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Effect of low temperatures on the storage life of two Samoan breadfruit (*Artocarpus altilis*) cultivars

Seeseei Molimu-Samasoni[1], Veronica Vaaiva[1], Ron B. H. Wills[1, 2*]

1, *Scientific Research Organisation of Samoa, Apia, Samoa*
2, *School of Environmental and Life Sciences, University of Newcastle, Ourimbah NSW 2258, Australia*

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***Corresponding author:**
School of Environmental and Life Sciences, University of Newcastle, Ourimbah NSW 2258, Australia.
Email: ron.wills@newcastle.edu.au

ABSTRACT

Purpose: Breadfruit is a tropical climacteric fruit consumed as an unripe starchy vegetable hence export requires some postharvest technology to inhibit ripening during marketing. Research in the Caribbean found storage at 12 °C was optimal to delay ripening without fruit developing chilling injury. Breadfruit is a major horticultural commodity in Samoa with New Zealand a target export destination. This paper examines the ability of low temperatures to extend the storage life of unripe Samoan breadfruit and thus facilitate export. **Research method:** Puou and Maafala breadfruit were stored at temperatures from 12 to 25 °C and observed for time to ripen and to exhibit chilling injury symptoms as these factors determine storage life. **Main findings:** Time to ripen increased as the temperature was lowered but chilling injury occurred on all fruit stored at 12 and 15 °C and many stored at 17 °C. The longest storage life was attained at 17 °C with 11 days for Puou and 16 days for Maafala fruit with storage terminated by a mix of fruit ripening and developing chilling injury. **Limitations:** Questions remain as to the importance of mild chilling injury to influence purchase. **Originality/Value:** Samoan breadfruit is more chilling sensitive than Caribbean fruit and thus must be transported at higher temperatures than Caribbean fruit. Use of 17 °C gave the longest storage life for Samoan breadfruit which is sufficient for the 10 days required to export by air to New Zealand but is less than the 21 days required to export breadfruit by sea.

INTRODUCTION

Breadfruit (*Artocarpus altilis* (Park.) Fosb.) is a staple indigenous horticultural produce in various tropical Pacific island countries particularly in Samoa where over 80% of households cultivate breadfruit trees as an on-going food source. While harvested fruit in Samoa are mainly used for home consumption, there is substantial trading on local markets particularly in the main harvest period (Samoa MAFFM, 2002; McGregor & Stice, 2018). In addition, there has been national interest over many years to be able to export breadfruit particularly to New Zealand if only to supply the Samoan expatriate population which is about 150,000, a group which is not dissimilar to the total population in Samoa of about 200,000 (Worldometers, 2018).

Breadfruit was introduced into the Caribbean in the late 18th century and apart from local consumption it has some importance as an export crop to Europe and North America (Andrews, 1991). This led to much of the research on the postharvest physiology of breadfruit being conducted on breadfruit grown in the Caribbean. Breadfruit is a climacteric fruit but is consumed as a starchy vegetable at a mature but unripe stage of development. Under ambient tropical conditions of 25-30°C, breadfruit ripens in 3-4 days after harvest (Worrell et al., 1998) and hence some technology is needed to extend the storage life to allow an export trade of unripe breadfruit to be established. Storage at reduced temperatures is well known to delay ripening of many produce (Wills & Golding, 2016) and a range of studies with breadfruit have suggested that optimal delay in ripening occurs when the produce is stored at 12-13°C, which has been reported to be above the threshold temperature for development of chilling injury with the time to ripen being about 12-14 days (Thompson et al., 1974; Maharaj & Sankat, 1990; Worrell et al., 2002).

The export of Samoan breadfruit to New Zealand can be by air or by sea. Export by air has been executed in the past (McGregor & Stice, 2018) but was found to be costly and pallet loads of fruit often experienced delays due to the restricted cargo space on flights to New Zealand. To allow time to accumulate pallet loads of fruit, to cope with delays in consigning pallets onto aircraft, and to allow about three days market life in New Zealand, a total storage life when fruit remain unripe of up to 10 days is considered desirable. Export by sea is more cost effective but fruit must remain unripe during the 6-8 day voyage in addition to time required for the 12-15 days between voyages when container loads of fruit are accumulated plus time for retailing in New Zealand. To establish a reliable sea borne export trade, a storage life of up to 21 days from harvest to sale in New Zealand is required. As the first step in developing an appropriate storage technology for the export of Samoan-grown breadfruit, the effect of temperature on the storage life was assessed with Puou and Maafala breadfruit, two cultivars commonly grown in Samoa that have been identified as having export potential (Samoa MAFFM, 2002).

