# Yield and tuber quality variability in commercial potato cultivars under abiotic stress in New Zealand

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## Abstract

At present, there is limited study done on the potential effects of abiotic stress (e.g. heat and moisture stress) often associated with climate change on the yield and tuber quality of commercial potato cultivars in New Zealand. This preliminary study aimed to determine if there is early evidence that abiotic stress is already affecting the current potato production system in New Zealand, and how it affects yield and tuber quality of potatoes. It also aimed to investigate if commercial potato cultivars have differential susceptibility to abiotic stress effects. Examination of weather data showed that occurrence of abiotic stress as a consequence of extreme weather conditions are evident in North Island potato production regions – Ohakune (Central North Island; 563 masl), Opiki (South-West North Island; 4 masl), and Hastings (Eastern North Island; 8 masl). On the other hand, data gathered from randomly collected potato tubers from five plants from the different sites revealed that yield is primarily affected by the increase in the volume of non-marketable or defective tubers that could reach as high as 85% of the total volume of tubers collected. This is largely due to the incidence of an array of tuber physiological defects like enlarged lenticels, growth cracks, netting, malformations, and pre-harvest sprouting. Also, initial findings show that commercial potato cultivars may have differential susceptibility to abiotic stress and related tuber physiological defects. Tubers of 'Nadine', 'Snowden', and 'Taurus' showed the least defects, while 'Fianna', 'Hermes', 'Agria', 'Vivaldi', 'Victoria', and 'Moonlight' exhibited greater susceptibility.

***Additional keywords:*** *Solanum tuberosum*, tuber physiological defects, heat stress, moisture stress, drought, waterlogging, climate change

## Introduction

The potato (*Solanum tuberosum* L.) is an economically important vegetable crop in many parts of the world. It is grown in about 150 countries and consumed almost daily by more than a billion people and ranks third after rice and wheat (FAO, 2015). In New Zealand, potato is the top vegetable commodity in terms of area planted (10,329 ha) and volumes produced (525,000 T) (Fresh Facts, 2017). Key regions of potato production are Auckland, Waikato, Hawke's Bay, Manawatu-Wanganui, in the North Island, and Canterbury in the South Island. Total export earnings amounted to more than NZD115 million in 2016 for combined fresh and processed potato products (Fresh Facts, 2017).

Potatoes are a temperate crop with optimum leaf and tuber production occurring between mean daily temperatures of 18-20°C (FAO, 2018), although, it is known to have specific temperature requirements. The above-ground leaf and stems grow best at a temperature range of 20-25°C while the ideal temperature for tuberisation and tuber growth is between 15-20°C (Rykaczewska, 2015). At temperatures below 15°C, tuberisation could be delayed by one week and at temperatures higher than 25°C by three weeks (Levy and Veilleux, 2007), while above 30°C tuber growth is sharply inhibited (FAO, 2018). High temperature in subsequent stages of potato plant development is generally known to induce various tuber physiological disorders (Martin *et al.*, 1992; Rykaczewska, 2017). Besides temperature, the potato crop is well known to be sensitive to both drought (van Loon, 1981) and waterlogging (Hincksman, 2011). The susceptibility of potatoes to drought is usually attributed to its shallow root system and inability to readily recover after exposure to a period of water stress (reviewed in Iwama, 2008; Opena and Porter, 1998). If soil is waterlogged for extended periods, yield reduction or total crop loss can occur through a decline in carbon assimilation and effects of plant pathogens.

With the advent of climate change, there is a need to study the potential effects of associated abiotic stress (e.g. heat and moisture stress) on the yield and tuber quality of commercial potato cultivars currently grown in New Zealand. Therefore, the goals of the preliminary study were to determine if there is early evidence that abiotic stress associated with climate change is already affecting the current potato production system in New Zealand, initially determine how it affects yield and tuber quality of potatoes, and investigate if commercial potato cultivars have differential susceptibility to abiotic stress effects.

## Materials and Methods

### Study sites

A study was conducted in three representative potato production sites in the North Island of New Zealand – A.S. Wilcox and Sons Ltd. in Ohakune (Central North Island; 39°25’ S, 175°23’ E; 563 masl; conventional-irrigated), Freshpik Farms Ltd. in Opiki (South-West North Island; 40°27’ S 175°27’ E; 4 masl; conventional-non-irrigated), and Lawson’s True Earth in Hastings (Eastern North Island; 39°37’ S 176°44’ E; 8 masl; organic-irrigated) during the 2017/2018 season.

### Weather data

Recent and historical weather data during potato growing months (October-April) from CliFlo, the web database that provides access to New Zealand Climate Database (NIWA, 2018) were obtained and analyzed.

### Potato cultivars and measurements

At physiological maturity at each site, potato tuber samples of five (5) plants/cultivar were randomly collected from middle rows in the field following a crop sampling protocol (NIABCUF, 2015) in March 2018. The potato (*S. tuberosum* L.) cultivars (main and late-main cultivars) collected were: fresh-market cultivars ‘Nadine’, ‘Vivaldi’, and ‘Victoria’ in Ohakune; multipurpose and/or processing cultivars ‘Snowden’, ‘Agria’, ‘Hermes’, ‘Taurus’, and ‘Fianna’ in Opiki; and multipurpose cultivars 'Agria' and 'Moonlight' in Hastings. Tuber fresh yield was calculated and number of tubers per plant was recorded along with harvest index (HI), defined as the ratio of tuber dry matter to total dry matter (Mackerron and Heilbronn, 1985). Ten randomly selected tubers from each cultivar were used to measure percent tuber dry matter (DM) content. DM was calculated as the dry weight/fresh weight multiplied by 100.

