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Subterranean Storage Pits for Kūmara (Sweet Potato, *Ipomoea batatas* L. Lam.): Ethnographic, Archaeological and Experimental Research in New Zealand

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ABSTRACT

Storage of tubers of kūmara (sweet potato) in pits was an essential part of the pre-European Māori horticultural cycle, but the details are not well understood. Ethnographic accounts of Māori storage pits (mainly dating to the late nineteenth and early twentieth centuries) and archaeological evidence of storage pits are reviewed. Contemporary recommendations for commercial storage of sweet potatoes are summarised and modern peasant systems in countries such as China are touched upon. An experiment in pit storage of the Māori cultivar 'Taputini' during the winter of 2004 is described. The experiment took place in Marlborough, close to the southern limit of Māori kūmara horticulture. Environmental conditions in the pit were closely monitored. It is 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. In the absence of artificial warming the tubers began to rot when the mean temperature fell below 8˚C and all tubers were rotten by day 154. Such intervention would greatly reduce the space available for storage for several reasons. We found that no more than 6% of the available pit volume could be used for tubers compared with earlier published estimates of 50%. Contrary to expectations, subterranean storage has only a trifling effect on lowering the average temperature from above-ground storage (ΔT=0.87˚C over 154 days), but diurnal temperature fluctuations are dramatically buffered by storage below ground. Even with human intervention, pre-European Māori at the southern limits of kūmara cultivation were only able to eat kūmara for about four, or at most six, months of the year.

Keywords: SWEET POTATO, KŪMARA, *IPOMOEA BATATAS*, STORAGE PITS, ETHNOGRAPHY, EXPERIMENTAL ARCHAEOLOGY.

INTRODUCTION

More than 40 years ago, Yen (1961) published an important paper on the adaptation of kūmara (sweet potato) by the New Zealand Māori. He pointed out that Māori had adapted what is essentially a perennial tropical plant to temperate conditions by developing an annual cycle of cultivation and storage. Yen believed that this was a major horticultural achievement. Although the sweet potato occasionally flowers and sets seed, vegetative propagation (by cuttings or tubers) is the only method of reproduction in areas of indigenous

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cultivation of the plant (Yen 1960: 368; Sauer 1950: 509). In the tropical Pacific, the sweet potato is propagated by stem cuttings from growing plants (Yen 1961: 338). The Māori adaptation was to store the tubers through the winter when the growing plants died.

In their subsequent interpretations, archaeologists have tended to focus on the difficulties of growing the plant successfully, rather than on the equally important problem of storing it through the winter. A recent review of archaeological evidence for Māori horticulture (Barber 2004) concentrates almost entirely on gardens, mentioning storage only in passing. Yet storage was critical to the success of the horticultural cycle. Although a great many storage structures have now been excavated by archaeologists, rather little attention has been given to how they were actually used, and what the effects of this type of storage were.

This paper describes an experiment in kūmara storage in the Cook Strait region, at the southern margin of Māori horticulture. In parts of this central region of New Zealand, such as Palliser Bay, there is extensive archaeological evidence of former gardens (Leach 1976, 1979a) but when James Cook's various expeditions visited Queen Charlotte Sound in the 1770s, no gardens were seen. Later Māori gardening in the area was based mainly on white potatoes and other European-introduced plants, not on kūmara. Māori very quickly adopted potatoes following their introduction to New Zealand by Europeans. Early ethnographic records of kūmara cultivation and storage are scarce; most accounts are from the late nineteenth and early twentieth centuries and are of limited value in understanding pre-European Māori practices.

In 1999, we began an experiment to see whether it was possible to grow Māori cultivars of kūmara successfully in the Cook Strait region under present climatic conditions (Harris *et al*. 2000). The gardening experiment has shown, among other things, that storage losses in modern buildings in this region are considerable after the first three months (Burtenshaw *et al*. 2003: 172). This suggested that it would have been very difficult to store kūmara for food up to the period of the next planting season, raising the possibility of a 'hungry gap'[2] in food supply (see below Fig. 16). Storing enough tubers for seed for the next planting season would have required great care.

The next stage of the research, therefore, was to experiment with the storage of the crop. We chose to experiment with a roofed rectangular storage pit, as the remains of these structures are the most numerous form of field evidence of storage, both as surface features and in excavations. Before designing the experiment, we explored several existing lines of evidence: ethnographic data on Māori storage practices, archaeological evidence about Māori storage pits, and modern information about the storage requirements of sweet potatoes. We review each of these before describing the storage experiment and its results.

ETHNOGRAPHIC ACCOUNTS OF PIT STORAGE

This section first considers general aims and aspects of pit storage, and then specific technical details relevant to a storage experiment. The ethnographic accounts leave no doubt that the primary purpose of pit storage was for kūmara. There is one reference to the fact that although taro and potatoes could be kept in separate bins in the same pit, neither were

[2] This term comes from Europe where in the Middle Ages it was not unusual for people to suffer hunger during the summer, when stored grain had been used up and the new harvest was not yet ready (Frank 1995).

ever stored with kūmara, as Māori believed that the latter "would be harmfully affected in some manner by such a usage" (Best 1974: 91). Of course other kinds of food, including fern root, could also have been stored in pits, but this possibility is not relevant to our current research. Similarly, kūmara need not always have been stored in pits. Crozet, in the Bay of Islands in 1772, described a communal storehouse containing many kinds of food including kūmara in a pā (Crozet in Ling-Roth 1891: 33). There is no indication in his account that this building was either a roofed pit or a raised pātaka.

GENERAL CONSIDERATIONS

Elsdon Best (1974, 1976) collated most of the information that had been recorded about kūmara storage. He listed four kinds of semi-subterranean and subterranean store, describing them as "a truly remarkable feature in Māori village life, and the places wherein their main crop was stored" (1974: 77). The four kinds of stores were 1. Semi-subterranean stores on level land. (Floor excavated; securely roofed.) 2. Rectangular excavation in a hillside or on the brow of a terrace. (Earthen walls; well roofed.) 3. Excavated pits, entered through hole on top. (Covering for entrance-hole, but no artificial roof.) 4. Caves (in most cases artificial, entrance in front) (Best 1974: 76). Figures 1 and 2 illustrate stores in use on the East Coast of the North Island in the late nineteenth and early twentieth centuries. Both Best and his informant Tuta Nihoniho gave *rua* as the generic name for all these kinds of storage structure, qualified in various ways to describe the different kinds. Archaeologists, however, have generally distinguished between roofed stores (Best's 1 and 2) and rua (Best's 3 and 4), sometimes using the term 'bell-shaped rua' for Best's category 3.

Figure 1: "Semi-subterranean storehouse for kumara. Waiapu district" (Best 1976: 225, Fig. 54). Photograph by James McDonald in 1923. Te Papa negative B.010494.

Figure 2: "A Rua Kumara. Store-pit for Sweet Potatoes, East Coast" (Best 1976: 226, Fig. 55A). This photo was previously published in a different work by Best (1974: 84, Fig. 43), where it was captioned "A Rua Kai or Food-store Pit, East Coast." Photograph by Augustus Hamilton, 9 February 1895. Te Papa negative B.001052.

Best drew on the publications of Colenso, Walsh, and other predominantly nineteenth century writers, and added information from his own observations and informants, particularly Tuta Nihoniho. This information dated from the nineteenth century and the first decades of the twentieth century. However, it is not easy to determine which information, if any, applied to pre-European cultivars of kūmara, and which to European-introduced varieties[3] or to white potatoes. Similarly, it is unclear whether the accounts of store roofs, in particular, apply to stores constructed without metal tools.

The accounts describe the difficulty of kūmara storage and the importance of curing and careful handling. Walsh (1902: 21) stated that the chief aim of storage was the exclusion of damp and the maintenance of a moderate and even temperature. He made no bones about the difficulties of kūmara storage:

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[3]In discussing cultivation, these sources often refer to the vines or runners of the plants. These are characteristic of kūmara cultivars such as 'Waina', introduced in the nineteenth century, and do not occur in the pre-European cultivars grown in our garden experiment. It is possible that the storage requirements of 'Waina' were different from those of pre-European cultivars.

> The storing of the crop required the greatest care and judgement, as, in spite of every precaution, it was barely possible to preserve the stock until the next planting time. Besides being a delicate article to handle, the kumara is susceptible to every change of weather. A single bruised or chafed tuber will soon rot and communicate the decay to those in contact with it, while a very short exposure to damp, or even to cold air, will quickly spoil the whole lot. (Walsh 1902: 21)

It is uncertain what precisely is meant by ‘damp’ here. As we describe in a later section, recommended humidity for modern sweet potato storage is 85–90 percent. Walsh (and Best, below) may have been referring to actual water in the store rather than high humidity.

Tuta Nihoniho also stressed the need for care, and the susceptibility of kūmara to damp (Best 1974: 100). Best, possibly still citing Tuta Nihoniho and noting that kūmara were always stored in pits and never in houses or pātaka (raised stores), added “Natives say that it is the warmth of the pits that preserves the tubers” (1974: 105). In his discussion of cave rua at Ihupuku pā near Waverley, also, he mentioned the importance of conserving warmth (1974: 96).

Colenso emphasised the labour involved:

> And when the *kumara* was fully ripe the labour in taking it up, sorting and packing it into its own peculiar baskets for store, including the weaving of those baskets, and the half digging, half building of the stores supposed to be absolutely needful for effectually keeping it (and which were often the best built houses in the village, and often renewed) – was very great. (Colenso 1875: 347)

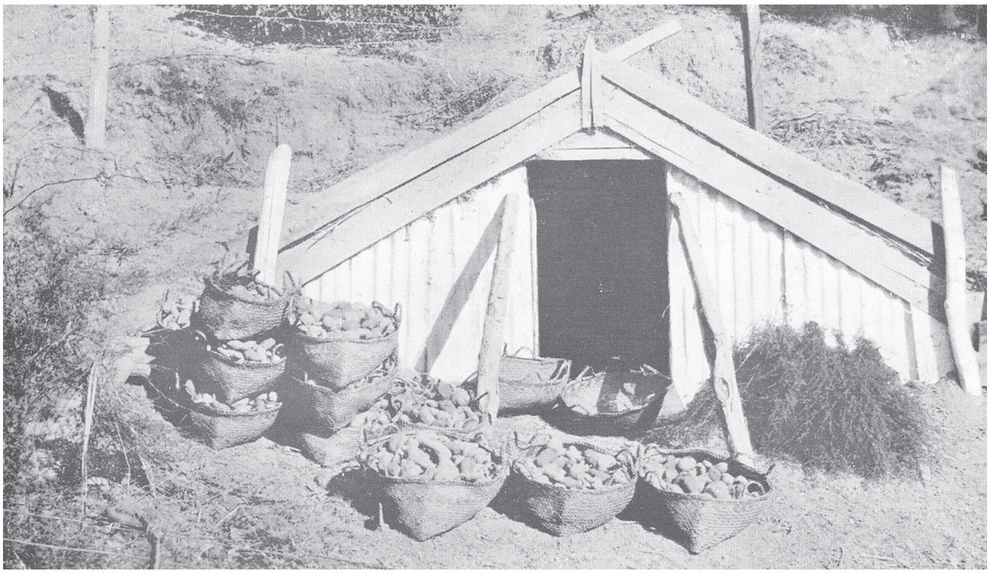

Figure 3: “Semi-subterranean storehouse for kumara. Waiapu district” (Best 1976: 225, Fig. 55). In this case, the baskets were used only to transport the kumara to the store, where they were stacked individually. Photograph by James McDonald in 1923. Te Papa negative B.010493.

PLACEMENT OF TUBERS

Virtually all of Best's sources stated that the kūmara were stacked individually in heaps one on top of another (Best 1974: 82, 100, 104; 1976: 171, 227). Baskets were used to transport the harvested kūmara to and from the stores (Fig. 3). In some cases, kūmara were sorted according to different kinds, which were kept in heaps in separate bins within a single large store. Even in smaller stores, kūmara were stacked in closely adjacent heaps. Colenso (above), however, seems to imply that kūmara were actually stored in the baskets in which they were transported to the store.

