopted by them often depends on the state of germination of the seeds. Some growers mentioned that they follow some beliefs that they believe contribute to the good development of taewa crops, such as welcoming of pregnant women into the gardens to walk around through the gardens as they believe the energy of life within a woman provides great crops and a good harvest. Other Māori growers commented that they say karakia (traditional prayers) at certain times throughout the day as they walk around the fields. Some growers commented that they remove the aerial part of the plant 10 days before the harvest date. They believe that in this way the skin quality of the seeds can be better and, consequently, the seed tubers can be healthier after being harvested. Once harvested, growers generally do not clean taewa seeds. They believe that the soil or dirt that remains around the taewa seed tubers after harvesting becomes a means of maintaining quality and contributes to maintain the dormancy period of them.

Usually, the growers separate the tubers for various purposes. Some tubers are separated for their own consumption, others to be sold in local markets, and others to be stored as seed for the next planting. According to one grower from Taumarunui in September 2021, they maintain the separation of distribution as follows:

33% they keep for consumption.

33% for seed.

33% for others (selling, etc.).

3.1.6 Māori storage methods

Māori growers from Taumarunui advised they usually store taewa tubers in the ground in a dug-out hole filled with fern. Potatoes are stored away from the light to maintain their dormancy; they would retrieve the potatoes when needed. The hole would usually have a hatch. They also store potatoes in food store houses (Pātaka), in a dry place (usually those they would use to potentially use as seeds) (Figure 19 and 20). Sometimes tubers are stored in a mound covered with fern, with sacks, and dirt over the top, or wrapped in fern and buried in sand, or stored out of the light in caves.

For transport and to other areas the potatoes would be stored in large hue (gourds). For easy food preparation pre-European/pre-colonization potatoes/kūmara would be preserved in bird/pig fat along with the birds wrapped in bark or placed in the gourds.

In Taranaki, and Manawatū, Māori growers generally use the same taewa storage methodology (personal communication, Howie Harris - New Plymouth).

Figure 18. Māori grower's and their seed taewa storage method in Taumarunui, New Zealand.

Figure 19. Participation at growers Hui (Taumarunui, Otaki, and Hastings). Pātaka storage, and Marae.

A collective of Māori growers from Hawkes Bay store their taewa seed in 44 Gallon Drums, usually putting 3 buckets inside drum with a board on top of each bucket to cover or in covered crates (rats can get into the crates). According to Hanui Lawrrence - Waipatu (personal communication), they frequently check tubers in storage in a shed. The crates allow air movement around the tubers, and they keep the shed doors always open. Māori growers from Ngati Porou, use a method they call Paakaro to store kūmara and parareka Māori. First, they lay a bedding of Mānuka bush, then a layer of mamaku then lay the whenua kai on top' then another layer of mamaku on top then another layer of Mānuka brush then cover with soil' acts like an incubator' (protection) it cracks to release heat and seals up (personal communication, Joe Allen, Taumarunui). When it's cold' they open it up about August to plant the parareka seed that have sprouted. They leave it open to let the Kai dry out then wrap the kūmara in newspaper and store in a cardboard box in a dark dry warm spot' (personal communication, Joe Allen – Tuhoe).

3.1.6.1 Fern pteridophyte flora in New Zealand

Polypodiaceae, (Polypods ferns) are the lineage of most derived ferns that diversified in the Cretaceous period, displaying an ecologically opportunistic response to the diversification of angiosperms (Schneider et al., 2004). The *Polipodiaceae* are a large group of over 7,165 species in 15 families, grouped in six suborders (Fayaz, 2011). *Pteridium aquilinum*, commonly named bracken fern, belongs to the phylum *Pteridophyta* and to the family *Dennstaedtiaceae* (Holttum, 1949); (Allan, 1961); (Brownsey & Smith-Dodsworth, 1989); (Der et al., 2009); (Štefanić et al., 2022). (Figure 20).

Fern are flowerless plants with divided leaves, and they tend to grow in damp, shady situations. They reproduce themselves from spores rather than seeds. Spores are tiny unicellular structures only just visible as specks of dust to the naked eye, and are produced by groups such as mosses, liverworts and lichens, as well as ferns (Brownsey & Smith-Dodsworth, 1989). *Pteridium* fronds and spores possess a wide array of toxic chemicals (McGlone et al., 2005). Pteridium fronds are defended by high levels of phenols and tannins and by the presence of a variety of genotoxins, including illudanes (Alonso-Amelot et al., 2001) as cited in McGlone et al. (2005). They are popular in ornamental horticulture and are highly valued as indoor/outdoor ornamental (Fernández & Revilla, 2003). The way of storing Kūmara potatoes through Pātaka or Whata by Māori growers throughout New Zealand's history, were also adopted for Māori taewa potatoes (Best, 1916). (Leach et al., 1979) as cited in Harris and Niha (1999), described a circular raised-rim storage pit on a bank of the Mākotukutuku stream in Palliser Bay. He interpreted this as a potato store that was probably in use in 1840 when it was recorded that potatoes were grown in the area. A layer of fern stalks was found on the floor of the pit. Leach et al. (1979) noted 'the use of fern covering as a floor suggests a continuation of an earlier practice designed to keep tubers off the damp floor of storage pits. Describing numerous potato storage pits at (Marshall, 1836) as cited in Harris and Niha (1999), recorded they were 'found in all directions as to completely honeycomb the whole of the ground.' He described these potatoes as being for consumption, while seed potatoes were put in baskets covered with fern.

Figure 20: Examples of fern (*Pteridium)* (photos courtesy Roskruge, 2024).

Chapter 4

Effect of the storage methods on the post-harvest dormancy of Māori seed potatoes (*Solanum tuberosum* L.) during winter in Aotearoa New Zealand

4.1 Introduction

In 2022 the world population reached 8 billion inhabitants. The latest projections by the United Nations suggest that the global population could grow to around 8.5 billion by 2030, and 10.4 billion by 2100 (United Nations, 2022). A growing earth's population will obviously create a growing demand for food. According to the World Health Organization (World Health Organization, 2018), by 2050, a global population of 9.7 billion people will require 70% more food than is consumed today. Among the crop species used to feed the world's population, the potato has been one of the crops that importantly has contributed to human nutrition. Potato (*Solanum tuberosum* L.) is a perennial herbaceous plant with edible tubers that belongs to the *Solanaceae* family (Yan et al., 2015).

In terms of production, potato is the fourth most important crop after wheat, corn and rice (Soare & Chiurciu, 2021). In New Zealand for example, more land is used for growing potatoes than any other crop, with over 10,000 hectares grown by 175 commercial potato growers each year (Tupu, 2022). In New Zealand the Māori growers grow taewa seeds potatoes. Taewa were a staple food crop of the Māori before the main European settlement began in the mid-19th century (Roskruge, 1999). Māori lived in permanent settlements and their cultivations were distributed around a district claimed by the residents. They practiced a form of rotational land use, generally used only wood ash as fertilizer, and cropped for no more than three annual seasons in the same piece of land (plot). Food storage was as important as the production of the crop itself. Without knowledge of potato storage, people were likely to be without good nutrition during winter months. The whole production system was based on the annual seasons, with planting in spring, crop husbandry in summer through to harvest in late autumn. The winter was always a period of rest for both the people and the land resource (Roskruge *et al.* 2019). Māori growers formerly stored potatoes in containers or baskets and covered these potatoes with dry fern leaves (Leach et al., 1979) as cited in Harris and Niha (1999).

For New Zealand Māori growers, the use of fern as a floor covering suggests a continuation of an earlier practice designed to keep tubers off the damp floor of storage pits. Potatoes for consumption were stored in pits while seed potatoes were put in baskets covered with fern leaves (Marshall, 1836) as cited in Harris and Niha (1999). The practice of covering stored seed potatoes with fern leaves is interesting as the practice is still undertaken today by Māori in Northland Harris and Niha (1999). For seed potato production, Māori growers often cover with dry fern leaves to keep out rats or other animals (Māori growers – personal communication, September 2021). Generally, along with fern, some growers believe that placing lavender leaves and flowers (*Lavandula angustifolia*) helps to ward off rodents (Māori growers – personal communication, July 2022).

Regardless of the final purpose for using potatoes, whether for consumption or seed production, the final objective of storage practices is to prevent this product from sprouting. Sprouting avoidance is one of the most significant challenges in the postharvest storage of potato tubers (Santos et al., 2019). Severe losses are incurred due to potato tuber sprouting and sprout growth since these cause alterations in tuber physical properties, such as reduced turgidity, induced tuber shrinkage, and fosters weight loss (Visse-Mansiaux et al., 2021). Post-harvest cool storage provides a necessary environment to prevent tuber weight loss, spoilage and sprouting (J Singh et al., 2008). Currently, common strategies for long-term storage of potato tubers include storage at low temperatures between 2–4 ˚C (90–95% relative humidity) or between 8–12 ˚C (at 85–90% relative humidity) (Paul et al., 2016). Another important point that can occur with potatoes during storage is related to mass loss because during storage the mass decreases mainly caused by evaporative moisture loss (Grubben et al., 2019).

Māori growers in New Zealand generally store taewa seed potatoes for 120 days (Māori growers – personal communication, September 2021). The present study hypothesizes that the Māori storage method (MSM) with normal air temperature + relative humidity + darkness provided by dry fern fronds confers a storage condition that preserves quality of the taewa seed potatoes in comparable conditions to the conventional trial storage method (CSM). The objective of this research was to verify whether the two storage methods (MSM and CSM) maintain the physiological quality of taewa potato seeds in the final storage period similar to the initial storage period and, if so, which storage conditions were favorable to the final result? Therefore, physiological attributes such as respiration rate, weight loss, and sugar content of the three Māori potatoes tubers (Tutaekuri, Moemoe, and Huakaroro) were then measured to identify physiological changes that could further help explain differences in these potato seeds during the dormancy period.

4.1.1 Material and methods

Two experiments with taewa potato seeds, varieties Moemoe, Huakaroro and Tutaekuri, were conducted between the autumn and winter of 2022 and 2023. The first experiment installed in November 2021 and harvested in March 2022. After being stored in two different methods, the respiration rate, weight loss and sugar content of these potatoes were measured while they were in a dormant period. In the following year's experiment, the trial was repeated (planting to obtain the seeds of the three varieties mentioned in November 2022 and harvesting in March 2023). For this second experiment, respiration rate (RR) and weight loss (WL) were evaluated once again. The sugar content (SSC) was not evaluated, being replaced by measuring sprouting (sprout length, sprout width, and sprout number). The experiment had a pre-established schedule, starting in November 2021/2022 to obtain taewa potato seeds with data collection in the laboratory extending until July 2023.

4.1.2 Climate data for Manawatu (Massey University)

In November 2021, a field study was set up to grow seeds of three Māori taewa potato varieties to test the storage methods effects on seed potatoes. The three varieties of taewa that were planted were the Moemoe, Huakaroro and Tutaekuri varieties. The same setup for this experiment was repeated in November 2022 for the second-year experiment. The first stage of the project was conducted in the Fruit Crops Unit (FCU), School of Agriculture & Environment at Massey University, located in Palmerston North City, (40° 22’55" S, 175° 36’22" E). The Manawatu region (Palmerston North) has a temperate, oceanic climate with an average rainfall of 900 to 1200 mm, about 75-100 mm of this occurring during the summer months. It is one of the driest areas of the North Island and inadequate rainfall during the summer months may affect any production system. Typical summer daytime maximum air temperatures range from 19 ˚C to 24 ˚C seldom exceeding 30 ˚C (NIWA[22], 2016).

Winters are relatively mild in Palmerston North. Typical winter daytime maximum air temperatures range from 10 ˚C to 14 ˚C. Manawatu records up to 2000 sunshine hours per year, but inland at Palmerston North it is much cloudier. February is the warmest month with a maximum average temperature of 23 ˚C and July is the coldest with an average minimum of 3.8 ˚C. Frosts occur inland during clear calm conditions in winter with over 40 ground frosts recorded annually. The predominant winds are from the west followed by the north-westerlies. Sea breezes occasionally occur along the coast during summer (NIWA, 2016).

4.1.3 Experimental design

4.1.3.1 Field production

The focus of this research is the post-harvest study of taewa potato seed. Seed of taewa varieties were made available by Māori growers from *Tahuri Whenua* for this research. Planting these seed was the first stage of this study. For this, an area was prepared on one of the plots located at the Fruit Crops Unit of Massey University. The total area of the experiment (2021/2022) was 19.6 m x 16 m (approximately 320 m^2), and the size of each plot was 8.3 m x 6.5 m with a spacing of 1 m between blocks. For the 2022/2023 experiment, the same measurements were repeated to obtain a new generation of seed for storage. The experiment at each trial site was set up in a Randomized Complete Block Design (RCBD) with four blocks, and each block was fully randomized (figure 21). Planting spacing between rows and between plants in the rows was 75 cm and 30 cm respectively (0.75 m x 0.30 m = 0.225 m^2). The trial had guard rows at each end and on sides that extend the trial site area (Roskruge[23], 2011).

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[22] New Zealand GNS Science (2016). Soil/Ground conditions. See in: http://www.gns.cri.nz/Home/Learning/Science-Topics/Earth-Energy/Using-Earth-Energy/Geothermal-Heat-Pumps/Soil-Ground-Conditions

[23] Roskruge, N. Taewa Māori (Māori Potatoes) *Solanum tuberosum* production notes – Taewa handout-pdf.2011. Retrieved on 16th of August,2021. See in: http://www.tahuriwhenua.org.nz/crop-info

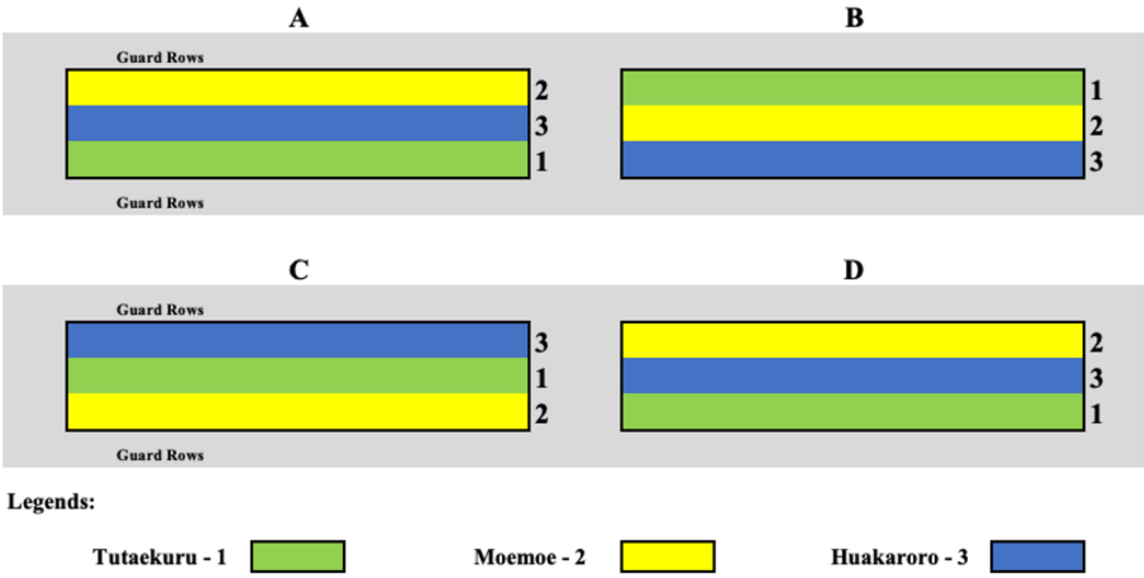

Figure 21. Taewa Māori plot layout/experimental design / total area of the experiment (2021/22 – 2022/23).

The soil was conventionally prepared with ploughing and harrowing between September and October 2021. For the 2022 experiment, the same procedure was adopted in an area (land) a few meters away. Then, glyphosate was sprayed throughout the experimental area (Figure 22). Soil samples were collected in the experimental area and the results of these samples are shown in table 1. Before planting, the rows were fertilized with Cropmaster15 fertilizer (15-15-30) mixed with the soil. Weekly visits were carried out after the emergence of the stems, to monitor the development and verify the needs of cultural practices and phytosanitary control.

For weed control, Sencor herbicide was used at the dose of 480 g/L applied before crop emergence. For blight disease, Ridomil MZ 72WP 2.5kg/ha was sprayed 60, 75 and 90 days after planting. The results of the entire soil analysis and the needs of cultural practices are in Appendix 2. The mounding was carried out when the crop reached about 20 cm in height, which occurred 30 days after planting. Irrigation was installed in the first week of January 2022 and was by conventional sprinkler. The area was irrigated throughout the experimental period and irrigation management was based on monitoring soil water conditions using a digital tensiometer (Figure 23). The proportion of rain (mm) in the planting period of the first experiment (2021/2022) and the second experiment (2022/2023) are presented in appendices 4a and 4b.

Figure 22. Planting, pre-emergent herbicide, and fungicide spraying. Massey University (2021/22 – 2022/23).

Figure 23. Irrigation of the experimental area. Massey University (2021/22 – 2022/23).

4.1.4 Potatoes sourcing and handling / Storage conditions

Traditional taewa potato storage by Māori has been practiced for many generations. In many traditional Māori systems, 10 days before harvesting the taewa, the haulm or aerial part of the plants is removed in the field. Māori growers believe that this activity helps- to harden the seed skins to be cured. This same procedure was simulated ten days before harvesting the seeds in this experiment. After harvesting, they store the seeds in containers without cleaning or removing the soil around these seed skins, as they believe that the soil will keep these seeds dormant for longer. Similar to the methods practiced by Māori growers, the taewa seeds used in this experiment also were kept with the soil around the skin since the time they were harvested. Before starting the experiment, the harvested tubers (beginning of April 2022) were stored in the PGU facilities (clean and dark place) for approximately two weeks to allow time for curing. After the curing period, the tubers were graded and distributed in the storage treatments accordingly.

The 2021/2022 experiment was conducted between April and August 2022. One week before starting the study, the storage was completely clean. The storage method used by Māori growers was called Māori Storage Method (MSM) and the method used by the industry, for example control of temperature, air, light, among others, was called Conventional Storage Method (CSM). In the MSM, all tubers were be kept in banana cardboard boxes (length 50 cm x width 40 cm x height 24 cm) collected from local supermarkets in the city of Palmerston North. Inside these banana boxes dry leaves of fern (*Pteridium sp*) were placed completely covering the tubers. The dry leaves of fern were obtained in the wooded areas around Massey University following instruction from the Māori grower informants. This material (banana cardboard boxes + dry leaves of fern + seeds of taewa potatoes) with properly identified samples were stored in a shed belonging to PGU/Massey University. All air and light entrances to the storing shed were sealed with black plastic for complete internal darkening. The banana boxes were stored on pallets. Rat baits placed in the corners of the shed were also used. In the CSM, wooden crates (length 30 cm x width 20 cm x height 8 cm) were used on the pallets with the samples duly identified in the temperature-controlled room at the PGU facilities.

For the two years of experiments (2021/2022 and 2022/2023), thermometers from the company Temperature Technology (https://www.t-tec.com) were used. Only one thermometer was used for each experiment (MSM and CSM). In the MSM experiment, the Thermochron® iButton HC data logger thermometer was used (The HC simultaneously logs both temperature (from -20 ˚C to 85 ˚C) and humidity (from 0 % RH to 100 % RH). In the CSM experiment, it was the Thermochron® iButton Temperature Logger TC thermometer was used (The TC model provides the broadest temperature range (-30 ˚C to 85 ˚C) to cover most applications (only these two temperature loggers - Thermochron® iButton HC and Thermochron® iButton TC were available to conduct the experiments). Therefore, the relative humidity in the CSM was not evaluated. The thermometers used in each storage method were suspended 1.5m high from the aforementioned boxes (banana boxes in the MSM and crates in the CSM) (Appendix 5, 6, 7 and 8). Rainfall data for the entire experiment periods 2021/2022 and 2022/2023 were obtained from the NIWA - National Climate Database (Cliflo) website (Appendix 4).

4.1.5 Sample preparation

After curing the seed samples were randomly selected before starting the next stage of the experiment. The experiment to obtain data was set up in a factorial design in randomized blocks with three blocks (Figure 24). In each block there were six banana boxes in the MSM and six crates in the CSM. Inside each banana box/crates there were six potatoes. In each block, there were two replicates (two boxes containing 6 potatoes in each box) referring to each variety of taewa, totaling six repetitions between the three blocks and a total of 36 potatoes for each variety.

In the experiment that simulates the storage of Māori growers, the entire internal area was properly sealed, with no light present. As it was a simulation shed (length 6.0m x width 4.0m x height 3.0m) that was located at PGU, there was no temperature control. The room (CSM) where the experiment was carried out with temperature control at 5 °C had the following measurements: Length 2.4m x width 2.2m. The height was 2.4m. This room was also completely dark.

For each of the three varieties in both storage methods: There were 6 boxes containing six seed taewa/potatoes in MSM and CSM, and the evaluation parameters for destructive sampling of the 2021/2022 experiment (respiration rate and sugar content at 0, 30, 60, 90 and 120 days of storage) were made in the respective boxes 1, 2, 3, 4 and 5 (Figure 24). For weight loss measurements (0, 30, 60, 90 and 120 days of storage), the weights of the six seeds that were stored in box 6 were measured. In the 2022/2023 experiment, the same methodology was repeated regarding the number of boxes of each storage method for respiratory rate and weight loss analyses. In this second experiment, the sugar content was replaced by sprouting measurements (length, width and number of sprouts).