### Tuber classification

Tubers were characterized using the *Descriptors for the Cultivated Potato* (Huaman *et al.*, 1977). Tuber size classification was based on the TAG Standards for Potatoes developed by T&G Global (T&G Global, 2018). Tubers were categorised as marketable and non-marketable (rejects). The incidence of tuber physiological defects, primarily enlarged lenticels, growth cracks, malformations (dumbbell, bottleneck, chained tubers and knobby tubers), and pre-harvest sprouting were determined as a percentage of the total number of tubers. The severity of enlarged lenticels was further categorised based on a 0-9 rating scale, where 0=none, 1=very few, 3=few, 5=moderate, 7=severe, and 9=very severe.

### Statistical analyses

Statistical analysis at this stage was done to compare cultivars within sites only, since no treatments were implemented, and potato cultivars were grown under different grower management systems. Analyses were carried out in R statistical package version 3.4.0 (R Core Team, 2017). Differences between cultivars were determined by Analysis of Variance and mean values were compared among cultivars using the Tukey's HSD test. A paired t-test was used to compare data within sites with only two representative cultivars.

## Results and Discussion

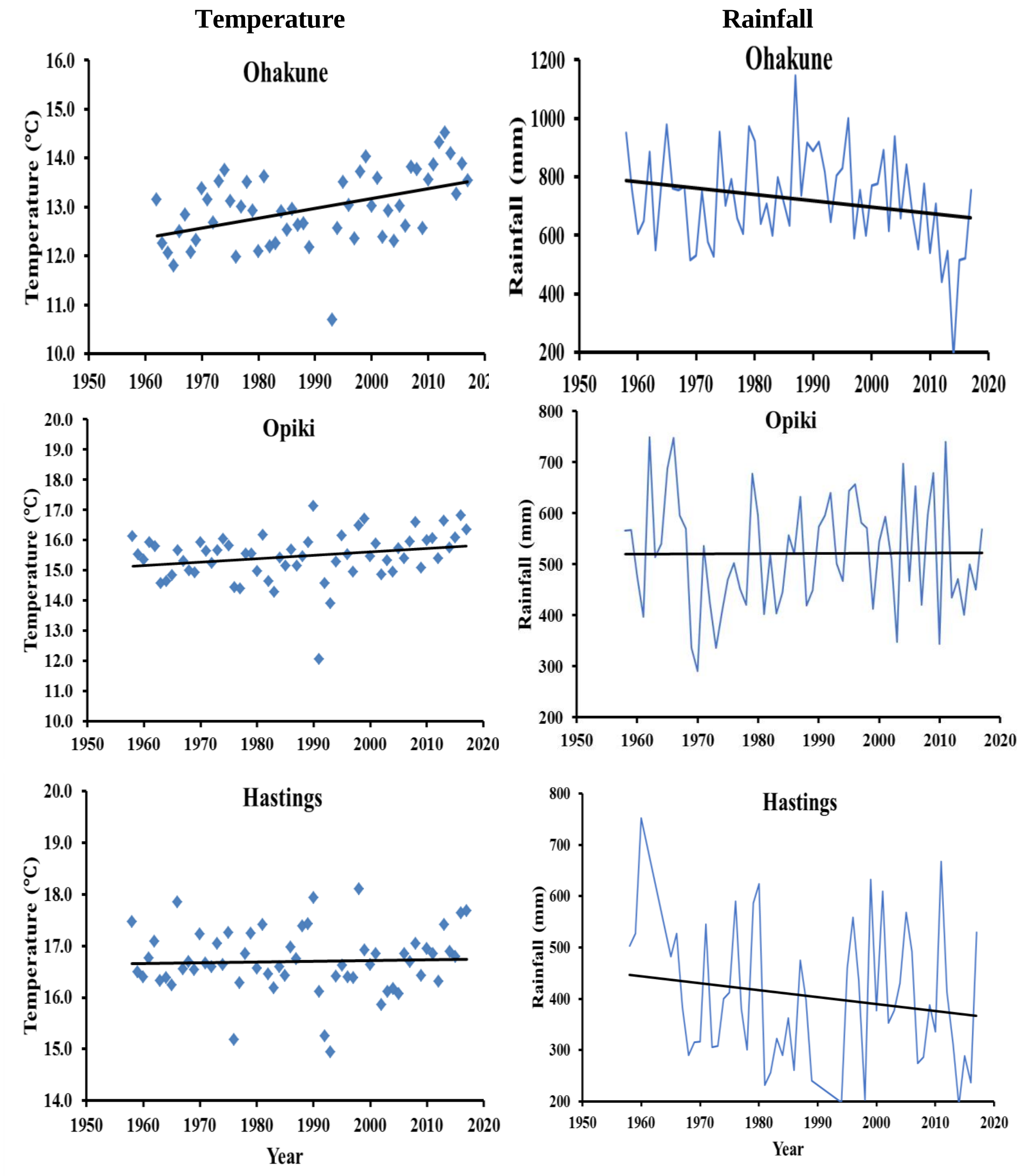
### Recent and historical weather data

Examination of recent (2017/2018) weather data during the potato growing months of October-April shows higher mean temperature in Hastings (18.2°C) and Opiki (17.2°C), compared to Ohakune (14.1°C), with more than 1°C increase from the 1967-2016 (50 year-average) data across sites (Table 1). Also, further examination of long-term temperature data shows an increasing trend across sites with Ohakune having the highest increase at 0.46°C (Figure 1), agreeing with the projection of the Ministry for the Environment (2016) that warming as a result of climate change in New Zealand will be greatest at higher elevations. In terms of the temperature profile for potato production, Ohakune had most days with temperatures below 25°C which were favorable for potato tuber growth, but Hastings and Opiki had a greater number of days with 25-29°C and ≥30°C (Figure 2), believed to delay and inhibit tuber growth, respectively (Levy and Veilleux, 2007; FAO, 2008). It is noteworthy as well that the number of days with 25-29°C and ≥30°C increased in the recent season (2017/2018) as compared thirty years ago (1987/88), especially in Opiki and Hastings, suggesting recent incidence of more severe heat stress.

**Table 1:** Recent and historical weather data in potato growing months (October-April) in Ohakune, Opiki, and Hastings. Data from Cliflo weather database (NIWA, 2018).

| Parameter | Potato Growing Months | | | | | | | Mean Temp | Total Rain |
|---|---|---|---|---|---|---|---|---|---|
| | Oct | Nov | Dec | Jan | Feb | Mar | Apr | (°C) | (mm) |