Best (1974: 90–91) wrote that floors of pits were covered with a layer of bracken and then a layer of rushes; sometimes there was a layer of timber slabs on the floor below the bracken. *Lycopodium* (club moss) and tree fern fronds were also used to protect stored

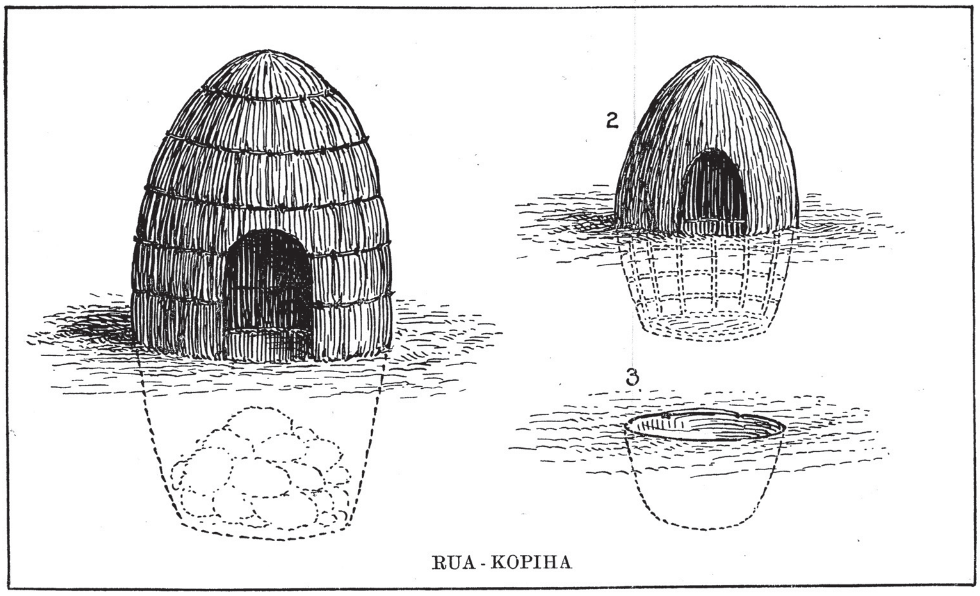

Figure 4: "Rua-kopiha" northwest of Auckland described by Graham (1922: 22).

kūmara. According to one account (Best 1976: 171) the tubers were stored in heaps on gravel and soft decayed wood, and those intended for food were separated from those set aside for seed by a screen of dry mānuka brush. Walsh (1902: 21) described the floor and walls of rua as lined with a layer of soft fern or *Lycopodium*, but was not specific about storage methods inside a roofed rectangular pit. Material on the floor of the pit would protect the tubers from contact with the earth and also provide some ventilation.

Graham (1922) described and drew an unusual variant of roofed storage pit in use near Otakanini, northwest of Auckland. The pits were apparently circular and basin-shaped (Fig. 4), about three feet (91 cm) wide and three feet deep, with a domed roof about four feet (122 cm) high made of raupō (bulrush, *Typha orientalis*) over thin stakes of mānuka (*Leptospermum scoparium*). They were neatly lined with bracken fronds and the kūmara were stacked in a pyramid-shaped heap on a thick layer of mingimingi[4]. Graham was told that these were kopiha or rua-kopiha, used only for storing kūmara. He recorded a story in which pits of this kind had been misused for smoking the heads of enemies. However, on the east coast, according to Tuta Nihoniho (Best 1974: 98), a rua kopiha was "a well-like pit, wholly subterranean, entered from the top". Williams (1971: 137) gives kōpiha as a pit for storing potatoes or taro.

Pits of the kind described by Graham have not been identified in excavations. However, one of us (JD) was shown a cluster of round depressions on a low mound at Kapowairua in the far north, which were said to have been used for storing kūmara in the first half of the twentieth century. It is possible that some surface features identified by archaeologists as 'collapsed [bell-shaped] rua' are remains of pits of this kind.

Tuta Nihoniho reported that pits were often inspected to see if there was anything that might cause decay, such as moisture dripping from the ridgepole. On fine days the door was often left open until the sun went off it (Best 1974: 106).

These descriptions all sound like the common method of storing potatoes in a clamp, in which the tubers are stacked directly on top of each other (Fig. 5). If so, it raises the interesting question of how to inspect all of the stored crop for signs of decay so that individual tubers could be removed.

PIT WALLS AND ROOF

Best (1974: 78) stated that pit walls were sometimes lined with slabs of wood or slabs cut from the trunks of tree ferns. The walls were lined with rushes or fern to prevent the kūmara from rotting as a result of contact with the earth or slab walls (Best 1974: 81). Rushes might be tied together in the form of a long mat and pegged in place at the corners of the pit until the stacked kūmara were sufficient to hold the lining in place (1974: 90–91).

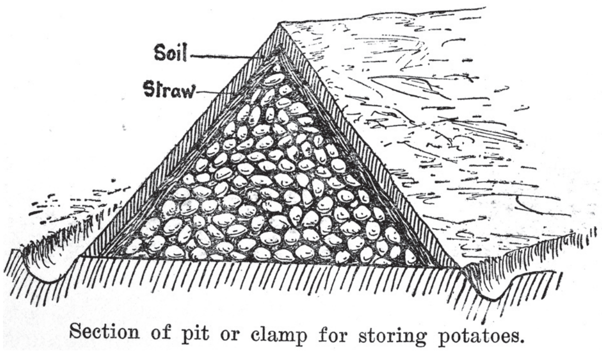

Figure 5: A potato clamp, commonly used by Europeans in New Zealand, described by Tannock (1934: 211).

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[4]The term mingimingi is used for several native shrub species of the genera Epacridaceae and Rubiaceae. In this context it is a plant that grows into a dense, springy tangled mass, which acts as a cushion for the tubers placed on it.

According to Tuta Nihoniho, floors and walls were lined with dry mānuka brush and bracken fronds to prevent the kūmara coming in contact with the earth (Best 1974: 104).

The roof was constructed of timber slabs, preferably of tōtara (*Podocarpus* sp.), which were covered with a layer of cut slabs of tree fern. Over this was laid a thatch of toetoe (*Cortaderia* and *Chionachloa* spp.) or the loose outer bark of mānuka or tōtara. The whole was then covered with earth and trampled, and would eventually be covered with herbage. End walls, above the ground surface, were also constructed of tōtara and tree fern slabs (Best 1974: 79–81, 104, 100–101). Walsh (1902: 21), in an otherwise skimpy account of pit roofs, adds that nīkau (*Rhopalostylis sapida*) fronds were laid over the earth covering of a pit roof to preserve the earth from erosion by rain.

Best does not mention the earthing up of end walls as well as roof. However, a photograph of a newly constructed roofed pit at Te Kaha in the late nineteenth century (Lawlor 1983: 234) suggests that both the rear wall and the front wall except for the door were earthed up.

HEARTHS AND DRAINS

We have found no mention of the use of fire inside pits, probably because the accounts emphasise construction and filling of pits, rather than their duration of use and the maintenance of the stored crop.

Best (1974: 82) reported that "In all cases these pits and semi-subterranean stores are so tended that storm-water does not collect near them. In many cases small drains carry off such waters."

MORE RECENT ACCOUNTS

Aspects of pit storage of kūmara have continued to the present day in the Bay of Plenty although recently, bell-shaped pits seem to have been more often used than roofed rectangular pits. In 1978, roofed kūmara stores in the eastern Bay of Plenty seen by one of us (JD) included one set into a slope with concrete walls and iron roof, a small, only slightly sunken version with walls and roof of corrugated iron, and the ruins of one with a heavy wooden ridge pole (Fig. 6), suggesting that this pit, at least, had a roof covered with earth. In 1982, Māori elders told Lawlor (1983: 237) that pits in their life-times had been roofed with tree-fern posts, covered with a thick thatching of toetoe leaves.

An experimental pit store was constructed in Auckland in 1979 under the guidance of a Māori elder who had helped his father build stores in this manner before the Second World War (Sutton and Phillips 1980). However, this was a quickly built, shallow, roofed pit, 20 cm deep with 33 cm high sod walls on the long sides and slightly higher end walls, very different from the pits described in earlier accounts. It did, however, have a tree fern ridge and rafters and was earthed over. Superficially, this store looked similar to the late nineteenth century example at Te Kaha described above.

Sutton and Phillips considered that the aim of such a store was to maintain the temperature above outside ground temperatures during winter, but to keep the humidity "low enough to prevent, or at least ameliorate, bacterial infection, mould and rot" (1980: 46). This last suggestion runs counter to the recommendation that modern kūmara require near saturation humidity for successful storage (see below).

Anecdotal accounts suggest the need for regular inspection of the stored kūmara (L. Walter, pers. comm. 2004) and regular lifting of the lid of a bell-shaped pit for ventilation

Figure 6: Ruins of a roofed storage pit near Te Kaha, 1978. Photo J. Davidson.

(Ranginui Walker, pers. comm. 2004[5]). We will see below that regular change of air is considered important in modern storage systems to reduce levels of CO_2.

SUMMARY

The ethnographic accounts, referring largely to Bay of Plenty and east coast North Island storage practices in the second half of the nineteenth century and the early decades of the twentieth century, emphasise bruising and dampness rather than cold temperatures as the main causes of rot. However, Best attributed pit construction to the need for greater warmth during storage than could be achieved in surface or raised structures.

The majority of accounts state that kūmara were individually stacked in heaps, not stored in baskets or on racks, and that considerable quantities of plant material, including bracken,

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[5]Dr Walker related that it was one of his jobs as a child to lift the roof of the rua periodically for ventilation. The older women of the family told him when to do it.

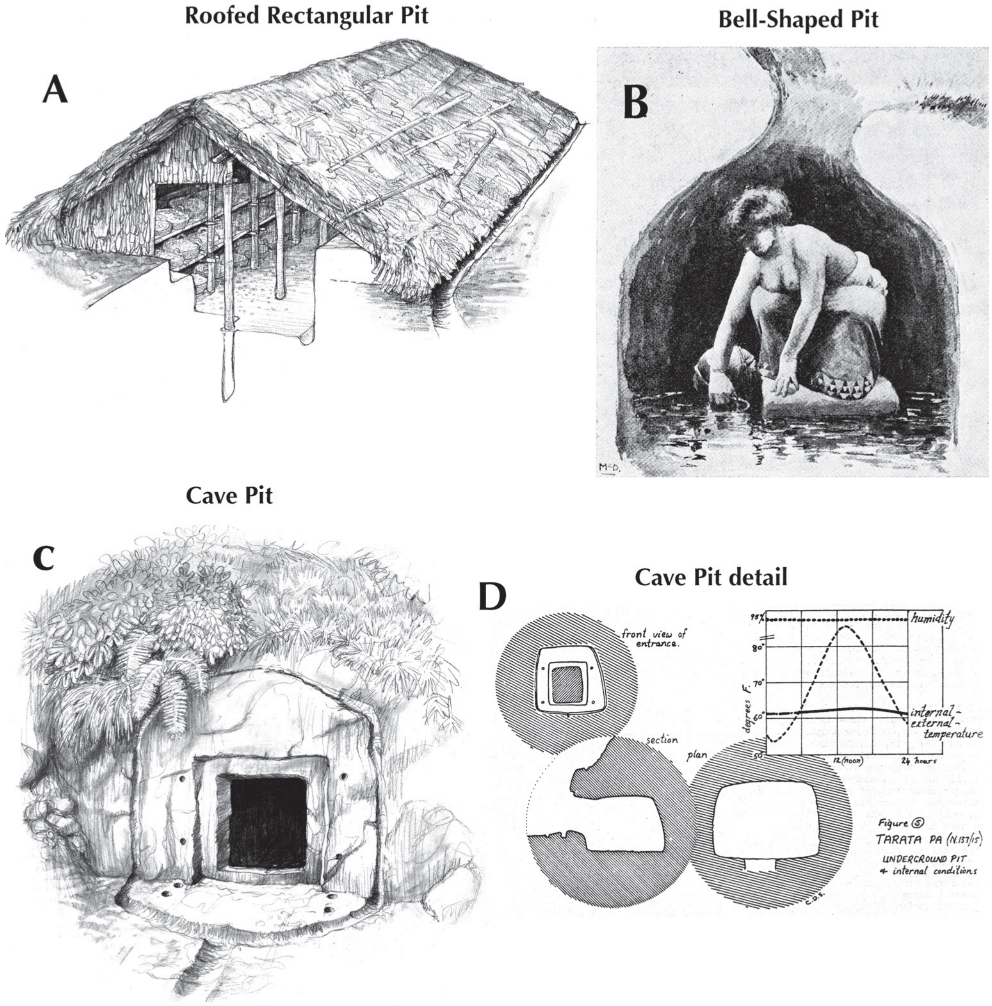

Figure 7: Types of storage pit. A: A roofed rectangular pit with kūmara stored in baskets on racks. B: A bell-shaped pit at Tunuhaere Pa in the Whanganui district. Best interpreted this pit as for water storage, but in form it is typical of bell-shaped pits used for kūmara storage. Note the upstand above 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).

rushes, dry mānuka foliage, tree fern fronds and club moss, were used as 'dunnage' to keep the kūmara away from earth walls and floors. This would be essential in pits in which tubers were stacked in heaps. However, the 'dunnage' would have little or no effect on internal temperatures and would not be necessary if tubers were stored on racks away from earth walls and floor.

There are accounts of substantial wall and roof timbers, extensive used of tree fern trunks and/or slabs cut from them, and of roofs being covered with a thick layer of earth. We might expect that under favourable circumstances, evidence of some of these materials and practices should be found in archaeological sites.