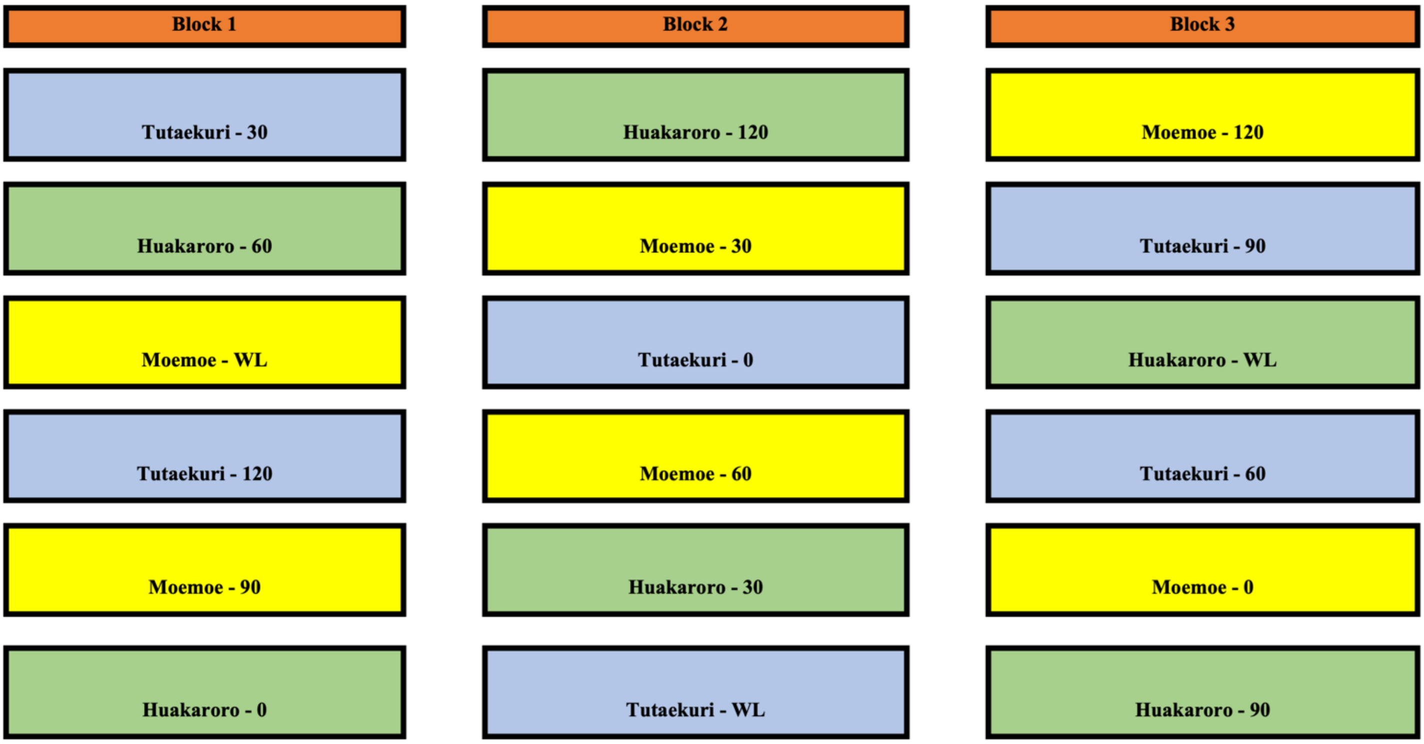

Figure 24. Experimental layout of taewa potato varieties in the trial sites - MSM and CSM. The three blocks consist of rows each with six box in MSM and six crates in CSM and the different dates indicate the randomization of storage duration of potato varieties within each block. Each box in MSM and crates in CSM constitutes six tubers with in between and within row spacing of 30 and 50 cm, respectively. The boxes indicating the acronym WL refer to the boxes in which weight losses were measured on the first day of storage (control) and at 30, 60, 90 and 120 days of storage.

Figure 25. Experimental storage area. A = Māori storage method (MSM); B = Conventional storage method (CSM).

4.1.6 Measurement of gas compositions created

Respiration was measured as described by Rupavatharam et al. (2015). Potato tubers were left overnight at laboratory conditions (20 ˚C) before assessments of respiration rate. Six tubers from each replicate/variety were placed in sealed 0.5 L glass jars containers with metallic lids that kept the container properly sealed with a rubber septum. Gas samples were collected twice from the headspace using a 1 mL syringe, immediately after sealing the jar and again later after a known period (Figure 26a). Incubation time was chosen to ensure that accumulation of CO_2 in the headspace did not exceed 0.5% (Hertog et al., 2004). Gas samples were analysed using a gas analyser fitted with a CO_2 infrared transducer (Analytical Development Company, Hoddesdon, UK) that uses N_2 as a carrier gas at a flow rate of 35 mL min^{-1}. The output signal was recorded on an integrator (HP3396A, Hewlett Packard, California, USA). Calibration of the gas analyser was conducted with commercially available 0.5% CO_2 β-standard (BOC Ltd., Auckland, New Zealand). Respiration rates representing carbon dioxide production rates (rCO_2) were calculated considering tubers weight and the resulting free volume in the jar and expressed in mol kg^{-1} s^{-1}, and it was calculated using Equation (1).

$$RR = (vol\ container - mass\ potato/potato\ density) * (CO_2f - CO_2i)*atmP*(0.00001)/(8.314*(Temp+273.15)*mass\ potato*times)/0.000000001 \quad (1)$$

To measure the potato density, the mass in grams was divided by the volume of the potato in cubic centimeters (cm^3), using the equation density = mass/volume. This process was repeated five times to estimate the error in the individual measurements.

4.1.7 Percent weight (wt) loss

The weight loss percentage was determined as described by Mahilum et al. (2022). The weight of each tuber (six potatoes per box) was obtained at 30-day intervals at MSM and CSM to one decimal place using an analytical scale with a maximum capacity of max 220 g (Vibra HT analytical balance, Precise Instrument), which was connected to a laptop. Initial weight (g) was measured immediately after curing. Final weight (Wt at 30-day) was measured after 30-day intervals. Weight loss was calculated as a percentage using Equation (2).

$$Wt\ loss\ (\%) = \frac{Wt\ initial\ (g) - Wt\ at\ 30\text{-}day\ intervals}{Wt\ initial\ (g)} \times 100 \quad (2)$$

4.1.8 Soluble solids content

The sugar content (Soluble solids content – SSC) was determined by squeezing approximately 0.3 mL of juice from grated tuber using a garlic crusher and measured with a refractometer (PR-32 α, Atago, Japan) (Figure 26b). The SSC was expressed as a percentage (Han et al., 2022).

Figure 26. Experimental respiration rate and sugar content in the post-harvest laboratory. Massey University.

4.1.9 Statistical analysis

Data on the respiration rate (RR), weight loss (WL), and sugar content (SSC) were analysed using a linear mixed model (Mixed Procedure) with variety, storage method and their interaction as the fixed factors and block as the random factor following by a Tukey-Kramer test for multiple comparisons. An exponential regression model (Nlin Procedure) was applied to fit the data on the change (y) of respiration rate, weight loss, and sugar content over the storage duration (day): $y = a \times \exp(b \times day)$, where "*day*" was the duration of storage, "*a*" was the initial respiration rate and "*b*" the increased rate of respiration. For weight loss, as the initial weight loss was 0 at the start of the study, we set $a = 1$ which reduces the variation of weight loss between treatments, the weight loss is controlled by the "*b*" in the regression model. The estimated parameters (i.e., *a* or *b*) in non-linear regression models for different varieties and storage methods were significantly different from 0 if both low and up 95% confidence limits (CLs) (i.e., > 0 or <0). The coefficients of determination (R^2) for regressions were calculated as the sum of square due to the model divided by the total sum of squares. All statistical analyses were performed using SAS v 9.4 (SAS Institute Inc, Cary, NC, USA).

4.2 Influence of storage conditions on the physiological characteristics of taewa seed potatoes (*Solanum tuberosum* L.) in Aotearoa New Zealand

4.2.1 Material and methods

This is a repeat of trial in chapter 4, done the following year, with some changes e.g. measuring sprouting, but not sugar content, and doing weight loss and respiration rate to compare results of the two trials, that is, the trials from the two years of the experiments (experiment 1 in 2022 and experiment 2 in 2023). Information regarding the characterization of the study area and treatments was described in section 4.2 and sub-sections 4.1.3.1 to 4.1.7.

4.2.1.1 Storage experiment

The experiment was carried out in a factorial design in randomized blocks with three blocks, each block being completely randomized. In each block there were six boxes in the MSM and six crates in the CSM. The same methodology applied in experiment 1 was repeated in the second year. Inside each banana box/crates there were six potatoes that were completely randomized before storage began (replication). This experiment began in March of 2023 and the trial was monitored regularly to determine the onset of sprouting.

4.2.1.2 Sprouting Measurements

Tubers were considered to have broken dormancy when an average sprout length was ≥1.7 mm (Knowles et al., 2009). During storage, three weekly visits were made to observe the beginning of seed sprouting. For all experimental boxes (MSM and CSM), all six seeds were carefully observed. Among them, the first container that showed at least the first four seed sprouting was the seed selected for measurements of length, width and number of sprouts during the test.

Tuber sprouting was evaluated as described by Gikundi et al. (2023), where measurements of sprouting widths were made when they were at least 0.5 mm. Measurements of length, width and number of shoots were taken every fourteen days for 70 days (0, 14, 28, 42, 56 and 70 days). For both storage methods, all shoot length and width measurements were measured with an electronic digital calliper with an accuracy of 0.01 mm (Figure 27).

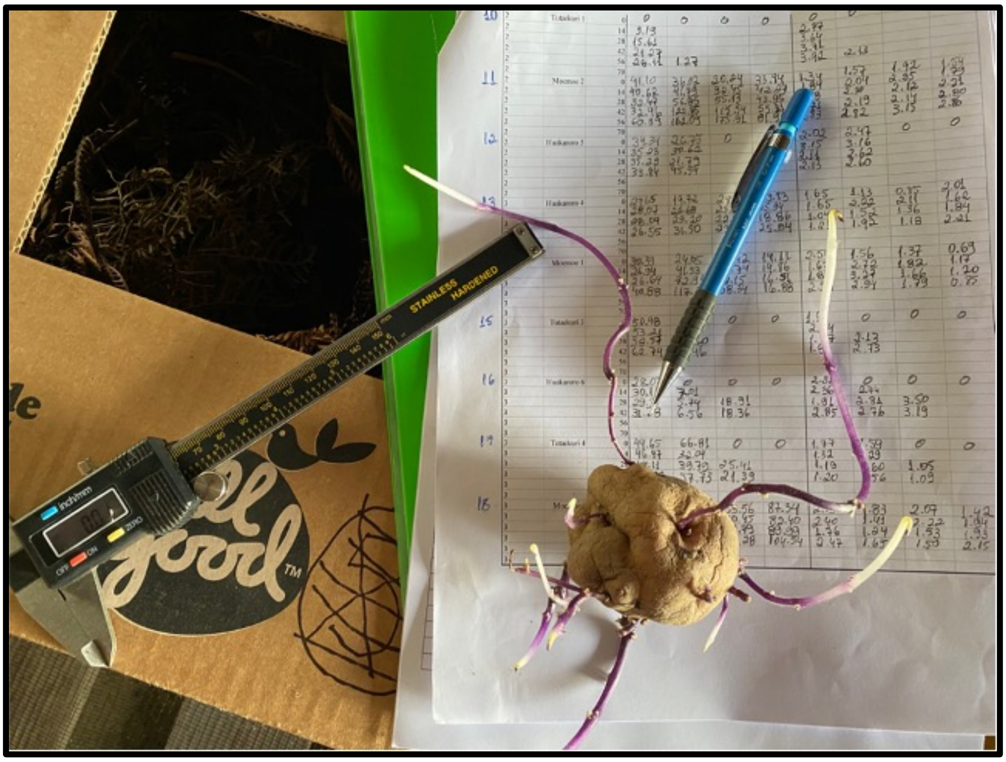

Figure 27. Measurements of length, width, and number of sprouts of Moemoe taewa potato variety.

The readings taken by Thermochron® iButton HC data logger referring to temperature trend and relative humidity in the shed (MSM) and temperature (Thermochron® iButton Logger TC thermometer) in the conventional room (CSM) are shown in the Appendix 7 and Appendix 8.

4.2.2 Statistical analysis of experiment

4.2.2.1 Respiration rate

4.2.2.1.1 Statistical analysis

Data on the respiration rate were analysed using a linear mixed model (Mixed Procedure) with variety, storage method and their interaction as the fixed factors and block as the random factor following by a Tukey-Kramer test for multiple comparisons. An exponential regression model (Nlin Procedure) was applied to fit the data on the change of respiration rate (RR) over the storage duration (day): RR = $a\times\exp(b\times\text{day})$ for 2022, and RR = $a\times\exp(b\times\text{day}+c\times\text{day}^2)$ for 2023, where day is the duration of storage, *a* is the initial respiration rate, *b* is an increase rate of respiration in 2022 or an decrease rate of respiration in 2023, and *c* is an decrease rate of respiration in 2023. The estimated parameters (i.e., *a*, *b* or *c*) in non-linear regression models for different varieties and storage methods were significantly different from 0 if both low and up 95% confidence limits (CLs) (i.e., > 0 or <0). The coefficients of determination (R^2) for regressions were calculated as the sum of square due to the model divided by the total sum of square.

4.2.2.2 Weight loss

4.2.2.2.1 Statistical analysis

Data on the potato weight loss were analysed using a linear mixed model (Mixed Procedure) with year, variety, storage method and their interactions as the fixed factors and block as the random factor following by a Tukey-Kramer test for multiple comparisons. An exponential regression model (Nlin Procedure) was applied to fit the data on the change of weight loss (WL) over the storage duration (day): WL = $\exp(b\times day)$, where *day* is the duration of storage, and *b* is an increase rate of weight loss. The estimated rate of weight loss (i.e., *b*) in non-linear regression models for different varieties and storage methods were significantly different from 0 if both low and up 95% confidence limits (CLs) (i.e., > 0 or <0). The coefficients of determination (R^2) for regressions were calculated as the sum of square due to the model divided by the total sum of square.

4.2.2.3 Bud sprouting characteristics

4.2.2.3.1 Statistical analysis

Data on the bud length, width, and sprout number were analysed using a linear mixed model (Mixed Procedure) with variety, storage method and their interaction as the fixed factors and block as the random factor following by a Tukey-Kramer test for multiple comparisons. A logistic regression model (GLIMMIX Procedure) was applied to fit the data on the change of bud length, width and number over the storage duration (day): $y = \exp(a + b \times \text{day})$, a is the intercept, b is the slope of regression. The slopes (i.e., b) in the regression models for different varieties and storage methods were significantly different from 0 if both low and up 95% confidence limits (CLs) (i.e., > 0 or <0).

All statistical analyses in respiration rate (RR), weight loss (WL), and bud sprouting characteristics were performed using SAS v 9.4 (SAS Institute Inc, Cary, NC, USA).

Chapter 5

All Results

5.1 Experiment 1

5.1.1 Results

5.1.1.1 Respiration Rate (RR)

The respiration rate was significantly higher in Māori storage method than in conventional storage method ($F_{1,168} = 11.15$, $P = 0.00010$) (Figure 28a); however, the respiration rate was significantly different between varieties with an order of Tutaekuri > Moemoe > Huakaroro ($F_{2,168} = 161.28$, $P < 0.0001$) (Figure 28b). The interaction between storage method and variety was significant, which resulted in a significant higher respiration rate in Tutaekuri than in Huakaroro and Moemoe regardless of storage method ($F_{2,168} = 5.53$, $P = 0.0047$) (Figure 28c).

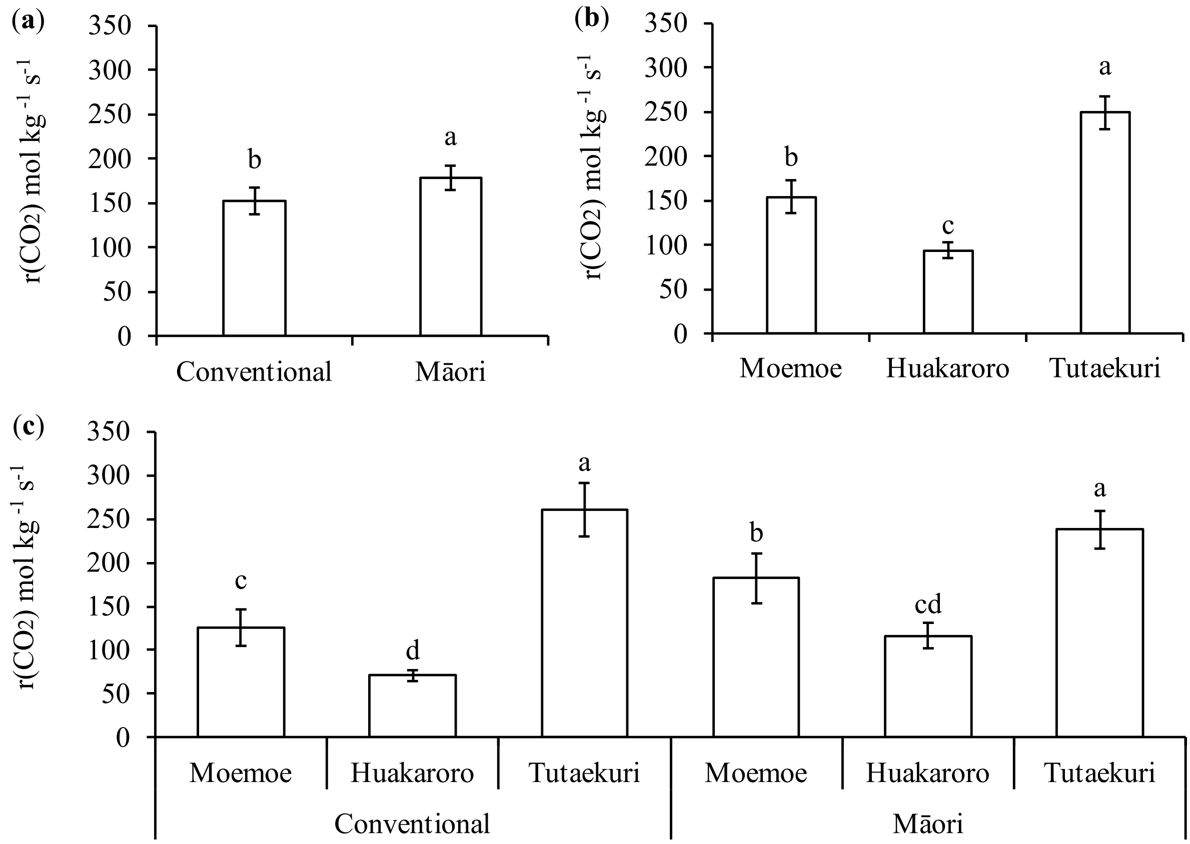

Figure 28. Effects of storage method (a), variety (b) and their interaction (c) on the average potato respiration rate during the experiment. Columns (means ± SE) with the same letters are not significantly different (P > 0.05).

As shown in Figure 29, the respiration rate of different potato varieties with different storage methods significantly increased over the storage duration ($P < 0.0001$). The rate of respiration increase was significantly greater in Moemoe (Figure 29c-d) than in Huakaroro (Figure 29a-b) and Tutaekuri (Figure 29e-f), regardless of storage method (Non-overlapped 95% CLs). The initial respiration rate was significantly higher in Tutaekuri (Figure 29e-f) than in Moemoe (Figure 29c-d) and Huakaroro (Figure 29a-b), regardless of storage method (Non-overlapped 95% CLs).

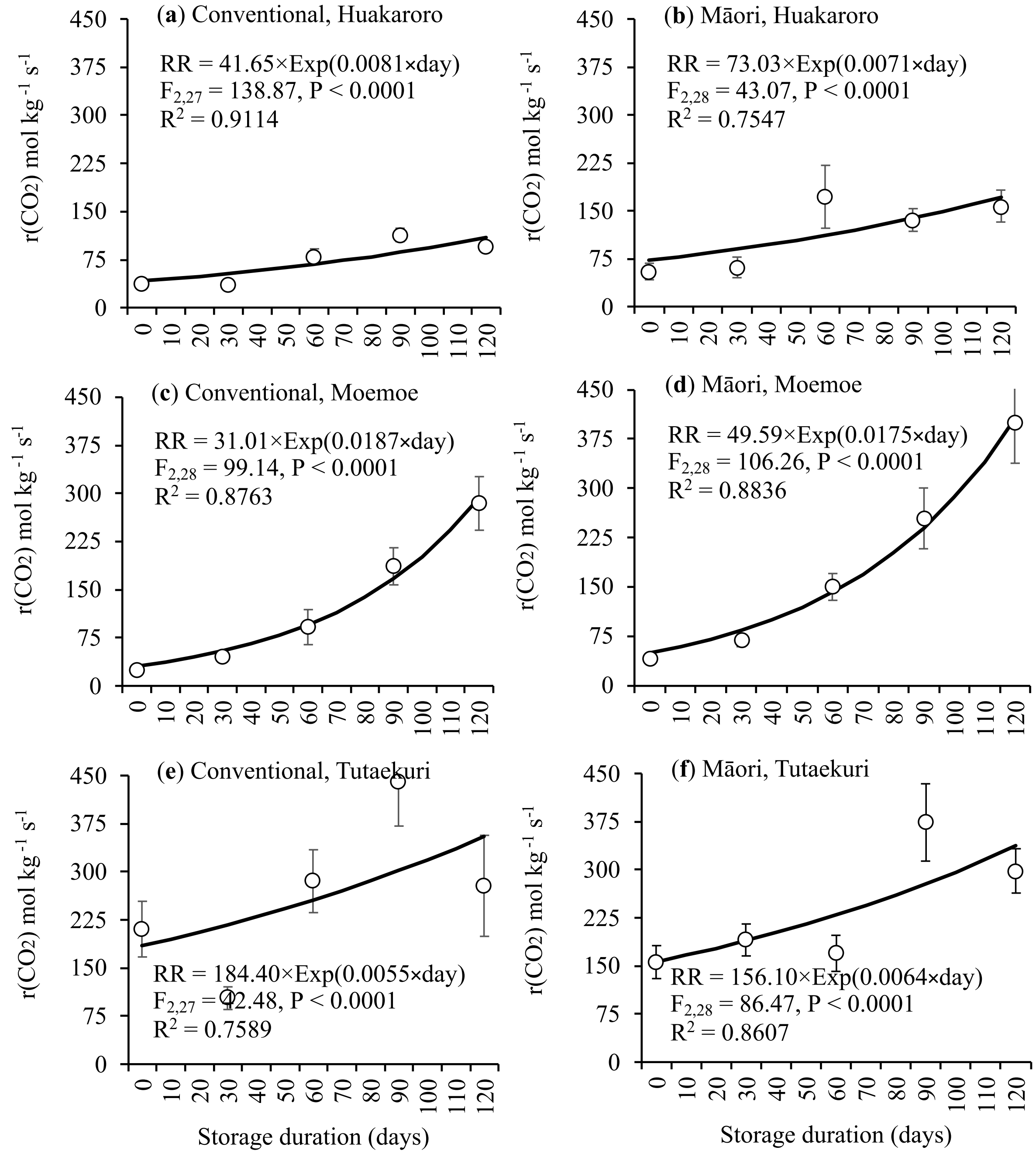

Figure 29. Respiration rate (RR) of different potato variety with different storage methods over the storage duration. All data were used for analysis, but the mean respiration rate (± SE) was presented in figures only.

5.1.1.2 Weight loss (WL)

The percentage of cumulative weight loss was significantly in Māori storage method than in the conventional one ($F_{1,28} = 120.98$, $P < 0.0001$) (Figure 30a). Whereas the weight loss was not significantly different between varieties ($F_{2,28} = 2.99$, $P = 0.0667$) (Figure 30b). The interaction between storage method and variety was significant with a significantly higher weight loss in Moemoe than in Huakaroro and Tutaekuri in Māori storage method but no significant difference between varieties in conventional storage method ($F_{2,172} = 13.15$, $P < 0.0001$) (Figure 30c).