| **Ohakune** | | | | | | | | | |
| Recent- 2017/2018 | | | | | | | | | |
| Temp (°C) | 10.6 | 12.2 | 15.2 | 18.7 | 16.6 | 14.3 | 11.1 | 14.1 | |
| Rain (mm) | 97.8 | 90.4 | 82.2 | 130.8 | 96.6 | 99.6 | 160.8 | | 758.2 |
| Historical- 1967-2016 | | | | | | | | | |
| Temp (°C) | 9.8 | 11.6 | 14.0 | 15.3 | 15.4 | 13.8 | 11.0 | 12.9 | |
| Rain (mm) | 134.8 | 120.5 | 116.8 | 94.4 | 82.5 | 82.4 | 121.5 | | 752.9 |
| **Opiki** | | | | | | | | | |
| Recent- 2017/2018 | | | | | | | | | |
| Temp (°C) | 13.7 | 15.3 | 18.5 | 21.6 | 19.5 | 17.4 | 14.4 | 17.2 | |
| Rain (mm) | 63.6 | 12.6 | 24.6 | 85.9 | 79.1 | 74.2 | 114.3 | | 454.3 |
| Historical- 1967-2016 | | | | | | | | | |
| Temp (°C) | 12.6 | 14.2 | 16.5 | 17.9 | 18.2 | 16.7 | 14.1 | 15.7 | |
| Rain (mm) | 85.7 | 85.2 | 86.1 | 65.6 | 66.1 | 75.7 | 89.3 | | 553.8 |
| **Hastings** | | | | | | | | | |
| Recent- 2017/2018 | | | | | | | | | |
| Temp (°C) | 14.4 | 16.5 | 19.2 | 22.7 | 21.1 | 18.6 | 15.0 | 18.2 | |
| Rain (mm) | 79.4 | 13.0 | 43.0 | 30.6 | 52.6 | 109.4 | 100.0 | | 428.0 |
| Historical- 1967-2016 | | | | | | | | | |
| Temp (°C) | 13.7 | 15.9 | 18.0 | 19.3 | 18.8 | 17.4 | 14.6 | 16.8 | |
| Rain (mm) | 40.0 | 41.0 | 47.9 | 41.2 | 58.4 | 87.2 | 71.5 | | 387.2 |

On precipitation in the recent season (2017/2018), total rainfall was below optimum in Opiki (454.3 mm) and Hastings (428.0 mm), and optimal in Ohakune (758.2 mm) (Table 1). Comparison of the 2017/2018 with the 1967-2016 (50 year-average) data showed a minor increase of rainfall in Ohakune and Hastings but decrease in Opiki. A general trend of decreasing rainfall which led to water deficit in Opiki and Hastings from November to December 2017 coinciding with potato vegetative and tuber initiation stages was observed. Only Opiki experienced actual drought condition since the site was entirely reliant on rainwater for potato crop production, while Hastings had supplemental irrigation. However, long-term rainfall data during potato growing seasons shows an increased trend in Opiki (19.53 mm) and decreased trend in Ohakune and Hastings by (-32.76 mm) and (-19.20 mm), respectively (Figure 1), consistent with the IPCC report that reduced soil moisture in many parts of eastern but more rain in western New Zealand will be experienced (Reisinger *et al.*, 2014).




| | Temperature (°C) | | |
|---|---|---|---|
| | Ohakune | Opiki | Hastings |
| 1958-1987 | 12.7 | 15.3 | 16.7 |
| 1988-2017 | 13.2 | 15.6 | 16.7 |
| diff. | 0.46 | 0.30 | 0.07 |

| | Rainfall (mm) | | |
|---|---|---|---|
| | Ohakune | Opiki | Hastings |
| 1958-1987 | 740.0 | 511.5 | 413.5 |
| 1988-2017 | 707.2 | 531.0 | 394.3 |
| diff. | -32.7 | 19.5 | -19.2 |

**Figure 1:** Variations in mean temperature and total rainfall in the last 30 years (1988-2017) and previous 30 years (1958-1987) during potato growing seasons in Ohakune, Opiki, and Hastings (October-April). Data from Cliflo weather database (NIWA, 2018).

