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# Yield and water use efficiency in buttercup squash (*Cucurbita maxima* Duchesne) and heritage pumpkin (*Cucurbita pepo* Linn)

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**Abstract**

There is scarce information on agronomic performance, which would support a resurgence of interest in the heritage pumpkin, Kamokamo, relative to exported Buttercup squash in New Zealand. Furthermore, pumpkin squash fruit yield and fruit sizes fluctuate with seasonal climate variability. A split-plot design field experiment was conducted, in order to compare their yield, water use efficiency and fruit size distribution under irrigation and rain-fed conditions. Rain-fed and irrigation were the main plots: replicated four times. The cultivars were subplots, planted at 2.2 plants $m^{-2}$ that received 700 kg $ha^{-1}$ Nitrophoska Blue TE at planting, followed by 66 kgN $ha^{-1}$ of Urea. Pumpkin fruit yield and yield components, water use efficiency and total biomass data was subjected to ANOVA, by using the PROC GLM procedure in SAS. Soil moisture content (%) was affected by cultivar ($p<0.0001$) and irrigation ($p<0.0001$). Fruit yield, total biomass and water use efficiency differed significantly amongst cultivars ($p<0.0001$). Kamokamo shows the highest fruit yield, total biomass and water use efficiency. Irrigation had no effect on its fruit yields ($p>0.05$) but it did affect its fruit size distribution ($p<0.05$) and water use efficiency ($p<0.01$). The results indicate that irrigation can modify standard marketable fruit sizes and that Kamokamo has a high yield and water use efficiency potential, compared to Buttercup squash.

**Keywords**: Irrigation, water use efficiency, fruit size distribution, Buttercup squash, Kamokamo.
**Abbreviations:** Analysis of Variance (ANOVA), General linear model procedure (PROC GLM), Statistical Analysis System (SAS), Water Use Efficiency (WUE).

## Introduction

Kamokamo (*Cucurbita pepo* Linn) is a heritage pumpkin cultivar originating from the Maori people in New Zealand (McFarlane, 2007). Generally, it sells in a niche market, in contrast to Buttercup squash (*Cucurbita maxima* Duchesne), which is an important commodity crop exported to Japan and Korea (Hume, 1982; Perry et al., 1997). However, there has been a resurgence of interest in Kamokamo, due to its cultural value and delicious flavour, in addition to its adaptability as a summer and winter squash. Currently, market access has facilitated an improvement in Buttercup squash production within New Zealand (Grant et al., 1989), Tasmania and Korea, whilst Japan recorded a yield decrease (Morgan et al., 2003). On the other hand, the industry experiences fruit yield and fruit size fluctuations between seasons, due to the crop's sensitivity to seasonal climate variability (Perry, et al., 1997). Pumpkin yield and standard fruit size are strongly influenced by water availability and also by genotypic variability (Al-Omran et al., 2005; Ertek et al., 2004). New Zealand farmers need to be able to manage pumpkin squash fruit quality and water conservation, due to a projected water scarcity (IWMI, 2000). Prudent use of water resources (Hoekstra et al., 2007) and the right pumpkin cultivars will help growers to meet yield and quality for market demands and this will maximise returns (Searle et al., 2003) within adverse climate variability (Perry, et al., 1997). However, there is scarce scientific information on the agronomic performance of pumpkin squash under different water environments in New Zealand. This field experiment was conducted, in order to measure fruit yield, water use efficiency and fruit size distribution in Buttercup squash, compared to the heritage cultivar, Kamokamo, under irrigation and rain-fed conditions.

## Materials and methods

### *Location*

The field experiment was conducted at Massey University's Pasture and Crop Research Unit, Palmerston North. This site is located at a latitude of $40^o$ 22. 54.02 S, longitude $175^o$ 36' 22.80 E, and an altitude of 36 m above sea-level. The soil type is Manawatu sandy loam, pH is 5.4, Olsten P was 36 mg/L, K was 0.22 me/100g with 106 kg $ha^{-1}$ of available N, at the beginning of the experiment.