MATERIALS AND METHODS

Samoan breadfruit (cvs Puou and Maafala) (known as Uto Dina and Bale Kana, respectively, in Fiji) at the commercially harvested stage of maturity of dark green fruit with large fruit segments were picked in the early morning. In the initial trial, fruit for each cultivar were obtained from a farm at two sites (Tufulele and Aleisa villages). In the subsequent larger experiment fruit were obtained from three farms at both Luatuanuu and Tulaele villages on the northern coast of Upolu, Samoa. All fruit were harvested with attached stalks and transported in a single layer to the laboratory. The stalks were trimmed to 3-5 cm length, and latex was allowed to drip from the fruits. For the initial experiment, 20 mature, unripe fruit per cultivar (each weighing between 700-900 g for Maafala, and 800-1000 g for Puou) were harvested from each farm and randomly distributed into two groups of 10 fruit. One group was placed in 13°C, while the other group was held at 25°C. For the subsequent experiment, harvest from each farm comprised 40 mature, unripe fruit that were randomly distributed into four groups of 10 fruit which comprised a treatment unit. In both trials, fruit from each unit were packed into a fibreboard carton inside an unsealed sheet of polyethylene film to minimise weight loss and held in chambers held at a range of constant temperatures. The 10 fruit in each unit were individually assessed daily for firmness and chilling injury. A fruit was considered to have reached the end of its storage life when the fruit was ripe as determined by finger pressure indicating fruit had a spongy texture, that is, there was a reversible compression of the fruit surface (Worrell et al., 1998), a technique that was shown by Maharaj and Sankat (1990) and Worrell et al. (2002) to be correlated with objective penetrometer assessment; or the fruit surface exhibited the level of chilling injury symptoms shown in Figure 1. The mean storage life a unit was calculated by averaging the time to ripen or develop chilling injury (whichever occurred first) of each fruit in a unit. Analysis of variance was conducted on the data from each experiment and where there were significant differences due to temperature or cultivar, the least significant difference between means at $P \leq 0.05$ was calculated from the variance in the ANOVA.

RESULTS AND DISCUSSION

The initial experiment compared the storage life of breadfruit held at an ambient tropical temperature of 25°C and the recommended low temperature of 13°C for Caribbean-grown breadfruit (Worrell et al., 2002). Analysis of variance generated a significant difference in the storage life between temperatures ($P<0.001$) and cultivars ($P<0.01$), but there was no significant interaction between cultivar and temperature. Table 1 shows that for each cultivar the mean storage life at 25°C was significantly greater than at 13°C with the limiting factor at 25°C being fruit ripening and at 13°C was development of chilling injury. Thus Samoan-grown breadfruit has a much higher threshold temperature to chilling than Caribbean-grown breadfruit. It is not possible to speculate on the difference in chilling sensitivity between Samoan, and by implication, South Pacific breadfruit, and Caribbean breadfruit and could be due to climatic or genetic differences. The possibility of genetic differences was indicated by Puou breadfruit having a shorter storage life than Maafala fruit at both temperatures.

The subsequent experiment then examined the storage life of Puou and Maafala fruit stored at a range of temperatures from 25 to 15°C. Analysis of variance revealed a significant effect of storage temperature ($P<0.001$) and cultivar ($P<0.001$) on storage life but no significant interaction between cultivar and temperature. Table 2 shows that for both cultivars the shortest storage life occurred at 25°C and was due to breadfruit ripening. Storage at 20°C resulted in a longer storage life due to a further delay in ripening. The longest storage life was achieved at 17°C where there was a further delay in ripening but acceptability was offset by the development of chilling injury on many fruit. However, fruit stored at 15°C had a shorter storage life than at 17°C with all fruit developing chilling injury. As in the previous study the storage life of Maafala breadfruit was greater than that of Puou with the greatest effect occurring at 17°C where there was about a five day or 40% longer storage life for Maafala.