THE ARCHAEOLOGY OF PITS

This section briefly outlines the history of pit archaeology and the interpretation of the evidence, and then considers technical aspects relevant to our experiment. Archaeologists have generally recognised three kinds of storage pit (Davidson 1984: 122): roofed rectangular pits (mainly Best's category 1, but also 2); rua (Best's categories 3 and 4), and small 'bin pits', not mentioned in the ethnographic accounts. Bin pits are generally straight-walled square or rectangular pits, small enough to be covered by a horizontal lid. 'Bin pits' were probably used for a range of purposes, not only or mainly storage of kūmara, and are not further considered here, except where they are found in the floors of roofed pits.

The term rua (which Best applied to all four of his categories of pit) is unfortunately well established in the archaeological literature to refer to a fully underground pit sealed by a lid or door. It can be either a bell-shaped pit entered through a narrow shaft at the top and closed by a lid, or a cave pit entered through a small doorway at the front. A roofed rectangular pit and the two types of fully underground pit are illustrated in Figure 7.

HISTORY AND INTERPRETATION

Some of the first 'modern' archaeological excavations in the North Island during the 1950s exposed the remains of rectangular roofed pits, some of considerable size and complexity, at sites such as Stingray Point on Great Mercury Island (Fig. 8) and Taylor's Hill in Auckland (Davidson 1984: 126; Leahy 1991). During the late 1950s and early 1960s, numerous rectangular pits and some fully subterranean pits were excavated and discussion developed about their functions, particularly whether the rectangular pits were houses (Duff 1961; Golson 1961: 21; Green 1963a; Parker 1960: 39; Parker and Buist 1961) or storage structures (Groube 1965: Law 1969a) or both. An attempt was also made to treat them like artefacts such as adzes that showed chronological variation (Parker 1962).

Twenty years after the first such excavations, Fox (1974) was able to review 112 rectangular roofed pits from 27 sites for which considerable detail was available. By this time, most archaeologists were satisfied that most of these very numerous structural features were for storage, although problems remain over very shallow pits (see, for example, Foster 2000: 134)[6]. Since 1974, many thousands of pits have been recorded as surface features and large numbers have been exposed by excavation. Their plans, depths, postholes, drains, slots, sumps and buttresses have been described, but there is still much that is uncertain about how they functioned. In recent years, large numbers of pits have been revealed during mitigation

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[6] It is possible that these are clamp-like features such as the rua whakatoke or rua tawaero described by Best and Tuta Nihoniho (Best 1974: 98, 107), in which tubers were stacked on a layer of dry manuka brush and rushes, covered with more manuka brush and toetoe leaves, and earthed over. However, Walsh's (1902: 22) more detailed description of whakatoke suggests that they were small and round.

Figure 8: Pit excavation at Stingray Point Pa, Great Mercury Island, in the 1950s. Photo courtesy of the Anthropology Department, University of Auckland.

projects and many have been at least partly excavated. These are often described in unpublished reports of limited circulation.

Modern storage requirements of kūmara in relation to pits were considered by Groube (1965: 93–97, 1970: 157), Law (1969a: 240) and Leach (1976: 153), all of whom noted the importance of avoiding low temperature and maintaining high humidity. Most archaeologists, however, have accepted that pits worked, without worrying too much about how they worked.

Smart (1962: 180–181) measured inside and outside temperature and relative humidity of several cave pits on a pā in the Waitotara Valley at short intervals over a 24 hour period. The internal temperature range was 60 to 65°F (15.6 to 18.3°C), compared with 53 to 84°F (11.7 to 28.9°C) outside (Fig. 7). The internal relative humidity was 93 to 95 percent. Smart thought that these 'rua' were for water storage, but noted that the conditions would have been suitable for kūmara.

Various archaeologists have expressed opinions on the requirements of kūmara storage, without citing modern horticultural recommendations. As noted above, the opinion of Sutton and Phillips about low humidity seems to run counter to modern advice. More recently, Campbell (2005: 25) has suggested that storage requirements include frost-free conditions, darkness, and relatively constant humidity and temperature, without citing the source of this observation.

Archaeological interpretations of pits have largely concentrated on economic and social rather than functional aspects. In an unpublished conference paper given in 1968, Law (n.d.) proposed that the estimated food value of the volume of kūmara tubers stored in pits could be used to calculate the population of the community using the pits. He used this method to estimate population size for Ongari Point pā in the western Bay of Plenty and Taniwha pā in the lower Waikato valley. The Taniwha pā estimates were later published (Law and Green 1972). Law also applied the method to other sites (Law 1969b, 1970, 1972). Jones and Law (1987) published details of the method and assumptions in a study of the distribution of recorded pits in the Tolaga Bay region of the North Island. They considered that tubers for consumption would last at least 4–6 months, but this important point is somewhat obscured by their references to kūmara as a staple food.

These attempts to derive population estimates from pits have been directed towards an understanding of the nature of the social groups responsible for pit construction and use. Related concerns have included the possible social interpretations of exceptionally large or long pits (Law 2000) and the social implications of large pits with carefully shaped rectangular posts rather than the more usual poles (Campbell 2004, n.d.; Furey pers. comm. 2004). But shaped posts and unshaped poles are sometimes found together in a single pit (e.g., Foster 2000: 131) and sometimes one of a group of otherwise similar pits contains shaped posts and the others poles (Sutton and Crosby 1993: 77).

Any attempt to estimate volumes of stored kūmara must take into account the precise nature of kūmara storage in pits, but this subject has been little discussed. Jones and Law (1987) assumed that the volume of stored kūmara occupied 50 percent of the volume of the pit up to the level of the ground surface, in contrast to Fox (1983) who preferred a lower figure of 30 percent. Jones and Law accepted the ethnographic data provided by Best to the effect that kūmara were piled up by hand and not stored in baskets or on racks. In an earlier paper, Jones (1983: 17) assumed that half the volume of the pit contained kūmara and estimated that 20 percent was kept for seed, with wastage of 10 percent. It must be noted that these views are not based on any real information; they are simply guesses. We discuss below the likely volume of stored kūmara in a pit.

These assessments have assumed that the stored kūmara was for subsistence and for seed. Jones and Law (1987: 93) make only passing mention of the possible role of food exchange in trade or as part of prestige events. More recently, however, Phillips and Allen (1996: 77, 79) have argued forcefully that kūmara surplus to subsistence needs was essential for the fulfilment of social obligations, while Law (2000) has suggested that very large pits, and particularly very long ones, may have been for prestige and the display of a community's stored crop.

Apart from these excursions into social and economic reconstructions, the numerous pit excavations of the last 30 years, particularly in Auckland and the Bay of Plenty, have added relatively little to what was already known at the time of Fox's (1974) review. Indeed, it has become possible to dismiss carefully excavated and well illustrated pits with the comment "there is nothing remarkable about them" (Irwin 2004: 49). What this shows is that archaeologists are not really learning much from pit excavations by simply clearing them out and measuring them. New approaches may be needed if further pit excavations are to advance our understanding of this important aspect of Māori subsistence activities. Full publication of recent extensive pit excavations may help to elucidate some of the issues raised in this paper.

EVIDENCE OF STORAGE TECHNIQUES

Archaeological evidence about how kūmara were actually stored inside pits is scant indeed. Archaeologists have simply assumed either that tubers were hand stacked in heaps, as most ethnographic evidence suggests (e.g., Jones and Law 1987), or that they were placed in baskets on racks (Fig. 7). Foster (2003: 214) has covered most possibilities in suggesting that the tubers were "laid gently into piles on the soft floor covering, stored in specially constructed bins or placed on racks".

In only two instances have macroscopic remains of actual kūmara tubers been reported from pits. Charred pieces of tubers were found amongst a quantity of burned material that looked like flax mats and baskets, in the fill of a pit at Waioneke pā, South Kaipara (J.R. McKinlay, pers. comm. 2005). The kūmara appeared to have been actually in a basket. But they were part of rubbish discarded into the pit after it had been abandoned as a store and was being used for dumping shells and other rubbish. They therefore contributed nothing to the understanding of storage techniques[7].

A much larger quantity of tubers was found in a burned storage pit (Pit O) at 'Haratua's pā' near Pouerua in the inland Bay of Islands. These kūmara, in contrast to those at Waioneke, appeared to have been stored in the structure when it was burnt. However, several questions remain unanswered about this pit, which was excavated by different methods during two successive seasons.

The carbonised tubers, some intact, some broken, and some slightly flattened, were scattered through a layer of brownish ash and soil, 30 to 40 cm thick, which rested directly on the pit floor. A single concentration of tubers, forming a crescent-shaped mass on the floor of the pit near the entrance, was interpreted as the remains of a single basket of tubers *in situ*. The kūmara-bearing deposit was covered by an 8-cm-deep black layer of charcoal and earth, containing unevenly distributed large lumps of charcoal and burnt timber, some pieces of which were thought large enough to be part of a ridge pole and rafters (Leahy and Nevin 1993: 39–41). Above this was the turf-covered modern pasture soil. During the second season, the kūmara-bearing deposit was excavated by 10 cm spits in 50 x 50 or 50 x 75 cm units. Tubers were found throughout, but were concentrated in the bottom half of the deposit, being most numerous in the bottom spit or occasionally in the second to bottom spit (Yen and Head 1993: 57). Other burnt organic material in the layer included bracken stems and fronds, mānuka seeds, and New Zealand flax (*Phormium* sp.)(Leahy and Nevin 1993: 53).

Leahy and Nevin tentatively suggested that the kūmara had been stored on layers of mānuka brush or bracken fronds, which had collapsed as the roof burned and the earth on top trickled through into the stored kūmara. The brush layers burned intensely and the earth, falling in as the roof burned, covered the kūmara tubers, causing them to carbonise (Leahy and Nevin 1993: 43). If the roof was indeed covered with earth, the fire must have started inside the pit. It could have been either a deliberate act of destruction or the accidental escape of a fire lit as part of pit or crop maintenance (discussed below).

Traces of burned bracken and mānuka have been found on the floors of a few pits, e.g., Station Bay pā (Davidson 1972: 2) and Te Awanga (Fox 1978: 19), although sometimes burned bracken in the fill of a pit is clearly part of a later event (Sutton and Crosby 1993: 78). Relatively little archaeological evidence has been reported of structures, such as racks or partitions, within pits. It is mainly confined to large pits, where postholes additional to those deemed necessary to support the roof have been considered part of such structures. Examples are reported from the greater Auckland Region (Allo and McKinlay 1971: 6–7;

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[7]See also Lynch (2001: 130) for a slightly different account of the context. Leach (1987: 85) reported that these remains consisted of one complete tuber and several fragments.

Bellwood 1972: 270; Coates 1986: 246; Davidson 1970a: 57; Foster 2000: 129, 2003: 206–207; Fox and Green 1982: 70;), and the Bay of Plenty (Campbell 2005: 26). Law (1970: 98) suggested that slots in a pit floor at Alberon Park in Auckland could have been part of bins, while Fox (1978: 19) interpreted rectangular sunken areas in the floor of a large pit at Te Awanga in Hawkes Bay as emplacements for wooden bins or baskets for selected kūmara or other supplies.

Both bin pits and small pits with undercut sides (like miniature bell-shaped pits without the shaft) in the floors of roofed rectangular pits have been reported from a number of sites (Foster and Sewell 1989: 14, 1995: 17; Golson 1960b: 14; Phillips and Allen 1996: 70; Sullivan 1972: 42); there are also rarer examples of small cave rua cut into the walls of roofed rectangular pits (Davidson 1975: 8; Fox 1980: 54; Lawlor 1983: 231, 233, 235; Wilkes 2000: 55). These raise more questions than they answer. Were they contemporary with the use of the larger pit? If so, and they were for some special part of the crop, such as seed for the next season or specially good varieties saved for important occasions, access to them would presumably have to be kept open. If they were in use after the larger pit, what was their purpose? Sullivan (1972: 42) believed that three such small pits in the floor of one big pit on Motutapu Island were used sequentially, one each season. Drawing partly on plant identifications from her excavation, she proposed that in each small pit, a framework of strong light branches, perhaps of kānuka (*Kunzea ericoides*), supported kits of seed tubers, allowing ventilation beneath. The pits could have been roofed over with fern fronds. However, these small pits within pits are generally too few in a site to account for all the tubers that would need to be kept as seed for the next season, as is sometimes also the case when a small number of presumed bell-shaped pits are noted among a much larger number of rectangular pits during recording of a site (e.g., Law 1969b: 30). Some features dug into the floors of pits are shallow, irregular, or too small to be suitable for storage (e.g., Leahy 1970: 64 and Fig. 5). These are sometimes interpreted as sumps. Lawlor (1983: 232) suggested that bins in the corner of a very large pit were probably to hold tree fern posts to reinforce the corners of the pit. Some floor features appear to post-date pit construction and their function is not understood (Campbell 2005: 26–27).