### *Experimental layout and crop management*

The experiment consisted of two New Zealand pumpkin squash cultivars, Ebisu (Buttercup squash) and Kamokamo (pumpkin), which were laid out as a split-plot, with rain-fed and irrigation regimes as the main plots: replicated four times. The two crop cultivars were subplots. Seeds were manually sown on 9th December, 2009, at a spacing of 75 cm between rows and 60 cm spacing within rows, with one plant per station (2.2 plants $m^{-2}$). Each plot was 4.5 m by 6 m.

### *Fertiliser application and plant protection*

The pumpkin squash received 12N:5.2P:14K:6s+2mg+5ca, using 700 kg $ha^{-1}$ Nitrophoska Blue TE at planting, followed by 66 kgN $ha^{-1}$, as a side dressing, on 19th January 2010, when the vines started running.

**Table 1.** Growth and yield components characteristics for Buttercup squash and Kamokamo

| Water regime Cultivars | DF (50%) | LAI | Vine Length (m) | Fruits per plant | Average Fruit Weight (kg) | SLA ($cm^2 g^{-1}$) |
|---|---|---|---|---|---|---|
| Irrigation | | | | | | |
| Buttercup | 41.0 | 2.21 | 5.47 | 1.21 | 2.06 | 144.48 |
| Kamokamo | 55.8 | 3.63 | 7.17 | 1.51 | 2.43 | 147.21 |
| Mean(n=8) | 49.6 | 2.92 | 6.32 | 1.36 | 2.24 | 145.84 |
| Rain-fed | | | | | | |
| Buttercup | 43.3 | 2.30 | 5.60 | 1.06 | 2.02 | 147.94 |
| Kamokamo | 56.0 | 4.14 | 6.63 | 1.16 | 2.73 | 150.86 |
| Mean(n=8) | 49.4 | 3.22 | 6.12 | 1.11 | 2.37 | 149.40 |
| CV% | 6.73 | 33.4 | 9.86 | 27.66 | 24.54 | 10.37 |
| Significance | | | | | | |
| Cultivar | **** | **** | ** | NS | * | NS |
| Water | NS | NS | NS | NS | NS | NS |
| $LSD_{0.05}$ | 3.73 | 0.51 | 0.69 | 0.39 | 0.64 | 7.69 |

**Note** : **** , ***, **, * and NS refers to statistical significance at p<0.0001, p<0.001, p<0.01; p<0.05 and p>0.05. DF (50%) is days to 50% flowering and LAI refers to leaf area index

Weeds were initially managed by herbicides and the secondary weeds were manually uprooted using hoes. Bravo and Metafort 60SL were sprayed in a mixture at 800 ml $ha^{-1}$, in 500-1000 litres of water per hectare, every 14-21 days, in order to control fungal diseases: powderly mildew (*Erysiphe cichoracearum*, Jaczewski) and bacterial diseases (Wikipedia:verifiability).

***Irrigation and crop water use measurement***

A boom traveller irrigator was used for irrigation. Irrigation application was based on replenishing the critical soil's moisture deficit in irrigation treatment. The crop water use ($ET_c$) was determined by a soil water balance approach as:

$$ETc = (P + I) \pm \Delta S - Dr - Ro \quad \text{(Equation 1.1)}$$

Where P was the rainfall; I was the irrigation applied to the individual plots; ΔS was the depth of water taken from the soil storage; Dr was drainage; and Ro was runoff (Fandika et al., 2007; Allen, et al., 1998). The daily weather data from NIWA/AgriResearch, Palmerston North were used to run the soil water balance model. Soil moisture change (ΔS) was monitored with a Time-Domain Reflectometer (TDR) before and 24 hours after irrigation, within 30 cm soil profile with an available soil water holding capacity of 100 mm $m^{-1}$. The FAO Penman-Monteith Equation (Allen et al., 1998) was used, in order to estimate reference evapotranspiration (ETo), as detailed below:

$$ET_0 = \frac{0.408 \cdot \Delta \cdot (R_n - G) + \gamma \cdot \left(\frac{900}{T + 273}\right) u_2 \cdot (e_s - e_a)}{\Delta + \gamma \cdot (1 + 0.34 \cdot u_2)} \quad \text{( Equation 1.2)}$$

where $\Delta$ = slope of the vapor pressure curve, $R_n$ = net radiation, G= soil heat flux density, $\gamma$ = psychrometric constant, T = mean daily air temperature at 2 m height, $u_2$ = wind speed at 2 m height, $e_s$ is the saturated vapor pressure and $e_a$ is the actual vapor pressure. Equation 4 applies specifically to a hypothetical reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 sec/m and an albedo of 0.23.