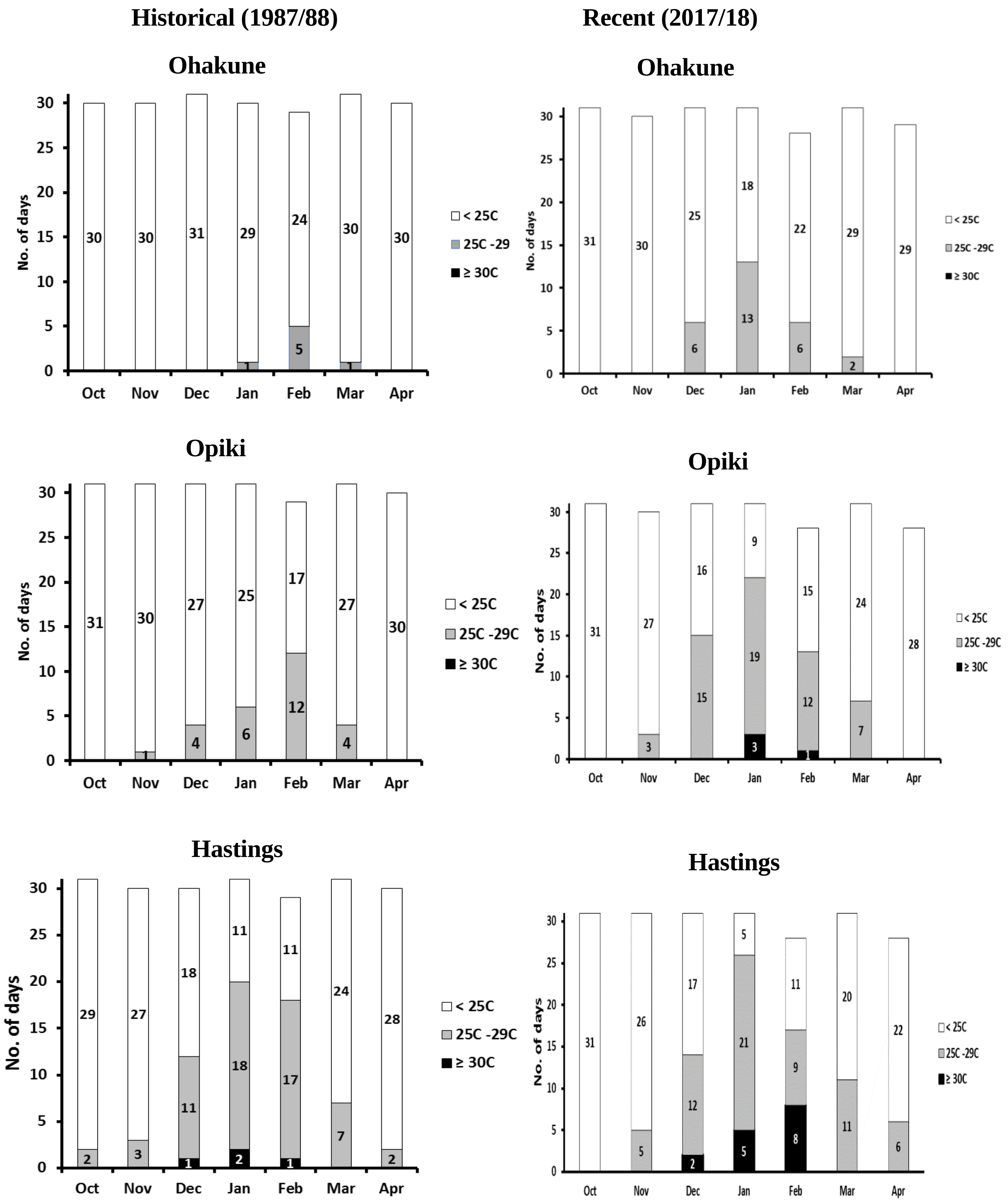



**Figure 2:** Temperature profile in recent (2017/18) and 30 years ago (1987/88) during potato growing seasons in Ohakune, Opiki, and Hastings. Data from Cliflo weather database (NIWA, 2018).

## Yield and tuber quality

Tuber yield and number of tubers per plant were higher in Ohakune with temperature and rainfall close to optimum levels for potato growth and development (Table 2). In contrast, tuber yield was lower in Opiki and Hastings where drought and a larger number of days with 25-29°C and ≥30°C occurred. These temperature ranges may have cause delay in initiation and development of tubers as previously reported (Levy, 1986; reviewed in Haverkort *et al.*, 1990; Ahn *et al.*, 2014; Rykaczewska, 2015, 2017). Heat stress is known to reduce photosynthetic activity along with reduction in tuber yield (Reynolds *et al.*, 1990; Hastilestari *et al.*, 2018). For every 5°C rise in leaf temperature above the optimum, there was a 25% reduction in photosynthetic rate (reviewed in Burton, 1981). On the other hand, under drought stress plants have an adaptive response of lower stomatal conductance, to conserve and maintain leaf water status, resulting in a lower leaf internal $CO_2$ concentration and lower photosynthetic rate (Chaves *et al.*, 2002).

