



## Specific Gravity and Tuber Dry Matter Characteristics of Taewa and Modern Potatoes in Response to Irrigation and Nitrogen

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### Abstract

Taewa has never been assessed tuber quality at varied N and irrigation. This study compared specific gravity (SG), tuber dry matter (tDM) and total sugar of Taewa and modern potato cultivars grown at different water and N regimes under glasshouse and field conditions at Massey University, Palmerston North. The glasshouse was 2\*2\*4 factorial design with two irrigation: 100% ET and 60% ET; two applied nitrogen: 50 kg N/ha and 200 kg N/ha as urea, two Taewa (Moe Moe, Tutaekuri) and two modern potato cultivars (Moonlight, Agria). The 2009/2010 field experiment was a split-plot, with irrigation and rain-fed regimes as the main treatments: four potato cultivars above were sub-treatments. The 2010/2011 field experiment was a split-split-plot, with three water regimes as the main treatments: three cultivars except moonlight were subplots; two N rates were sub-sub-treatments. Specific gravity was determined on ten thoroughly washed potato samples from each treatment by weighing the tuber in air and in water, using Mettler PJ3600 Delta Range scale. Specific gravity was calculated by dividing weight of tuber in Air by the difference between weight of tuber in air and weight tuber in water. The tDM was determined, by oven drying chopped potato at 70 °C, until the change in tuber dry matter was constant. The tDM was calculated, by dividing the final dry weight by the initial fresh weight and then multiplying it by 100%. Total sugars were determined from ground potato samples of 0.5g, taken from the outer equatorial portion of each tuber, excluding the skin at Massey Nutrition laboratory. The results revealed significant variations in tuber quality between Taewa and modern potato cultivars regardless of water and N regimes. Taewa had high SG ( $p < 0.05$ ,  $p < 0.01$ ,  $p < 0.0001$ ), tDM ( $p < 0.05$ ,  $p < 0.0001$ ,  $p < 0.0001$ ) and low total sugar content ( $p < 0.0001$ ,  $p < 0.05$ ), proving an exceptional processing quality, compared to modern potato cultivars. It was concluded that Taewa produces more suitable quality for high processing cost recovery and processing colour quality in crisps than modern potato. Therefore, Taewa can provide potential genetic resources for improvement in the processing quality of modern potato within the Asia and Pacific region.

**Keywords:** Specific gravity, tuber dry matter content, total sugars, nitrogen, irrigation, Taewa and modern potato.

### Introduction

Potato tuber quality is assessed based on tuber dry matter (tDM); specific gravity (SG); reduced sugar content; nutritional value; and external tuber shape and size (Westermann. *et al.*). Irrigation and nitrogen reduces SG and

tDM. The nitrogen effect on SG and tDM is significantly high with irrigation, compared to water stress (Lawrence. *et al.*, 1985; Dahlenburg, A.P. *et al.*, 1990). (Dahlenburg, A.P. *et al.*, 1990) reported SG decrease with N

increase, from 80–320 kg N ha<sup>-1</sup>, where N above 150–200 kg ha<sup>-1</sup> reduces SG, whilst increasing the cases of misshapen tubers, crisps colour and hollow hearts (Sparrow. *et al.*, 2003). (Belanger, G. *et al.*, 2002) reported a SG decrease, with an N increase above 50 kg N ha<sup>-1</sup>, under irrigation. Nitrogen increases the nitrate accumulation in the tubers, thereby declining SG (Belanger. *et al.*, 2002). The effect of NO<sub>3</sub>-N concentration, on stressed potato fertilised with high N, is reduced by applications of water, thereby avoiding human risk to N-levels (Belanger, G. *et al.*, 2002; Quoting Carter, 1974 and Beidmond, 1992). Cultivars with small tubers had more N concentration than the large tubers, because tuber increase enhances the starch pool (Logan, 1989) and protein decreases it (Belanger, G. *et al.*, 2002). Late maturing cultivars have also been reported as having greater SG than early maturing cultivars (Belanger, G. *et al.*, 2002).