***Crop physiological measurements***

Leaf area was measured using a leaf area metre on three leaf samples of different sizes, at every crop stage after plant emergence. The leaf samples were then oven dried to constant weight at 70C$^o$ for 48 hrs. Specific leaf area (SLA) was calculated as SLA ($cm^2g^{-1}$) = leaf area (cm)/weight of leaf samples (g). The specific leaf area ($cm^2g^{-1}$) was determined, as a measure of leaf thickness (Amanullah et al., 2007; Vile et al., 2005).

***Fruit size distribution, fruit yield, total biomass and harvest index***

At harvest (29th March and 31st March 2010), fruit yield (kg), number of fruit, individual fruit weight, total fruit yield and total biomass were measured. Harvest index was calculated as the ratio of total biomass. The pumpkin squash fruit was graded into marketable and non-marketable grades (NM): marketable fruit was that above 1 kg, without any damage and non-marketable were <1kg and those with damage. Marketable fruits were further graded as S (1-1.2kg), M (1.2-1.4 kg), L (1.4-2.5 kg) and XL (>0.2.5kg), where S is small, M is medium, L is large and XL is extra large, according to export quality grades in New Zealand. A percentage of fruit size distribution graph was developed, based on fruit weight, in order to determine the effect of irrigation on fruit size distribution.

***Water Use efficiency (WUE) and Statistical Analysis***

WUE, defined as fresh matter production per unit water used as rainfall, plus irrigation, plus change in soil moisture content (Mostafazadeh-Fard et al., 2010; Sinclair et al., 1984). Data on soil moisture, growth, fruit size distribution, fruit yield, yield components and WUE were analysed with the General Linear Model (GLM) procedure of the Statistical Analysis System (SAS, 1990) and differences amongst treatment means were compared by the Least Significant Difference test (LSD) at 5% probability (Meier, 2006).

**Results**

***Weather characteristics and soil moisture content***

The growing season for the pumpkin squash was from 9th December, 2009 to 30th March, 2010 (110 days), which is equivalent to four months. The seasonal crop water requirement for the pumpkin squash was estimated at 442.12 mm. Precipitation managed to supply 232.80 mm, which was 53% of the estimated total water requirement.