**Table 2:** Tuber yield parameters of 10 commercial potato cultivars in Ohakune, Opiki, and Hastings.

| Potato Cultivars | Tuber Fresh Yield (t/ha) | Number of tubers/plant | DM[a] (%) | HI[b] (%) |
|---|---|---|---|---|
| | | **Ohakune** | | |
| Nadine | 91.9±5.5 a | 26±2.2 a | 15.0±0.1 b | 0.90±0.02 a |
| Vivaldi | 66.8±7.2 a | 18±3.5 ab | 16.4±0.6 b | 0.82±0.03 b |
| Victoria | 67.4±9.9 a | 12±1.7 b | 18.8±0.7 a | 0.80±0.01 b |
| | | **Opiki** | | |
| Snowden | 46.7±9.5 a | 6.2±0.37 b | 20.7±0.15 ab | 0.83±0.01 a |
| Agria | 63.2±12.1 a | 4.8±1.3 b | 18.8±0.16 b | 0.68±0.04 b |
| Hermes | 55.0±8.6 a | 8.2±2.2 b | 20.1±0.18 ab | 0.68±0.03 b |
| Taurus | 51.3± 3.2 a | 9.8±1.9 ab | 21.9±0.53 a | 0.74±0.04 ab |
| Fianna | 75.7±10.5 a | 17.8±3.2 a | 18.9±0.26 b | 0.70±0.02 ab |
| | | **Hastings** | | |
| Agria | 51.3±9.2 ns | 9.2±0.97 ns | 19.7±0.27 *** | 0.54±0.03 ns |
| Moonlight | 65.2±6.3 ns | 11.6±1.47 ns | 17.8±0.18 | 0.59±0.02 ns |

[a]Dry Matter; [b]Harvest Index. Error bars indicate a ± standard error of the means. Ohakune and Opiki: different letters in a column indicate means are statistically different on Tukey's HSD test ($P \leq 0.05$); Hastings: statistically different on t-test ($P \leq 0.001$).

**Table 3:** Tuber size distribution of 10 commercial potato cultivars in Ohakune, Opiki, and Hastings.

| Potato Cultivars | Tuber Size Distribution[a] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Undersize (<30 mm) | | Gourmet (31-50 mm) | | Table (51-90 mm) | | Large (>90 mm) | |
| | Ave. No. | % | Ave. No. | % | Ave. No. | % | Ave. No. | % |
| **Ohakune** | | | | | | | | |
| Nadine | 1.0±0.5 a | 3.8 | 5.0±1.6 a | 19.2 | 18.6±0.2 a | 71.5 | 1.4±0.9 a | 5.3 |
| Vivaldi | 0.6±0.4 a | 3.2 | 2.8±1.1 a | 15.2 | 12.2±2.9 ab | 66.3 | 2.8±0.4 ab | 15.2 |
| Victoria | 0.4±0.2 a | 3.2 | 1.0±0.3 a | 8.2 | 5.6±1.2 b | 45.9 | 5.2±0.7 b | 42.6 |
| **Opiki** | | | | | | | | |
| Snowden | 0.2± 0.2 a | 3.2 | 0.8±0.3 b | 12.9 | 3.6±0.8 bc | 58.0 | 1.6±0.9 a | 25.8 |
| Agria | 0.0±0.0 a | 0.0 | 0.2± 0.2 b | 4.1 | 1.2±0.5 c | 25.0 | 3.4±0.8 a | 70.8 |
| Hermes | 0.2±0.2 a | 2.4 | 1.8±1.1 ab | 21.9 | 4.8±0.8 bc | 58.5 | 1.4±0.5 a | 17.0 |
| Taurus | 0.4± 0.4 a | 4.0 | 1.6±0.9 ab | 16.3 | 7.2±1.0 ab | 73.4 | 0.6±0.4 a | 6.1 |
| Fianna | 0.2± 0.2 a | 1.1 | 4.6±1.0 a | 25.8 | 11.4±2.2 a | 64.0 | 1.6±0.8 a | 8.9 |
| **Hastings** | | | | | | | | |
| Agria | 0.4±0.2 ns | 4.3 | 0.6±0.4 | 6.52 | 5.0±0.3 ns | 54.3 | 3.2±1.0 ns | 34.7 |
| Moonlight | 1.0±0.4 ns | 8.6 | 2.4±0.6 ** | 20.69 | 4.8±0.3 ns | 41.3 | 3.4±0.7 ns | 29.3 |

[a]Based on T&G Global TAG Standards for Potatoes. Error bars indicate a ± standard error of the means. Ohakune and Opiki: different letters in a column indicate means are statistically different on Tukey's HSD ($P \leq 0.05$); Hastings: statistically different on t-test ($P \leq 0.05$).

Our initial findings show that tuber dry matter (DM) increased under drought conditions. The majority of the potato cultivars in Opiki (non-irrigated) have relatively higher DM (average of 20.1%, with 'Taurus' with the highest of 21.9%) as compared with cultivars in both Ohakune and Hastings (irrigated) (average of 16.7% in Ohakune and 18.8% in Hastings, respectively) (Table 2). An increase in the DM as a result of drought stress was also found in an earlier study (Lahlou *et al.*, 2003). Harvest index (HI), was higher in potato cultivars planted in Ohakune, where environmental conditions were favorable for tuber growth and bulking, with the cultivar 'Nadine' (0.90%) surpassing 'Vivaldi' (0.82%) and 'Victoria' (0.80%). In contrast, under higher temperatures in Opiki and Hastings the HI was lower. Elevated temperatures are reported to enhance dry matter partitioning of the haulm, which promotes haulm and root growth but restrict tuber growth (reviewed in Levy and Veillux, 2007; Lafta and Lorenzen, 1995).