Similarly, sugar concentration in potato tuber increases above an acceptable range, with N increase (Dahlenburg, A.P. *et al.*, 1990). In contrast, (Logan, 1989) reported that reducing sugar content was not significantly influenced by irrigation or N, potato cultivars, in Australia. However, another research on sweet potato, by (Ekanayake. *et al.*, 2004), reported that irrigation significantly reduced the levels of reduces sugars with genotype and irrigation interaction (Ekanayake. *et al.*, 2004). (Singh, J. *et al.*, 2008) compared Taewa and modern cultivars' quality characteristics and found that Taewa (Moe Moe and Tutaekuri) had higher tDM and SG, in New Zealand. However, Taewa quality was not assessed at varied N and irrigation, in order to identify the potential of potato quality in Taewa, with different agronomical practices. A study was conducted to compare specific gravity, tuber dry matter and total sugar of Taewa and modern potato cultivars grown at different water and nitrogen regimes under glasshouse and field conditions.

## Materials and Methods

### Location and Establishment

Three experiments were carried out, one in a glasshouse at the Plant Growth Unit, Massey University, Palmerston North from 23<sup>rd</sup> June 2009 to 11<sup>th</sup> November 2009 and two in the field from 10<sup>th</sup> November, 2009 to May, 2010 and from 27<sup>th</sup> October, 2010 to April, 2011. Seed of Taewa or Maori potato cultivars, Moe Moe (*Solanum tuberosum* L.) and Tutaekuri (*Solanum andigena* Juz. & Buk.) and modern cultivars, Moonlight and Agria (*S. tuberosum* L.) were planted in 15 l plastic planting bags in a glasshouse whilst in the field, seed tubers were planted in furrows at 30 cm between plants and 75 cm between rows. Soil type was Manawatu sandy loam, a recent alluvial soil. The soil properties were: pH 5.4, Olsen P 36 mg/l, K 0.22 me/100g, and available nitrogen (N) 106 kg/ha. Bulk density was 1.35 g/cm<sup>3</sup> and volumetric soil water content at field capacity and wilting point were 0.35 and 0.17 m<sup>3</sup>/m<sup>3</sup>, respectively.

### Treatment and Experimental Design

The glasshouse experiment was laid out as a 2 x 2 x 4 factorial experimental design with four replicates (two water regimes x two nitrogen (N) fertilizer rates x four potato cultivars). Irrigation treatments in glasshouse were based on reference crop evapotranspiration (ET) and were implemented by applying 60% ET and 100% ET to plants every four days up to day 77 after planting, and subsequently, every two days. Irrigation to replenish the planting bags to field capacity was determined by weighing the *B. napus* reference bag before and after irrigation to obtain the mean reference crop evapotranspiration within the irrigation interval. The two nitrogen fertilizer application rates were 0.70 g N (50 kg N/ha<sup>1</sup>) and 2.12 g N (200 kg N/ha) as urea.

The 2009/2010 field experiment was laid out as a split-plot, with rainfall and irrigation regimes as the main treatments, each being randomised and replicated four times: potato cultivars were sub-treatments. The potatoes received 12N:5.2P:14K:6S+2Mg+5Ca, using 500 kg Nitrophoska Blue TE at planting and this was followed by 100 kg N ha<sup>-1</sup> of urea, as a side dressing, on 15<sup>th</sup> December, 2009. The

2010/2011 field experiment was laid out as a Split-split-plot, with rainfall ( $P_e$ ), partial irrigation (PI) and full irrigation regimes (FI) as the main treatments, each being randomised and replicated four times: Three potato cultivars were sub-treatments and two nitrogen levels were sub-sub-treatments. Potato received 12N:5.2P:14K: 6S+2Mg+5Ca, using 500 kg ha<sup>-1</sup> Nitrophoska Blue TE at planting. All plots received the same amount of fertiliser at planting and this was followed by 20 and 180 kgN ha<sup>-1</sup> of urea (as a side dressing) on 10<sup>th</sup> December, 2010. Irrigation was applied with a Trailco boom traveller irrigator and crop water use for irrigated and rain-fed treatments was determined.

$$\text{Specific gravity} = \frac{\text{Weight of tuber in Air}}{(\text{Weight of tuber in Air} - \text{Weight of tuber in water})}$$

Equation 1

The tuber dry matter content (tDM) was determined, by oven drying chopped potato at 70 °C, until the change in tuber dry matter was constant, which was soon after determining its specific gravity. The initial and final weight, for each sample, was measured and the tDM% was calculated, by dividing the final dry weight by the initial fresh weight and then multiplying it by 100%. Furthermore, another tDM and starch was predicted, using regression models, according to Haase, (2003).