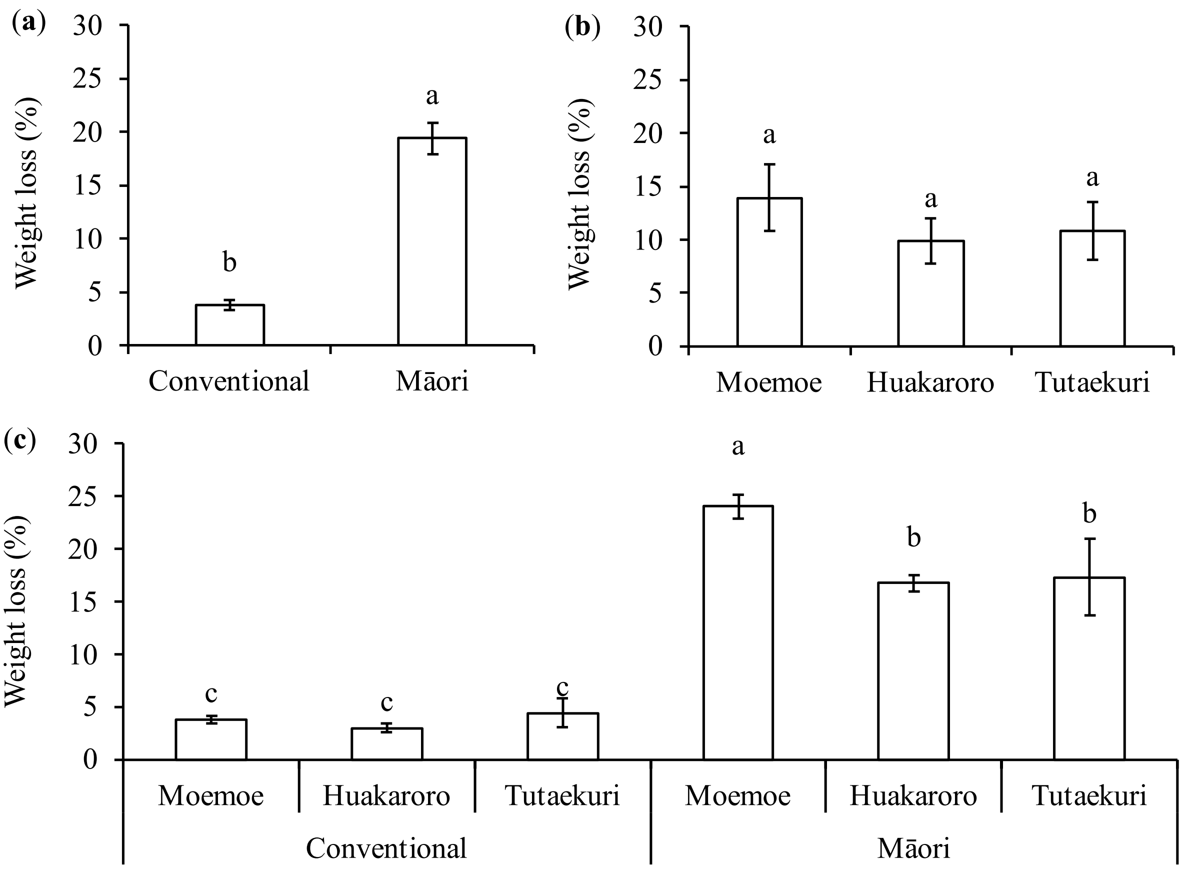

Figure 30. Effects of storage method (a), variety (b) and their interaction (c) on the cumulative potato weight loss during the experiment. Columns (means ± SE) with the same letters are not significantly different (P > 0.05).

The weight loss of a given potato variety and storage method significantly increased with the prolonged storage duration ($P < 0.0001$) (Figure 31). For each variety, the rate of weight loss was significantly faster in Māori storage method than in conventional storage method (non-overlapped 95% CLs. As stated in statistical analysis section, if the CLs do not overlap then there is a significant difference in slope between two regression lines) (Figure 31).

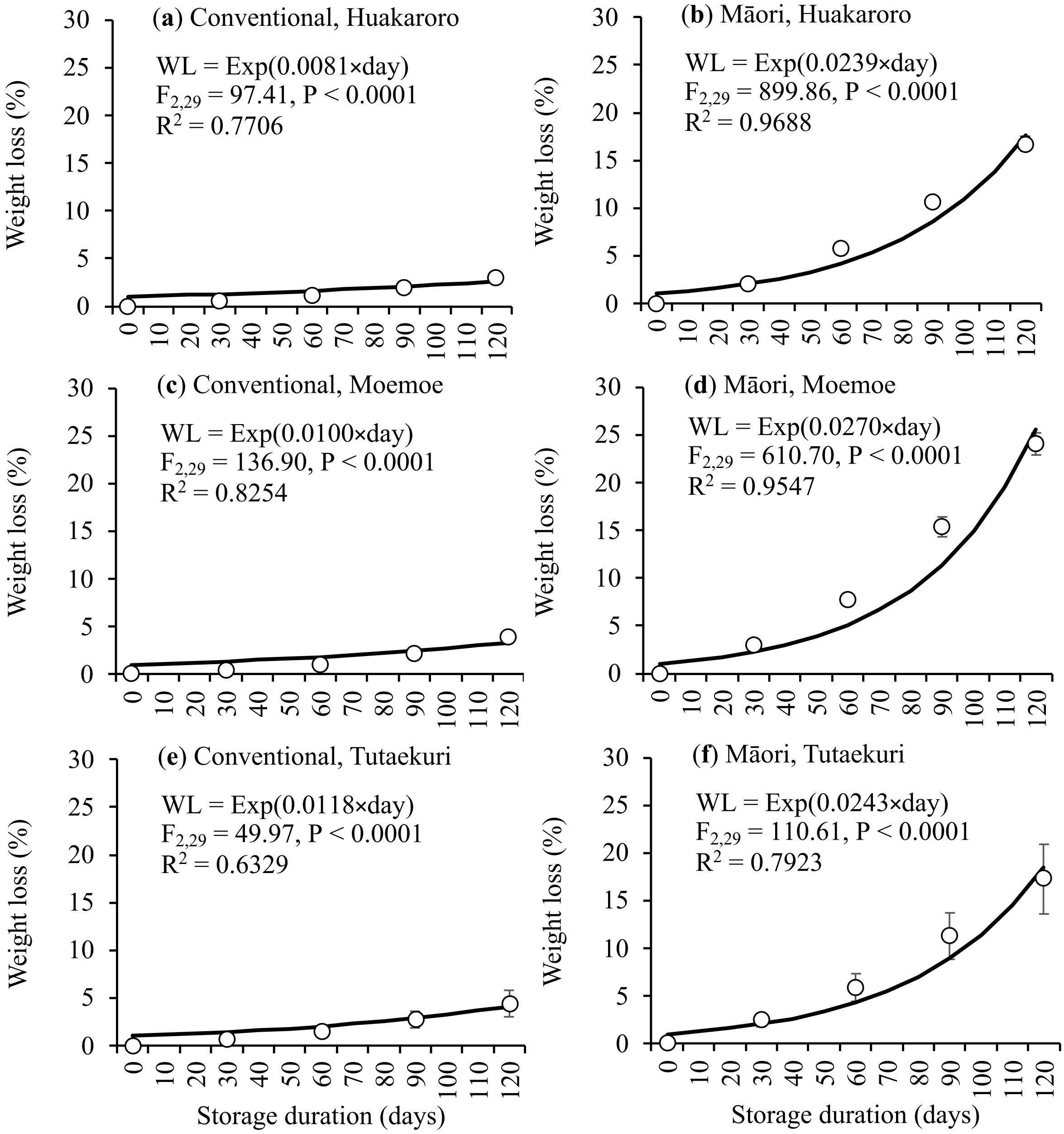

Figure 31. Weight loss (WL) of different potato variety with different storage methods over the storage duration. All data were used for analysis, but the mean weight loss (± SE) was presented in figures only.

5.1.1.3 Sugar content – Soluble solids content (SSC)

Sugar content was significant higher in sugar in Māori storage method than in conventional storage method, as it was measured five times at day 0, 30, 60, 90, and 120 days ($F_{1,168}$ = 11.15, P = 0.0010) (Figure 32a), it was significantly different between varieties with an order of Tutaekuri > Moemoe > Huakaroro ($F_{2,168}$ = 161.28, P < 0.0001) (Figure 32b). The interaction between storage method and variety was significant ($F_{2,168}$ = 5.53, P = 0.0047) (Figure 32c).

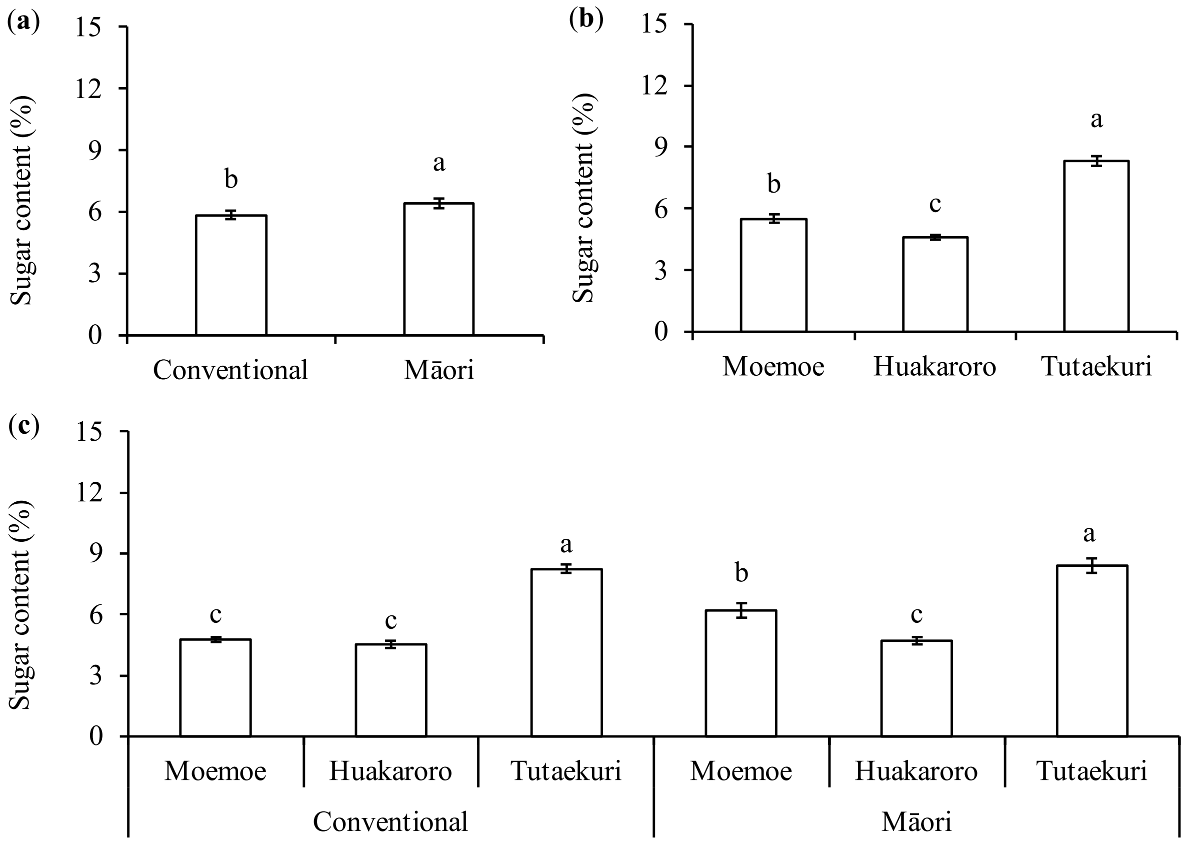

Figure 32. Effects of storage method (a), variety (b) and their interaction (c) on the potato sugar content, as it was measured five times at day 0, 30, 60, 90, and 120 days. Columns (means ± SE) with the same letters are not significantly different (P > 0.05).

The sugar content of different potato varieties with different storage methods significantly increased over the storage duration (P < 0.0001) (Figure 33). The rate of sugar content increase of Moemoe in Māori storage method was significantly greater than that when potatoes of three varieties were stored conventional storage method (non-overlapped 95% CLs). The initial sugar content was significantly higher in Tutaekuri (Figure 33e-f) than in Moemoe (Figure 33c-d) and Huakaroro (Figure 33a-b), regardless of storage method (non-overlapped 95% CLs).

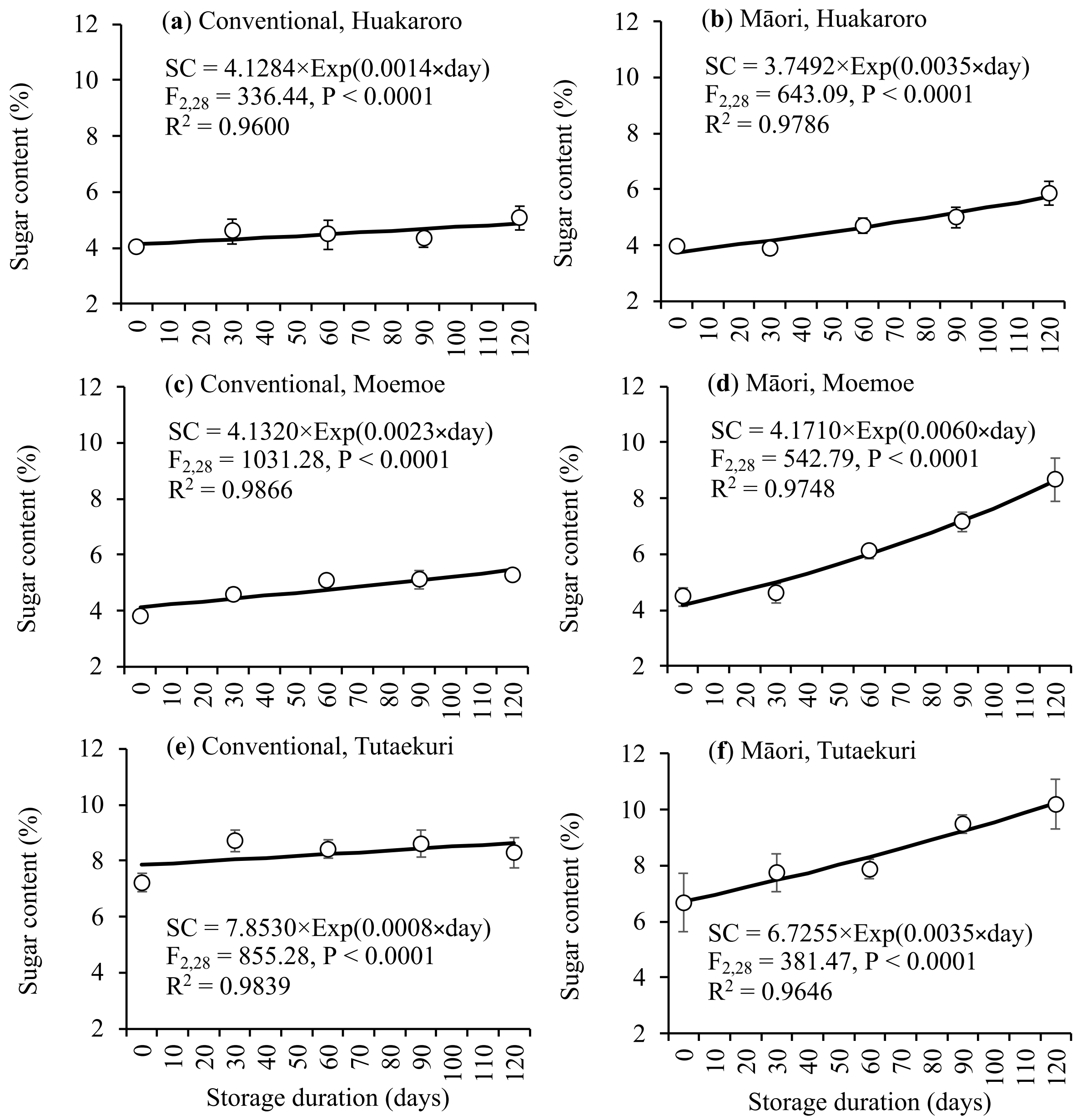

Figure 33. Sugar content (SSC) of different potato varieties with different storage methods over the storage duration. All data were used for analysis, but the mean sugar content (± SE) was presented in figures only.

5.2 Experiment 2

5.2.1 Results

5.2.1.1 Respiration Rate

The respiration rate was significantly higher in 2022 than in 2023 ($F_{1, 346} = 40.03$, $P<0.0001$) (Figure 34a). There was no significant difference in respiration rate detected between storage methods ($F_{1,346} = 0.41$, $P = 0.5238$) (Figure 34b); however, the respiration rate was significantly different between varieties with an order of Tutaekuri > Moemoe > Huakaroro ($F_{2,346} = 29.46$, $P < 0.0001$) (Figure 34c). The significant interaction between year and storage method induced a significant respiration rate of potatoes in 2022 than in 2023 regardless of storage method ($F_{1,346} = 4.21$, $P = 0.0411$) (Figure 34d). The significant interaction between year and variety resulted in a significantly higher respiration rate in 2022 than in 2023 regardless of the potato varieties ($F_{2,346} = 14.56$, $P < 0.0001$) (Figure 34e). However, there was no significant interaction detected between storage method and variety ($F_{2,346}= 2.00$, $P = 0.1370$).

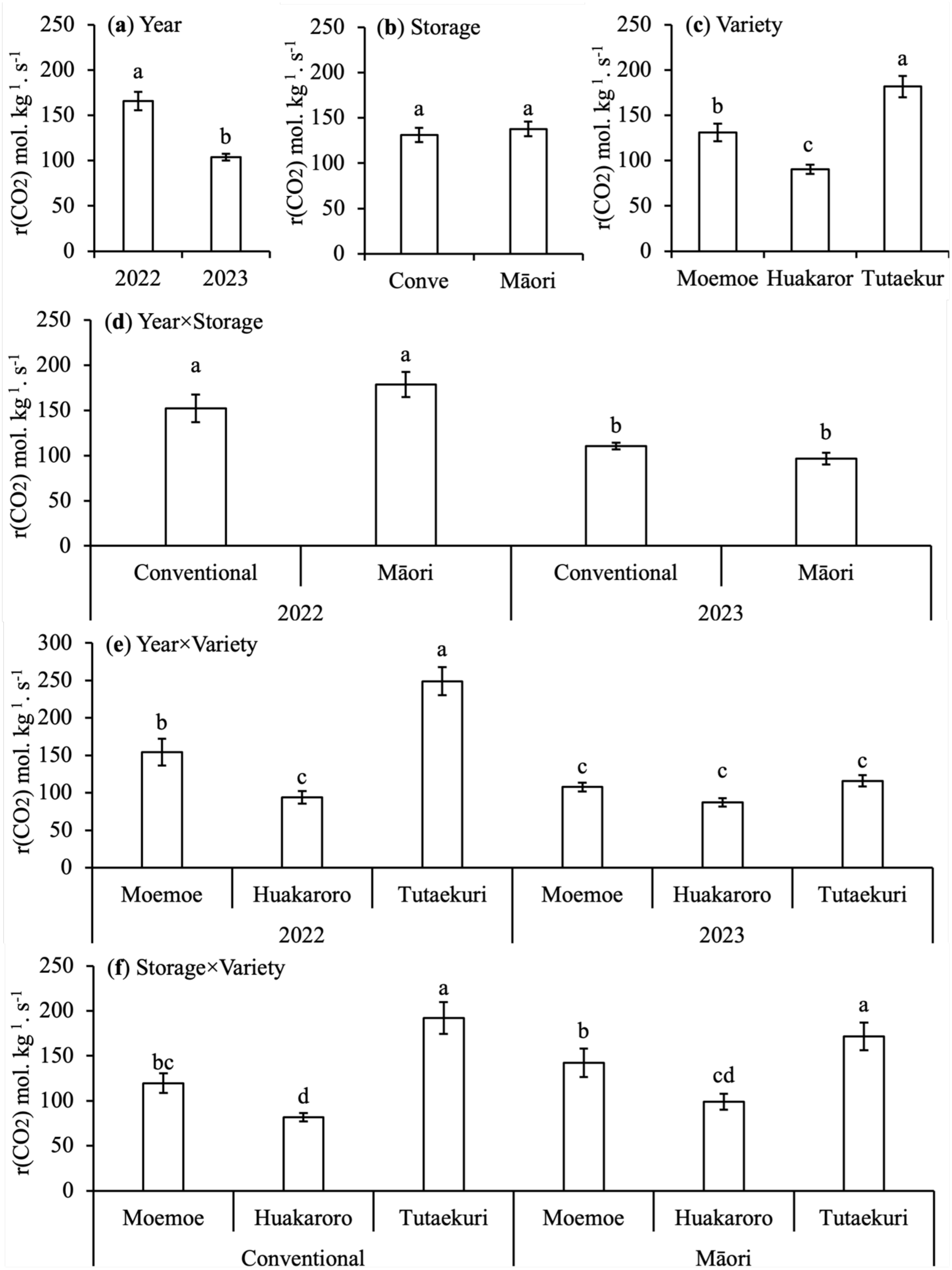

Figure 34. Effects of year (a) storage method (b), variety (c) and their interactions (d, e, f) on the potato respiration rate. Columns (means ± SE) with the same letters are not significantly different (P > 0.05).

As shown in Figure 35, the respiration rate of different potato variety with different storage methods significantly increased over the storage duration in 2022 ($P < 0.0001$). The rate of respiration increase was significantly greater in Moemoe than in Huakaroro and Tutaekuri (Non-overlapped 95% CLs), regardless of storage method (Figure 35, Table 1). The initial respiration rate was significantly higher in Tutaekuri than in Moemoe and Huakaroro (Non-overlapped 95% CLs), regardless of storage method (Figure 35, Table 1).

In 2023, the respiration rate tended to increase during the early conventional storage then decrease during the late conventional storage in Moemoe and Huakaroro; however, in other storage situations, it significantly decreased during the early storage period then significantly increased during the late storage period (Figure 35, Table 1). Compared to the conventional storage of Tutaekuri, the decreasing or increasing rate of respiration was significantly faster for the Māori storage method regardless of the potato varieties (Non-overlapped 95% CLs) (Figure 35, Table 1).