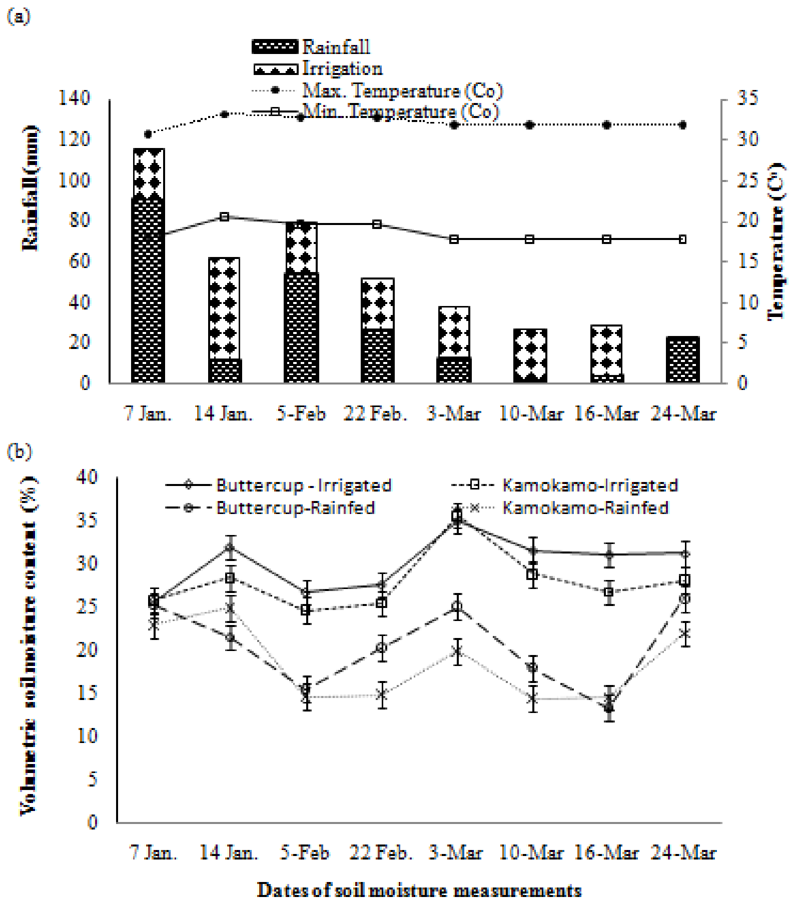


**Fig 1a-b:** Soil moisture measurements in correspondence to periodical precipitation (mm), irrigation (mm) and temperature (C°)

Irrigation added 175 mm, which met at least 100% of the crop water requirement within the irrigated treatment. The rain-fed Buttercup and Kamokamo used 255.1 and 260.4 mm, whilst the supplementary irrigated crops used 407.6 mm and 413.2 mm, respectively. Irrigation was a requirement in January, February and March when precipitation was not well distributed (Fig.1a). Volumetric soil moisture content (%) differed with water regime, crop cultivar and between measurement dates ($p<0.0001$, $p<0.05$, $p<0.0001$), respectively. Soil moisture in rain-fed treatments ranged between 15-25%, whilst irrigated treatments ranged between 20-35%, except in February when soil moisture was depleted to less than 20%. Kamokamo extracted more water than Buttercup squash within both water regimes. The results show that, in February, irrigation and rainfall could not completely compensate crop evapotranspiration and hence more water was extracted from the soil, even under irrigated conditions (Fig. 1b).

***Pumpkin squash growth and yield components characteristics***

With and without irrigation, cultivars differed in leaf area index at all four different sampling stages ($p<0.0001$). Kamokamo had a higher leaf area, LAI and SLA, compared to Buttercup squash (Fig.2 and Table 1). The leaf area increased from day 21 to day 80 (from emergence). Buttercup flowered earlier than Kamokamo ($p<0.0001$), regardless of the water regime ($p>0.05$). Kamokamo had longer vines than the Buttercup squash ($p<0.01$), which also contributed to a larger leaf area. The number of fruit per plant were insignificantly high under the irrigation regime, with the highest being seen in the Kamokamo ($p>0.05$). The mean fruit weights were significantly higher in Kamokamo under a rain-fed regime ($p<0.05$), but it was not different within the irrigated treatments. The mean fruit size had more influence on yield, compared to the number of fruit (Table 1). It can be speculated that more flowers for the Kamokamo were sustained under irrigation, than under the rain-fed conditions. The fewer flowers maintained under rain-fed conditions grew into larger fruit than those whose fruit was maintained in irrigated conditions (Plate 1).

***Pumpkin squash fruit size distribution***

The fruit size distribution for large marketable fruits (L=1.4 – 2.5 kg) was significantly higher to other fruit size ranges ($p<0.05$). The irrigated treatments had a higher % of fruit within this fruit size range (L=1.4 – 2.5 kg), with the highest