### Total Sugars

After specific gravity and tDM determination, total sugar was determined on composite samples from the eight samples above. Potato samples of 0.5g was taken from the outer equatorial portion of each tuber, excluding the skin, giving 2.5 g fresh weight for composite samples for each experimental plot. All the samples were frozen and sent to Massey Animal Nutrition laboratory for total sugar analysis.

### Specific Gravity (SG) and Tuber Dry Matter Content (Tdm %)

After harvesting, ten potato tubers were randomly selected from each experimental plot, to be used for tuber dry matter content and specific gravity determination. The samples were thoroughly washed and dried before weighing. The expression of specific gravity (SG) was determined by weighing the potato in air and in water (Haase, 2003; Smith, 1975), using Mettler PJ3600 Delta Range scale, to two decimal places. Immediately, the specific gravity was calculated using the following **equation 1**:

### Statistical Analysis

The data on specific gravity, tuber dry matter and total sugars were analysed with the General Linear Model (GLM) procedure of the Statistical Analysis System (SAS, 2008) and differences amongst treatment means were compared by the Least Significant Difference test (LSD), at 5% probability (Meier, 2006). Pearson correlation analysis was used to determine the relationship between tuber dry matter and specific gravity parameters.

### Results

#### Glasshouse experiment

Specific gravity and tuber dry matter content were significantly different between potato cultivars ( $p < 0.05$ ), but not between irrigation and N (Table 1, Fig.1). Moe Moe had the highest SG and tDM%, whilst Moonlight had the lowest SG and tDM%, respectively. Significant interactions were observed for tDM% between cultivars\*irrigation\*N ( $P < 0.001$ ) and irrigation\*nitrogen ( $P < 0.01$ ). Figure 1 shows that high N, with high irrigation, decreased tDM%, compared to high N with low irrigation.

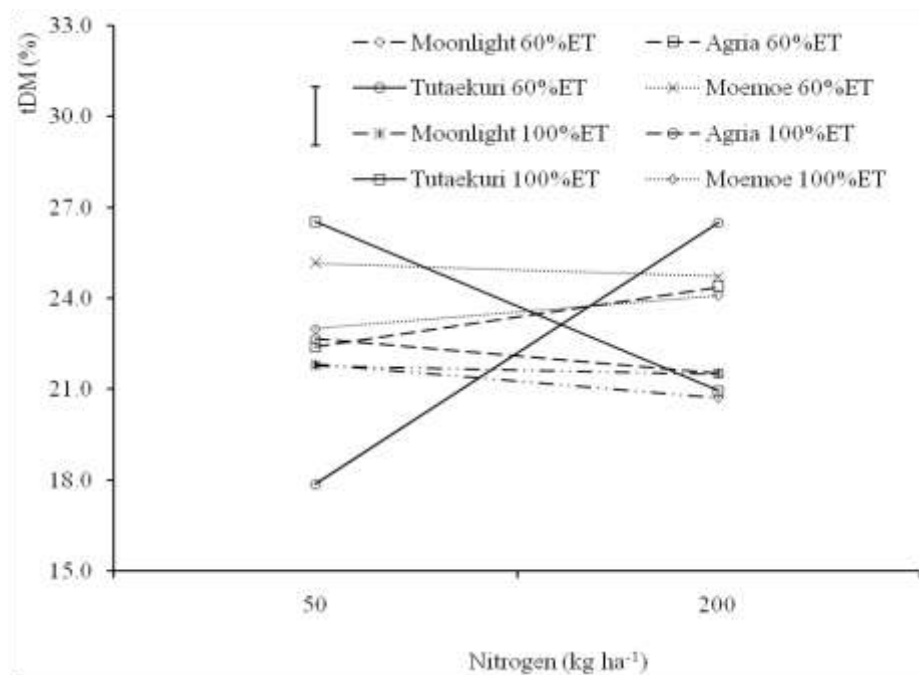
**Table 1:** Specific gravity (SG) and tuber dry matter content (tDM %) of four potato cultivars in glasshouse experime