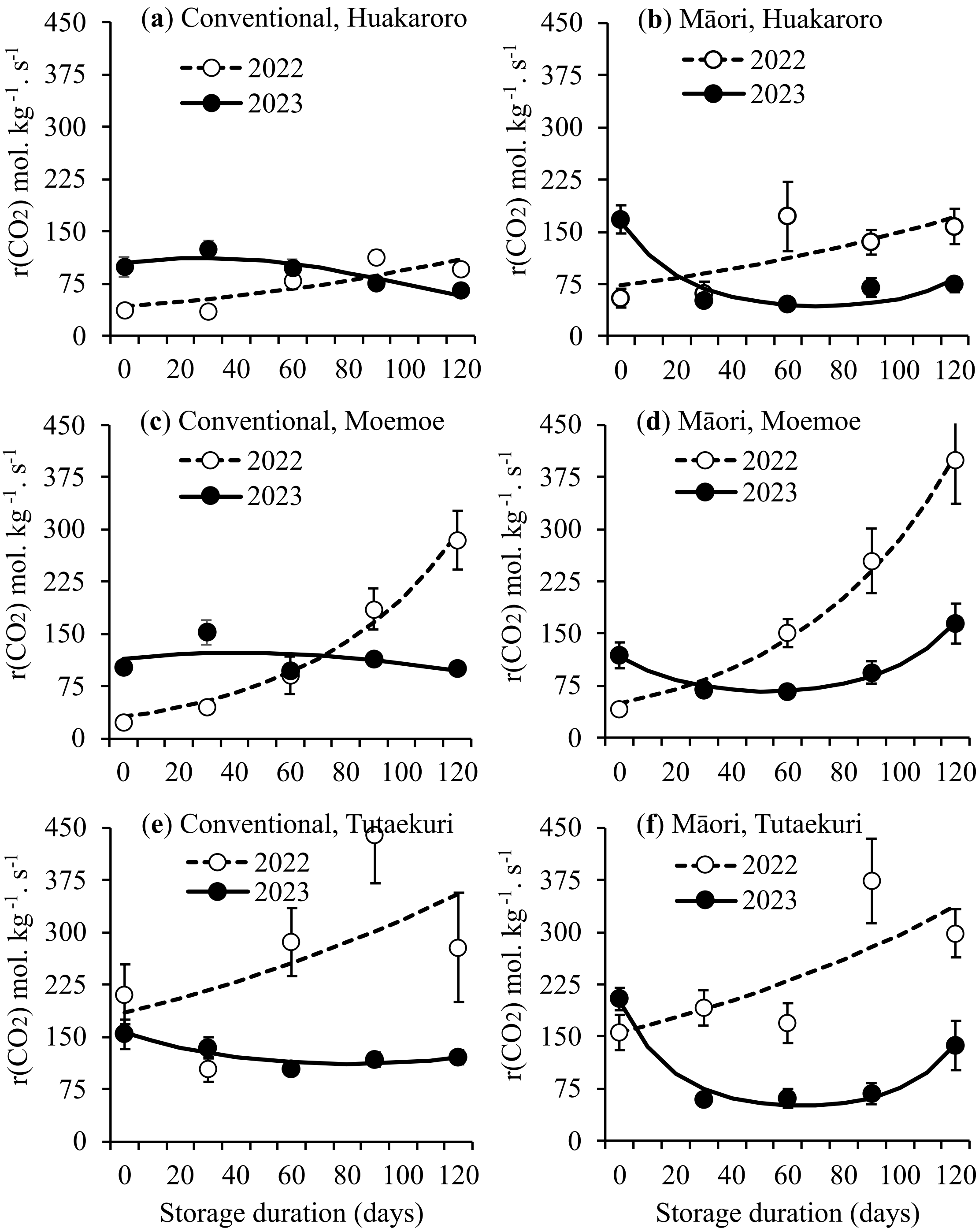

Figure 35. Respiration rate (RR) of different potato varieties with different storage methods over the storage duration (days): RR = a×exp(b×day) for 2022, and RR = a×exp(b×day+c×day^2) for 2023. All data were used for analyses, but the mean respiration rate (± SE) was presented in figures only.

Table 1. Summary of linear regressions (Figure 35) for taewa potato respiration rate (RR) over the storage duration (days) for each storage method (SM) and variety: RR = a×exp(b×day) for 2022, and RR = a×exp(b×day+c×day^2) for 2023. Equations followed by the same letter are not significantly different in slope (a) (overlapped 95% CLs: P > 0.05). df = 2,28 for 2022, and df = 3,27 for 2023.

Year	Storage	Variety	*a*	*b*	*c*	F	P	R^2
2022	Conventional	Moemoe	31.01 b	0.0187 a		99.14	< 0.0001	0.8763
		Huakaroro	41.65 b	0.0081 b		138.87	< 0.0001	0.9114
		Tutaekuri	184.40 a	0.0055 b		42.48	< 0.0001	0.7589
	Māori	Moemoe	49.59 b	0.0175 a		106.26	< 0.0001	0.8836
		Huakaroro	73.03 b	0.0071 b		43.07	< 0.0001	0.7547
		Tutaekuri	156.10 a	0.0064 b		86.47	< 0.0001	0.8607
2023	Conventional	Moemoe	114.50 bc	0.0034 a	-0.00004 b	121.98	< 0.0001	0.9313
		Huakaroro	104.80 c	0.0045 a	-0.00008 b	119.76	< 0.0001	0.9301
		Tutaekuri	155.50 ab	-0.0084 a	0.00005 b	152.18	< 0.0001	0.9442
	Māori	Moemoe	116.60 bc	-0.0212 b	0.00020 a	69.55	< 0.0001	0.8854
		Huakaroro	165.00 ab	-0.0375 b	0.00026 a	85.22	< 0.0001	0.9045
		Tutaekuri	201.80 a	-0.0432 b	0.00033 a	62.42	< 0.0001	0.8740

5.2.1.2 Weight loss

The percentage of cumulate potato weight loss was significantly higher in 2022 than in 2023 ($F_{1,60}$ = 55.70, P < 0.0001) (Figure 36a), higher in Māori storage method than in the conventional one ($F_{1,60}$ = 194.77, P < 0.0001) (Figure 36b), and higher in Moemoe than in Huakaroro and Tutaekuri ($F_{2,60}$ = 5.61, P = 0.0058) (Figure 36c). There was significant interaction between year and storage method, leading to a significantly higher potato weight loss in the Māori method in 2022 with a significantly lower weight loss in the conventional one in 2022 ($F_{1,60}$ = 55.71, P < 0.0001) (Figure 36d). The significant interaction between year and variety resulted in a significantly higher weight loss in 2022 than in 2023 regardless of the potato varieties ($F_{2,60}$ = 3.89, P = 0.0258) (Figure 36e). A significant interaction was detected between storage method and variety, from which a significantly higher weight loss was detected in Moemoe in Māori storage method with a significantly higher weight loss in the conventional method regardless of the varieties ($F_{2,60}$= 5.18, P = 0.0084) (Figure 36f).

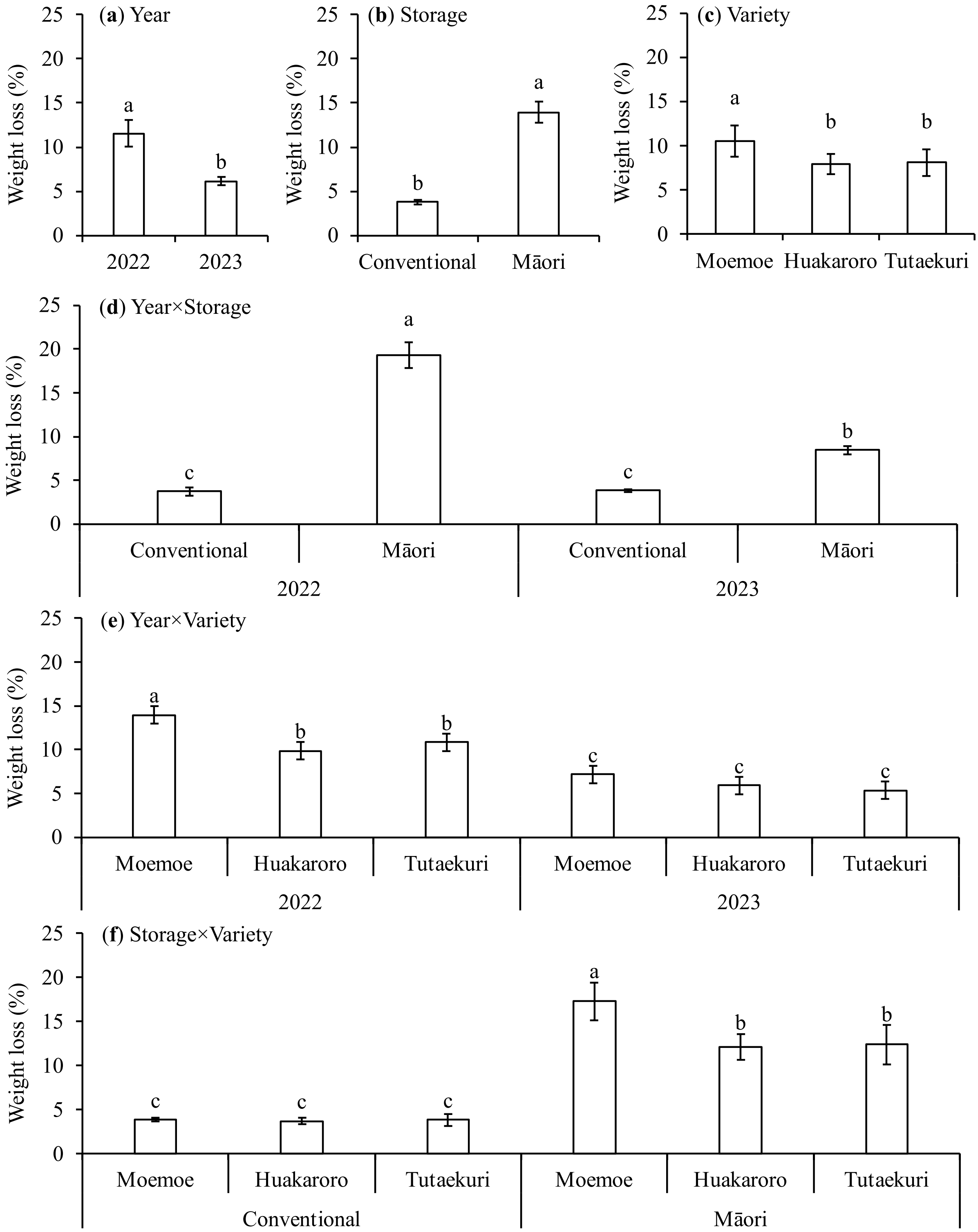

Figure 36. Effects of year (a), storage method (b), variety (c) and their interactions (d, e, f) on the cumulative potato weight loss during the experiment. Columns (means ± SE) with the same letters are not significantly different ($P > 0.05$).

The weight loss of a given potato variety and storage method significantly increased with the prolonged storage duration in both 2022 ($P < 0.0001$) (Figure 37, Table 2). For each variety, the rate of weight loss was significantly faster in Māori method than in conventional method (non-overlapped 95% CLs), and it was significantly faster in 2022 than in 2023 regardless of the storage methods and varieties (non-overlapped 95% CLs) (Figure 37, Table 2).

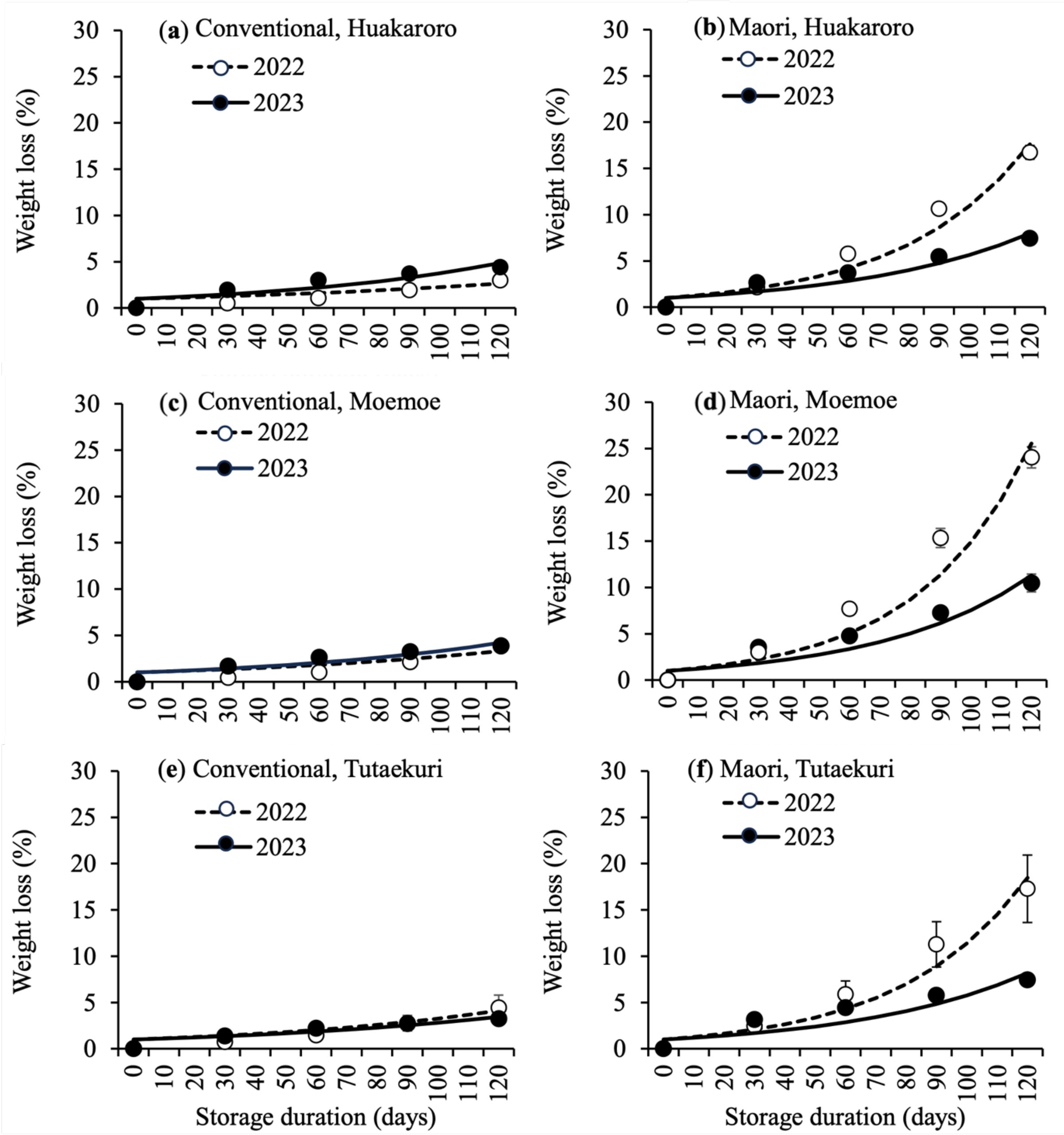

Figure 37. Weight loss (WL) of different potato varieties with different storage methods over the storage duration (days) in 2022 and 2023: WL = exp(a×day). All data were used for analyses, but the mean weight loss (± SE) was presented in figures only.

Table 2. Summary of linear regressions (Figure 37) for taewa potato weight loss (WL) over the storage duration (days) for each storage method (SM) and variety in 2022 and 2023: WL = exp(a×day). Equations followed by the same letter are not significantly different in slope (a) (overlapped 95% CLs: P > 0.05).

Year	SM	Variety	*a*	$F_{(1,29)}$	P	R^2
2022	Conventional	Moemoe	0.0100 e	136.90	< 0.0001	0.8254
		Huakaroro	0.0081 e	97.41	< 0.0001	0.7706
		Tutaekuri	0.0118 e	49.97	< 0.0001	0.6329
	Māori	Moemoe	0.0270 a	610.70	< 0.0001	0.9547
		Huakaroro	0.0239 a	899.86	< 0.0001	0.9688
		Tutaekuri	0.0243 a	110.61	< 0.0001	0.7923
2023	Conventional	Moemoe	0.0120 d	468.54	< 0.0001	0.9418
		Huakaroro	0.0132 d	315.49	< 0.0001	0.9157
		Tutaekuri	0.0103 e	377.25	< 0.0001	0.9285
	Māori	Moemoe	0.0202 b	389.11	< 0.0001	0.9306
		Huakaroro	0.0173 c	613.53	< 0.0001	0.9549
		Tutaekuri	0.0175 c	406.28	< 0.0001	0.9334

5.2.1.3 Bud sprouting characteristics

The potato bud length was significant longer in Māori storage method than the conventional one ($F_{1,126}$ = 89.23, P < 0.0001) (Figure 38a). The bud length was significantly different between varieties with an order of Moemoe > Huakaroro > Tutaekuri ($F_{2,126}$ = 12.51, P < 0.0001) (Figure 38b). The significant interaction between storage method and variety resulted in significantly longer buds in Moemoe in Māori storage method than in other combination treatments ($F_{2,126}$ = 11.20, P < 0.0001) (Figure 38c).

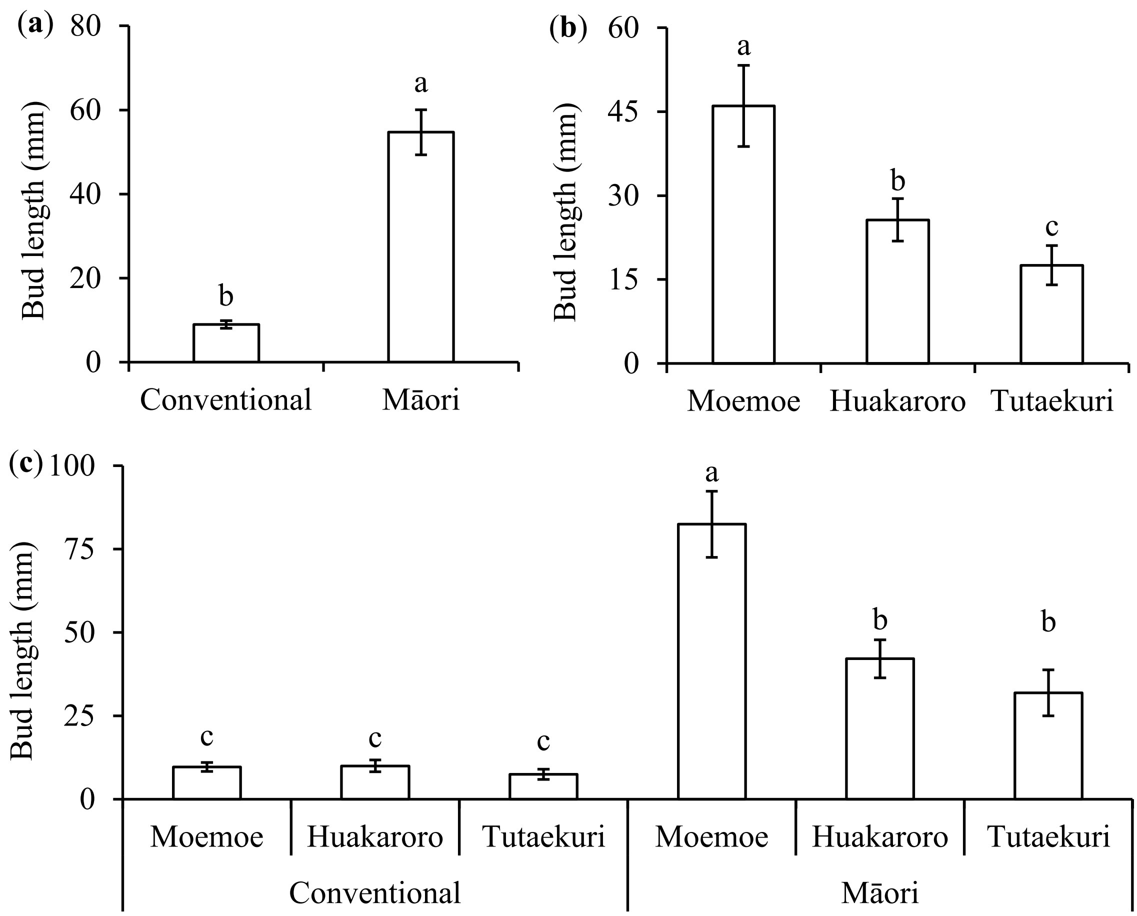

Figure 38. Effects of storage method (a), variety (b) and their interactions (c) on the potato bud length. Columns (means ± SE) with the same letters are not significantly different ($P > 0.05$).

There was no significant difference in potato bud width detected between storage methods ($F_{1,126} = 0.02$, $P = 0.8805$) (Figure 39a); while it was significantly wider in variety Moemoe than in Huakaroro and Tutaekuri ($F_{2,126} = 7.90$, $P < 0.0006$) (Figure 39b). The interaction between storage method and variety was not significant ($F_{2,126} = 0.01$, $P = 0.9865$) (Figure 39c).

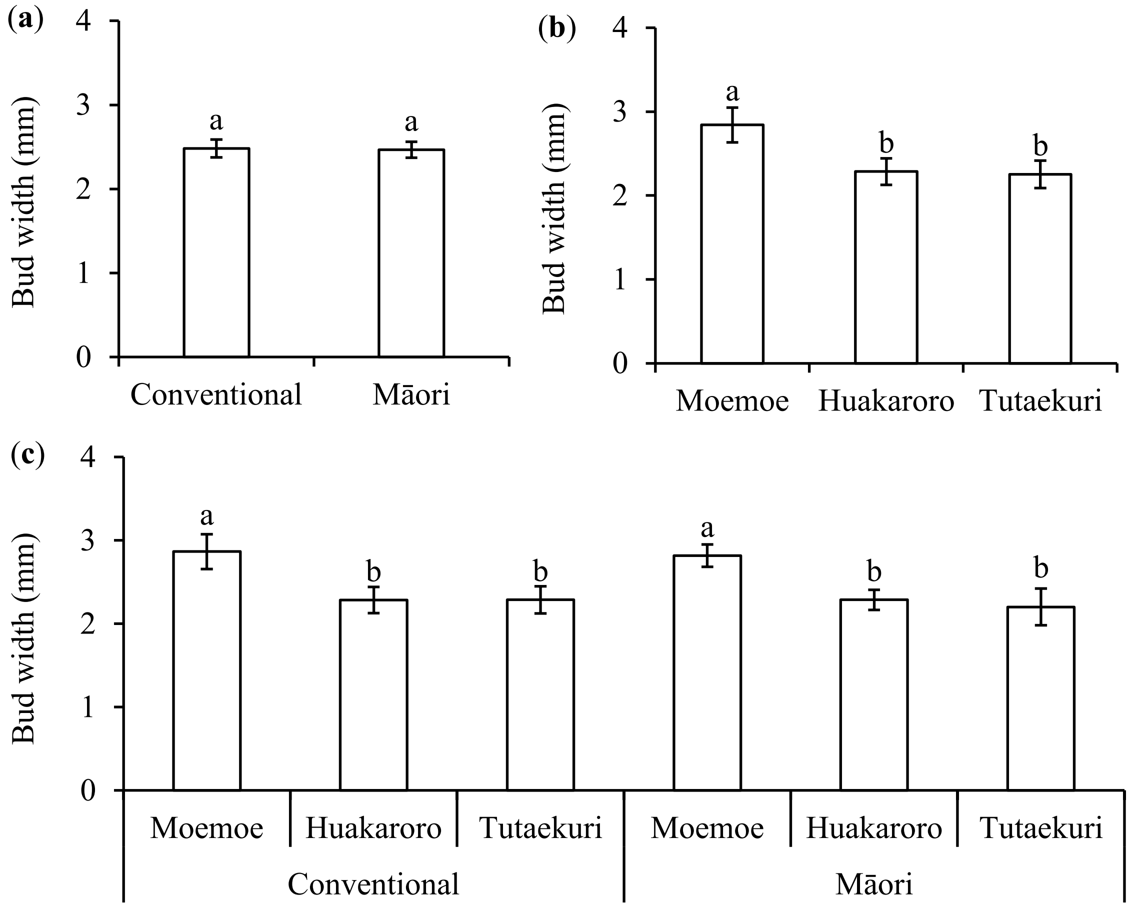

Figure 39. Effects of storage method (a), variety (b) and their interactions (c) on the potato bud width. Columns (means ± SE) with the same letters are not significantly different ($P > 0.05$).

The sprout number was significantly higher conventional storage method than in Māori one ($F_{1,28} = 4.63$, $P = 0.0402$) (Figure 40a), and it was significantly higher in variety Moemoe than in Huakaroro and Tutaekuri ($F_{2,28} = 16.94$, $P < 0.0001$) (Figure 40b). The interaction between storage method and variety was significantly, which resulted in a significantly higher sprout number in Moemoe than in Huakaroro and Tutaekuri regardless of storage method ($F_{2,28} = 0.02$, $P = 0.9826$) (Figure 40c).