Recently, soil samples from the floors of pits have been examined for evidence of starch grains of kūmara or other root crops. At Hamurana Road site, Rotorua, starch grains showing features diagnostic of kūmara were found in three samples from what are thought to be garden soils, and in samples from the bases of two rectangular pits, but not in a sample from a rua (Campbell and Horrocks 2006). However, three samples from pits at two sites at Rowesdale, Tauranga, yielded no significant starch residues of any sort (Campbell 2005: 26). This might suggest that kūmara had not been placed directly on the floor or on supportive layers of vegetation that could permit the occasional tuber to fall to the floor and rot there. It is equally likely, however, that pits were so thoroughly cleaned out, that little or nothing escaped on to the floor. Campbell suggested that any kūmara that fell to the floor would be susceptible to fungal infection and would be quickly removed; thus "if any microfossil evidence of kūmara starch was found it would be more likely to indicate a failure in kūmara storage and, perhaps, premature pit abandonment rather than the more normal, desirable outcome of successful over-wintering of this valuable resource" (ibid.).

We are forced to conclude that there is as yet no clear archaeological evidence about how kūmara were placed in pits. We therefore do not have a clear idea of the relative volume of tubers compared to total pit size. We suggest that storage systems in pits may well have varied regionally.

PIT WALLS, ROOF, AND FLOOR

Many pits appear to have been filled deliberately as soon as they ceased to be used, often with sterile material presumably obtained by digging new pits (e.g., Ambrose, n.d. 17; Clough and Turner 1998: 14; Furey 1987: 121, 2004 pers. comm.). Such pits generally have a homogeneous fill with little or no trace of any organic material that might have formed part of the walls or roof. In some cases, posts appear to have been deliberately removed. Such deliberate acts of filling old pits, apparently during the digging of new pits, suggests that an old pit was, for some reason, no longer serviceable (Ambrose n.d. 17–18). One speculation is that a pit that had been used for some time was thought to be contaminated by an agent that might cause rot if the pit was used again. It was therefore filled in with the soil from a new pit. If this is so it would suggest that pre-European Māori possessed some understanding of the role of micro-organisms in causing tuber degeneration.

Pits that were left open after abandonment were sometimes filled with an interesting collection of rubbish, which was not necessarily related to the superstructure of the pit. For example, charcoal in the lower fill of large pits on Mt Wellington (Golson 1960a: 32), interpreted by Groube as burned remains of the roof (Groube 1965: 85), was later found to consist largely of shrub species found in burned layers in many places on the site, not only in pits (R. Wallace pers. comm. 1991).

The burned timber in Pit O at Haratua's pā, presumed to be from the pit roof, was identified as taraire (*Beilschmiedia tarairi*), hīnau or pōkākā (*Elaeocarpus* sp.), podocarp (probably tōtara, *Podocarpus* sp.), and matai (*Podocarpus spicatus*) (Leahy and Nevin 1993: 41, 52). Lawlor (1983: 236) reported carbonised remains of a wooden plank and tree fern posts in a pit which had been burned at Maruka near Kawerau in the Bay of Plenty. It was assumed that the roof had collapsed under the weight of earth covering it; it was not possible to determine whether any of the tree fern was from wall lining. Remains of planks and tree fern posts were found in other pits. Lawlor (1983: 233) suggested that the pit roofs were like those described by Tuta Nihoniho (in Best 1974: 98–99) and consisted of tree fern slabs or posts covered by toetoe thatch and earthed over, although no evidence of the thatch was found. A large amount of burned tawa (*Beilschmiedia tawa*) on the floor of a pit at Raupa in the Hauraki Plains was interpreted as part of the pit superstructure (Prickett 1990: 98, 101), although this pit floor also had a localised area of other burning which may have been a hearth feature.

Sutton *et al*. (1990: 123–124) reported charred tree fern spicules and wood fragments from a pit in an open settlement at Pouerua, concluding that these represented the burned superstructure of the store. Marshall (1990: 147) interpreted charcoal from near the base of a pit in another undefended site at Pouerua as indicating that both the walls and roof were made of tree fern. Sullivan (1972: 43) found burned remains of fallen posts and tree fern stems in a large pit.

Traces of tree fern, assumed to be wall lining, have been reported from other sites in various parts of the northern half of the North Island (e.g., Law 1972: 111; Law and Green 1972) and also from Pari Whakatau in Marlborough (Duff 1961: 280). Jones (1983: 14) described tree fern logs lying parallel to the main axis of a pit as probably a floor or lining rather than part of the superstructure.

Fill layers have sometimes been interpreted as soil from the pit roof (e.g., Furey 1987: 121), as at Haratua's pā. Elsewhere, archaeologists have assumed that roofs were covered with soil (Campbell 2005: 26; Lawrence and Prickett 1984: 11).

Scalloping and slots in the side and end walls of pits, as well as actual postholes at their bases, have been reported as evidence of walls or wall linings in a number of sites, although they often occur irregularly, in small numbers, or on only one wall (Ambrose 1962: 61; Campbell 2004: 3–4; Cassels and Walton 1991: 191; Golson 1960b: 14; Law 1970: 97–78, 1972: 113; Law and Green 1972: 261; Lawrence and Prickett 1984: 11; Shawcross 1964: 89). Green (1963a: 153) drew attention to "small irregular erosion channels" in the corners and walls of pits at the Kauri Point Undefended Settlement, as possible evidence of the former existence of wall posts. Duff (1961: 279–280) described holes for massive wall posts in Pit C at Pari Whakatau, set in such a way that the posts would have stood free of the walls, and speculated that the gap between posts and wall was filled with tree-fern logs. The only evidence of this, however, was the presence of numerous pieces of charred tree fern in the pit fill.

Not all claims for wall posts have stood the test of time. Fox and Cassels (1983: 73) rejected an earlier interpretation of wall posts at Aotea, and the supposed wall posts at Sarah's pā (Green 1963b: 85; Law and Green 1972: 266) are based on postholes outside the pit, not set in the wall. Slots and post holes on the outer edges of pits may also be evidence of superstructure. Leahy (1970: 64) reported possible slots in which the roof beams of a pit might have been set on Motutapu Island, while Lynch (2001: 128, 129, 130) described numbers of postholes encircling pits and possibly associated with pit roofs at Waioneke.

A most unusual form of pit wall construction is the use of scoria block retaining walls to prevent collapse where pits were dug into soft scoria on Mt Wellington (Davidson 1993: 43). No evidence of perishable wall lining was found in these pits.

In only one case has an intact pit lining been reported. This was a long narrow pit, 12 ft x 3 ft x 3 ft (3.7 x 0.9 x 0.9 m) lined with slabs of timber, reported by Teviotdale and Skinner (1947: 35) at Paterangi in the Hauraki Plains. The authors speculated that this structure may have been of historic age and used for the steeping of maize. It may therefore have nothing to do with kūmara storage. However, Best (1980: 73) reported a possible pit feature at Paterangi and more typical pits were found at the Hauraki Plains site of Raupa (Phillips 1986; Prickett 1990, 1992) so the Paterangi pit cannot be completely disregarded.

Apart from this example, wood has been only rarely reported from pits. In addition to examples of charred or carbonised wood already mentioned, Parker (1959: 19–20) reported traces of wood, in a very bad state of preservation, on the floor of one of the pits at Skipper's Ridge.

Bark has sometimes been found on pit floors or in the fill of floor drains in pits, most notably at Hamlins Hill in Auckland where it is reported from a drain by Davidson (1970b: 108), from several places on the floor of a pit by Nichol (1980: 21) and lining the floor of one pit and the floor and lower walls of another by Walton (1979: 107, 111). Curved pieces of bark were also found in the drains of two pits at Alberon Park in Auckland (Law 1970: 97–98). McFadgen (1970: 70) found a number of pieces of bark in the bottom fill of a pit at Mokau, North Taranaki. Coster (1977: 248) found a layer of thin flat sheets of bark, possibly kauri (*Agathis australis*), on the floor of an unusual cave pit inland from Tauranga.

Despite ethnographic accounts of the use of organic material and sometimes gravel on the floor of pits, archaeologists have excavated a great many down to the underlying natural with only rare reports of recognisable deposits on the floor. This may be at least partly due to an over-emphasis on pit dimensions and floor features such as postholes and drains. However, at Richmond Park, Campbell (2004:7) found a thin layer of dark soil in the base of all pits, which he considered to derive from trampling and/or, in the case of a small pit, organic material. McFadgen (1970: 70, 72) described occasional beach pebbles in the bottom fill of a pit at Mokau in Taranaki and a sterile blue sand layer (assumed to be natural) in the base of another pit at the same site. At Otakanini, Bellwood (1972: 270) found silt on the floor of a pit, which he interpreted as the result of standing water, although the pit had drains. Fox (1978: 18–19) reported a thin layer of fine sandy soil with a seam of charcoal and small pebbles in the base of a large pit at Te Awanga.

BUTTRESSES AND DRAINS

Along with postholes, buttresses and drains are the most commonly reported features of excavated rectangular pits. Buttresses (blocks of natural material protruding into the pit from one or both ends or occasionally a long side) have sometimes been interpreted as related to entrances, although not all can be interpreted in this way. Their purpose remains essentially unknown.

Drains, leading to corner sumps or actual tunnels to the slope outside, are very common in areas where the natural soil is relatively impermeable, and absent in areas where pits are dug in material such as scoria or volcanic ash. They are generally assumed to be just what the name implies, drains to remove water from pits. Their number, and the care given to their construction, suggest that pit roofs leaked badly. However, at Hamlins Hill, where there was an elaborate system of partially stone-covered drains, Walton (1979: 111) found part of the system drained into rather than out of one pit, which he suggested might have been used opportunistically as a sump. In some areas, notably the Bay of Plenty, where pits do not usually have drains, floor features other than postholes are sometimes interpreted as sumps.

FIRE HOLLOWS AND BURNT FLOORS

Features sometimes described as ‘hearths’ have been found in pits in many areas. In the early days of pit excavations, they were sometimes taken as evidence that some pits, at least, were dwellings (e.g., Golson 1961: 21–22; Parker 1962). These features are not the rectangular, stone-edged hearths often found in Māori houses, but small bowl-shaped depressions containing remains of fire. Examples are reported from Pouerua in Northland (Marshall 1990: 148; Sutton and Crosby 1993: 74), the Auckland area (Bellwood 1972: 271; Coates 1986: 246; Davidson 1970b: 107, 1972: 2), Coromandel-Bay of Plenty (Ambrose n.d.; Golson 1961: 21; McFadgen and Sheppard 1984: 17[8]; Parker 1959: 19, 1962: 223; Shawcross 1964: 89), Hawkes Bay (Fox 1978: 19), and North Taranaki (Lawrence and Prickett 1984: 11, 13; Parker 1962: 225).

Often, evidence of a small, localised fire has been found on the floor of a pit, without the usual bowl-shaped hollow. This has been reported from the Auckland area (Foster and Sewell 1993: 20 [not mentioned in Foster and Sewell 1999]; Fox and Green 1982: 69; Leahy 1970: 64), Hauraki (Prickett 1990: 98, 101), Coromandel-Bay of Plenty (Golson 1961: 22; Green 1963a: 151; Phillips and Allen 1996: 70) and Marlborough (Duff 1961: 284). Sometimes, however, such fires are assumed to have been made after abandonment of the pits for storage (Sewell 1992: 11).

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[8] Interestingly, McFadgen and Sheppard argued that this pit at Ruahihi was probably not for kūmara storage because of the fireplace and the off-centre position of the two postholes. This interpretation of the fireplace is not sustained by the review presented here.

In some cases, both hearths and surface fires are found in the same site or site cluster. Thus at Pāpāhīnu, south Auckland, Foster and Sewell (1995: 20, 53) reported a small scoop hearth in one pit and an area of burnt subsoil in another at R11/1800. At nearby R11/229, a burned depression, interpreted as a hollow to hold heated rocks, was found in a large but very shallow pit, which nonetheless had a typical pit drainage system. At a site in the eastern Bay of Plenty, near Te Kaha, Bowers and Phillips (1998) found a burned area of floor in one of three fully excavated pits, a scoop hearth in another, and one of each kind of fire feature in the third. One of these pits also contained an upper burned layer thought possibly to be the remains of the roof. Here and elsewhere, it is not always easy to identify the exact nature of burned material on pit floors.

In a 1967 conference presentation, Ambrose provided a detailed discussion of bowl-shaped fire features at Kauri Point pā, where they were found mostly in the larger rectangular pits. Ambrose argued that "the recurring fire hollow can be explained functionally as a renewal process for storage to achieve the same affect [sic] by fumigation with smoke and heat as was achieved by the re-digging of the smaller pits" (Ambrose n.d.: 18). Fox (1974: 146) put forward a similar suggestion—that "the small hearths recorded in several [large] pits are probably attempts to get rid of rot…". She later claimed that pits were easily disinfected by burning and could therefore last for years, and made reference to the British experimental Iron Age farm at Butser, where grain storage pits were successfully sterilised by intense brushwood fire (Fox 1975: 203–204). As described below, fire is used to fumigate disease-infected sweet potato stores in China.