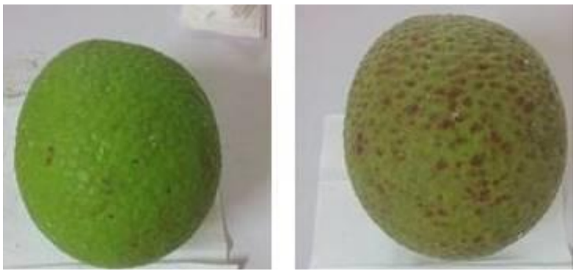

Fig. 1. Breadfruit freshly harvested (left) and showing chilling injury (right)

Table 1. Storage life of Puou and Maafala breadfruit based on time to ripen (assessed as firmness) or chilling injury (CI)

Temperature	Storage life (days)		Limiting
(°C)	Puou	Maafala	factor
25	6.4^{b}	9.0^{b}	Ripening
13	4.0^{a}	4.9^{a}	CI

Values for each cultivar and temperature are the mean of 20 fruit (10 fruit x 2 farms). Mean values for each cultivar with different letters are significantly different at P=0.05.

Table 2. Storage life of Puou and Maafala breadfruit based on time to ripen (assessed as firmness) or chilling injury (CI)

Temp	Storage life (days)		Limiting factor	
(°C)	Puou	Maafala	(% Ripe)	(% CI)
25	5.2^{a}	5.5^{a}	100	0
20	9.1^{b}	9.6^{b}	100	0
17	11.0^{c}	15.8^{d}	24	76
15	9.0^{b}	13.1^{c}	0	100

Values for each cultivar and temperature are the mean of 60 fruit (10 fruit x 3 farms x 2 villages). Mean values for each cultivar with different letters are significantly different at P=0.05.

It should be noted that much of the breadfruit marketed in Samoa has various forms of skin damage that are incurred during growth, in postharvest handling and from latex staining. Thus, there is acceptance in the market to purchase breadfruit with some surface browning. While it might be expected that non-Polynesians in New Zealand and other developed countries would not be inclined to accept breadfruit with surface defects, the tolerance for browning due to chilling injury symptoms has not been evaluated for the Polynesian population in the target export market of New Zealand. To this end, a photograph of freshly harvested Samoan breadfruit and one with chilling injury (see Fig. 1) was circulated in an on-line survey conducted on social media asking Samoans living in New Zealand and Australia which fruit they considered acceptable for purchase. There were 41 respondents, and it was somewhat surprising that breadfruit with chilling injury was acceptable for purchase by 98% of respondents compared to 88% acceptance of the unmarked green breadfruit. While such findings need to be evaluated with real fruit, it does indicate a certain tolerance, and possibly a preference, for chilling injury affected fruit. In the main trial in this paper, all fruit at 17°C with chilling injury symptoms did eventually ripen. If chilling injury was ignored, the time to ripen was about 16 days for Puou and 18 days for Maafala fruit. The greatest increase occurred with Puou breadfruit as this cultivar was more susceptible to chilling injury than Maafala.

Thus, Maafala and Puou breadfruit stored at 17°C both have a storage life greater than 10 days regardless of whether storage was terminated by ripening or chilling injury. This provides the required postharvest period for export by air to cope with any expected time delay between harvest and arrival at the export destination. The storage life is, however, much lower than the required 21 days for a reliable sea-based export industry. If chilling injury is considered to not be a major marketing issue, at least for the Polynesian diaspora, the extended storage life of 16-18 days would still require the application of some additional technology to be able to market consistently good quality breadfruit. Obvious technologies for evaluation would be the application of modified atmospheres which has been found to give some extension in storage life of Caribbean breadfruit (Maharaj & Sankat, 1990) and/or reduction of atmospheric ethylene which is known to inhibit ripening of many climacteric fruits (Wills et al., 2001). In addition, it is recognized that other factors such as seasonal variability in quality and the need to comply with quarantine requirements need to be evaluated and could impose greater requirements on a storage regime.

CONCLUSIONS

Breadfruit grown in Samoa is much more susceptible to chilling injury than fruit grown in the Caribbean where chilling injury is not observed at 12°C. The longest storage life was attained at 17°C (11 days for Puou and 16 days for Maafala fruit) with chilling injury terminating the storage life of more fruit than ripening. This storage period is adequate for the export of breadfruit from Samoa to New Zealand by air. If chilling injury was able to be ignored, the time to ripen was about 16 days for Puou and 18 days for Maafala fruit. This storage period is less than the targeted 21 days; to allow the reliable shipment of fruit by sea and hence some additional technology is required to either prevent chilling injury development and/or further delay ripening at 17°C. Maafala breadfruit would seem to offer the better export opportunity due to it having a longer storage life than Puou.

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Conflict of Interest
The authors have no conflict of interest to report.

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