Cultivars (n=16)	Specific garvity	Measured tDM(%)	Predicted tDM(%)	Predicted starch (%)
<b>Moonlight</b>	1.0788 <sup>b</sup>	20.9 <sup>b</sup>	19.8 <sup>b</sup>	15.4
<b>Agria</b>	1.0818 <sup>ab</sup>	22.0 <sup>ab</sup>	20.4 <sup>ab</sup>	16.2
<b>Tutaekuri</b>	1.0901 <sup>ab</sup>	22.8 <sup>a</sup>	22.2 <sup>ab</sup>	17.5
<b>Moe Moe</b>	1.0965 <sup>a</sup>	24.0 <sup>a</sup>	23.6 <sup>a</sup>	18.7
<b>Sign. Nitrogen (n=32)</b>	P<0.05	P<0.05	P<0.05	P<0.06
<b>60%ET</b>	1.0883	22.4	21.8	17.2
<b>100%ET</b>	1.0855	22.4	21.2	16.7
<b>Sign. Nitrogen (n=32)</b>	Ns	Ns	Ns	Ns
<b>50</b>	1.0894	22.5	22.0	17.4
<b>200</b>	1.0843	22.4	20.9	20.9
<b>Sign. Interactions</b>	Ns	Ns	Ns	Ns
<b>I*N</b>		P<0.01	Ns	Ns
<b>C*I*N</b>		P<0.001	Ns	Ns

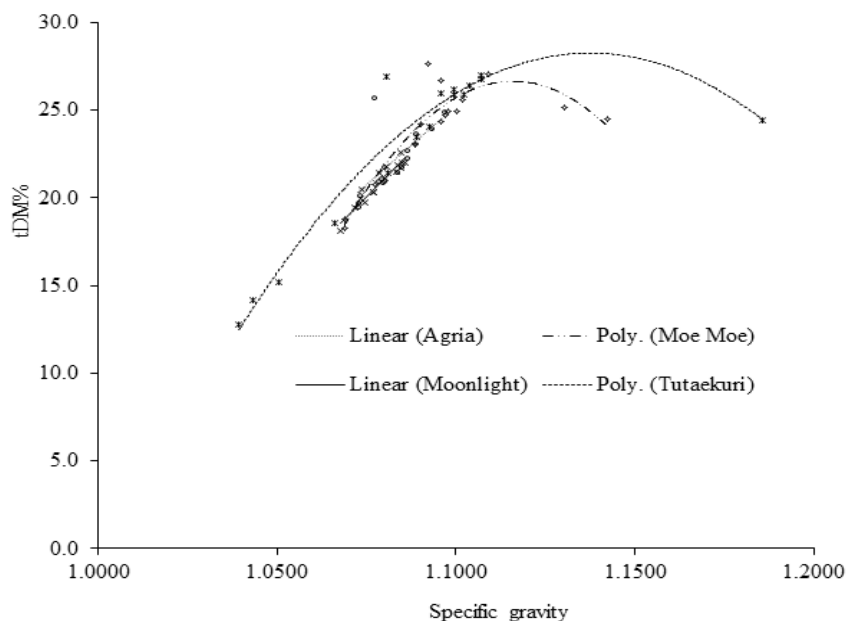
Note- Column rows with same letters are not significantly different

The interaction between cultivars\*irrigation\*N on tDM% was very prominent for Tutaekuri (Fig. 1). The predicted starch content (%) was also highest in Taewa, although it was not significantly different from the modern cultivars (P≤0.06). Specific gravity, amongst the four potato cultivars, was highly positively correlated with the tDM%. The SG and tDM% relationship in the modern cultivar was linear, whereas the SG and tDM% relationship in Taewa was curvilinear

(Fig.2). Agria tDM% = 178.1(SG) - 170.64 R<sup>2</sup> = 0.49; Moonlight tDM% = 206.3(SG) - 201.7, R<sup>2</sup> = 0.91; Moe Moe tDM% = - 3696.1(SG)<sup>2</sup> + 8249.2(SG) - 4576.1, R<sup>2</sup> = 0.85 and Tutaekuri tDM% = -1638.2(SG)<sup>2</sup> + 3726.7(SG) - 2091.2, R<sup>2</sup> = 0.94 (Fig.2). Measured tDM% also had a moderately strong correlation with predicted starch content and predicted tDM% (r = 0.66, P<0.0001). Potato cultivars with high SG, that being Taewa, had increased tDM% and predicted starch content (Table 1, Fig 1 & 2).