All subsequent interpretations of localised fire features on pit floors, which are not obviously related to the burning of pits walls and roofs, have followed this 'sterilisation' interpretation. It has never been suggested that some of these fires might have served the simpler purpose of raising the temperature in the pit during the coldest part of the storage season. This may be because fire features are usually recognised in a minority of pits at any one site.

PIT DEVELOPMENT AND VARIABILITY

Yen (1961: 345–346) presented a three-stage model of kūmara adaptation by pre-European Māori, consisting of Introductory, Experimental and Systematic stages. The development of pit storage in the second stage was linked to a supposed deterioration in climate after initial settlement and establishment of the plant without the need for storage. This model was expanded to include other crops by Leach (1976, 1979b: 246–247), who postulated *introduction*, soon followed by *experimentation* with short-term storage devices. *Regional consolidation* saw the development of local preferences in pit styles, followed by *expansion from secondary centres*. Leach saw these two stages as perhaps the equivalent of Yen's Systematic stage. Next came *retrenchment* during which gardens in marginal areas such as Marlborough were abandoned, followed by *revival* in response to European introductions. Implicit in this model, too, is the effect of climatic deterioration in marginal areas.

It is now evident that pits were in general use in the northern part of the North Island from at least about AD 1450 onwards and perhaps earlier. A pre-AD 1300 date for a pit at Skipper's Ridge (Davidson 1975: 36–37) may have some inbuilt age, but should not be completely discounted. However, an early date for a large pit at Maioro (Green 1983) has not been supported by a new date from the same context (Green pers. comm. 2006). Storage pits were associated with Archaic items in a dune site at Hahei on the Coromandel Peninsula, considered by the excavator as most likely to date to the fourteenth century

(Harsant 1983, 1984). Any initial experimentation with storage is likely to been accomplished very rapidly.

Apart from the appearance of 'raised rim' pits[9] in eastern areas from East Cape to the northern South Island, there is little or no evidence of regional styles in rectangular roofed pits. There is, however, enormous variation in size, length-width-depth proportions, presence or absence of buttresses, and presence or absence of fire features. As Lawlor pointed out (1983: 241), following Walsh (1902: 21), local conditions influenced form. Thus bell-shaped and cave pits could be dug only in some places and some of the variation in roofed rectangular pits (e.g., presence or absence of drains and stone retaining walls) can be attributed to the nature of the material in which they were dug. The distribution of cave pits is outside the scope of this paper but deserves future attention. In some areas, cave pits and rectangular roofed pits are sometimes found in the same sites; this could reflect functional differences but might simply be a matter of personal and family preference.

Law (1969b: 29) has illustrated the very considerable variation in size of rectangular pits within a single large pā, and the equally considerable variation in size of pits in six excavated sites (Law 2000: 36). Variation in size was obviously related to the amount and type of tubers to be stored, but was certainly also influenced by social factors (Law 1969b, 2000; Phillips and Allen 1996). There is scope here, too, for more thorough analysis of large samples of pits.

In recent years, there has been very little discussion of chronological change in pit storage. Clough and Turner (1998) have tentatively suggested that at the Waipuna site in Auckland, used for storage possibly between about AD 1350 and 1700, surface storage structures (indicated by drains and postholes) were replaced by roofed pits, which got progressively deeper over time. This echoes the much earlier suggestion by Parker and Buist (1961) and Parker (1962) that the pits at Kumara-kaiamo became deeper over time. However, the variations in depth, form and features within as well as between many sites suggest that Māori were constantly experimenting with storage.

SUMMARY

Despite the vast numbers of pits excavated over the past 50 years, archaeological evidence about many aspects of pit construction and function is still sparse. There is little evidence of how tubers were stacked or otherwise placed in stores; organic remains that may relate to roofs, side walls, internal partitions or floor coverings are relatively few and often ambiguous. Fire features, following Fox and Ambrose, are generally interpreted as devices for sterilising pits. Although pit variations can certainly be attributed in part to local conditions and probably also to social considerations, it should also be recognised that successful kūmara storage was always a challenge requiring constant experimentation.

MODERN STORAGE REQUIREMENTS OF KŪMARA

Ipomoea batatas had its origin in a tropical climate of the Americas. It is still unclear whether this was in Mexico or northern South America (Yen 2005: 183), although there is

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[9] These are rectangular pits, often large, with a raised bank around the edges, and often signs of a drain outside the bank.

general agreement that it reached Polynesia from the latter (Green 2005). The formation of swollen storage roots or tubers is a survival adaptation which enables the plant to endure a dry season or period when there is not enough water for it to continue growing. It is not an adaptation for surviving cold seasons. Unlike dry grain crops such as wheat and rice, sweet potatoes have a high moisture content and relatively thin and delicate skin. They remain metabolically active after harvest, are easily damaged, and are perishable (Coleman 1978: 30). This means that some respiration (the conversion of carbohydrates for metabolic energy resulting in some loss of dry matter) and some transpiration (water loss to the environment) continues during the storage period. Careful post-harvest handling and storage are therefore critical in ensuring the survival of tubers from one season to the next. Long term storage of kūmara requires two things: 1: environmental conditions that will enable life activity to continue; but 2: at as slow a rate as possible. If it is too cold, the tuber will die. If it is too hot, the tuber will quickly sprout and lose its food value (Cooley 1951: 384).

In temperate climates, modern post-harvest treatments developed by the US Department of Agriculture involve immediate curing by holding tubers at 29.4˚C and 85–90% relative humidity for four to seven days, followed by storage at 13–16˚C and 85–90% relative humidity (Kushman and Wright 1969: 7, 9). The purpose of curing is to heal injuries before disease producing organisms gain entrance (ibid.: 7). For modern kūmara in New Zealand, Brash and Odey suggest curing at 30˚C and 85–90% relative humidity for three to five days (Brash and Odey 1999: 20). Wallace (2000: 76) gives the following recommended post-harvest treatments in New Zealand: heat-curing tubers at 29.5˚C and 90–95% relative humidity for four to seven days, followed by increasing the temperature to 43.5˚C for 24 hours, then storage conditions of 12.5–15.5˚C and 85–90% relative humidity. He stated that "under these conditions tubers should keep for seven months" (Wallace 2000: 76). Curing in this manner was not possible for pre-European Māori. They did, however, ensure that harvesting took place on a "perfectly dry sun-shiny day" (Colenso 1880: 12).

The importance of curing cannot be over-emphasised. Kūmara are very easily infected in sites of external tissue damage. At the first sign of infection, respiration inside the tuber increases rapidly with rapid production of ethylene and substances known as coumarins and furanoterpenes at the site of the infection. These substances are toxic to pathogens and prevent penetration (Uritani 1982: 425).

Woolfe (1992) devotes a chapter to a review of publications on the storage and cooking of the sweet potato, including a section on Chinese traditional peasant storage systems, which account for 80 percent of the world's production (Woolfe 1992: 228). Some Chinese 'well cellar' stores are remarkably similar to Māori bell-shaped pits (ibid.: fig. 5.4, p. 230). Of particular interest is the following observation:

> When old pits are reused, they must first be cleaned by scraping a 2 cm layer of soil off the walls to expose new soil and removing the old soil. Disease-infected pits should be disinfected by burning wood or straw or by fumigation with sulphur (Woolfe 1992: 228).

Cold wet soils before or during harvest, or subsequent exposure to temperatures below 10˚ C, cause chilling damage, resulting in tissue breakdown (Woolfe 1992: 222). Chilling renders the tubers more susceptible to attack by rot fungi. Arinze and Smith (1982, cited by Woolfe 1992: 222) suggest this may be due to an increased sensitivity of any damaged tissue to pathogenic pectic enzymes[10], and to a reduced capacity for synthesising phyoalexins[11].

In humid tropical climates, sprouting frequently occurs in conditions of high temperature and humidity (Woolfe 1992: 237). Increased temperatures result in increased tuber respiration (Jenkins 1982, cited by Woolfe 1992: 222, 236). Ventilation is necessary during storage to provide oxygen for this natural respiration, to prevent the accumulation of respiration by-products such as carbon dioxide (Woolfe 1992: 222) and ethylene (Uritani 1982: 425), and to avoid any condensation of moisture on the tubers. Modern sweet potato storage facilities utilise heating and ventilation systems to maintain temperature and humidity. For traditional cellar storage in China, 30–50 percent spare space is allowed in order to maintain aerobic conditions (Woolfe 1992: 228). Several methods were used in China to ventilate their stores, such as opening of the store door or inserting bamboo tubes as air inlets.

Variation between cultivars in their tolerance of cold conditions and in their general storage performance has been reported, and research on screening genotypes for storability has been carried out in the Philippines (Woolfe 1992: 241), but no useful information relevant to the Māori cultivars has been reported. However, we have some evidence of variable response to cold conditions by two Māori cultivars. In mid-May 2004, the minimum temperature dropped below 10˚C in an unheated room at the Open Polytechnic where some of our tubers were stored. When this occurred, there were significant signs of rot in tubers of the 'Taputini' cultivar, and some had to be removed. However, tubers of the 'Rekamaroa' cultivar did not show the same signs of decay.

Woolfe's research on the effectiveness of small-scale storage systems clearly shows how difficult it is to keep sweet potatoes for long periods after they have been harvested. Various experiments were carried out in Papua New Guinea, for example. In one case, tubers were kept in a house with a small fire constantly burning as a heat source and moistened copra bags hung in the rafters to raise the humidity. This permitted tubers to be kept for only two or three weeks. Elsewhere, covering the roots with dry grass and soil to form a clamp maintained them for 30 days. In another experiment, a conical clamp with a heat source placed underground permitted storage for 40–50 days (Woolfe 1992: 234–235). In the Philippines, roots were stored in a trench covered in sand and sheltered with a roof. At the end of this period it was found that 35 percent had decayed and 45 percent had sprouted (ibid.). Finally, roots were stored successfully for up to four months in Barbados, West Indies, in a slightly subterranean clamp covered in trash and soil (ibid.).

An alternative to preserving live tubers is to slice them into thin chips and dry them in the sun. Woolfe reports many examples of societies doing this as an effective way of keeping the food for up to a year (Woolfe 1992: 242–245). The chips may be rehydrated or ground into flour. There is a parallel to this in the ethnographic accounts of the Māori preparation of kao, in which tubers were converted to a sugary delicacy by scraping, sun drying and cooking (Walsh 1902: 23–24; Colenso 1880: 12; Best 1976: 138–139 citing John White and describing East Coast practice). Although kao is described as an esteemed delicacy, there is no indication that it was made on a large scale. Colenso actually states that a few of the immature tubers (about two-thirds ripe) were used for kao. This would enable drying in hot

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[10]The enzymes that permit the pathogen to penetrate and infect host cells.

[11] A form of antibiotic produced by the tubers in response to attack by pathogens.

sun, but would greatly limit the quantity that could be made. By normal harvest time, it is unlikely that there would be sufficient solar heat for effective sun drying.

CONCLUSIONS

Modern recommendations for commercial kūmara in New Zealand suggest that with the best curing and storage conditions a crop can be expected to last for seven months. A review of predominantly peasant storage systems in various parts of the world showed that crops did not usually last anything like that time. Māori gardeners therefore faced a challenge in storing seed tubers until the next planting season, and are unlikely to have been able to keep more than small amounts of kūmara for consumption that long.

Storage temperature is critically important. In colder climates, stored tubers are prone to rot; in hot climates they are prone both to rot and to premature sprouting. Both these problems might have been experienced by Māori gardeners. Cold is a factor at the southern margins of kūmara cultivation in New Zealand, but in the warmest parts of the north of the country, storage temperatures might at times have been too hot.

THE STORAGE EXPERIMENT

AIMS

Our aim was to ascertain the effects of subterranean pit storage, and particularly how it measured up against modern requirements of kūmara storage, by replicating the conditions of a rectangular semi-subterranean store (without attempting to use authentic materials), monitoring the temperature, humidity and light levels both inside the pit and in a small above-ground control structure, and observing the state of the stored tubers in both structures. We aimed to document the differences between the pit and the control structure and to determine whether simply placing the kūmara in the pit store was sufficient for their long-term survival or whether further intervention was required, and if so, what form this might take. This experiment was intended to have a duration of several years; however, funding constraints restricted it to a single season—from harvest to planting over the winter of 2004. Tubers were placed in the store on 29 April 2004 and the last measurements were taken on 1 October.

THE EXPERIMENTAL STORE

We placed our experimental gardens adjacent to archaeologically recorded garden sites at Robin Hood Bay and Palliser Bay. We chose a location for our experimental store in the vicinity of an archaeological pit site at Seventeen Valley near Blenheim.

The site is now in the middle of a vineyard and looks out over the lagoon towards Wairau Bar. Originally it consisted of three groups of large pits on the edge of a river terrace, with stone rows on the slope dropping away towards the stream below to the west. The site is undated. One group of pits and the stone rows were destroyed some years ago; the remaining two pit groups have been gifted to Rangitane o Wairau and are now preserved in fenced and grassed enclosures. Our experimental store is in a corner of one of the enclosures, some distance from the archaeological pits.