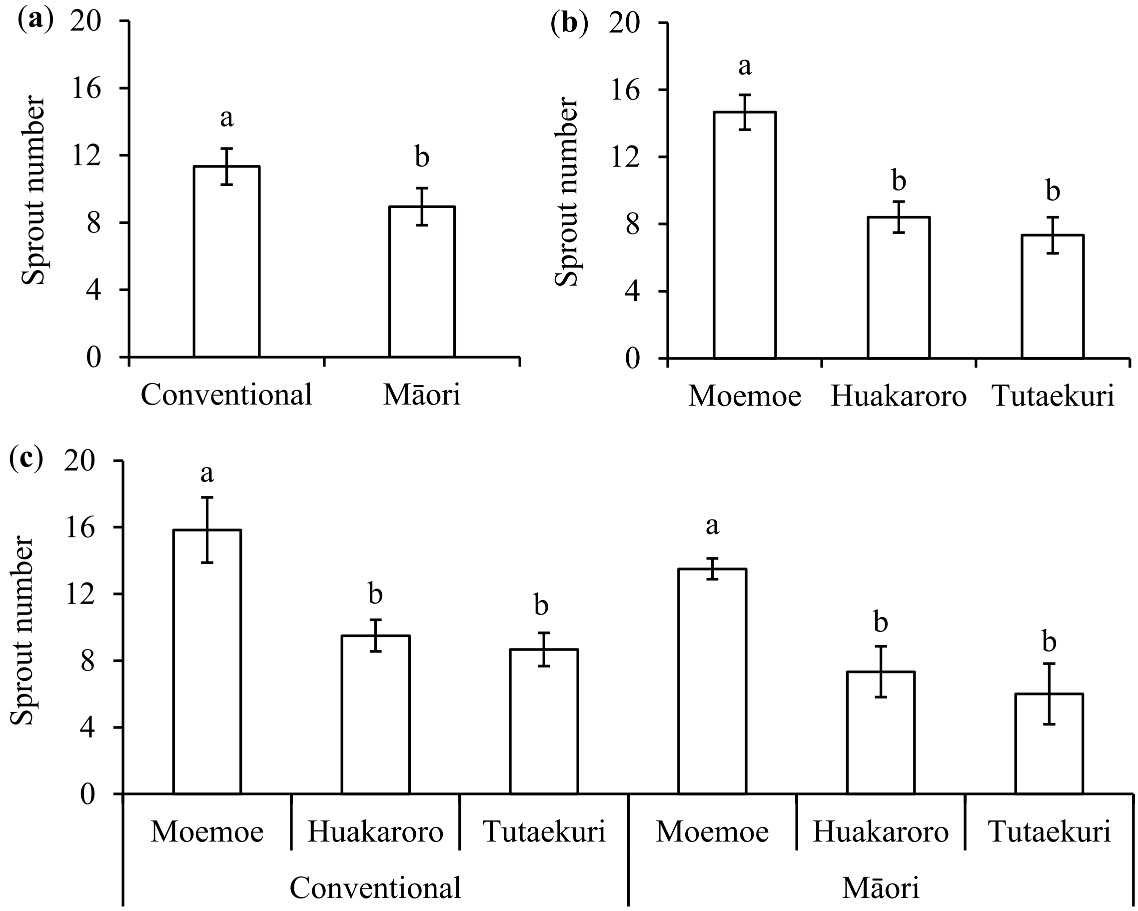

Figure 40. Effects of storage method (a), variety (b) and their interactions (c) on the potato sprout number. Columns (means ± SE) with the same letters are not significantly different ($P > 0.05$).

As shown in Figure 41, storage duration had no significant effect on bud length in conventional storage method regardless of variety or in Tutaekuri in Māori storage method. The bud length significantly increased with storage duration in varieties Huakaroro and Moemoe with a similar increase rate (i.e., slope) (overlapped 95% CLs).

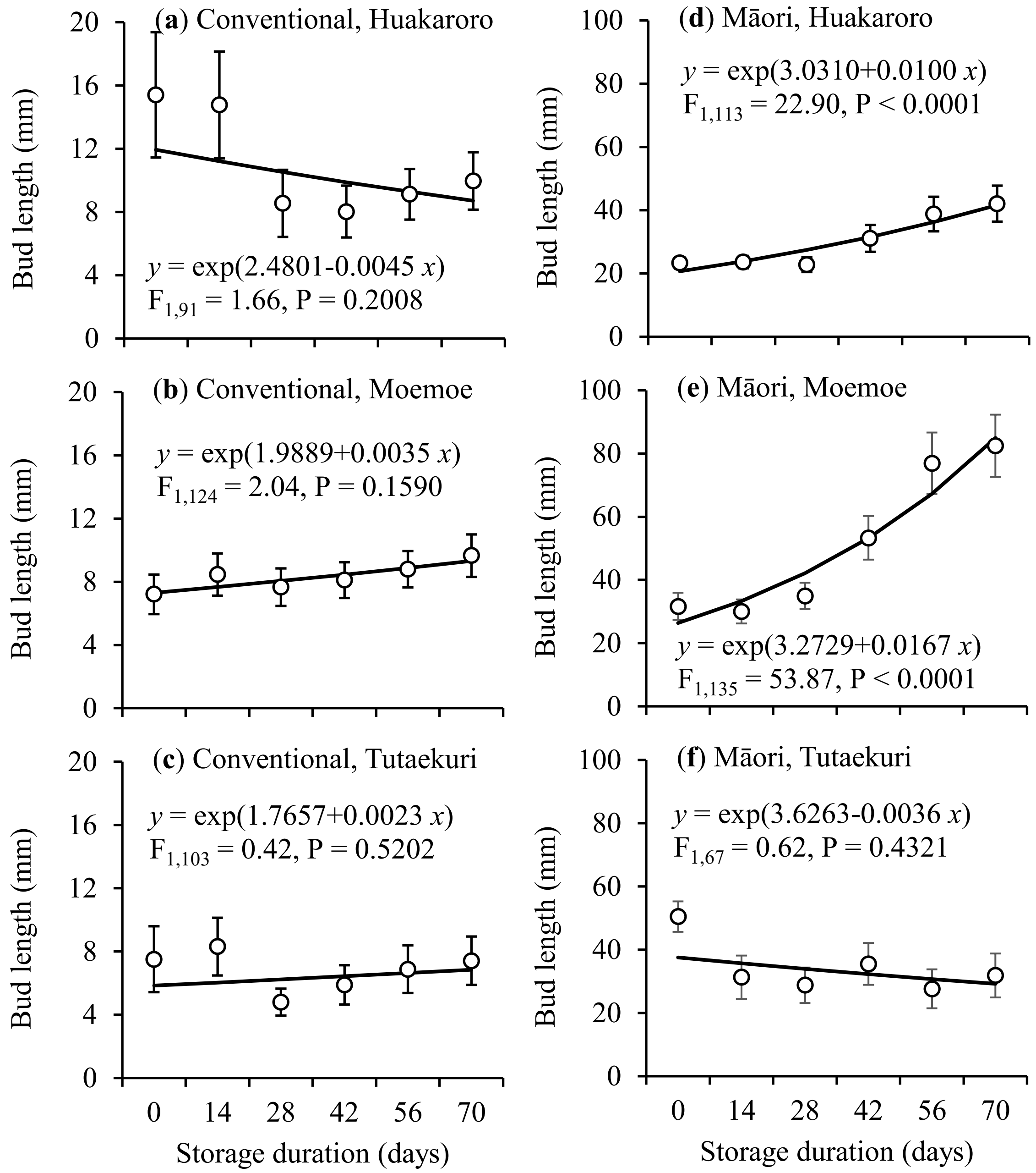

Figure 41. Bud length of different potato varieties with different storage methods over the storage duration (days): Bud length = exp(a + b × day). The first measurement was performed on 05 July 2023 (i.e., day 0) for conventional method and on 07 June 2023 for Māori method. All data were used for analyses, but the mean bud length (± SE) was presented in figures only.

Storage duration had no significant effect on the bud width, except that in variety Moemoe in Māori storage method, where the bud width significantly increased with storage duration (Figure 42).

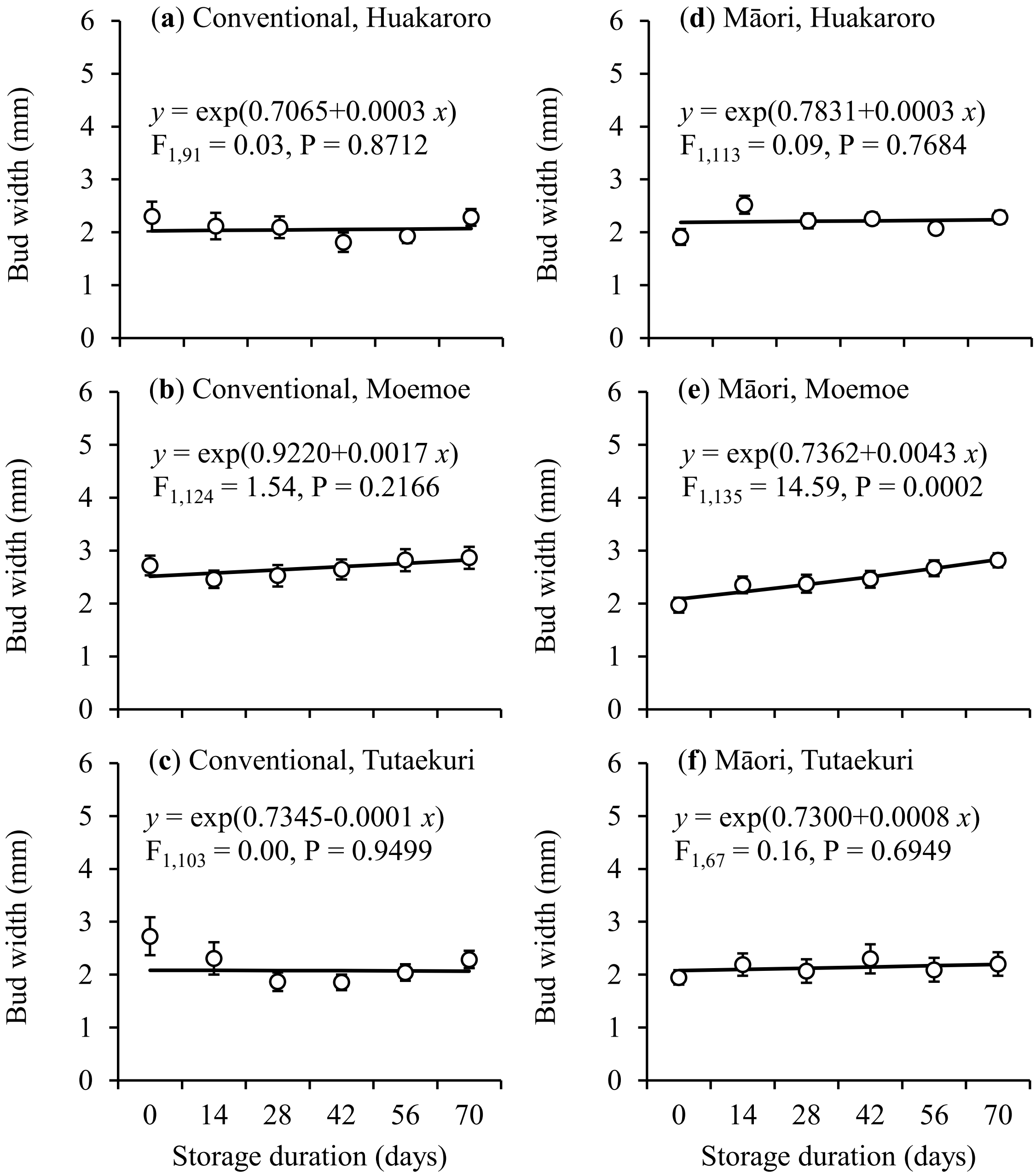

Figure 42. Bud width of different potato varieties with different storage methods over the storage duration (days): Bud width = exp(a + b × day). The first measurement was performed on 05 July 2023 (i.e., day 0) for conventional method and on 07 June 2023 for Māori method. All data were used for analyses, but the mean bud width (± SE) was presented in figures only.

The sprout number significantly increased over the storage duration in different potato varieties and different storage methods (Figure 43). The increase rate was significantly greater in variety Huakaroro in Conventional storage than in varieties Huakaroro and Moemoe in Māori storage method (Figure 43a, 43d and 43e).

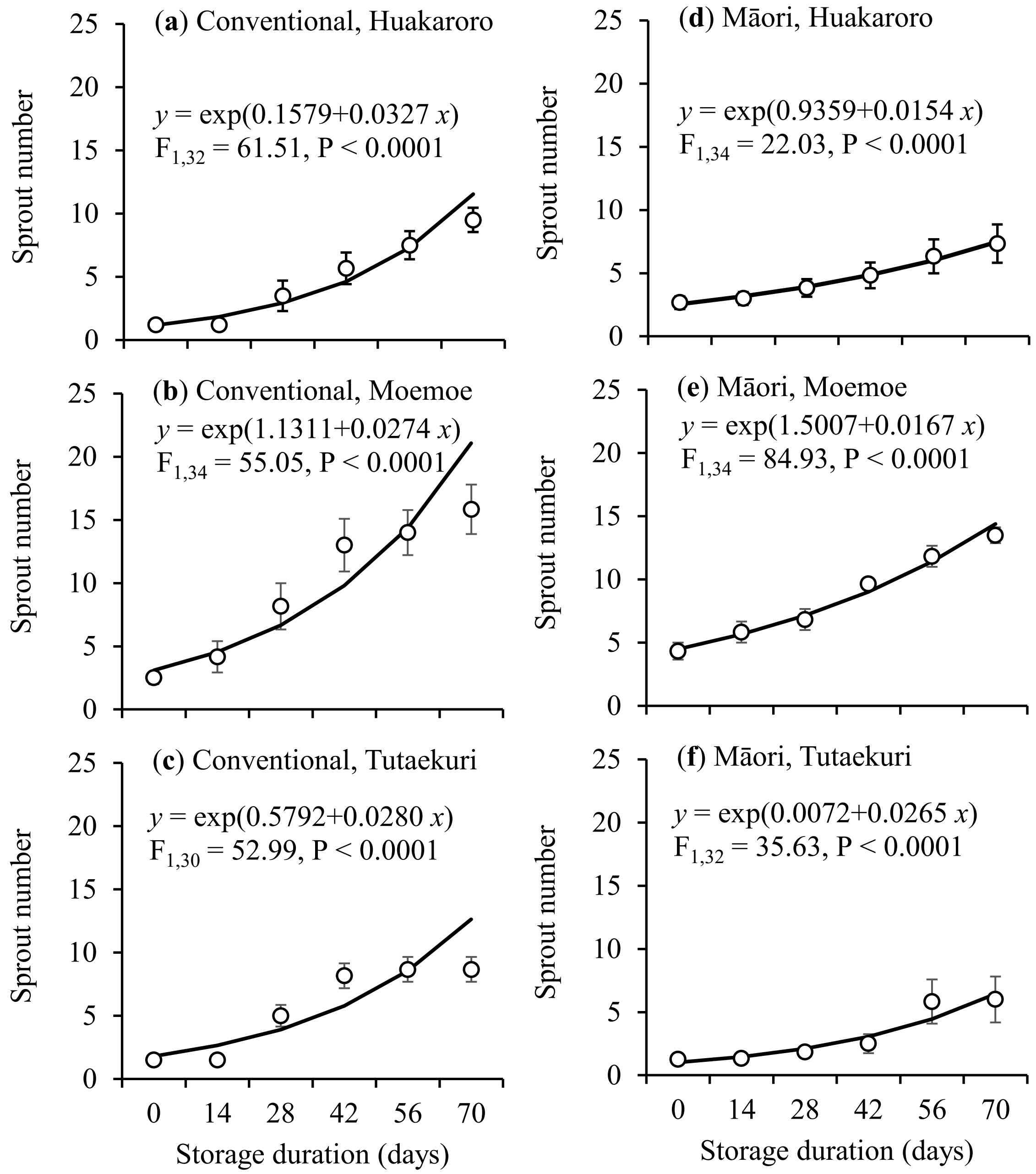

Figure 43. Sprout number of different potato varieties with different storage methods over the storage duration (days): Sprout number = exp (a + b × day). The first measurement was performed on 05 July 2023 (i.e., day 0) for conventional method and on 07 June 2023 for Māori method. All data were used for analyses, but the mean sprout number (± SE) was presented in figures only.

Chapter 6

General Discussion and Conclusion

6.1 The history and the importance of seed potato

The potato, from the time of its discovery to the present time, it is one of the most well-known and efficient vegetables in the history of humanity. As an important vegetable crop and also a source of industrial raw materials for human and animal consumption, the potato is one of the vegetables that has been most researched in basically all agricultural areas in universities and research centers around the world.

In Chapter 1, the possible origin of potato cultivation was discussed in relation to some archaeological discoveries in the areas surrounding Lake Titicaca, on the border of current Bolivia and Peru (D. Spooner et al., 2005). Remains of ancient potatoes dating back to around 4000 BCE have been revealed in that region (Hawkes, 1990). However, Spooner et al. (2014) suggests that the potato may have first been domesticated as early as 6000 BCE. Research discovered through archeology can bring us knowledge of ancient civilizations and their traditions for the involvement of research, becoming relevant as a complement to understanding the behavior of some vegetable varieties, in this case the potato tuber, especially in terms of concerns the way these tubers were stored in the past until today. As mentioned, research on potatoes has repercussions on several areas of this plant's biology, in different climatic situations and storage manipulations.

The importance of potato cultivation for the horticultural industry in New Zealand, and the importance of potato seed technology, was introduced in Chapter 3. Māori taewa varieties were discussed from their origin, history of culture and characteristics, mainly describing three varieties (Moemoe, Huakaroro and Tutaekuri) that were used in this research. Much was also said about the storage methods used by the ancestors and the way they conducted storage, which were also carried out with the variety kūmara (*Ipomoea batatas*). The results of interviews carried out with several taewa potato growers were also presented. As demonstrated, many growers continue to follow the same procedures adopted by their ancestors when using fern to cover taewa seeds while dormant. The dry fern covering on the taewa seeds in this experiment was used only as a simulation of the way Māori growers have stored taewa seeds throughout history. Fern cover has not been investigated separately from temperature control.

Consequently, there was no effect of covering with dry ferns. Some innovations that were expanded over time were the addition of gallons or barrels that began to be used as a means of storing these seeds. Regardless of the way storage is conducted, something that should be highlighted in this study is that basically the method of storing taewa seeds remains the same as in the past, where some growers apply their cultural experience and knowledge and do not use cutting-edge technology as is generally used in large farms that use precision agriculture, for example.

The literature review in Chapter 2 highlights several important points related to the development of potato tuber seeds from planting to harvest and the possible causes that occur in these tubers while they are in a state of dormancy during the period of storage. Basically, this chapter reviewed the aspects of the physiology of the potato tuber that relate to harvesting and storage. This information provides an essential background to post-harvest management. As this research was developed with the aim of producing healthy and viable seed tubers for the future seasons, storage management is about preserving the quality of potatoes, so they remain suitable for their end use. But, before the storage itself, managing the planting of tubers in the field is a key factor in the success of storage. Planting and cultural treatments in the field for good management and consequently the harvest of healthy tubers was presented in chapter 4. In chapter 4, all procedures adopted from best practice within the industry and applied since the preparation of the experimental area were covered, including soil analysis (included in the appendix 2) and all cultural treatments, since spraying the herbicide Glyphosate and application of fertilizer 15:15:30 (N:P: K) at the time of planting. As this is scientific research, during the planting period and maintenance of cultural practices, technological procedures were adopted such as the use of chemical fertilizers, herbicides, fungicides, etc., as a way of avoiding future problems such as competitiveness between weeds and potatoes, presence of future known potato diseases, such as late blight of potato, which could compromise the progress of the research, even though these are not necessarily procedures used by Māori growers, as mentioned in the personal interviews.

The explanation of the history of potato storage around the world was reviewed in chapters 1 and 3. As explained, most of the countries in which potato cultivation began to be consumed and consequently used in the culture of these places, involved countries on the European continent, Latin America, and North America. Global statistics also indicate that potato production is shifting towards developing countries especially with strong increase in production in Asia and Africa, in particular in East Africa (Campos & Ortiz, 2020).

As mentioned in Chapter 3, Māori potato growers reported that they all follow the Maramataka (Māori Calendar) guidelines. (see Appendix 1). As this research is based on simulating the procedures adopted by these growers, specifically in post-harvest management, this research also adopted the taewa planting time following the growers' traditions, that is, for the Manawatu region, the planting time it is generally held in November. It is important to consider the soil and crop conditions, weather forecast, and long-term weather records when deciding the harvest date (Singh & Kaur, 2016). Meteorological records from the planting period of this experiment's two years of research can be found in the appendices. Conditions of harvesting such as the timing of the harvest, tuber health, and soil conditions can significantly affect tuber health throughout storage and the quality of tubers (Singh & Kaur, 2016). For most crops to achieve their yield potential they need to grow in soil with a good structure to access nutrients and water (Johnston & Poulton, 2018). Top dressing with N and K was applied 30-45 and 60-90 days after planting at a dose of 25 kg ha^{-1} of N and 25 kg ha^{-1} of K_2O in the experimental area. At the time of harvesting this experiment, collection was carried out using only a garden fork. The garden fork was carefully placed in the soil around the rows as a way of avoiding wounds on the potatoes as this could provide an entry point for storage rot diseases and also wounds could accelerate the respiration rate and subsequent weight loss of stored tubers. The harvest for the two years of research were carried out on sunny days, with temperatures around 15 $^{\circ}$C, and the soil was not showing excess moisture. For the two harvests carried out, the days were ideal for harvesting and aligned to the criteria given by the Māori growers interviewed.

The main point of this research is focused after the potato harvest. In any case, it is important to point out this information prior to harvest as a way of highlighting the importance of correct management from both a traditional and conventional production system when installing planting as a way of avoiding problems during the development of the plant and consequently future potato seeds. Harvesting the potato crop is a critical part of the entire potato production and marketing operation (Wasukira et al., 2017). One of the simplest and most effective ways to reduce water loss and decay during post-harvest storage of potatoes is curing after harvest (Soliman et al., 2017).

As Māori growers have done since ancient times, they keep the remaining soil around the potato seeds from the time of harvest. They adopt these measures because they believe that the soil contributes to the protection of the tubers and is responsible for maintaining seed dormancy while they are in storage. According to what Māori growers believe, in cultural expression - is to allow Papatuanuku or Mother Nature to continue to embrace the tuber so that man can access it as needed in the future (out of season) (Nick Roskruge - personal communication, May 2024). Singh and Kaur (2016) state that soil in the tuber impedes air circulation and exchange through the pile and on the surface of the tuber and increases rot, black pit and dehydration. After collecting the seeds, they were kept inside cardboard boxes that were left open for good ventilation in a closed room at the Fruit Crops Unit (FCU), School of Agriculture & Environment at Massey University, for a period of approximately 14 days. Regarding the use of dried fern leaves, Māori growers do not believe that these dry leaves are responsible for the dormancy of stored seeds. When Māori producers cover taewa seeds with dry fern, their idea is not to prevent sprouting or allow the seeds to rest for longer, but rather to protect the tubers from the presence of rodents.