**Table 2.** Fruit yield and total biomass yield components in Buttercup squash and Kamokamo.

| Water regime/ Cultivar | Vines+ Leaves Plant$^{-1}$ (kg) | Vines+ Leaves Plant$^{-1}$ (t ha$^{-1}$) | Marketable Fruit Yield (t ha$^{-1}$) | Total Fruit Yield (t ha$^{-1}$) | Total Biomass (t ha$^{-1}$) | Harvest Index (HI) |
|---|---|---|---|---|---|---|
| Irrigation | | | | | | |
| Buttercup | 1.9 | 43.0 | 54.3 | 54.7 | 97.7 | 0.56 |
| Kamokamo | 3.2 | 71.1 | 72.8 | 78.0 | 149.1 | 0.52 |
| Mean (n=8) | 2.6 | 57.1 | 63.6 | 66.3 | 123.4 | 0.54 |
| Rain-fed | | | | | | |
| Buttercup | 1.9 | 42.2 | 46.9 | 47.4 | 89.6 | 0.54 |
| Kamokamo | 3.4 | 75.0 | 65.4 | 67.7 | 142.7 | 0.47 |
| Mean (n=8) | 2.6 | 58.6 | 55.9 | 57.6 | 116.1 | 0.50 |
| CV (%) | | 16.2 | 16.2 | 26.1 | 24.4 | 16.9 |
| Cultivar | **** | **** | NS | * | *** | NS |
| Water reg. | NS | NS | NS | NS | NS | NS |
| $LSD_{0.05}$ | 0.48 | 10.6 | 18.7 | 17.1 | 22.9 | 0.1 |

Note: ****, ***, **, * and NS refers to statistical significance at p<0.0001, p<0.001, p<0.01; p<0.05 and p>0.05.

**Table 3.** Water use efficiency on yield and biomass basis for Buttercup squash and Kamokamo.

| Water regime | Cultivar | Total Water applied (m$^3$ ha$^{-1}$) | CWU (m$^3$ ha$^{-1}$) | $WUE_{fy}$ (kg ha$^{-1}$ m$^{-3}$) | $WUE_{v+l}$ (kg ha$^{-1}$ m$^{-3}$) | $WUE_{tb}$ (kg ha$^{-1}$ m$^{-3}$) |
|---|---|---|---|---|---|---|
| Irrigation | | | | | | |
| | Buttercup | 4078.9 | 4075.8 | 13.42 | 10.54 | 23.96 |
| | Kamokamo | 4078.9 | 4132.0 | 18.87 | 17.21 | 36.08 |
| | Mean (n=8) | 4078.9 | 4103.9 | 16.15 | 13.88 | 30.02 |
| Rain-fed | | | | | | |
| | Buttercup | 2328.0 | 2551.1 | 18.58 | 16.54 | 35.13 |
| | Kamokamo | 2328.0 | 2603.8 | 25.99 | 28.81 | 54.81 |
| | Mean (n=8) | 2328.0 | 2577.5 | 22.29 | 22.68 | 44.97 |
| Sign. | Cultivar | | | p<0.05 | p<0.001 | p<0.05 |
| | Water regime | | | p<0.05 | p<0.001 | p<0.01 |
| CV (%) | | | | 25.17 | 20.2 | 20.15 |
| $LSD_{0.05}$ | Cultivar | | | 7.74 | 5.91 | 12.09 |
| | Water regime | | | 5.47 | 4.17 | 8.54 |

Note: CWU is crop water use per ha, $WUE_{fy}$ refers to crop wáter use efficiency on yield basis; $WUE_{v+l}$ refers to crop wáter use efficiency on fresh vines and leaves basis; $WUE_{tb}$ refers to crop water use efficiency on total biomass basis; ****, ***, **, *; and NS refers to statistical significance at p<0.0001, p<0.001, p<0.01, p<0.05 and p>0.05.

being seen in the irrigated Buttercup squash, Ebisu (82.9%). Kamokamo had more extra large fruit and small non-marketable fruits than Buttercup squash, especially under rain-fed conditions. The fruit size distribution shows that irrigation facilitated the development of standard marketable fruit sizes, compared to those in rain-fed conditions (Fig. 3 & Plate 1).