Figure 9: Construction of the experimental storage pit at Seventeen Valley, Marlborough.

Figure 10: The experimental storage pit and control at Seventeen Valley, Marlborough.

We built a store 2400 x 1800 mm in plan, with its floor 1200 mm below ground surface. It had a natural earth floor, plywood walls and a pitched plywood roof. The rear wall and roof were lined with black polythene, covered with earth, and grassed over. The door was in the north gable end, which was lined with raupō, largely for aesthetic reasons. We used two different mechanical excavators, pre-cut timber, and modern tools such as electric drills. Adjacent to the pit store was a small above-ground control in the form of a miniature pātaka (a structure raised on posts). An electric fence was installed to prevent the two sheep that grazed the enclosure from standing on the pit roof or damaging the monitoring equipment (Figs 9 and 10).

A wooden ladder provided access to the floor. The west half was left open for easy access to, and monitoring of, the tubers, which were stored on three racks along the eastern side (Fig. 11). We stored only one Māori cultivar—'Taputini'—which has been the most prolific of the three cultivars we have grown in the experimental gardens. Twenty-three baskets containing 320 tubers were placed in the pit.

Data loggers were placed in both the pit and the control to monitor air temperature, soil temperature, relative humidity and light levels. The air temperature monitor in the pit was on the south wall 100 cm above the floor and that inside the control was 100 cm above the ground surface. The soil temperature probes were 30 cm below the pit floor at the south end and 30 cm below the ground surface under the control. A rain gauge was installed adjacent to the control box. Information was collected at two-minute intervals. We visited the store at intervals of two to three weeks between harvest and the new season's planting to download the data, reset the monitors, inspect the stored tubers and remove rotten ones. On these occasions we also ventilated the pit by leaving the door open during our visit.

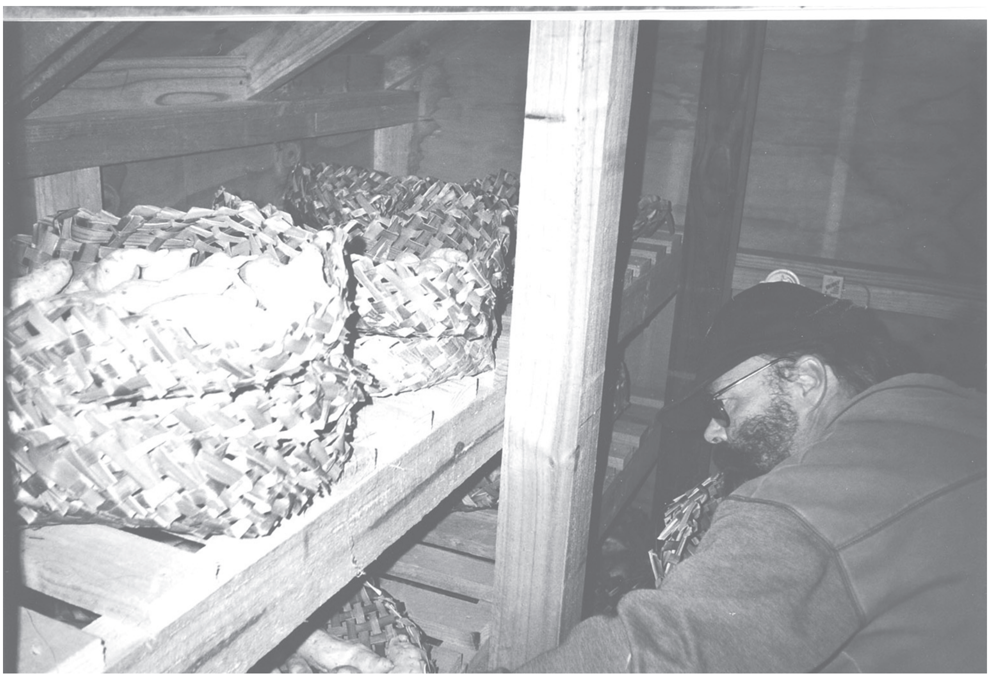

Figure 11. Graham Harris placing baskets of kūmara in the experimental storage pit.

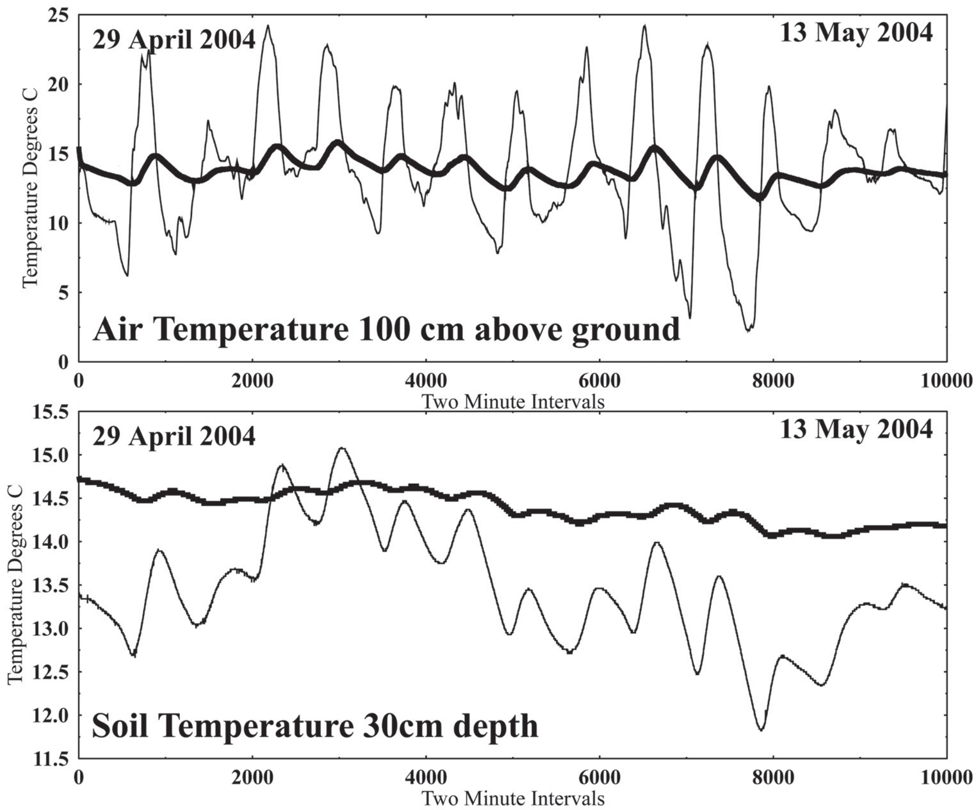

Figure 12: Diurnal changes and temperature lag in the experimental storage pit and control. The bold lines relate to the experimental storage pit and the fine lines to the control station. The air temperature loggers were 100 cm above the floor of the pit and inside the control station 100 cm above the ground surface. The soil temperature probes were 30 cm beneath the pit floor and 30 cm beneath the ground surface under the control station.

Two unforeseen factors may have had a deleterious effect on the experiment. For the first time in five years we had bad weather for the harvest and the tubers did not get the normal exposure to sunlight to assist 'curing'. As a result, we had a greater than usual loss through rot in tubers stored in an unheated modern building at the Open Polytechnic of New Zealand, and this will have been a factor in the storage pit. However, it should be noted that storage losses through rot at the Open Polytechnic were significant in earlier seasons too when the crops had been better cured (Burtenshaw *et al*. 2003: 172). In each case, tubers were stored in individual paper bags loosely placed in cartons in an unheated building. Rot set in from August onwards.

We initially stored the kūmara in baskets of New Zealand flax (provided by Veranoa Hetet at the request of GH). These were freshly made from unprocessed flax leaves, which resulted in a rapid and extremely impressive growth of fungus on and around the baskets[12]

Our response was the temporary removal of the entire contents of the store on Day 17. We then lit a small fire on the floor, which provided both heat and abundant smoke for about 30 minutes, after which we doused the fire with earth. The tubers were temporarily stored in a modern building. On Day 27 we replaced the crop, now in plastic trays lined with newspaper. The few faint remains of the fire were dispersed and largely destroyed by trampling feet on subsequent visits.

DIURNAL CHANGES AND TEMPERATURE LAG

The most obvious change in the storage environment occurs diurnally, and the effects of this can be seen in the top part of Figure 12. This gives the pattern of temperature change in the pit and the control station for both air temperature and soil temperature for the first 10,000 readings, starting when the tubers were first placed in the pit and the door closed. In the control station, diurnal air temperature range was at least 10˚C per day, sometimes as much as 20˚C. Inside the pit, however, the diurnal changes in air temperature were only about 2˚C. Thus, the most dramatic effect of subterranean pit storage is the reduction of temperature fluctuations by one order of magnitude. This can be attributed to low thermal conductivity of soil, or high thermal resistance. This is closely related to another property of soil—thermal inertia; that is, it takes a long time to heat the soil up during the daytime and also a long time to cool it off at night time compared to air, for example. Consequently, the air space enclosed by the walls and roof of the pit also warms up only slowly during the day, and cools off equally slowly at night. This is the reason for the dramatic difference in the magnitude of diurnal changes between the air in the control and the air in the interior of the pit.

Although the magnitude of these short term (daily) fluctuations is greatly reduced inside the pit, this does not mean that the average temperature will not go down if there is a sustained period of cool temperatures outside. It will take longer to have an effect, but it will occur in due course. This is a very important distinction, as we will see shortly. In Figure 12, particular notice should be taken of the fact that the average temperature inside the pit is more or less the same as outside in the control station. This may seem surprising at first.

A somewhat less noticeable feature in Figure 12, but just as important, is that there is a time lag between the changes being experienced outside and inside the pit. Even though the degree of fluctuation each day is less, the same diurnal changes can be seen each day, but there is a noticeable shift in the timing of these. The minimum temperatures in the pit occur well after the corresponding minima outside. Analysis of the collected data shows that this time lag is fairly consistent at about 150 minutes (2.5 hours). Thus it can be seen that as the

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[12]Samples of this were identified by M. Dance as having the following six fungi and a dry bacterium in order of apparent dominance: *Rhizopus stolonifer, Penicillium janthinellum, Epicoccum purpurascens, Ulocladium chartarum, Mucor plumbeus, Acremonium strictum*, and *Streptomyces* sp. These are all common soil residents. *R. stolonifer* is known to attack kumara specifically, but others are also known to cause soft storage rot.

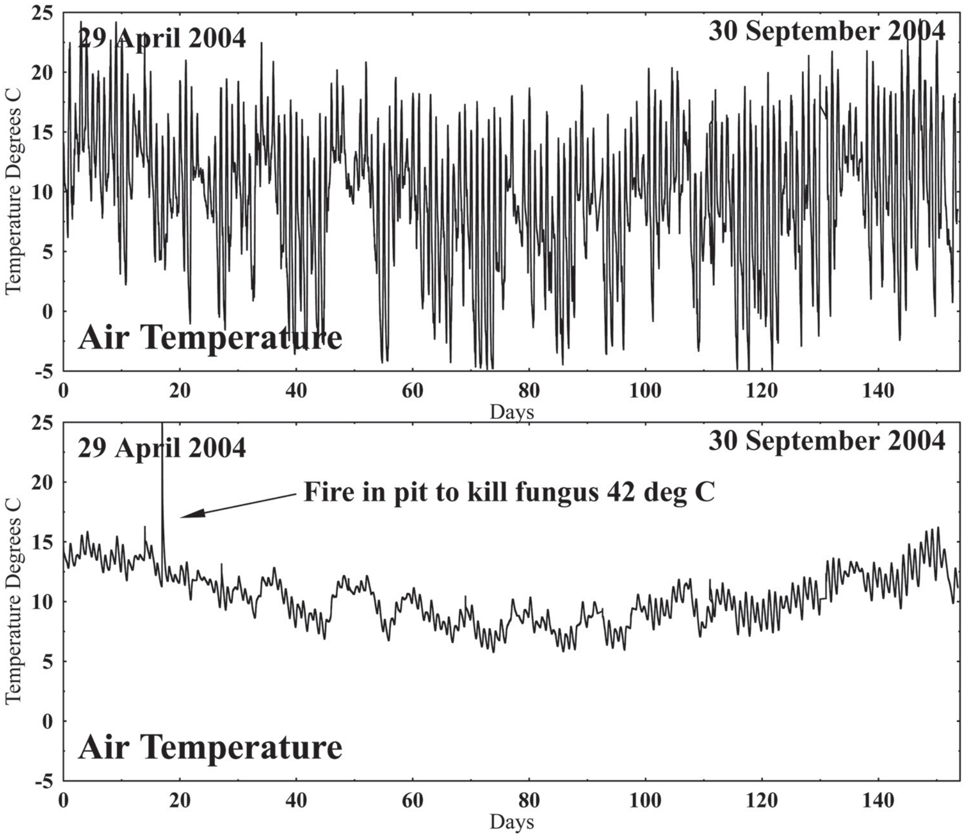

Figure 13: Air temperature records for the entire 154 day period of storage. Upper: the control station. Lower: inside the pit. See text.

air temperature outside is falling, the air temperature inside the pit it still rising. This temperature lag is the main reason that the overall fluctuations inside the pit are so small. In short, the effect of temperature lag is to dampen down fluctuations.