In general, table (51-90 mm) is the most common tuber size across sites (Table 3). There were no clear effects of drought or heat in Opiki and Hastings on the decrease of tuber size as found in previous studies (Martin *et al.,* 1992; Rykaczewska, 2017). However, high yielding cultivars such as 'Nadine' in Ohakune and 'Fianna' in Opiki, tend to have higher volume and larger tubers than other cultivars. In terms of tuber external qualities, all ten potato cultivars were within the standard characteristics (i.e. tuber shape, eye depth, skin and flesh colour) based on cultivar passport data from breeder companies, except for the skin colour of 'Snowden', 'Agria', and 'Hermes' in Opiki, and 'Agria' and 'Moonlight' in 'Hastings' (data not presented). The regular yellow or white skin colours of the cultivars were masked by brown colour due to severe skin netting. Netting are shallow fissures that give the skin a distinctive netlike-appearance, often related to climatic conditions and physiological factors (Potatoes South Africa, 2016).

**Marketable and non-marketable tubers**

Data from the three sites show that commercial potato cultivars have a varying percentage of marketable and non-marketable tubers (Figure 3). The percentage of non-marketable tubers is most likely to be a response to suboptimal growth conditions (Hirut *et al.* 2017; Aien *et al.*, 2017). The highest percentages of marketable tubers were recorded in 'Nadine' (98%) in Ohakune, and 'Taurus' (68%) and 'Snowden' (63%) in Opiki. In contrast, the highest percentages of non-marketable or defective tubers were observed in 'Moonlight' (85%) in Hastings, 'Victoria' (73%) in Ohakune, and 'Agria' (73%) in Opiki. The most common reasons for very high percentage of non-marketable tubers was the incidence of tuber physiological defects such as enlarged lenticels, growth cracks, netting, malformations, and pre-harvest sprouting (Figure 4).

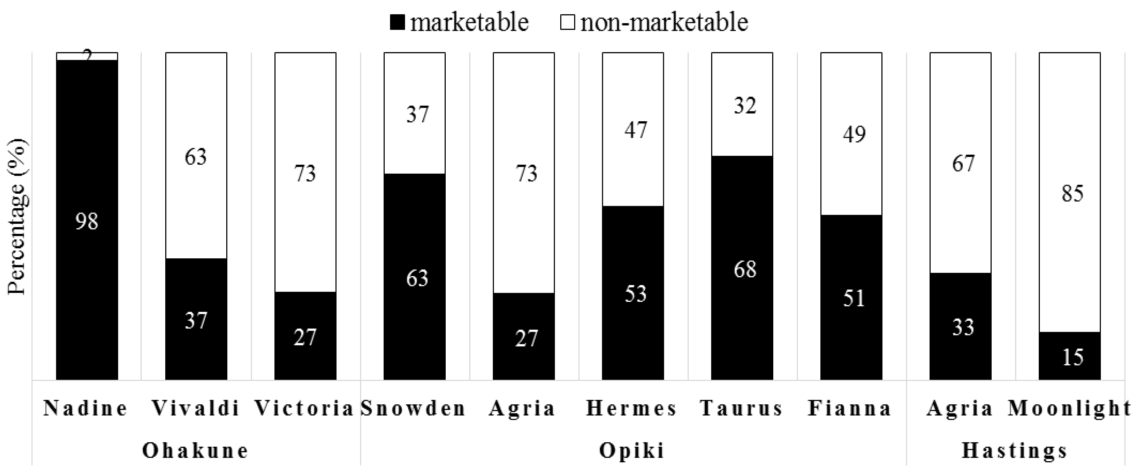



**Figure 3:** Percentage distribution of marketable and non-marketable tubers of 10 commercial potato cultivars in Ohakune, Opiki, and Hastings. In Ohakune and Opiki, values with different letters in a column indicate means are statistically different based on Tukey's HSD test ($P \leq 0.05$). In Hastings values are not statistically different based on t-test.