The present study contributed to the understanding of the behavioral mechanisms affecting the storage of taewa Māori potatoes during two different research storage methods, Māori Storage Method (MSM), which was a simulation of the way Māori growers have stored taewa tubers since the colonization of Aotearoa New Zealand, covering these tubers with dried fern and generally stored in cardboard boxes or crates without temperature or relative humidity control. Light levels were the only control carried out in the simulation of the Māori storage method, as the shed where the experiment was carried out was completely sealed at the doors, windows, and roof. The other method was called conventional storage method (CSM), method generally used by potato producing industries, so they remain suitable for their end use – be that fresh consumption, processing, or as seeds for the next crop.

The management and conditions prior to storage - from previous seed selection through storage, planting etc, are all strong influences on the future storage of taewa seed - from a Māori (Cultural) perspective this represents the generational view of the seed - that the single season approach and intervention to put in storage is just a small part of the continuum which is the life of taewa - ongoing and multigenerational (Nick Roskruge - personal communication, May 2024). The tuber dormancy duration is largely dependent on the genotype along with pre-and postharvest conditions. In general, there is a lot of common ground between both cultural and commercial approaches to seed selection and storage. Therefore, the characterization of germplasm under different storage environments is desired to optimize storability that directly or indirectly regulates the keeping quality of potatoes (Carli et al., 2010). As tuber dormancy commences during tuber formation, it is presumed that the factors affecting tuberization (e.g., nutrient, water supply, temperature, and day length), also affect dormancy and sprouting

(Suttle, 2007). Other factors during this storage research, such as relative humidity, light, etc., may also contribute to breaking dormancy and consequently the emergence of sprouts.

It is important to highlight that for potato seed growers, it is necessary to keep these seeds stored until the time of planting the next harvest. Regardless of the purpose of potato seeds in the production pattern and consequently in the marketing system, all these factors mentioned above may influence the storage duration of the seeds, even though this tuber is in a state of dormancy, it continues to breathe, as dormancy is the complete inability to sprout or grow even if environmental factors are at optimal level (Deligios et al., 2019). Storage conditions must be set to minimize sprouting, respiration, dehydration, and disease (Copp et al., 2000). In storage, potatoes combining their stored carbohydrates with oxygen from the air and converting them into energy, water, and carbon dioxide (Becker & Fricke, 1996); (Fennir et al., 2003); (Pringle et al., 2009); (Lufu et al., 2019). Therefore, it is important to understand and manage the physiological processes that occur in harvested tubers after harvest, because potatoes also have an inbuilt capacity to be stored for long periods of time. The results of the collection of basic data into the testing of respiration rate, weight loss, sugar content, and the combination of data on respiration rate, weight loss for the years 2022 and 2023 together with sprouting characteristics (chapter 4), respectively, established that storage methods, associated with temperature had a significant influence on the characteristics and physiological functions of potato seeds and could potentially affect the quality of the taewa tubers.

Many growers, by using the average daily temperature, are able to calculate the thermal time. The thermal time is the unit of measurement for Growing Degree Days (GDD) is typically in degree-days, which combines degrees (usually Celsius or Fahrenheit) with days. GDDs are calculated based on the average daily temperature above a certain base temperature, representing how much warmth is available to help plants grow.

The formula for GDD is:

GDD = (Max Temp + Min Temp)/2 - Base Temp

where:

- Max Temp and Min Temp are the daily maximum and minimum temperatures,
- Base Temp is the threshold temperature below which plant growth is negligible.

The base temperature for the accumulated thermal time of a potato is 45 °F (7 °C) (Streck et al., 2007) (Timlin et al., 2006). Based on the data obtained from maximum and minimum temperature accumulated between sowing and harvest time for each season and also during the storage period for the two experiments, the results were:

2021/2022 = GDD field = 2.679.35 °F

2022/2023 = GDD field = 2.634.35 °F

2022 = GDD storage = 1757.40 °F

2023 = GDD storage = 1225.05 °F

How much thermal time was accumulated between sowing and harvest time for each season? The calculation shows that for the two years of the experiment (2021/22 and 2022/23), GDD field representing how much warmth is available to help plants grow. Basically, there is not a discrepant difference in terms of those years/experiments. Unlike the results presented by GDD storage, where it is clear that the temperature of the first experiment (2021/2022) presented higher cumulative data than the results of the second experiment. This proves the difference presented for the respiration rate and weight loss between the first and second years/experiment.

The next topics in this chapter cover the key findings of this research, the implications of the two storage methods regarding the responses of taewa seeds and suggestions. Finally, all the information obtained from this research with taewa seeds potatoes can be useful and of great importance to the scientific community in research areas such as agriculture in general and social research, more specifically in the interaction between Māori communities and other producers of taewa who cultivate it and also to contribute to the management of the accessions collection of taewa of the Māori community in Aotearoa New Zealand.

6.2 Effects of respiration rate on potato physiological characteristics for the 2022 experiment

Respiration is a very important physiological process during storage of potato tubers (Schippers, 1977). The respiratory process of potatoes is an important factor during storage because storage temperature and humidity level are the most critical factors regulating dormancy break (Muthoni et al., 2014). In this process, the carbohydrate is oxidized by O_2 into CO_2 and releases energy in the form of adenosine triphosphate (ATP), which supports the metabolism of living plant organs (Ponce-Valadez & Watkins, 2008). The carbon dioxide (CO_2)

measurement unit in this study was based on the article by Banks et al. (1995) where these authors established the unit (mol kg^{-1} s^{-1}) that is used to express gas exchange. Banks et al. (1995) suggested this unit of measurement because to obtain respiration rate results it is necessary to use the Ideal Gas Law - pV = nRT (Nobel, 1999) to obtain the rates of transfer of all gases of physiological interest in postharvest research, where container volumes, gas flow rates, total pressures, temperatures, molecular weights, and periods of time must be measured. These measurements were carried out following an experimental protocol standard in the post-harvest laboratory from the School of Food and Advanced Technology, Massey University, Palmerston North/Aotearoa New Zealand.

As shown in the results (Figure 28a), the respiratory rate was significantly higher in MSM than in CSM, due to environmental factors, such as temperature and relative humidity, which were little modified and not controlled. The MSM storage conditions, temperature between 5 ˚C and 18 ˚C (Appendix 5), and relative humidity around 80-85% (appendix 6) were a predisposition to maintain and stimulate physiological activity of the tubers, increasing the respiration rate of the potatoes. On the other hand, the CSM environmental conditions (temperature between 5 ˚C and 6 ˚C, appendix 5) lowered the metabolic activity of the potatoes, inducing to a more stable condition for the potatoes, and thus to remain similar as they were now of the storage. In figure 13 of chapter 3, observe the difference between the shapes of the varieties in this study. The Tutaekuri variety has a different shape compared to the Huakaroro and Moemoe tubers. Huakaroro and Moemoe were rounder and more uniformly shaped than Tutaekuri, which were on average large, elongated tubers. The Tutaekuri variety has a long shape and purple skin and pulp, Moemoe is round with purple skin and white pulp; Huakaroro is oblong in shape with yellow skin and pulp (J Singh et al., 2008). There are four types of potato shape (round, oval, pointed oval and kidney) (Burton, 1989). Tutaekuri are generally more elongated seeds and consequently have a greater surface area than Moemoe and Huakaroro. The shape of this variety may be an explanation as contributing to the difference in respiratory rate being greater than that of Moemoe and Huakaroro.

Tuber shape is mostly under genetic control, but it can also be influenced by soil texture and water stress (Harris, 2012). Sastry (1985), assessing shrinkage of foods in refrigerated storage and Soliman et al. (2017) studying the effects of different storage conditions on the measured quality parameters of potato tubers, report that the respiration rate is directly proportional to tuber surface area and inversely proportion with tuber mass. It is the reason why the shape is related to the respiration rate. Tutaekuri was also the variety that began to sprout later than the others (figure 40 in chapter 5), even though it had a higher respiration rate since the beginning of the evaluations. Some explanation for this is genetic as representing the origin of the tubers - especially from an altitude or climate which naturally extended dormancy (Andean origins) - and the selection of these varieties has followed centuries of practice rather than selection for commercial purposes (Nick Roskruge - personal communication, May 2024).

The respiration rate of the varieties in the different storage methods increased significantly (Figures 28a, b, c), with these respiration rate results being higher at the beginning of the experiment for the Tutaekuri variety (~180 r(CO_2) mol kg^{-1} s^{-1} in CSM and 150 r(CO_2) mol kg^{-1} s^{-1} in MSM) and after 120 days of storage, the highest rates of respiration showed greater results for the Moemoe variety (~ 300 r(CO_2) mol kg^{-1} s^{-1} in CSM and ~ 400 r(CO_2) mol kg^{-1} s^{-1} in MSM). The respiration rate is minimal at about 5 °C and increases slowly up to about 15 °C, above which respiration begins to increase sharply (Singh & Kaur, 2016). In the results of this research, the respiratory rate was affected by the type and time of storage. Silveira et al. (2017) and Emragi et al. (2021) both had similar results. Emragi et al. (2021) working with Rio Grande Russet seeds, presented a significant respiration rate in terms of storage duration, which may consequently cause the beginning of potato seed germination due to the combined effect of temperature and consequently the respiration rate, while Silveira et al. (2017) working with three native colored-shed potatoes (i.e., Bruja, Michuñe roja and Michuñe azul) presented results in which the respiration was affected by the storage time.

The environmental temperature in MSM (Appendix 5) varied between 5 °C and 18 °C. During the storage period, respiration rates were on the order of < 75 to 375 mol kg^{-1} s^{-1} (figure 29) at most storage temperatures for both storage methods. Factors that can be considered include storage time, temperatures, variety, and degree of sprouting. The evolution of CO_2 was low at the beginning and then high, mainly for MSM. In the first 2 months of storage for both methods, the rate of CO_2 evolution per whole tubers of Moemoe and Huakaroro varieties, except the Tutaekuri variety, was generally lower in both methods (CSM and MSM). Dwelle and Stallknecht (1978) had similar results when they worked with potato tubers (Russet Burbank, Kennebec, Targhee, Pioneer, Norchip and Aberdeen selection A68678-1) at different storage temperatures (1.7, 4.4, 5.8, 7.2 or 10.0 °C) and 95% relative humidity, found that for all varieties except Norchip, CO_2, evolution during the first months of storage was generally lowest at 7.2 °C (45 °F) and higher at the other temperatures studied. For MSM, the increase in respiration rate observed during storage occurs earlier than the CSM method because this is associated with sprouting and the end of dormancy due to environmental factors.

6.3 Effects of respiration rate on potato physiological characteristics for the 2022 and 2023 experiments

Temperature is the most important environmental factor in the postharvest life of fresh vegetables because of its dramatic effect on rates of biological reactions, including respiration (Soliman et al., 2017). For the two years of evaluations in this study, the ambient temperature and tuber respiration in the MSM experiment resulted in greater losses than in CSM (5 ˚C). The readings by Thermochron® iButton HC data logger referring to temperature trend and relative humidity in the shed (MSM) showed higher values in the 2021/2022 experiment than in the 2022/2023 experiment.

During the first months of storage of taewa varieties in the CSM, the rate of CO_2 evolution by tubers of Moemoe and Huakaroro was generally lower than 100 r (CO_2) mol kg^{-1} s^{-1} and higher at the other measurements (MSM). In the figure 35 in chapter 5, this U-shaped curve in the MSM for the year 2023 is remarkably similar to the rates of CO_2 evolution curve reported by Dwelle and Stallknecht (1978). The factor that most determined this characteristic was the ambient temperature and consequently the storage temperature, affecting the dormancy of the taewa potato tubers. Of these environmental conditions, the temperature seems to have a major influence (Muthoni et al., 2014). This was as expected. Clearly technology has an advantage now in being able to maintain a selected temperature which traditional growers could not do so easily before" (Nick Roskruge - personal communication, May 2024). High storage temperature reduces the dormancy period accelerating the physiological ageing processes (Cortelezzi et al., 2021).

In addition to temperature, CO_2 is another important point to be observed during the storage period. For both experiments, mainly for the CSM experiment, a visit to the site was carried out twice a week to observe the general appearance of the potatoes. During these visits, the access door was left open for a few seconds to allow fresh air to enter. The heat produced from respiration during storage can increase the storage temperature (Singh & Kaur, 2016).

To maintain the temperature of the potatoes at a specific level, the heat evolved by the potatoes during respiration must be removed by cooling. It is also important to have a steady supply of fresh air during storage to provide the oxygen needed in respiration and to remove CO_2 released during respiration. Tuber respiration results in CO_2 levels of 0.1% to 4–6% in commercial storage (Singh & Kaur, 2016). This CO_2 observation is very important, regardless of the purpose of using the potato (seed or consumption), as accumulation of CO_2 as high as 4% may cause black heart, eventually resulting in rot, and affect the future use of stored potatoes (Singh & Kaur, 2016). In the case of Māori growers, they are more interested in future crop establishment - not processing uses (Nick Roskruge - personal communication). Tuber glucose and fructose content may also increase if CO_2 is maintained at 3–4%; however, CO_2-induced sweetening is reversible and variety-dependent (Singh & Kaur, 2016).

Tuber dormancy varies with physiological maturity of tubers (Haider et al., 2021). This difference can be explained in terms of tuber size, with smaller tubes of the same clone having longer dormancy than larger ones. The physiology of tuber dormancy is another point to be observed during storage, especially when dealing with the structure of potato tuber, as botanically, the potato tuber is a modified stem that expands to store nutrients and is a means of vegetative propagation (Longman, 1993), because like other vegetative organs, the potato tuber has typical cell constituents of any stem comprising pith, vascular tissues, and cortex (Haider et al., 2021), and all of this with the attribute of the environment of storage, will demonstrate responses or behaviors that will respond differently. This is the case for both storage methods in this research. Basically, this result suggested that the ambient conditions did affect respiration rate at greater extent in either of the two different years storage with different grades. The respiratory rate was affected by the type and time of storage. Works with similar results have been reported for varieties and storage Dwelle and Stallknecht (1978); Copp et al. (2000); Knowles et al. (2009); Grudzińska et al. (2022). In a study conducted by Mehta and Kaul (2003), in the same way as Māori growers who destroy the haulms one or two weeks before harvest to 'harden' the skins, they found results similar to this research where average respiratory rates decreased at the beginning of storage and then average respiratory rates increased up to 120 days. These authors state that this increase is associated with the end of dormancy, budding and advanced growth of shoots.

6.4 Sugar content (SSC) effects on potato physiological characteristics for the 2022 experiment

The sugar content of the potato is affected by several factors, including variety, growing conditions, maturity at harvest, post-harvest handling stress and the storage environment

(Uppal & Verma, 1990). In the present study the values of sugar content were recorded at monthly intervals. During the storage period, a higher sugar content (%) was recorded in MSM compared to storage at 5 °C (CSM). Tutaekuri variety presented the highest sugar content among the varieties for both storage methods (figure 32 and 33). Weather conditions in the MSM research probably influenced sugar accumulation in the stored, while in CSM the low temperature was the cause of the accumulation of sugar content in the Tutaekuri variety. A marked increase in respiration rate concomitant with sugar accumulation is a frequent result of low temperature storage (Amir et al., 1977). The sugar content was affected by the type and time of storage. Works with similar results have been reported for varieties and storage (Emragi et al., 2021).

During storage, the mass was decrease mainly caused by moisture loss through evaporation and the reducing sugar level increases mainly due to senescence and cold-induced sweetening (Grubben et al., 2019). In the specific case of the Tutaekuri variety of this study, there was no increase in the sugar level throughout storage, however the alterations in potato sugar content (%) during storage time showed that the highest percentage of sugar content (SSC) was consistently in the Tutaekuri variety. In terms of temperature, when the temperature is reducing to 3 °C for example, also results in a sharp increase in respiration because of the high concentration of reducing sugars formed by the breakdown of starch. The activity of the enzyme invertase, which hydrolyses sucrose into glucose and fructose, is also high at lower storage temperatures. At 0 °C, the rate of respiration is the same as that at 20 °C (Singh & Kaur, 2016). Tutaekuri was the variety that presented the highest percentage of sugar content and was also the variety that presented a different size than the other varieties, having a more elongated and larger shape. It may also align to genetic factors such as Andean origins. Different finding was reported by Pandey et al. (2017), when they assessed the status of sugar and starch content of two harvests (90 DAP and 120 DAP) with potato in relation with seed storage (120 days at ambient condition). According to the results of these authors, potato tuber size and reducing sugars had the significant negative correlation. Among the sizes, small sized tubers showed the significantly maximum value for reducing sugars as compared to medium and large sized tubers. The concentration of reducing sugars increases as the storage season progresses. However, starch mobilization becomes substantial during the later stages of sprouting which can be correlated with the accumulation of soluble sugars (Viola et al., 2007).

Potato starches have been studied extensively in relation to their structural, physico-chemical and functional properties, and it has been suggested that the extent of variation in these starch properties among different varieties is considerably higher in potatoes than in other botanical starch sources (Singh et al., 2006). For this research, starch content analysis was not measured, however Jaspreet Singh et al. (2008) stated that the Moemoe and Tutaekuri varieties had a higher starch content of 12.9 and 12.5%, respectively, more than Huakaroro (12%).

6.5 Effects of weight loss on potato physiological characteristics for the 2022 experiment

There are several variables that may affect the rate of moisture loss from potatoes, that is, vapor pressure difference between the inside of the potato and the surrounding air, ambient temperature, surface area, weight of the tuber, species, maturity, mechanical damage, ability to heal wounds, age and possibly many others (Butchbaker, 1972). Tuber weight loss is most significant during the first few days after harvesting due to high rates of respiration and field heat (Voss et al., 2011). When potatoes are stored, weight loss occurs, as the postharvest life progresses. The duration of storage affects losses (Burton, 1992). This happens because it is predominantly governed by periderm characteristics and sprouting behaviour (Haider et al., 2021). In general, the weight loss directly regulates the longevity of tubers, hence their storage quality.

For this experiment, the weight loss of those taewa potato varieties significantly increased with the prolonged storage duration, more specifically for the MSM. Assuming they mature at the same rate, the maturity of the tubers was not a dependent condition during the dormancy period, as the three Māori varieties were harvested four months after planting. As time storage increased, CSM kept potato varieties closer to what they were at time 0, than MSM (figure 30, chapter 5). With prolonged storage, weight loss increased significantly in MSM, with the greatest weight loss being for the Moemoe variety (Figure 30). Due to environmental conditions, weight loss was significantly greater in Māori storage method than in the conventional one. As mentioned previously, the payoff for the lack of technology is some loss of integrity such as through moisture loss. Perhaps also another key point to note is that no breeding process has been applied to taewa so no emphasis on skin quality or storage which has been applied in modern varieties (Nick Roskruge - personal communication, May 2024).

For weight loss, the interaction between storage method and variety was significant with a significantly higher weight loss in Moemoe due to the water loss being greater in this variety and having a higher respiration rate in both storage methods. Tuber weight losses due to sprouting were significantly influenced by storage temperature, mainly for the Moemoe variety, which is the variety that started the first sprouts and the largest number of sprouts per variety. Similar results to those presented by the Moemoe variety were found by Gikundi et al. (2023) when evaluating the storage capacity of three Irish potato varieties (Shangi, Unica, and Dutch Robijn), under four storage conditions: (1) room temperature (RT) (21.7 ± 5 °C) and ambient relative humidity (RH) (73.5 ± 6.7%); (2) 10 °C/75% RH; (3) 10 °C/ambient RH and (4) 7 °C/75% RH for 3 months. Weight loss was one of the parameters analysed in this experiment, where the Shangi variety exhibited the highest weight loss at room temperature/RH (6.9–35.13%).

Potatoes are vegetables that have a high moisture content. It consists of 63-83% moisture content (Puttongsiri et al., 2012). The shrinkage that was visibly observed in the skin appearance of the Moemoe variety is mainly due to moisture loss. Another factor that also affected this shrinkage was the respiration rate throughout storage. The difference in temperature in the two storage methods is related to the resistance that taewa varieties may present regarding moisture transfer, that is, the water vapor from the tubers due to the difference in temperature and the relative humidity (RH) of the air environment for each research storage method. Respiration and transpiration contribute to loss in weight and alteration of external appearance (Burton, 1992). In CSM, due to the controlled temperature between 5 °C and 6 °C, there is less weight loss and reduced respiration rate. Ninety-eight percent of the moisture that leaves a tuber during storage is lost through its skin by evaporation. Only 2.4% leaves the tuber via the lenticels along with the carbon dioxide produced by respiration (Burton, 1989).

In the room where the CSM was conducted, there were fans that provided internal ventilation in that area throughout the storage period. Even with the presence of fans in the CSM, the loss of moisture for the taewa varieties was not comparable to that occurring with the taewa seeds in the MSM experiment. This is due to the controlled temperature of the room, the water vapor pressure of the air inside the room and into the potato skins, and due to the weekly visits, that allowed O_2 to enter and CO_2 to leave the room. An important observation by Singh and Kaur (2016) says that during the storage period, the rate of moisture loss from the crop is proportional to the difference in water vapor pressure (WVP) within the cells of the potato skins and the WVP of the air in the voids. The difference is often referred to as the water vapor pressure deficit (WVPD). The lower the RH of the ventilating air, the greater will be the WVPD and there will be greater moisture loss though evaporation. In addition, the colder the ventilating air compared with the tubers, the greater will be the WVPD. In the MSM the relative humidity results from the 2022 and 2023 experiments (Appendix 6 and 8), did not present values below 60% and consequently there was no water vapor pressure deficit (WVPD). In the CSM, with a temperature around 5 °C, the air in the CSM became colder and consequently the RH higher (probably over 70%) and therefore the seeds showed lower weight loss than the results presented in the MSM.

Ventilation of the crop with air cooler than the crop, no matter how humid, will always result in moisture loss through evaporation. When the pressure within the cells of the tuber skins and the vapor pressure of the air in the voids surrounding the tubers are the same, no evaporation will take place. Schippers (1971) found weight loss was much more dependent on relative humidity than on temperature, working with temperatures of 5 °C to 10 °C and relative humidity's of 80 to 100%. The behaviour of the tubers in this experiment regarding weight loss throughout the storage period are similar to the results demonstrated by Ali et al. (2017) when they evaluated changes in physico-chemical composition of potato tubers at room storage condition, among which one of the physical-chemical attributes evaluated was the weight loss of potato tubers during 90 days in storage to evaluate the influence of storage at room temperature on the physico-chemical composition of potato in three varieties Diamont, Desiree and Kruda. Physiological weight loss (g/100g), showed that significant differences ($p \leq 0.05$), were found in storage means and their interaction (storage × varieties) means. While mean values of varieties were not statistically significant ($p \leq 0.05$). Other research with similar results can be found at Butchbaker et al. (1973), and Soliman et al. (2017).

6.6 Weight loss effects on potato physiological characteristics for the 2022 and 2023 experiment

The readings by Thermochron® iButton HC data logger in the shed (MSM) recorder of this experiment presented higher values in the 2021/2022 experiment than in the 2022/2023 experiment (Figure 36 and 37). The results of both experiments showed that the Moemoe variety was the one that showed the greatest difference in loss of weight, mainly in MSM due to the ambient temperature, which is the major factor influencing respiration rate and weight loss of tuber during storage (Ghazavi & Houshmand, 2010). For CSM, there was no significant difference in weight loss due to temperature control. During storage, water is lost from the tuber due to evaporation. The suberized cell walls of the periderm act as a barrier to water loss (Burton, 1989).