In the bottom part of Figure 12, the soil temperature data are given for the same time interval. In this case, the average temperature inside the pit is considerably above the soil temperature under the control station at the same depth. In addition, fluctuations in soil temperature in the control are considerably less than the air temperature, although exactly the same diurnal changes can be observed. On the other hand, diurnal changes are very difficult to detect in the soil temperatures inside the pit. These effects are also attributable to temperature lag, caused by poor thermal conductivity of soil.

AVERAGE TEMPERATURES INSIDE AND OUTSIDE THE PIT

In Figure 13, the changes in air temperature are shown for the full period of 154 days of storing the kūmara tubers. The order of magnitude dampening of fluctuations inside the pit is again clear. The huge rise in temperature during the firing of the pit to kill fungus is also visible. What is most important in this illustration is that it shows that average temperatures both inside the pit and outside in the open air closely follow each other! In other words, the idea that storing kūmara tubers in a subterranean pit will keep them warmer than if they were kept above ground is a simplification. The average air temperature for close to 110,000 records for the control station was 9.50˚C compared to 10.37˚C for the pit, a difference of only 0.87˚C. The minimax values, on the other hand, are considerably different: -5.4˚C and +24.4˚C for the control station, and +5.8˚C and +16.3˚C for the pit. This conforms with research carried out by Smart (1962, see also Figure 7).

However, the trifling difference in the average temperature inside and outside the storage pit was a surprising result, and challenges an item of faith amongst New Zealand archaeologists. Although the soil surrounding the pit at its base is clearly warmer than the soil closer to the surface (lower Fig. 12), any warming of the air inside the pit that this may cause appears to have been lost through the roof and thin wall near the door. Having a much thicker layer of soil over the roof might have the effect of increasing the mean air temperature differential between the inside and outside of the pit. We may therefore hypothesise that the mean temperature differential would be greater in the case of both the cave pit and the bell-shaped rua than the roofed rectangular pit, since they have a far greater thickness of insulating soil above the stored tubers (see Figure 7).

TIME SPENT AT DIFFERENT TEMPERATURES

Important though absolute temperatures might be for storing these tubers, of equal significance is the length of time that the tubers sit at any one given temperature. After all, a short flash of flame may not kill the tuber; neither may a short flash of very cold air. This was one of the reasons for setting such a short time interval (2 minutes) on the data loggers, because it would permit analysis of time spent at different temperatures. Here again, the results surprised us.

This analysis is presented in Figure 14, which shows the cumulative percent of time spent at each temperature both inside and outside the pit. The greatly differing shape of these two curves reflects the degree of fluctuation around ambient temperature experienced at the two locations. These are very useful graphs, because they instantly show how long the tubers were sustained at various temperatures. For example, although tubers in the pit never experienced temperatures of 5˚C or less, those in the control box were kept below 5˚C more than 23 percent of the total time. A more startling result of this cumulative time analysis is that the critical temperature of 10˚C, at which modern research has shown kūmara tubers will begin to rot, was sustained both inside and outside the pit at near identical amounts of time: 54.45 and 54.12 percent respectively. This surprising result demonstrates that in Marlborough today without human intervention, there would be no practical benefit in storing kūmara below ground insulated by soil, rather than above ground exposed to the elements. The result would be the same, none of the crop would survive for planting the following season. To be sure, the uninsulated outside environment offers more severe conditions for kūmara, and the rot might start earlier, but in the end the result would be the same.

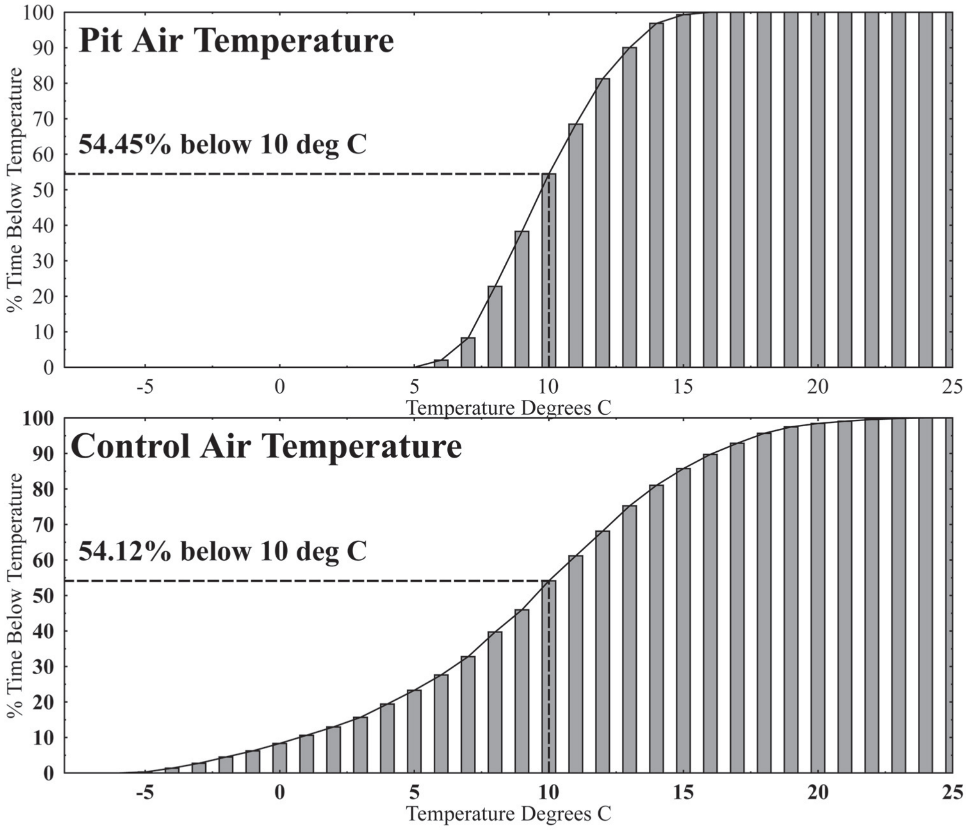

Figure 14: The cumultative percent of time spent at different air temperatures in the pit and the control. See text.

WHAT HAPPENED TO THE KŪMARA CROP?

The main aim of this experimental research was to find out what, if any, advantage there would be in storing kūmara in a subterranean pit, and in particular how this insulated underground environment stands up against the yardstick of what we understand to be the modern requirements for kūmara storage. Strictly speaking, it was not necessary actually to put any kūmara tubers in the pit to determine this. A storage pit in this location at the top of the South Island would not preserve kūmara unless there was human intervention to raise the temperature during periods of sustained cold weather. So what actually happened to the kūmara?

The fate of the kūmara crop is shown in Figure 15. We inspected the pit contents ten times. On each occasion we downloaded and reset the data loggers, and carefully examined all the tubers for rot. The first sign of rot in the pit was observed on one small tuber on 17 June (day 50). On 7 July there was no further rot in the pit but several tubers were rotting in the control. On the 31st July (day 94) another four tubers in the pit and 20 in the control were found to be rotten. After that rot spread rapidly through the crop. On each occasion,

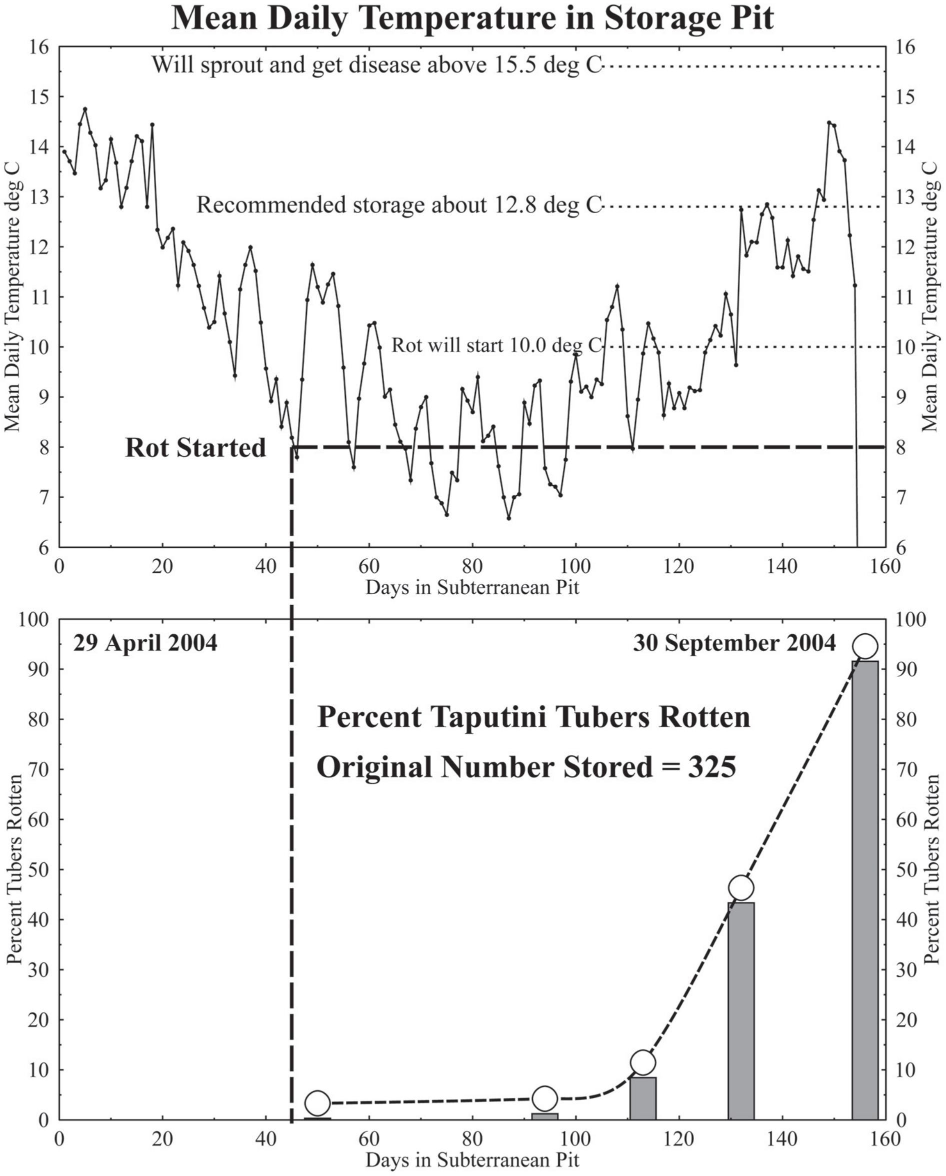

Figure 15: The mean daily air temperature inside the pit over the entire period of storage, together with the percent of tubers found to be rotten. See text.

any rotten tubers were carefully removed to reduce the risk of cross-contamination, something which pre-European Māori would have done too. However, in this experiment we were not intent on saving the crop, but on finding out what would happen to it in normal conditions, without fires lit inside to warm the atmosphere. All but 14 tubers in the pit were destroyed by rot by 1 October (day 156). Six of the remaining tubers, all very small, were unaffected, and the other eight, also mostly small, were just starting to rot. Only one partly rotted tuber remained in the control; the others were destroyed by rot.

It is interesting that no signs of rot were observed in the pit until the mean daily temperature there reached 8°C. Further research is needed to determine whether this means that 'Taputini' is more tolerant of cold conditions than modern varieties.

HUMIDITY, LIGHT LEVELS, AND MOISTURE

As might be expected, the humidity in the control varied diurnally and according to changing weather patterns. Humidity in the pit was constant at ≈90 percent or above until the door was opened for inspection.

There is apparently a difference between kūmara and white potatoes in the response to light and lack of light. White potatoes are not normally kept in total darkness because it encourages early and excessive sprouting. This does not seem to be the case with kūmara; we did not observe early or excessive sprouting on the tubers in the pit.

In spite of high humidity inside the pit, conditions on the racks, floor, and the kūmara themselves remained dry to touch. The rear wall and parts of the roof near the rear wall began to be wet on their surfaces from mid-winter onwards, but this moisture did not affect the crop. A closed environment like this underground would have high humidity whether there was rain or not; indeed, this is proven by the first two weeks of records, which were the same as all other periods.

THE FIRE TO DESTROY FUNGUS

This was only a small fire of about 30 cm diameter in a scooped-out hollow in the middle of the floor on the west side of the pit. Only a handful of dry sticks was used. This small fire had an instant and dramatic effect on the inside of the pit. With such a small doorway, not a lot of fresh air was able to circulate so the pit filled with dense hot smoke, and the data logger recorded 42.4˚ C. It was impossible to be inside the pit while the fire was burning. If the fire had been left alone it would have continued for quite a long time anaerobically, because of lack of air circulation. We let it burn for only about 30 minutes. The data loggers showed that it took ten hours before the temperature returned to ambient.