**Figure 1:** Interaction between potato cultivar, irrigation and N on DMC% in the glasshouse. Error bar represents ±SEM



**Figure 2:** Specific gravity and tuber dry matter content (%) relationship for four potato cultivars grown in glasshouse, 2009

**Field Experiment 1**

Specific gravity and tDM (%) were significantly different between cultivars ( $P > 0.01$ ,  $P < 0.0001$ ) but not between water regimes ( $P > 0.05$ ; Table 2). Tutaekuri had the highest SG and tuber tDM (%), whilst Agria had the lowest SG and tDM (%). Tutaekuri was significantly different from all the cultivars in SG and tDM%, whilst Agria and Moonlight were least in all traits. Moe Moe

was intermediate in SG traits (Table 2). Specific gravity, within the four potato cultivars, was highly and positively correlated with the tuber dry matter content,  $tDM (\%) = 49.329 (SG) - 32.548$ ,  $R^2 = 0.21$ , ( $P < 0.01$ ) and percentage freeze-dried matter, percentage FDM =  $53.043 (SG) - 35.16$ ,  $R^2 = 0.16$ ,  $P < 0.05$  (Fig. 3). Potato cultivars with high SG and thus, Taewa had increased tDM % (Table 2 and Fig. 3).

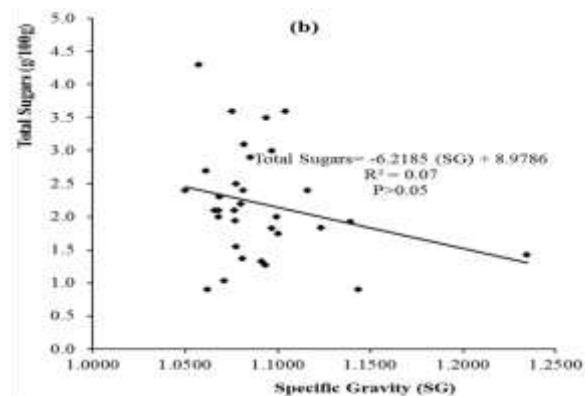
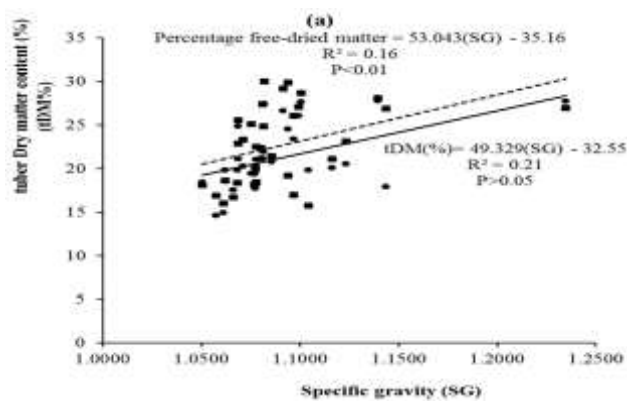
**Table 2:** Effect of water regime and cultivars on total sugars, percentage of freeze-dried matter, specific gravity and dry matter content, in 2009/2010 growing season

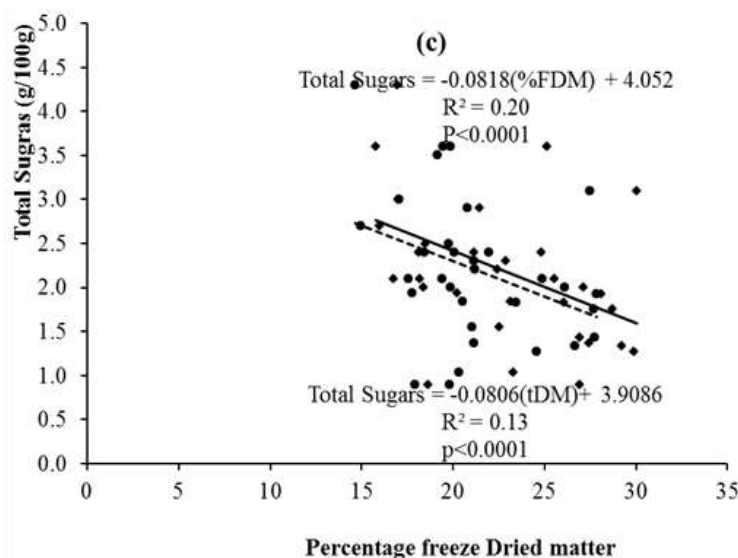
Water Regime Cultivar	Percentage of Freeze-Dried Matter	Freeze -Dried Sugars (g/100g)	Specific Gravity (SG)	Tuber Dry Matter (tDM %)
Water regime (n=16)				
Irrigation	22.1	2.27	1.0915	21.40
Rain-fed	23.3	2.12	1.0899	21.12
Significance	Ns	Ns	Ns	Ns
Cultivar (n=8)				
Agria	18.2 <sup>c</sup>	2.27 <sup>ba</sup>	1.0707 <sup>c</sup>	18.36 <sup>b</sup>
Moonlight	19.9 <sup>c</sup>	2.84 <sup>a</sup>	1.0804 <sup>bc</sup>	19.56 <sup>b</sup>
Moe Moe	24.5 <sup>b</sup>	1.81 <sup>b</sup>	1.0982 <sup>ab</sup>	20.49 <sup>b</sup>
Tutaekuri	28.2 <sup>a</sup>	1.86 <sup>b</sup>	1.1137 <sup>a</sup>	26.62 <sup>a</sup>
Significance	P<0.0001	P<0.05	P<0.01	P<0.0001
CV%	10.4	35.1	2.22	8.53