Experiments that evaluate the number of layers or the thickness of the periderm of potato varieties using optical microscopy or the use of scanning electron microscopy (SEM) could be options that would probably identify the difference in weight loss and/or the presence of wrinkles that were presented by the Moemoe variety of this experiment. A possible explanation that suggests the greater weight loss of the Moemoe variety was probably due to the thinner periderm or the smaller number of cell layers compared to the other varieties in this study. Again, this suggestion aligns to comment previously that the varieties have not been selectively bred for skin factors, so this is not unexpected. Another possible explanation for the weight loss of potato varieties is that during starch hydrolysis, loss of dry matter occurs, resulting in weight loss (Singh & Kaur, 2016). In this experiment, the weight loss was affected by the type and time of storage.

6.7 Sprouting parameters of taewa potato tubers (length, width, and number of shoots) for the 2023 experiment

The dormancy period in potato is characterized by the absence of visible sprout growth and is under environmental, physiological, and hormonal control (Sonnewald & Sonnewald, 2014) and the sprouting begins at the end of the dormancy period (Suttle et al., 2016). Sprouting is prompted through many physiological changes including changes in hormonal regulation, antioxidants system and starch metabolism. Abscisic acid (ABA)/ cytokinin and ABA/ gibberellic acid (GA_3) balance are regulating factors for bud break and sprout growth progressively (Haider et al., 2021).

No sprouting control was carried out in this experiment during the storage period, although much literature Blenkinsop et al. (2002); Cunnington (2008); Makhlouf and Abdeen (2014); Visse-Mansiaux et al. (2021), addresses chemical or non-chemical control methods for controlling potato seed germination. The beginning of tuber sprouting in the experiment depended on storage temperature and variety. This suggests that the cumulative temperature during storage is the predominant factor affecting physiological aging, although its effect is moderated by light conditions and genetic factors (P. C. Struik, 2007). Various storage environments, such as fluctuations in temperature, humidity, and light, can affect the dormancy period (Es & Hartmans, 1987). In this study, the temperature followed by relative humidity and possibly the genetic characteristics of the taewa varieties had the largest influence on the beginning of sprouting. As mentioned previously, the starch content was not a response variable analysed in this experiment, but the quality of seed potato depends on the starch content, which is related to sprouting vigour (Pandey et al., 2017). The earliest germination was observed in the Moemoe variety, and the latest in Tutaekuri. Varieties stored at 5 ˚C began to sprout in the first week of July (4 months after harvest), while the varieties stored in MSM began to germinate in the first week of June (3 months after harvest).

Depending on the variety, maturity, soil, and weather conditions, potatoes remain dormant for about 5–9 weeks after harvest (Burton, 1978a), with extreme cold wet weather prolonging dormancy, whereas extreme dry warm weather shortens dormancy. The beginning of sprouting was also influenced by the weather conditions in the experiment year. Taewa potato tubers grown in 2023, characterised by high rainfall, began to sprout in MSM three month after harvest. An important point about it is that in sprouted tubers, more weight is lost than in unsprouted ones. A strong correlation exists between weight loss and length and number of sprouts (Pandey et al., 2007).

Among the three varieties in this research, the Moemoe was the one that started sprouting first for both storage methods. The shoots had different diameters, but in general most of them were long and thin. This variety was the one with the most wrinkles or shrivel appearance on the skin. Tubers become shriveled when they are dehydrated. This can have a number of causes, including excessive forced air ventilation; tuber moisture loss due to skin blemish diseases like silver scurf; long-term storage and sprouting (für Europa, 2014). Liu et al. (2023), found starch degradation generally occurs in potatoes during storage, and it is converted into sugars or other substances; the decreased starch content causes the tubers to shrink and become wrinkled. The same explanation was put forward by Singh and Kaur (2016), when they said this sprouting, the breaking of dormancy, and will affect the quality of the tubers during storage by remobilizing storage compounds, mainly starch and protein, and shrinking tubers owing to loss of water. They also said that increased physiological aging and higher RH favored sprout growth, which is more pronounced at a higher temperature. Higher CO_2 concentration also favors sprout growth. Jaspreet Singh et al. (2008), evaluated fresh tubers from four traditional taewa and one modern potato variety of New Zealand, which were stored at 4 ˚C and 80–90% relative humidity for six months after harvest. Starch was isolated from tubers after every three-month period, and its physico-chemical and functional properties measured. Considerable changes in these properties occurred during storage because six months of storage of the varieties at low temperature altered the granule size distribution of their starch. The starches isolated from varieties stored for three and six months showed shifts from particle size range to smaller particle size. Storage thus resulted in decreases in the large granule percentage to a significant extent, with Moemoe starches showing the largest decreases whereas the decrease was smallest for Huakaroro starch. These results presented by Jaspreet Singh et al. (2008), are probably an important factor that explains this effect of the appearance of wrinkles as morphological characteristics in the Moemoe variety. For the other two varieties (Huakaroro and Tutaekuri), the presence of wrinkles was not noticeable as it was in Moemoe. When the tuber is intended for use as seeds and consequently this seed will be planted for the next crop, the presence of wrinkles on the skin of the tubers, if there is no presence of disease or rot, will not be an obstacle to the next planting.

The results of this study showed that the Moemoe variety, during the 120-day storage period, was the variety that presented the greatest wrinkles noticeable. This is physiological loss caused by the biological processes in the potato because the living tubers use some of their carbohydrates for support. While the potato seed is in dormancy, this period is regulated by endodormancy. Following the endodormancy period, sprouting can occur anytime if not controlled. Sprouting results in quality loss through remobilization of starch and proteins. Therefore, sprouting is accompanied by remobilization of nutrients and shriveling (Nxumalo et al., 2017). During this process heat is produced. When sprouting occurs the rate of these processes increases several times. In the case of seed potatoes, light can be used to reduce sprout growth (Booth & Shaw, 1981). The fact is that if these Moemoe seeds are healthy, for Māori growers, this will not be a problem when the intention is to plant these seeds for the next crop. The numbers of sprout per tuber increases with the size of the tuber and sprouts of smaller tubers grow more slowly than those of the larger one (Hertog et al., 1997). Park et al. (2009) reported that sprouting rates of larger micro-tubers sprouted significantly earlier while the small tubers sprouted very late.

An important observation regarding the bud length results observed in figure 38 of chapter 5 refers to the black tips on potato sprouts. Throughout the observations carried out during weekly visits, it was observed that the Huakaroro variety was the one that showed a greater presence of black tips in the sprout (assumed to be fungal, most likely scurf *Helminthosporium solani*) of these seeds in the CSM method. The length that was measured in the following weeks of evaluation, the sprout had reduced in length when measured due to the black tips that had rotted and fell off. The Moemoe variety length were longer each time of measurement. Among the three varieties, Tutaekuri showed limited sprout growth between the intervals.

6.8 Practical implications of the study for potato Māori growers in Aotearoa New Zealand

For this research, the presence of dried fern as cover for the taewa tubers in the MSM was not a key point that would interfere with the behavior of these tubers. Internally, the tuber is full of starch stored in the swollen parenchyma cells and for this research, it is believed that dry fern did not interfere or contribute to the normal activities that occur in the structure of the tuber. Fern is a plant that has several uses for several different areas, from medicinal values (Grosu & Ichim, 2020), to food (Maroyi, 2014), treat skin diseases and gastrointestinal disorders (Piluzza & Bullitta, 2011); (Kardong et al., 2013), for controlling insect pests, used as ornamentation, and conservation of biological diversity (Mannan et al., 2008), etc. According to interviews with Māori growers from some regions of the North Island of Aotearoa New Zealand, this method of storing taewa seeds was carried out by Māori ancestors and the growers maintain this same philosophy to avoid losing or forgetting this tradition for future generations. During the interview with growers, some ladies reported that they sometimes mix lavender (*Lavandula angustifolia* Miller) with dry fern leaves to cover the taewa seeds, as they believe that the smell of lavender will keep animals/rats away from the storage sheds. For this research, the raw material of dry fern as a complement to the maintenance of taewa potatoes did not represent any influence on the behavior of the tubers while they were in dormancy. The dry fern leaves only served to cover the seeds and this dry material did not interfere with dormancy and consequently with the storage of these seeds in the MSM.

Regardless of whether the taewa tubers are covered or not with dry fern leaves at room temperature and without the presence of light or covered with other plant materials such as dry grass leaves, or dry leaves of fruit trees, or covered with newspaper or probably just stored in cardboard boxes or crates without the presence of any plant or industrial covering, the results presented would probably be very similar to the results of this study.

Future studies for dormancy breaking involving the evaluation of the concentration of phytohormones, like GA_3 (ppm) concentrations, in these taewa varieties throughout the period of dormancy or the study of the periderm of the skin of these seeds using SEM microscopes, in addition to the study of surface area and shape of these varieties using the same storage methods as this study, can probably show enriching results that will complement more information about the physiology of these varieties that have long been cultivated by Māori growers throughout the history of Aotearoa/New Zealand.

6.9 General Conclusions

- The dry fern covering on the taewa seeds in this experiment was used only as a simulation of the way Māori growers have stored taewa seeds throughout history. Fern cover has not been investigated separately from temperature control. Consequently, there was no effect of covering dry ferns.
- The present study has revealed that the coverage with the use of dry fern leaves on the taewa seed samples, in season conditions, did not interfere in the reduction of losses and physiological actions of these seeds during the storage time, even though this occurred during the winter season. Due to environmental conditions, greater weight loss, respiration rate and percentage of sugar content of varieties occurs during the Māori storage method.
- For MSM, the increase in respiratory rate observed during storage occurs earlier than the CSM method because this is associated with sprouting and the end of dormancy due to environmental factors.
- There appeared to be a general trend that during the storage period the respiration rate increased, particularly for Māori method storage. In this experiment, storage temperature is the main environmental factor affecting tuber dormancy on taewa potatoes, and this was as expected. Clearly technology has an advantage now in being able to maintain a selected temperature which traditional growers could not do so easily before.
- Physiological factors like moisture loss and consequently the appearance of wrinkles on the skin of the Moemoe and Huakaroro varieties become important parameters that affect the physiological losses of taewa potato seeds throughout dormancy.
- The time of storage of taewa seeds affected the respiration rate, weight loss, sugar content, length, width, and number of sprouting.
- The storage period increased the possibility of weight loss, especially in the 2021/2022 experiment in Māori method storage.
- The response variables (respiration rate, weight loss, and sugar content) presented characteristics of each variety, highlighting the Tutaekuri variety with the highest respiration rate and percentage of sugar content. Tutaekuri was also the variety that began to sprout later than the others. The variety that showed the highest percentage of weight loss was Moemoe. Some explanation for this is genetic as representing the origin of the tubers - especially from an altitude or climate which naturally extended dormancy (Andean origins) - and the selection of these varieties has followed centuries of practice rather than selection for commercial purposes.

- There is most likely a relationship between the shape of the tubers of the Tutaekuri variety and the increase in respiration rate and sugar content. Future research can be carried out to assess whether there are any influences of tubers size on some response variables.
- The study indicated that importance should be given to the storage behavior of taewa varieties while in dormancy to obtain better conservation quality for the regular supply of tubers for use in seeds.
- For good storage of taewa potato seeds, good harvest and post-harvest practices and ventilated areas, can be useful in reducing physiological losses of these seeds. Monitoring light, temperature, relative humidity, among others, in the environment used as storage can contribute to preventing weight loss, high respiration rate and consequently preventing economic losses.
- The results of this study may be useful to taewa potato growers in selecting appropriate storage times and as an observation of the response of the morphological characteristics of these varieties for the specific use of seeds. Understanding and managing dormancy in potato seeds is crucial for agricultural practices to Māori growers to ensure proper planting schedules and healthy crop growth.

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Personal Communications – various Tahuri Whenua hui and dates

Hanui Lawrence (Waipatu) – July 2022 and other dates.

Joe Allen (Taumarunui) – March 2022 and other dates.

Pal Toroa(Taumarunui) – March 2022 and other dates.

Joy Meihana (Taumarunui) – March 2022 and other dates.

Howie Harris – September 2021.

Nick Roskruge - May 2024.

Appendices

Appendix 1 Maramataka (Māori Calendar). (Roskruge, 2021).

MARAMATAKA MĀORI

Māori Calendar for Fishing and Horticulture

Hei whaka Māori i tēnei e mau ake nei; No 1 (Whiro) – ko te ra i muri iho o ta to pakeha new moon (the day after the new moon on the calendar); No 15 (Rakaunui) – ko te ra i muri iho o ta te pakeha full moon (the day after the full moon on the calendar)[1].

DAY	NAME	NOTES
1	Whiro	**He rā kino tēnei mō te ono kai mō te hī ika, hoki.** A bad day for fishing or planting, the moon is out of sight.
2	Tirea	**He pō ahua pai tēnei mō te hī koura, tuna mō te ono kai.** A good day for planting, fishing, torching eels and crayfishing.
3	Haohaoata	**He rā tino pai tēnei, mō te hī tuna, koura ono kūmara ono hoki i ētahi atu kākano.** A very good day for planting kūmara or any seed, also crayfishing or torching eels, especially if the moon is out of sight.
4	Ōuenuku	**He rā pai mō te ono kai, he rā pai mō te hī ika.** A good day for planting and fishing, from dawn to midday.
5	Ōkoro	**He rā pai ano tēnei mō te ono kai hī ika hoki.** A reasonable day for fishing, good day for planting from midday to sunset.
6	Tamatea kai ariki	**He rā ahua pai mō te ono kai mō te hī ika, he rā hau, he kaha te ia tērā pea e marangai.** Fair day for planting and fishing. It is windy and the sea currents are strong, expect a change in weather.
7	Tamatea angaanga	**He rā pai mō te hī ika, kia tupato te haere ki te hī ika i ngā ngaru pua i ngā kohu. He rā pai ki te ono kai.** A very good day for fishing, watch out for the weather. It is either a big heave or a misty day. A good day for cropping also.
8	Tamatea āio	**He ririki te tuna, te ika me te kūmara i tēnei ra engari he nui tupato te hunga ehi moana.** Eels, fish, kūmara etc. are plentiful but small in size. If boating, keep an eye on the weather.

[1] This version is sourced from Te Ikaroa a Maui, the south-west coast tribes of Taranaki- Whanganui and variations will exist between tribes to reflect the differences in geographical and environmental factors which they use.

MARAMATAKA MĀORI CONTINUED

Māori calendar for fishing and horticulture

DAY	NAME	NOTES
9	**Tamatea whakapau**	**He pai mō te ono kai i te ata ki te rā -tu. Kaore i tino pai mō te hī ika pou ngā Tamatea.** Fair for planting from morning to midday only. Only fair for any sort of fishing.
10	**Ari**	**He rā kino tēnei.** A bad day. OK for crayfish only.
11	**Huna**	**E hara i te rā pai ki te ono kai ki te hī rānei he noho mohoao te noho a te tuna, a te koura.** Not a good day for planting or fishing. Flounders, eels and crayfish will get very timid.
12	**Māwharu**	**He rā tino pai tēnei me te ono kai, he nunui te kūmara engari kaore e roa ka pirau he rā pai ki te hī ika.** A very good day for planting but the produce does not keep for very long. A good day for fishing.
13	**Atua**	**E hara i te rā pai mō te ono kai, mō te hī ika rānei.** It is not a good day for planting or fishing.
14	**Turu**	**He pai tono mō te hī ika mō te ono kai, i muri ō te rā tu, ki te rā to.** A fair day for fishing, especially on the incoming tide, and for planting from midday to sunset.
15	**Rākaunui**	**He rā tino pai mō te ono kai, ahakoa he aha taua kai rā pai mō te hī ika kaore e tino pai mō te hī tuna.** A very good day for planting and general gardening, not so good for eeling but good for other fish.
16	**Rākaumatohi**	**He rā tino pai mō te ono kai, mō te hī ika, kaore mō te tuna.** As for Rākaunui, a very good day for planting and fishing but not eeling.
17	**Takirau māheahea**	**Takirau māheahea, kua makoha te marama te ririki te kūmara, te koura, te tuna.** The moon is losing its brightness. Kūmara planted on this day are small, also crayfish and eels. Best from dawn until midday.
18	**Oike**	**E hara i te tino rā pai, mō te ono kai mō te hī ika rānei.** It is only another day, not the best for planting or fishing.
19	**Korekore te whiwhia**	**E hara i te rā pai, mō te ono kai, mō te hī ika rānei.** It is only another ordinary day for either planting or fishing.

MARAMATAKA MĀORI CONTINUED

Māori calendar for fishing and horticulture

DAY	NAME	NOTES
20	**Korekore te rawea**	**E hara i te pō pai tēnei.** Not a very good day at all.
21	**Korekore tūroa**	**He pai tēnei rā atu i te rā -tu, ki te rā -to. Koia nei ētahi rā pai ki te patu tuna, koura, ika me ngā momo kai katoa.** A very good day from midday until sunset for both planting and fishing.
22	**Korekore piri ki ngā Tangaroa**	**He rā pai ki te ono kai ki te hī ika, koura, tuna.** A very good day for planting, fishing, crayfish and eels.
23	**Tangaroa piri ā mua**	**He rā pai tēnei ki te ono kai, ki ngā mahi hī ika koura.** A very good day for planting, fishing, crayfish and eels, especially from noon until sunset.
24	**Tangaroa piri ā roto**	**He rā pai tēnei ki te ono kai, ki ngā mahi hī ika koura.** A very good day for fishing, crayfish and eels. This is the best day for planting kūmara, taewa and other root crops, in general the best day for any planting in the garden. Also excellent for deep-sea fishing.
25	**Tangaroa ā kiokio**	**He rā pai tēnei ki te ono kai, ki te hī ika, koura, tuna.** A very good day for planting, fishing, crayfish and eels.
26	**Ao tāne**	**He rā pai tēnei ki te ono kai, ki te hī ika, koura, tuna.** A very good day for planting, fishing, crayfish and eels. Also excellent for deep sea fishing.
27	**Ōrongonui**	**He rā tino pai tēnei mō te ono kai hī ika, koura, tuna. He pai mō te waihanga whakaaio.** A very good day for planting, fishing, crayfish and eels. Also a good day for business.
28	**Mauri**	**E hara i te rā pai tēnei he oro mauri te kai ka oma.** Not a very good day for planting or fishing. Fish, eels and crayfish are very elusive.
29	**Ōmutu**	**E hara i te rā pai tēnei.** It is not a good day at all!
30	**Mutuwhenua**	**E hara i te rā pō pai tēnei kua hinapouri te ao e ai ki ngā kōrero ō neke rā.** It is not a good day at all: the world is in darkness!

KO MAHINGA O TŌKU MĀRA KAI (ESTABLISHING MĀRA KAI). A Resource Kit for the Establishment and Management of Mara Kai Aligned to Marae and Communities (Roskruge, 2021).

Appendix 2 Trial site characteristics and 2022/23 crop management.

Location of trial	Massey University Fruit Crop Unit (FCU)
Region and zone	Manawatu – Palmerston North
Coordinates	40° 22’55" S, 175° 36’22" E
Farming system	conventional irrigated
Previous land-use	2019/2020 – Corn followed by grass/pasture
Soil Classification NZ	Manawatu sandy loam
pH	6.1
Olsen Phosphorus (mg/L)	30
Potassium (me/100g)	0.38
Calcium (me/100g)	6.5
Magnesium (me/100g)	1.18
Sodium (me/100g)	0.08
CEC (me/100g)	12
Total Base Saturation (%)	67
Volume Weight (g/mL)	1.03
Sulphate Sulphur (mg/Kg)	3
Extractable Organic Sulphur* (mg/Kg)	3
Potentially Available Nitrogen (15cm Depth*) (kg/ha)	78
Anaerobically Mineralizable N* µg/g	51
Soil Sample Depth* (mm)	0-150
Soil Type*	Sedimentary
Date of planting	November 18, 2021 November 07, 2022
Irrigation**	25mm (12/01/2022) 25mm (21/01/2022) 25mm (31/02/2022) 25mm (10/02/2022) 25mm (21/02/2022) 25mm (03/03/2022)

Fertilizer	Cropmaster15 fertilizer (15-15-30) N (15.1%), P (10%), K (10%), S (7.7%)
Plant protection	Glyphosate (13.8L/ha^{-1}) x1 Sencor herbicide (480 g/L) x1 Ridomil MZ 72WP (2.5kg/ha) at 60, 75, 90 DAP
Date of Harvesting	March 18, 2022 (120 DAP) March 07, 2023 (120 DAP)

*The soil nutrient results in this table demonstrate the levels found in the reference attached in the appendix 3.

** The irrigation system was only used in the 2022 planting experiment. In the 2023 planting, irrigation was not used due to rainwater – proportion of rain (mm) in the experiment 2022/2023.

Appendix 3 Soil analysis result.

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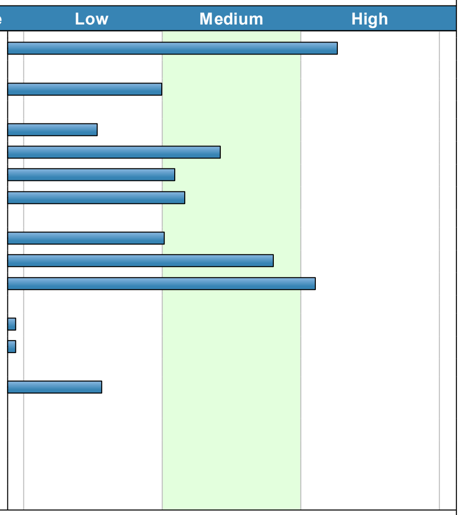
Certificate of Analysis

Client:	Massey University	**Lab No:**	2756260 shvpv1
Address:	C/- The Registrar Private Bag 11222 Palmerston North 4442	**Date Received:**	04-Nov-2021
		Date Reported:	08-Nov-2021
		Quote No:	
		Order No:	PN563830
		Client Reference:	
Phone:	06 356 9099 ext 85187	**Submitted By:**	Mark Osborne

Sample Name: PGU 1 **Lab Number:** 2756260.1
Sample Type: SOIL Potato (S64)

Analysis		Level Found	Medium Range
pH	pH Units	6.1	5.4 - 5.8
Olsen Phosphorus	mg/L	30	30 - 60
Potassium	me/100g	0.38	0.50 - 1.00
Calcium	me/100g	6.5	4.0 - 10.0
Magnesium	me/100g	1.18	1.00 - 3.00
Sodium	me/100g	0.08	0.00 - 0.50
CEC	me/100g	12	12 - 25
Total Base Saturation	%	67	35 - 75
Volume Weight	g/mL	1.03	0.60 - 1.00
Sulphate Sulphur	mg/kg	3	20 - 50
Extractable Organic Sulphur*	mg/kg	3	12 - 20
Potentially Available Nitrogen (15cm Depth)*	kg/ha	78	100 - 150
Anaerobically Mineralisable N*	µg/g	51	
Soil Sample Depth*†	mm	0-150	
Soil Type*†		Sedimentary	
Base Saturation %		K 3.1 Ca 54	Mg 9.7 Na 0.7
MAF Units		K 8 Ca 8	Mg 27 Na 4



The above nutrient graph compares the levels found with reference interpretation levels. NOTE: It is important that the correct sample type be assigned, and that the recommended sampling procedure has been followed. R J Hill Laboratories Limited does not accept any responsibility for the resulting use of this information.
IANZ Accreditation does not apply to comments and interpretations, i.e. the 'Range Levels' and subsequent graphs.