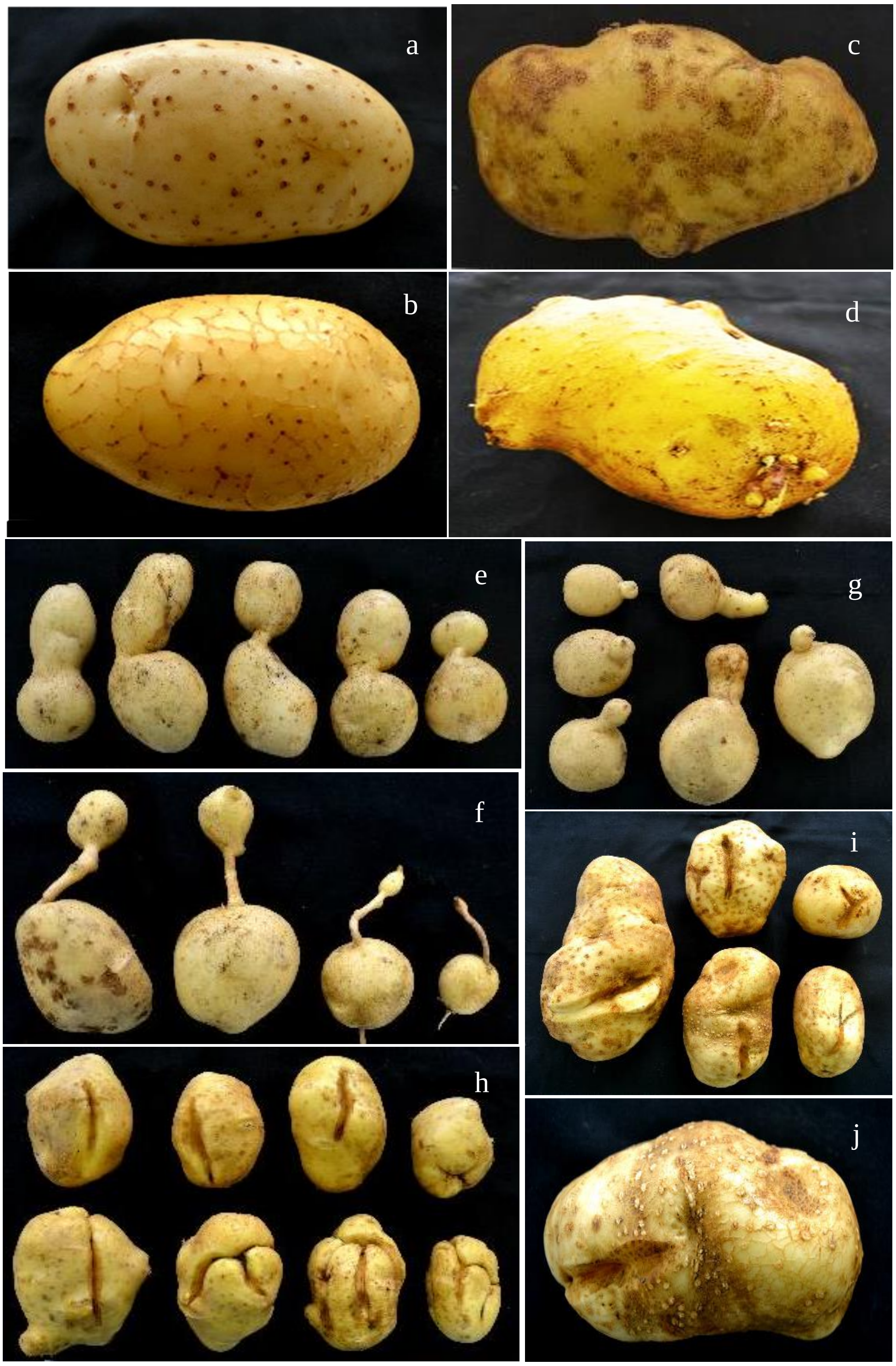



**Figure 4:** Potato tuber physiological defects in Ohakune: (a) enlarged lenticels in ‘Vivaldi’, (b) superficial growth cracks centered on lenticels in ‘Victoria’; in Opiki: (c) knobby-tuber and (d) pre-harvest sprouting in ‘Agria’, (e) dumbbell-tubers, (f) chained tubers, and (g) bottleneck tubers in ‘Fianna’; in Hastings: (h) growth cracks in ‘Agria’, and (i) growth cracks, and (j) suberized and enlarged lenticels in ‘Moonlight’.

## Tuber physiological defects

Initial findings show that the incidence and type of tuber physiological defects in commercial potato cultivars are affected by weather conditions. The type and severity of tuber physiological defects are greater under higher temperatures in Hastings, and combined drought and heat stress like those observed in Opiki. At Ohakune the temperatures were closer to the published optimum temperature and water requirements for potato growth and development. Commercial potato cultivars also exhibited differential susceptibility to tuber physiological defects (Figure 5); however we were not able to test an interaction between cultivar and site effects.

In Ohakune, 'Nadine' showed reduced incidence of enlarged lenticels with most tubers having none to light severity, while 'Vivaldi' and 'Victoria' had severe and medium ratings, respectively (Figure 6). In Opiki, 'Snowden' and 'Taurus' showed less growth cracks and malformed tubers compared to 'Agria', 'Hermes', and 'Fianna'. Of note is that 'Agria' in Opiki exhibited the highest percentage (54%) of pre-harvest sprouting among the assessed cultivars. In Hastings, 'Agria' and 'Moonlight' both showed tuber physiological defects, particularly to enlarged lenticels, netting, and growth cracks (Figure 5).