**Note:** FD - Sugars is total sugar on freeze-dried basis and Fresh-Sugars is total sugar on fresh weight basis. (g/100g); \*, \*\*, \*\*\* and \*\*\*\* refers to p at P<0.05, <0.01, P<0.001 and P<0.0001

Total sugars on freeze-dried matter basis and percentage of freeze-dried matter significantly differed between potato cultivars (P<0.01, P<0.0001), but not between water regimes (P<0.05; Table 2). Moonlight had the highest total sugars, although it was not significantly different from Agria. However, they were both different from Moe Moe and Tutaekuri,

which were least but not statistically different to Agria. Tutaekuri had a significant highest percentage freeze-dried matter content, which was different from all the potato cultivars, whilst Agria was similar to Moonlight. Moe Moe had an intermediate percentage freeze-dried matter amongst the four potato cultivars (Table 3).





**Figure 3:** Relationships between (a) specific gravity and tuber dry matter content; (b) specific gravity and total sugars; and (c) percentage of FDM and total sugars, in potato cultivars

The total sugars on a freeze-dried matter basis negatively related to the percentage of freeze-dried matter or dry matter content (%), ( $P < 0.05$ ) and tDM at harvest: but not to SG ( $P > 0.05$ ). However, the increase of both tDM and SG decreased the total sugar content (Fig. 3). The equations for total sugars' relationship with tDM are: total sugars = - 0.0818(%FDM) + 4.05,  $R^2 = 20$ ; total sugars = - 0.0806 (tDM %) + 3.91,  $R^2 = 0.13$ , whilst the equation for total sugars to specific gravity is total sugars = - 6.2185 (SG) + 8.9786,  $R^2 = 0.07$ , as presented in figure 3. The cultivars with high total sugars (that is modern cultivars) had low tDM (%) and SG (Table 2 and Fig. 3).

**Field Experiment 2**

There were significant differences in SG, tDM % and predicted starch between cultivars ( $P < 0.0001$ ), but not between irrigation and N regimes in 2010/2011 field experiment ( $P > 0.05$ , Table 4). Tutaekuri had the highest SG predicted starch and tDM %, whilst Agria was not different from Moe Moe. Potato cultivar with high SG, Tutaekuri, had increased tDM% and predicted starch (Table 4).

**Table 4:** Tuber dry matter (tDM %) and specific gravity for Taewa and Agria, 2011

Treatments	Specific Gravity (SG)	Tuber Dry matter Content (tDM%)	Predicted Starch (%)
<b>Cultivars</b>			
Agria	1.05908 <sup>b</sup>	16.3 <sup>b</sup>	11.9 <sup>b</sup>
Moe Moe	1.06555 <sup>b</sup>	17.6 <sup>b</sup>	12.9 <sup>b</sup>
Tutaekuri	1.08859 <sup>a</sup>	22.6 <sup>a</sup>	17.2 <sup>a</sup>
Significance	$P < 0.0001$	$P < 0.0001$	$P < 0.0001$
<b>Water regime</b>			
Full irrigation	1.07218	19.0	14.2
Partial irrigation	1.07156	18.9	14.1
Rain-fed	1.07021	18.6	13.8
Significance	Ns	Ns	Ns
<b>Nitrogen (KgN ha<sup>-1</sup>)</b>			
0	1.07301	19.2	14.4
140	1.06961	18.5	13.7
Significance	Ns	Ns	Ns