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Certificate of Analysis

Client:	Massey University	**Lab No:**	2756260 shvpv1
Address:	C/- The Registrar Private Bag 11222 Palmerston North 4442	**Date Received:**	04-Nov-2021
		Date Reported:	08-Nov-2021
		Quote No:	
		Order No:	PN563830
		Client Reference:	
Phone:	06 356 9099 ext 85187	**Submitted By:**	Mark Osborne

Soil Analysis Results

	Sample Name:	PGU 1					
	Lab Number:	2756260.1					
	Sample Type:	SOIL Potato					
	Sample Type Code:	S64					
pH	pH Units	6.1	-	-	-	-	-
Olsen Phosphorus	mg/L	30	-	-	-	-	-
Potassium	me/100g	0.38	-	-	-	-	-
Potassium	%BS	3.1	-	-	-	-	-
Potassium	MAF units	8	-	-	-	-	-
Calcium	me/100g	6.5	-	-	-	-	-
Calcium	%BS	54	-	-	-	-	-
Calcium	MAF units	8	-	-	-	-	-
Magnesium	me/100g	1.18	-	-	-	-	-
Magnesium	%BS	9.7	-	-	-	-	-
Magnesium	MAF units	27	-	-	-	-	-
Sodium	me/100g	0.08	-	-	-	-	-
Sodium	%BS	0.7	-	-	-	-	-
Sodium	MAF units	4	-	-	-	-	-
CEC	me/100g	12	-	-	-	-	-
Total Base Saturation	%	67	-	-	-	-	-
Volume Weight	g/mL	1.03	-	-	-	-	-
Sulphate Sulphur	mg/kg	3	-	-	-	-	-
Extractable Organic Sulphur*	mg/kg	3	-	-	-	-	-
Potentially Available Nitrogen (15cm Depth)*	kg/ha	78	-	-	-	-	-
Anaerobically Mineralisable N*	µg/g	51	-	-	-	-	-
Soil Sample Depth*†	mm	0-150	-	-	-	-	-
Soil Type*†		Sedimentary	-	-	-	-	-

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Certificate of Analysis

Client:	Massey University	**Lab No:**	2756260 shvpv1
Address:	C/- The Registrar Private Bag 11222 Palmerston North 4442	**Date Received:**	04-Nov-2021
		Date Reported:	08-Nov-2021
		Quote No:	
		Order No:	PN563830
		Client Reference:	
Phone:	06 356 9099 ext 85187	**Submitted By:**	Mark Osborne

Analyst's Comments

† Customer supplied data. Please note: Hill Laboratories cannot be held responsible for the validity of this customer supplied data, or any subsequent calculations that rely on this information.

Sample 1 Comment:
The medium or optimum range guidelines shown in the histogram report relate to sampling protocols as per Hill Laboratories' crop guides and are based on reference values where these are published. Results for samples collected to different depths than those described in the crop guide should be interpreted with caution.
For pastoral soils, the medium ranges are specific for a 75mm sample depth, but if a 150mm sampling depth is used the nutrient levels measured may appear low against these ranges, as nutrients are typically more concentrated in the top of the soil profile. These soil profile differences are altered upon cultivation or contouring.

Sample 1 Comment:
The Potentially Available Nitrogen (kg/ha) test above assumes the sample is taken to a 15 cm depth. If the depth is 7.5 cm, then the result reported above should be divided by two.
To calculate Potentially Available Nitrogen (as kgN/ha) for other sample depths use the reported Anaerobic Mineralisable Nitrogen (AMN) result in the following equation:
AN (kg/ha) = AMN (µg/g) x VW (g/ml) x sample depth (cm) x 0.1
Note that the AN and AMN results reported include the readily available Mineral N (NH4-N and NO3-N) fraction, which is typically quite low.

Summary of Methods

The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively simple matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis. A detection limit range indicates the lowest and highest detection limits in the associated suite of analytes. A full listing of compounds and detection limits are available from the laboratory upon request. Unless otherwise indicated, analyses were performed at Hill Laboratories, 28 Duke Street, Frankton, Hamilton 3204.

Sample Type: Soil

Test	Method Description	Default Detection Limit	Sample No
Sample Registration*	Samples were registered according to instructions received.	-	1
Soil Prep (Dry & Grind)*	Air dried at 35 - 40°C overnight (residual moisture typically 4%) and crushed to pass through a 2mm screen.	-	1
pH	1:2 (v/v) soil:water slurry followed by potentiometric determination of pH. In-house.	0.1 pH Units	1
Olsen Phosphorus	Olsen extraction followed by Molybdenum Blue colorimetry. In-house method.	1 mg/L	1
Sulphate Sulphur	0.02M Potassium phosphate extraction followed by Ion Chromatography. In-house.	1 mg/kg	1
Potassium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	1 MAF units	1
Calcium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	1 MAF units	1
Magnesium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	1 MAF units	1
Sodium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	2 MAF units	1
Extractable Organic Sulphur*	Determined by NIR, calibration based on; 0.02M Potassium phosphate extraction. Total extractable S determined by ICP-OES from which the Sulphate-S is subtracted.	2 mg/kg	1
Potentially Available Nitrogen*	Determined by NIR, calibration based on Available N by Anaerobic incubation followed by extraction using 2M KCl followed by Berthelot colorimetry. (Calculation based on 15cm depth sample). Note that any Mineral N present is included in the AN/AMN result reported.	10 kg/ha	1

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Sample Type: Soil

Test	Method Description	Default Detection Limit	Sample No
Anaerobically Mineralisable N*	As for Potentially Available Nitrogen but reported as µg/g.	5 µg/g	1
Potassium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	0.01 me/100g	1
Calcium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	0.5 me/100g	1
Magnesium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	0.04 me/100g	1
Sodium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	0.05 me/100g	1
Potassium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	0.1 %BS	1
Calcium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	1 %BS	1
Magnesium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	0.2 %BS	1
Sodium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	0.1 %BS	1
CEC	Summation of extractable cations (K, Ca, Mg, Na) and extractable acidity. May be overestimated if soil contains high levels of soluble salts or carbonates. In-house.	2 me/100g	1
Total Base Saturation	Calculated from Extractable Cations and Cation Exchange Capacity.	5 %	1
Volume Weight	The weight/volume ratio of dried, ground soil. In-house.	0.01 g/mL	1

These samples were collected by yourselves (or your agent) and analysed as received at the laboratory.

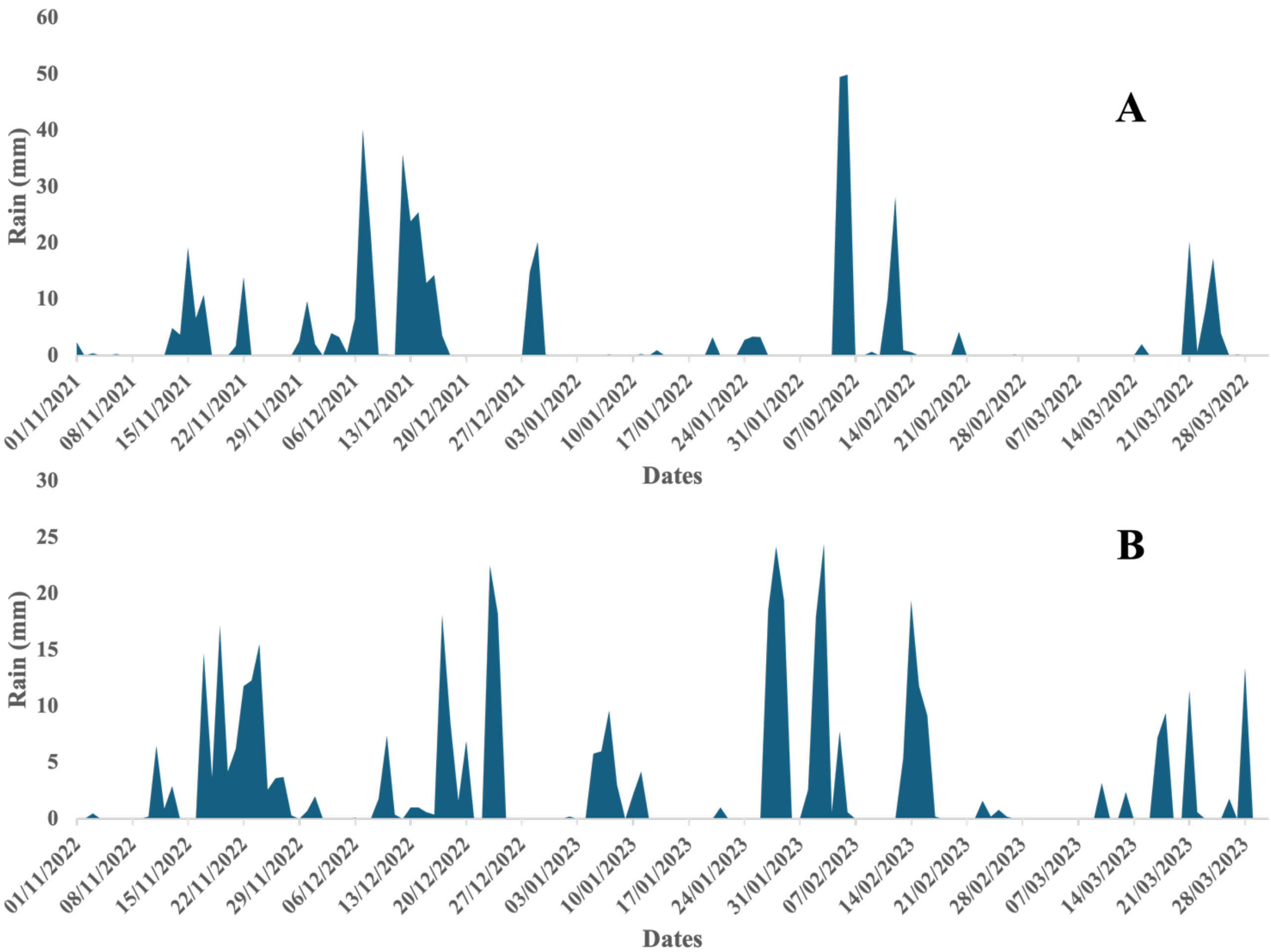
Testing was completed between 04-Nov-2021 and 08-Nov-2021. For completion dates of individual analyses please contact the laboratory.

Samples are held at the laboratory after reporting for a length of time based on the stability of the samples and analytes being tested (considering any preservation used), and the storage space available. Once the storage period is completed, the samples are discarded unless otherwise agreed with the customer. Extended storage times may incur additional charges.

W. M Homewood.

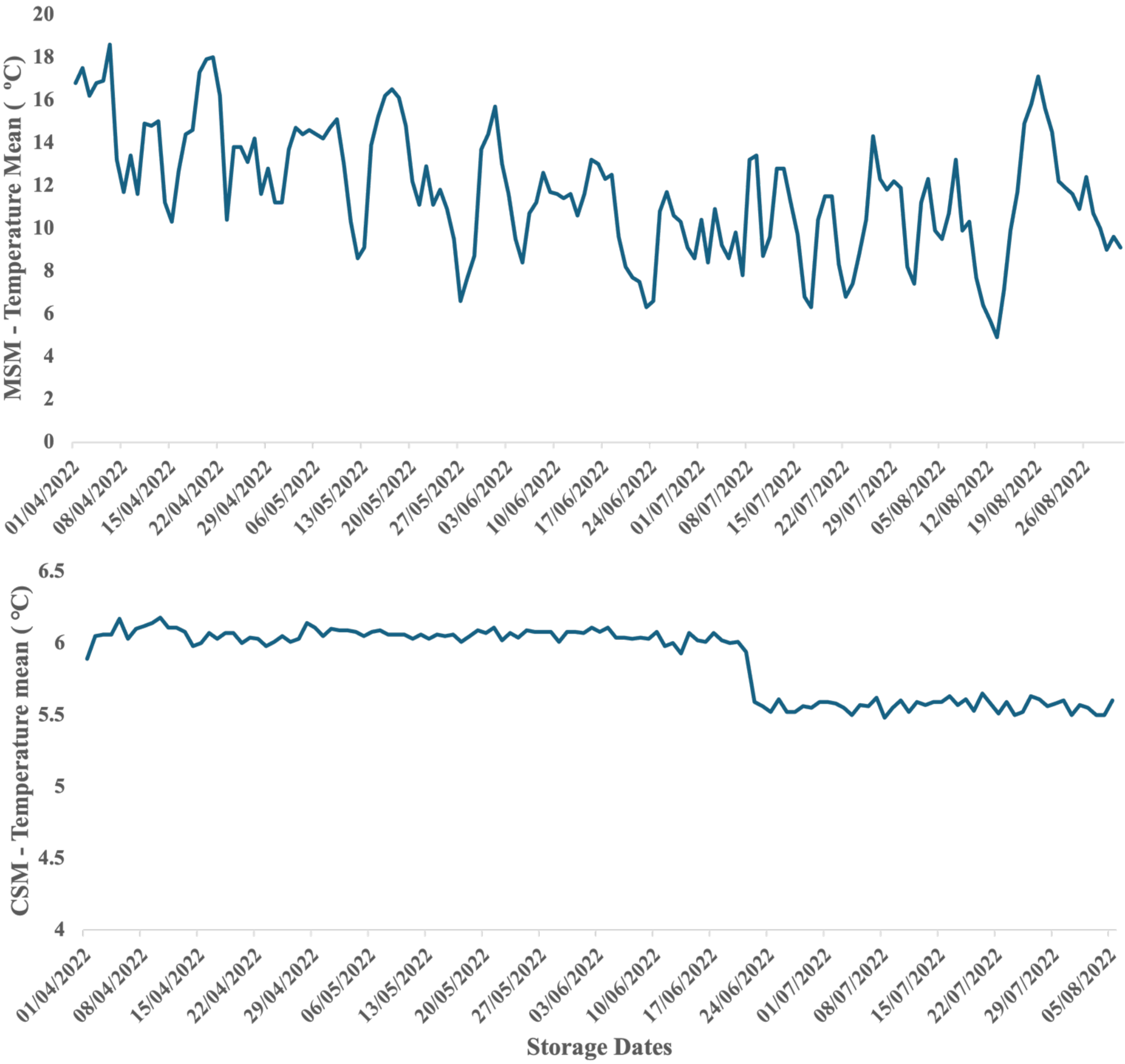
Wendy Homewood
Operations Support - Agriculture

Appendix 4 Proportion of rain (mm) in the planting period of 2022 (A) and 2023 (B).
Source: Cliflo.Niwa/Agresearch. 2023.

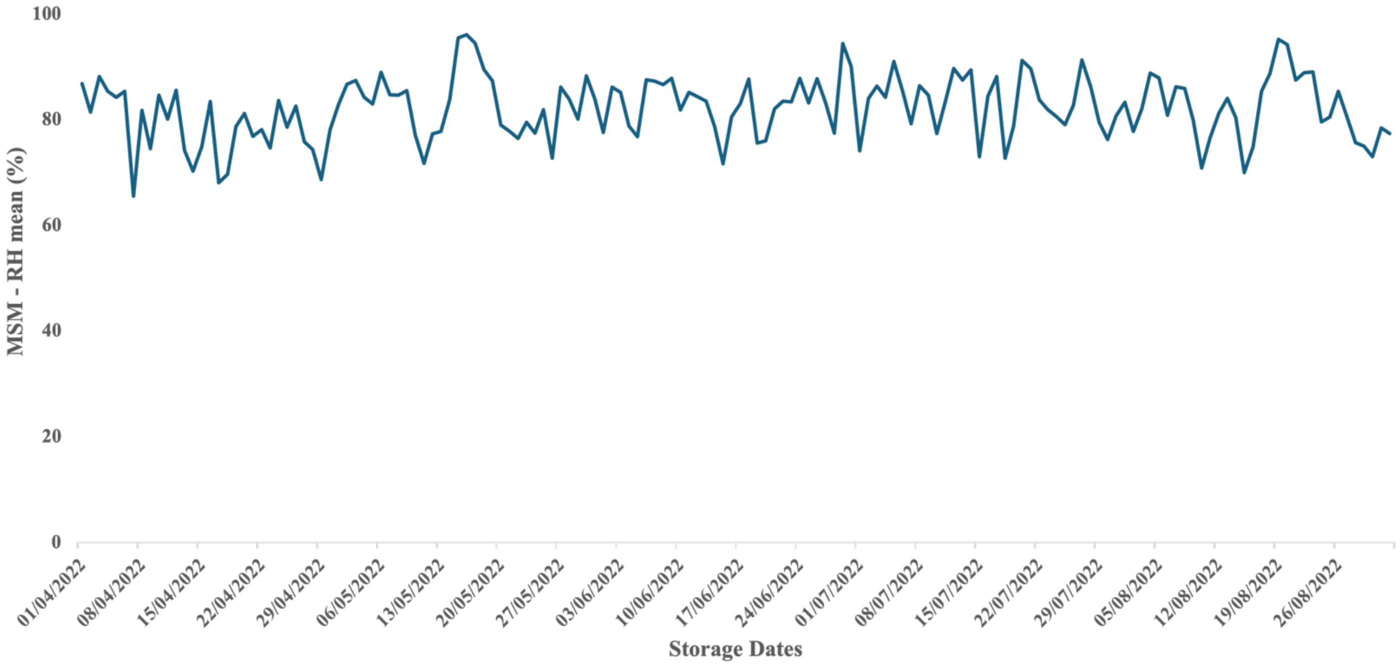


Appendix 5 Temperature trend in the shed (Māori storage method) and conventional room temperature, 2022.

Source: Data logger.

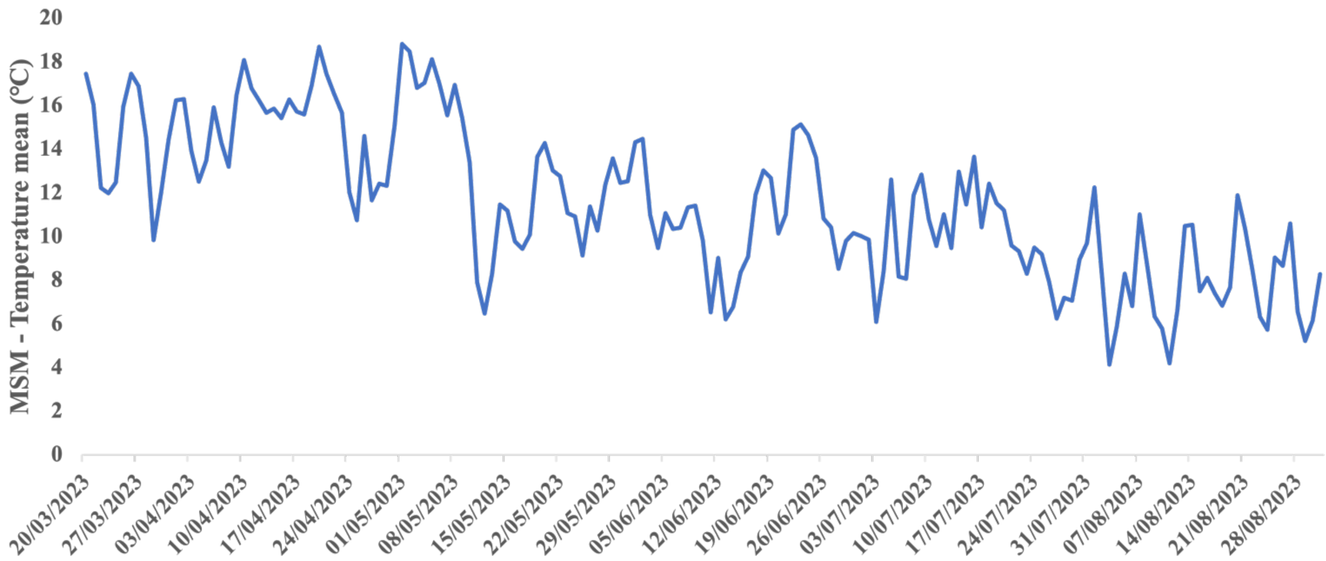


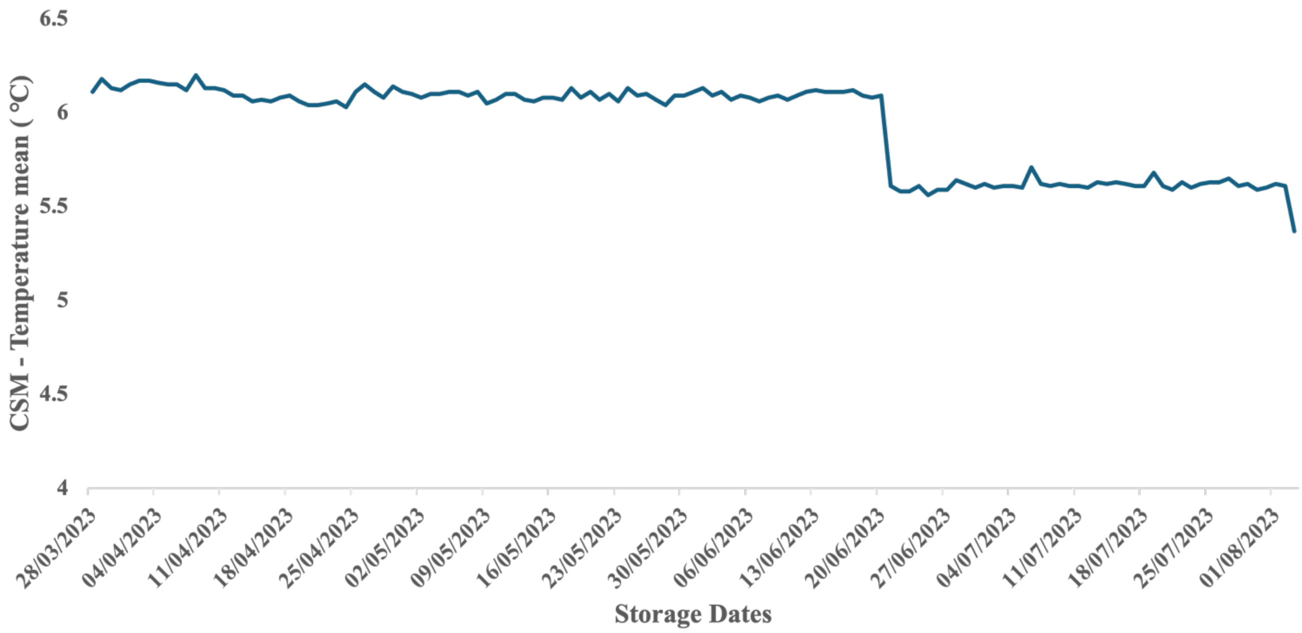
Appendix 6 Relative humidity (RH) in the shed experiment (Māori storage method). Source: Data logger.



Temperature and rainfall trend in the 2023 experiment's storage condition.

Appendix 7 Temperature trend in the shed (Māori storage method) and conventional room temperature, 2023.
Source: Data logger.





Appendix 8 Relative humidity (RH) in the shed experiment (Māori storage method).
Source: Data logger.