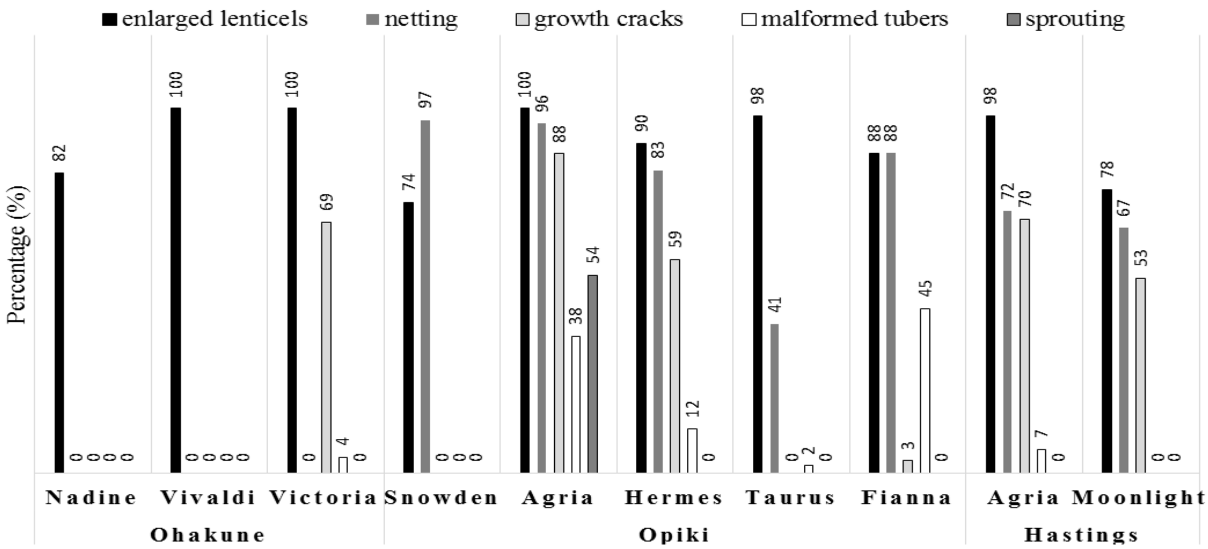



**Figure 5:** Percentage of tuber physiological defects in 10 commercial potato cultivars in Ohakune, Opiki, and Hastings.

The severity of tuber physiological defects particularly the enlargement of lenticels and formation of malformed tubers appeared to be indicative of suboptimal soil conditions. Enlarged lenticels form when soil oxygen is reduced due to waterlogging (Hillerm and Thornton, 2008; Potatoes South Africa, 2016). It was also more severe in Ohakune (high rainfall) and Hastings (increased irrigation to mitigate high temperatures) as compared to the dry conditions in Opiki (Figure 6). On the other hand, the formation of malformed tubers associated to moisture stress (drought) or high temperature that interrupt or stop tuber growth (Hillerm and Thornton, 2008; Potatoes South Africa 2016) were common in Opiki than in Ohakune and Hastings (Figure 5). Furthermore, growth cracks associated with high internal turgor pressure and rapid water uptake after prolonged dry soil conditions (Jefferies and Mackerron, 1987) were higher and more severe in Hastings as compared to Ohakune and Opiki. Further studies are planned using similar cultivars and modified experimental design to better evaluate the environmental drivers for yield and quality indicators in commercial potato crops.

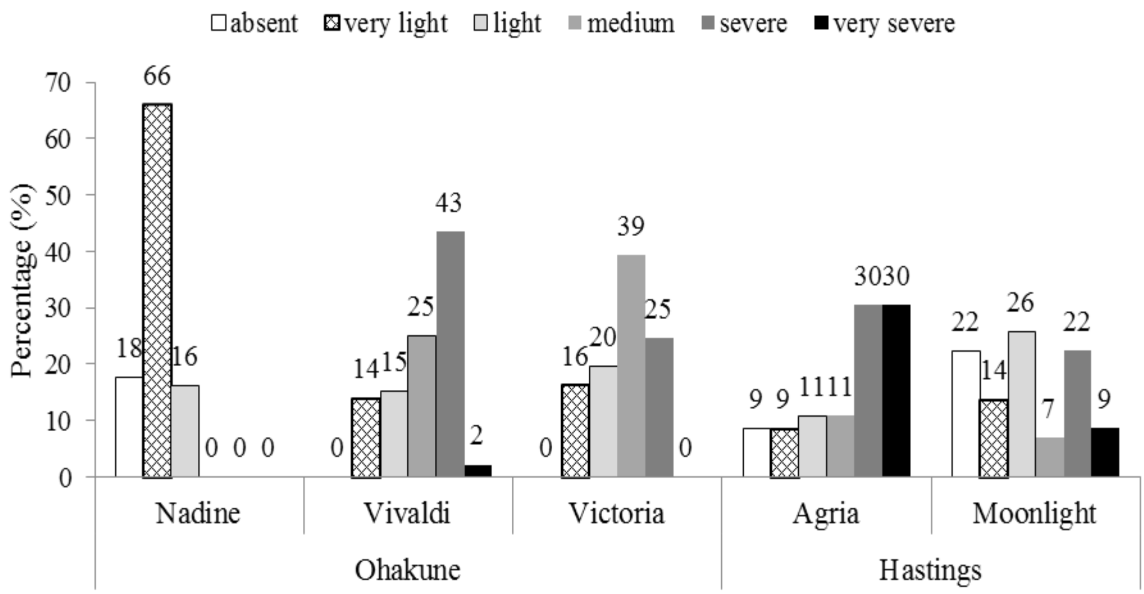



**Figure 6:** Percentage of severity of enlarged lenticels in potato cultivars in Ohakune and Hastings.

## Conclusions

Our data indicated that abiotic stress (e.g. heat and moisture stress) linked with climate change were likely causes of reductions in tuber economic yield (commercial marketable yield). Firstly, fresh yield was highest when temperatures were close to optimum reported for growth and development, thereby potentially promoting the photosynthetic capacity of the crop and maximizing tuber fresh yield, number of tubers/plant, and harvest index. Secondly, stresses such as sub and supra optimum temperatures, and drought increased the incidence of physiological disorders (enlarged lenticels, growth cracks, netting, malformations, and pre-harvest sprouting) in potato tubers and increased the percentage of non-marketable or defective tubers. While we did not have common cultivars across sites, there was evidence for differing susceptibility among cultivars to abiotic stress and associated tuber physiological disorders. 'Nadine', 'Snowden', and 'Taurus' showed the least defects even under adverse conditions, while 'Fianna', 'Hermes', 'Agria', 'Vivaldi', 'Victoria', and 'Moonlight' exhibited greater susceptibility. Further study is required to validate the responses of commercial potato cultivars to abiotic stress associated with climate change under a range of environment and ideally under controlled-environment experimentation.

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