## Discussion

The values of SG, as a measure of tDM in potato, are influenced by genotypes, environment and their interaction (Killick, R.J. *et al.*, 1974; Jefferies, R.A. *et al.*, 1993b; Werner. *et al.*, 1998; Bélanger. *et al.*, 2002; Kellock. *et al.*, 2004; Singh. *et al.*, 2008). In this study, SG was not strongly affected by irrigation and N in all experiments, but it was strongly influenced by genotypes. Taewa had the highest SG and tDM compared to modern cultivars, thus indicating their great genotypic differences in tuber quality. However, the SG range in Taewa (especially Tutaekuri) was above the normal SG range of 1.055 to 1.0950 (Kellock. *et al.*, 2004). This result is not very surprising because (Verma. *et al.*, 1971) once reported SG as high as 1.12 in potato. Taewa results on SG and tDM also substantiate Singh's (2008) findings that also reported a high SG and tDM in Moe Moe and Tutaekuri, compared to the modern cultivar, Nadine.

It is probable that heredity and long growing cycle for Taewa enhanced the accumulation of tDM, which resulted in high SG. (Werner. *et al.*, 1998) reported that SG increases with a long growing season. Tutaekuri also demonstrated that irrigation and N increase would steadily decrease tDM in the glasshouse. This interaction is paramount for the use of SG in tuber quality determination in Taewa, because figure 2 shows that SG is a surrogate trait to tDM in tuber quality (Kellock. *et al.*, 2004). These genotypic differences in tuber quality are essential for modern production systems, because they can be used to set standards of input management in Taewa and they can also provide genetic resources for improving modern potato processing quality. It is apparent that Taewa growers need to be aware of how they manipulate the soil moisture and N environment, in order to maintain a high level of tuber quality. However, the field study did not affirm reports on the effect of irrigation and N on SG and tDM (Killick, R. J. *et al.*, 1974; Kellock. *et al.*, 2004). Soil moisture hardly affected SG, as also reported in Russet Burbank and Shepody's potato cultivars (Bélanger. *et al.*, 2002). It is likely that the soil

moisture modification was within the crop water requirement range for potato and hence, it could not influence SG and tDM.

Specific gravity and tDM range for 2010/2011 field experiment in Taewa (especially Tutaekuri) was within the normal SG range of 1.055 to 1.0950 (Kellock. *et al.*, 2004), unlike the glasshouse and 2009/2010 study, which were above these values. Nevertheless, SG and tDM for Tutaekuri was still high compared to modern cultivars. It is probable that psyllid infestation reported in this season disrupted the tDM accumulation process in Taewa, thus resulting in lower tDM and SG than other years as once reported in modern potato by (Teulon. *et al.*, 2009).

Tuber dry matter content in association with starch and sugars concentration in potato are also usual benchmarks for processing potato quality assessment (Marquez, G. *et al.*, 1986). High sugars in modern potato, Moonlight in 2009/2010 can negatively affect colouring in potato fries (Marquez. *et al.*, 1986; Kumar, D. *et al.*, 2004), whereas high tDM in Taewa can positively affect productivity of the processed product and the amount of oil used in chips (Kellock. *et al.*, 2004). Specific gravity and tDM are positively related to starch, but negatively related to sugar concentration (Iritani. *et al.*, 1976). The high predicted starch concentration in Taewa than Agria in 2010/2011 meant that modern potato had high concentration of total sugars in 2010/2011, as also determined in 2009/2010. These findings suggest that Taewa can produce more processed products with less oil, compared to modern potato cultivars. The study therefore, contributes to Asia and Pacific region potato research needs on potato with high tDM and low total sugar content as debated by (Pandey, 2008).

Maori people might have wanted to grow Taewa because of its high solid and mealiness texture that easily meets their food and cooking satisfaction (Singh, J. *et al.*, 2008). In addition, Maori people believe that Taewa has nutritional attributes which can control particular health problems (McFarlane, 2007). The study generally implies that Taewa can

produce more processed products with less oil, compared to modern cultivars.

### Conclusion

The study reveals significant variations in tuber quality between heritage and modern potato cultivars regardless of water and N regimes. Taewa has high solid texture and minimum total sugar content, prove an exceptional processing quality, compared to modern potato cultivars. The results on high tDM and low total sugar content in Taewa also contribute to Asia and Pacific region potato research needs. It can be concluded that Taewa has more suitable quality for high processing cost recovery and processing colour quality in crisps than modern potato. Therefore, Taewa can provide potential genetic resources for improvement in the processing quality of modern potato within the Asia and Pacific region.

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