***Pumpkin squash fruit yield and biomass production***

With or without irrigation, the amount of vines plus leaves per plant and per hectare, total fruit yield and total biomass production, varied in Buttercup squash and Kamokamo, respectively (P<0.0001, P<0.0001, P<0.05, P<0.001) (Table 2). Marketable fruit yield and harvest index (HI) did not differ between the two (p>0.05) and their water regimes (p>0.05). Kamokamo prevailed over Buttercup squash in all the above traits, except in HI. The average amount of vines plus leaves per plant and the average fruit weight contributed greatly to a high total biomass production within the Kamokamo (p<0.0001). Despite this fact, the insignificant effects of the water regimes on the fruit yield and total biomass production traits and the minor levels of water stress effects could be traced through the reduction of HI and fruit yield under the rain-fed conditions (Table 2). Most of the non-marketable fruits were based on immaturity and low weight (<1 kg) other than physiological water stress impairment.

***Water use efficiency (kg ha m$^{-3}$)***

WUE on the vines plus leaves production, fruit yield and total biomass (based on total actual water used) was affected by both the water regime and the crop cultivars (p<.05, p<0.001, <0.01) (Table 3). The WUE on fruit yield basis was higher than WUE on a vine plus leaves basis (under irrigation) both in Buttercup squash and Kamokamo, whilst under the rain-fed conditions this was only true with Buttercup squash, whilst Kamokamo had a higher WUE on vine plus leaves. The results indicate that although Kamokamo may maximise water use, water stress may affect its fruit yield, which is also expressed by a HI decline under the rain-fed conditions (Table 2 & Table 3).

**Discussion**

Pumpkin squash fruit yield increases with increasing water application and declines when water is in excess or limited (Al-Omran et al., 2005). In this study, irrigation resulted in no response to yield components (p>0.05) or cultivar (p<0.0001),

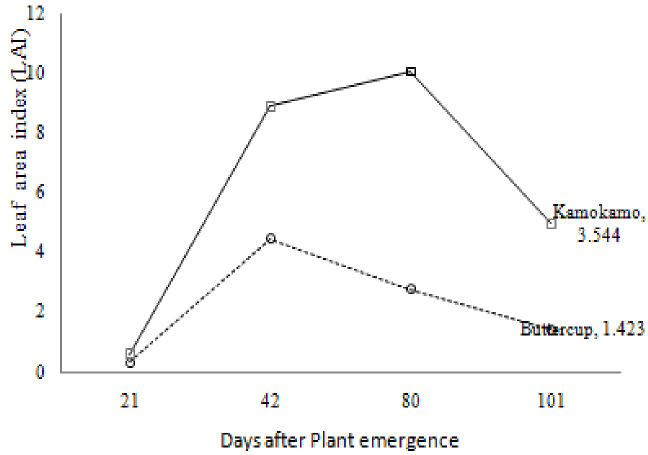


**Fig 2.** Change of leaf area index (LAI) in Buttercup squash and Kamokamo during the growing season

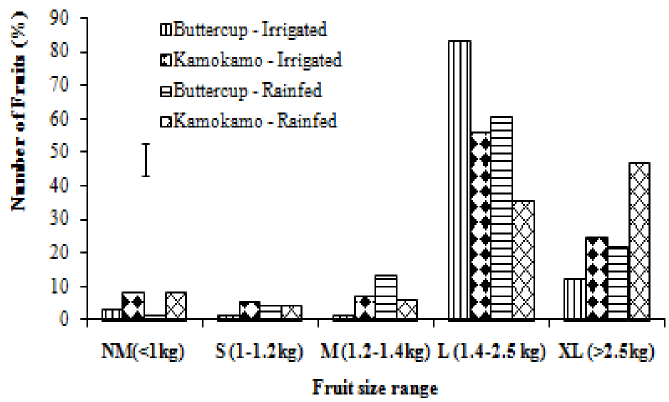


**Fig 3.** Number of size distribution (%) for irrigated and rain-fed Buttercup squash and Kamokamo – NM is non-marketable, S is small, M is medium, L is large and XL is extra large marketable fruit sizes. Error Bar represents $LSD_{0.05}$