This is a useful finding because it shows that even very modest human intervention would materially affect the environment inside the pit. It would be useful, for example, to see what effect placing some hot stones inside the pit would have as an alternative to a fire. In any event, even the smallest smouldering fire would be all that would be needed to keep the temperature above the critical value. It is difficult to imagine how anyone could go away and leave a pit with kūmara in it for any length of time in this location. It would require vigilance (probably attention each day) to keep the crop through the winter.

DENSITY OF TUBERS IN THE PIT

Another useful aspect of this experiment was some practical experience of how many tubers one could store in a semi-subterranean pit. The interior dimensions of this pit were 2400 x 1800 x 1200 mm deep, that is 5.18 m^3. We did an experiment packing kūmara tubers in cartons and found that 57.8 percent by weight was taken up by voids. This compares with a figure of 29 percent reported for potatoes (Jones and Law 1987: 87). Therefore, if our storage pit was completely filled with tubers it would take 2,390 kg (assuming ρ=1.09, ibid.). We stored 23 baskets of kūmara, arranged so that they were easy to inspect for signs of rot[13]. The total weight was 13,200 g (average tuber was 41.25 g), so the proportion of the volume occupied by kūmara was 0.55 percent. Even if we stored 10 times the number of kūmara in the pit (230 baskets), this would still only represent 5.5 percent of the pit volume. In our opinion, it would be very difficult to store 230 baskets of kūmara in this pit and still have enough room to be able to get in and sort through them periodically for signs of rot.

This was an important object lesson to us, casting doubt on earlier estimates, cited above, that kūmara pits may have contained 30 to 50 percent by volume of kūmara (Jones and Law 1987: 87). It might be possible to do this in climatic conditions where it is unnecessary to inspect each kūmara for rot, and they can be piled up in the manner suggested in Figure 5 for potato clamps; however, in a climatic region where there is a strong possibility of rot during the period of storage, regular maintenance would demand space inside for a person to move and manipulate baskets. Moreover, we found that the small door did not permit anywhere near enough light for reliable inspection inside the pit. We also found torches inadequate and it was quicker and more reliable to pass each basket outside for inspection in sunlight. It would be pointless taking a flaming brush torch inside for illumination. In any event, the smoke would drive a person out very quickly with such poor ventilation.

THE IMPLICATIONS

Our experiment has shown that a pit store without regular human intervention near the southern limit of Māori horticulture would not be adequate to preserve a sufficient portion of the crop for the next season's planting, or as food for more than three or four months after harvest. Inadequate curing could have been a contributing factor in this experiment, but better curing is still unlikely to have ensured the survival of enough tubers for the next season's planting.

What could be done to improve the technology? The obvious answer is that the pit needs to be kept warmer. The use of indigenous materials would not improve insulation to the point where the temperature would seldom or never fall below the danger point.

Any future experiment should explore the possibilities of minimal elevation of temperature during the cold frosty mid-winter months. It may be that the occasional introduction of heated stones or smouldering timber would be sufficient to buffer the pit. We have noted above that reported examples of scoop hearths and fires on pit floors are not very common. We should point out, however, that our little fire on the ground left very little trace. This raises the possibility that archaeologists intent on identifying floors and locating postholes and drains may have failed to distinguish between the remains of fire on the floor and charcoal in the fill. It should also be noted that apart from a single example from Marlborough (Duff 1961: 284), all the fire features reported are from the northern half of the North Island, where such intervention would probably be less necessary than in Marlborough.

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[13]The original flax baskets were stored two deep (Fig. 11) but after the fire to destroy fungus, the new plastic trays were placed on the shelves in a single layer.

Where kūmara were stored on racks, there would be little problem in lighting a small fire on the pit floor. But even where tubers were stacked directly on plant material on the pit floor, it would be possible to clear an area for hot stones or a small fire if necessary.

We suspect that the three-weekly ventilation was inadequate, and that regular opening to prevent ethylene build-up is another necessary form of intervention during storage. Ranginui Walker's anecdote, cited above, shows that Māori during the historic period understood the importance of this. In a real life situation, also, people would be opening some stores, at least, at regular intervals to remove tubers to eat.

The tendency of 'Taputini' to rot during storage at the Open Polytechnic as well as in the pit suggests that it highly unlikely this variety could ever have been stored in heaps as Best and others described. It is necessary to inspect the store regularly and remove any tubers showing signs of rot. Partly rotten tubers could of course be eaten. We cannot see how it would be possible to inspect large piles or bins in near total darkness and remove rotting tubers from their lower levels. Baskets, such as Colenso described, seems more plausible. We had the benefit of a fluorescent light and torch in the pit for inspection and removal of suspect tubers. However, we found this task easier if the baskets were passed to someone outside and inspected in sunlight.

Storage in baskets and on racks would of course greatly reduce the volume that could theoretically be stored in the pit. Although we only stored 13.2 kg of tubers, it might be possible to increase this by five times—perhaps to 66 kg. The average total yield of our 25 m^2 garden over the past five years has been 24.1 kg, suggesting that a pit of the size of our experimental one would be able to store the total harvest from 68.5 m^2 of garden.

It is known that different modern varieties respond differently to the effects of cold. Any future experiments should include other Māori cultivars such as 'Rekamaroa' and 'Hutihuti'. It would be ironic indeed if Māori in the Cook Strait region were unable to continue with kūmara horticulture because the cultivar that grew best in this region did not keep well and the cultivars that stored well did not yield well.

DISCUSSION AND CONCLUSIONS

The main results of our experiment are as follows:

- In a roofed rectangular pit there is only a tiny increase in mean temperature compared with outside air temperature during the period of storage; but the pit dramatically buffers against rapid rises and falls of temperature outside.
- Constructing a small pit store is labour intensive, even using modern technology.
- Storing kūmara in pre-European times would have been far more difficult than growing it, at least at the southern margins of the region where kūmara horticulture was possible.
- At least in marginal regions, regular human intervention would have been essential during storage to keep the crop warm enough, ventilate it, and inspect it for rot.
- A 'hungry gap' during the summer months must have been a significant problem, even in the warmer north of New Zealand.

Understanding of kūmara storage would be increased by further experimental work in warmer regions of New Zealand (such as the Bay of Plenty, where so many pit excavations have been carried out), and with other cultivars such as 'Rekamaroa', 'Hutihuti' and nineteenth century introductions such as 'Waina'. As we have noted, storage systems may have varied according to region, cultivars and purpose (keep for seed, eat now, or eat in two months' time). Systems described ethnographically might well work for nineteenth century cultivars in warmer regions but would not work for 'Taputini' in Marlborough. Any further

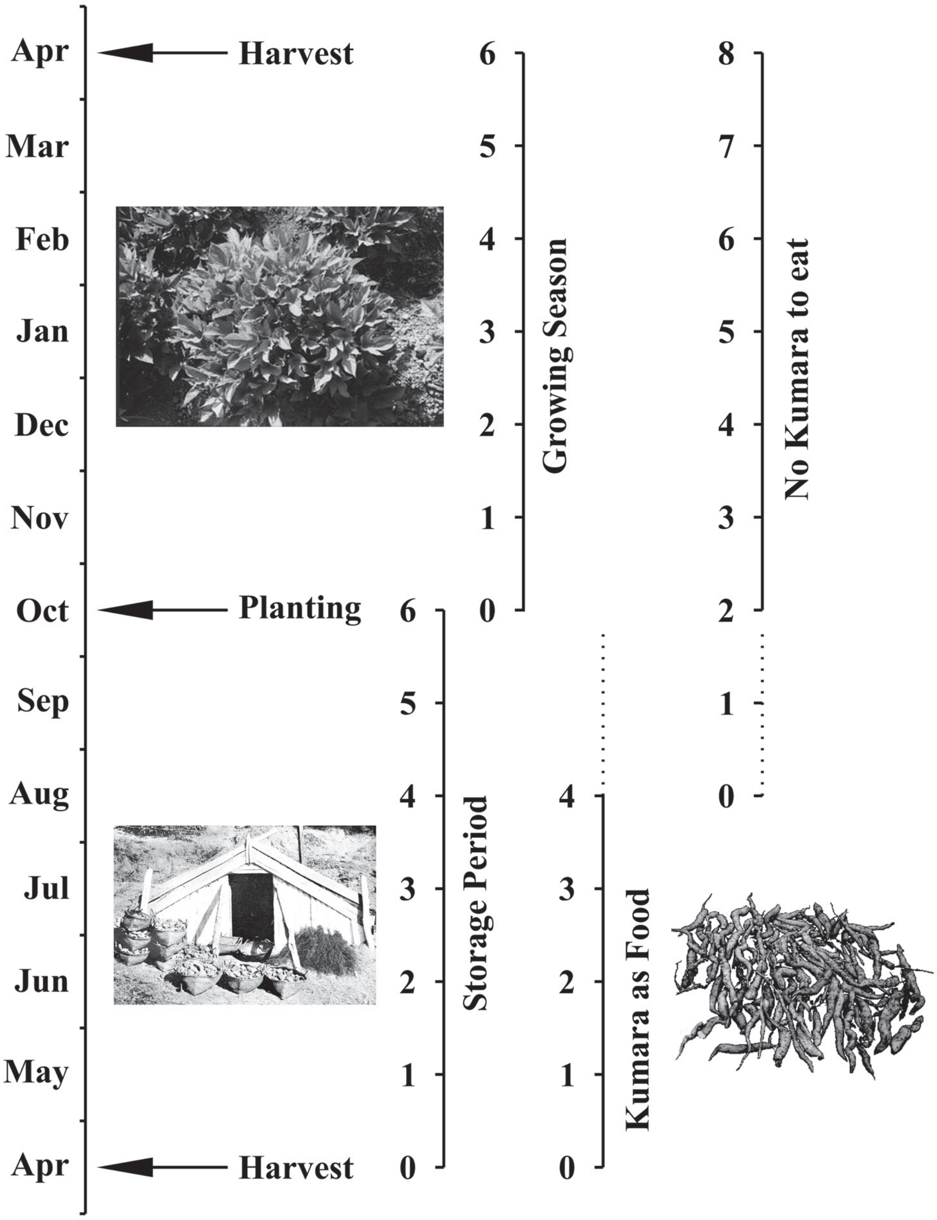

Figure 16: The place of kūmara in the Māori horticultural cycle. Note the long period when no tubers are available as food. See text.

work in the Cook Strait area should also include other cultivars, and involve carefully monitored interventions. Ideally, another storage season in Marlborough would begin with harvesting on a "perfectly dry sun-shiny day" (Colenso 1880: 12), and would have a system for identifying dangerously low temperatures so that artificial warming can be made. In addition, regular air-changes should be made.

An important result of the experiment is confirmation of the 'Hungry Gap' as it applies to kūmara. There can be little doubt that in Marlborough, kūmara was not available as food much beyond one third of the annual calendar (mid April to mid August). There would have been considerable difficulty keeping enough seed tubers over the remaining two months until planting (mid August to mid October). After that there would be no kūmara to eat until the next harvest, except perhaps for small quantities of kao, probably reserved for special occasions.

Was this also the case in climatically milder regions further north? In October 1769 Cook obtained "about 10 or 15 pounds" of kūmara at Anaura Bay and "now and then a few" at Tolaga Bay, but noted that they were scarce (Cook in Beaglehole 1968: 183, 186). These were trifling amounts. Banks, writing about Māori diet generally as Cook prepared to leave New Zealand, described fern root as "the foundation of all their meals, all summer at least from the time their roots[14] are planted till the season of digging them up" (Banks in Beaglehole 1963 II: 21). These early observations suggest that although the situation may have been less dire further north, there was little kūmara available by October. What was available may have been reserved for gifts and exchange rather than day to day consumption. Taken together with Walsh's (1902) comments about the difficulty of storing tubers until the next planting, and Wallace's (2000) recommendation that under modern practice in New Zealand tubers should keep for seven months, the early historical evidence suggests that the 'hungry gap' — i.e., a significant part of the year without kumara — was not confined to marginal regions.

This seasonal round is illustrated in Figure 16. The seasonal restriction of kūmara as food has been touched on by previous researchers, but does not appear to have been widely accepted by archaeologists. It is very evident to us, however, that economic models for northern Māori must start with the assumption that there was no stored kūmara to eat on a daily basis for nearly half the year, and perhaps for longer than this.

As we have shown, archaeological understanding is deficient about how kūmara were stored in pits, and how Māori actually met the challenge of keeping their seed tubers for long enough to maintain the supply for year after year. We hope that future pit excavations will pay more attention to the floor deposits and microscopic and biochemical residues that they may contain, in addition to the present focus on dimensions, post-holes, buttresses and drains.

ACKNOWLEDGEMENTS

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[14]such as kumara, taro, yam.

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