**Plate 1.** Fruit size outlook for irrigated and rain- fed buttercup squash and kamokamo.

indicating that water was not a limitation, possibly due to the optimal weather experienced during the season (Fig. 1). Irrigation (estimated by water balance) doubled the rainfall supply and that might have supplied an excess, which spatially reduced the fruit yield. However, irrigation influenced the standard fruit size for the export market, both in Buttercup squash and Kamokamo (Fig. 3). The results on standard fruit size indicate that, although irrigation may not be of significant importance for total fruit yield in a good year, it facilitates quality control for marketable fruit sizes, compared to rain-fed conditions (Fig. 3 & Plate 1). In this case, irrigation plays an important role in the reduction of pumpkin squash fruit variability. However, irrigation, in order to manipulate fruit size, needs to be well modelled, as previously done with plant densities (Lima, et al.,, 2003; Searle, et al., 2003). Total yields and marketable yields were slightly above what most growers obtain in New Zealand (Buwalda et al., 1987), Tasmania, Australia (Morgan et al., 2003) and other parts of the world. As also reported by Morgan (2003), the cultivar had more influence on the pumpkin squash yield, when the environment was not limiting. In this case, the results indicate that Kamokamo has a high yield and water use efficiency potential, compared to Buttercup squash, Ebisu. It was also observed that the high yield in Kamokamo was contributed to by its ability to extract more water, its large leaf area index, specific leaf area and larger fruit size (Table 1 and Fig. 2). This contradicts St. Rolbiecki, (2000), who found that *Cucurbita maxima* cultivars showed high production efficiency, compared to the *Cucurbita pepo* species of pumpkin squash (St. Rolbiecki et al., 2000). WUE on total yield and total biomass basis vary with crop types, management system, year or location, and also with different parts of the harvested material crops (Nielsen, et.al., 2006). In this study, Kamokamo (18.87 – 25.99 kg $ha^{-1}$ $m^{-3}$) had a higher $WUE_{fy}$ than Buttercup (13.42 – 18.58 kg $ha^{-1}$ $m^{-3}$). Irrigation management decreased WUE, as also reported in potato (Battilani, et.al., 2004). Nevertheless, the value for $WUE_{fy}$ and $WUE_{tb}$ in Kamokamo (up to 25.99 and 54.81 kg ha $m^{-3}$) and Buttercup (up to 18.58 and 35.13 kg ha $m^{-3}$) were above those reported amongst the world's major crops (wheat, rice, maize, oats, potato, grain legumes and forage grasses) (FAO, 2009; Siddique, et.al., 2001). Unlike cereals and grain legume crops, which have a higher WUE on their forage part than their grain part (Nielsen, et al., 2006), pumpkin squash had a higher WUE in its fruit part than its forage part and it was above forage crops, which are considered to have a higher WUE than grain crops (Nielsen, et al., 2006). These findings project that pumpkin squash has a high ability to transform water into more carbon than most of the world's major crops, including forage grasses. In this study the old cultivar, Kamokamo, had more shoot biomass, fruit yield and WUE but it had low HI, compared to the modern cultivar, Buttercup squash. The high forage and low HI supports Siddique, et al. (1990), who reported that modern crops have enhanced HI whilst old cultivars have more forage. Conversely, the inconsistency is that improvement of HI in Buttercup squash has not increased WUE above Kamokamo, as reported in grain crops, where WUE improved with the enhancement of HI in modern crops (Siddique, et al., 1990). Above all, fresh biomass is very essential in determining production in cucurbit species, rather than HI (Loy, 2004). This indicates that Kamokamo, a heritage cultivar, has more potential for yield and WUE traits, than the modern Buttercup cultivar and this potential needs to be fully exploited in the future, within the pumpkin squash industry.

## Conclusion

The results indicate that irrigation application improves the development of standard marketable fruit sizes in pumpkin squash. It was also observed that total fruit yield and total biomass yield differences were due to cultivar differences, rather than irrigation. Increased water supply decreased WUE. The cultivars with the highest WUE were those with high yield potential. Total fruit yields, total biomass and WUE components, were highest in Kamokamo and this was a result of a high mean fruit weight, leaf area and water extraction, respectively. On the other hand, both Kamokamo and Buttercup squash outweighed the WUE observed in major world crops. Pumpkin squash, it can be suggested, is a crop with high water productivity traits.

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