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Effect of climate change on the quality of Citrus fruit produced in South Africa

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Abstract

Climate change is an observed reality with a significant impact globally. South Africa is not immune to this phenomenon. Like the rest of the world, South Africa experiences rise in mean air temperature and changes in rainfall trends. Since plant systems are influenced by weather, it is expected that climate change will have an effect on the production and quality of fruit. The objective of this study was to determine the impact of climate change on the quality of citrus fruit produced in South Africa. In conducting the study, historical fruit quality data was collected from packhouses in the Eastern and Western Cape provinces of South Africa over a period of 12 and 8 years respectively. Trend analysis was done on the data to determine whether there is a trend that can be observed over the period of data collection. The total soluble solids of fruit showed a marginal increase over the period of observation. Titratable acidity showed a marginal decrease. The incidence of sunburn on fruit seemed to increase over time. Other disorders like decay, creasing and oleocellosis did not show a definite trend of increasing or decreasing over time. Rind disorders seemed to decrease during the period of observation. This report discusses how the observed trends were influenced by changes in rainfall and temperature over the period of observation. It is then concluded that in this case study, the impact of climate change was not very profound and it had both negative and positive effects. The current results point towards a bleak future for citrus producers. To remain profitable, it may be necessary for producers to invest in climate change adaptation technologies.

Key words: Climate change, citrus fruit, fruit quality, oleocellosis, titratable acidity

Introduction

Climate change has been identified as a serious threat to food security, human livelihood, and sustainable development in many parts of the world (Midgley *et al*., 2005; Ziervogel *et al*., 2014; Verschuur *et al*., 2021). The Intergovernmental Panel on Climate Change (IPCC) 6th summary for policy makers report of 2021 pointed out that overwhelming scientific evidence exists, showing that the earth's atmosphere is warming, and there are changes in the earth's rainfall patterns. Climate change and its deleterious effects is a global phenomenon and South Africa is not immune to this vulnerability. Zeirgovel *et al*. (2014) reported that the mean annual air temperature in South Africa has increased about 1.5 times the global average, in the past five decades. This study further reported weak and non-significant rainfall trends, in both magnitude and direction, but pointing towards a decreasing trend. Climate change projection models show that, inland areas will experience higher temperature increase than coastal areas. Rainfall trends will also vary, with the Eastern parts of the country receiving higher rainfall than the Western parts (DFFE, 2013, Engelbrecht, 2019). Since Plant systems, and by extension yield and fruit quality, are influenced by environmental factors, it is expected that climate change will influence the production and quality of fruits (Adams 1988).

Commercial fruit production in South Africa occurs on 203, 989 hectares of land, spread over the nine provinces of the country (Fruits South Africa, 2023). To the land planted with different fruit types, citrus covers about 49% of this land, making it the most planted fruit type in South Africa. By virtue of being widely planted, citrus also has the highest production and export volumes of all fruits produced in the country (Fruits South Africa, 2023). Admittedly, the extent of climate change in the production regions will influence citrus production and fruit quality. It has been shown that climate change may influence the phenology of citrus fruit, leading to early flowering in some areas but also delayed flowering was reported in other regions (Fitchett *et al*., 2014;

Abobatta, 2019). Colour change on lemons was found to be delayed, by one week to two months due to the rise in air temperature (Erena *et al*., 2019). Internal fruit quality in most cases was found to improve with climate change, but there were also cases where the soluble solids were worse off due to this phenomenon (Abobatta, 2019, Nawaz *et al*., 2020; Wang *et al*., 2022).

Undoubtedly there is a wealth of information on the impact of climate change on the quality of citrus fruits. However, there is an opportunity to examine this effect at different stages of the value chain, starting on the farm, through to the packhouse and ending in the market. The objective of this study was to examine the effect of climate change on the quality of citrus fruits at different stages of the value chain.

Materials and methods

In the Western Cape, data was obtained from fruit quality records of a packhouse in Simondium area of the Western Cape (33°49´57´´S 18°57´09´´E). The selected packhouse, packs fruit from several growers and as standard procedure, they check quality of fruit delivered to the packhouse. The data used in this study is historical quality data collected by the packhouse, from 2013 to 2021 (8 years).

In the Eastern Cape, citrus fruit quality data was obtained from a packhouse in the Sunday's River Valley. This data was collected from retention samples, which are fruit samples that the packhouse keeps back after a day's pack to monitor for any defects that may develop in the exported fruit. These are fruit samples from standard packhouse which are then kept in a room at ambient temperature and evaluated weekly. The data obtained from the Sunday's River Valley was for historical fruit quality data from 2010 to 2021 (12 years).

Quality parameters evaluated on citrus fruit

Total Soluble Solids measured as Brix – the TSS was measured by juicing a sample of 10 fruit, using a fruit juicer and filtering the juice on a wash. One millilitre of the juice was placed on an Atago refractometer and brix reading recorded. Titratable acidity was measured by sampling 25 ml of citrus juice and titrating with 0.1N Sodium hydroxide to an end point pH of 8.2. The titratable acidity was calculated using the formula (ml NaOH/25 ml) x (0.1 N NaOH/0.1562).

Fruit classification - the sample of 100 fruit was classified based on presentation, clean blemish free fruit was classified as super select, clean fruit with a few small blemishes was classified as Class 1, fruit with some blemishes but still of export quality was classified as Class 2, fruit with a lot of blemishes and not suitable for export, was classified as Class 3 also known as out of grade fruit, considered unsuitable for export.

The incidence of Oleocellosis was measured as a percentage of fruits with the disorder irrespective of size and severity. The incidence of sunburn was measured as a percentage of fruits with the disorder irrespective of size and severity. The incidence of creasing was determined by counting the number of fruits with the disorder irrespective of size and severity.

Decay was separated by type:

- Alternaria rot (*Alternaria citri*) – the incidence of Alternaria rot was determined by counting the fruits with this type of decay irrespective of the size of the lesion.
- Anthracnose (*Colletotrichum gloeosporioides*) - the incidence of anthracnose was determined by counting the fruits with this type of decay irrespective of the size of the lesion.
- Brown rot (*Phytophthora citrophthora)* - the incidence of brown rot was determined by counting the fruits with this type of decay irrespective of the size of the lesion.
- Stem end rot (*Lasiodiplodia theobromae*) - the incidence of stem end rot was determined by counting the fruits with this type of decay irrespective of the size of the lesion.
- Blue mould (*Penicillium italicum*) - the incidence of Blue mould was determined by counting the fruits with this type of decay

irrespective of the size of the lesion.

- Green mould (*Penicillium digitatum*) - the incidence of green mould was determined by counting the fruits with this type of decay irrespective of the size of the lesion.
- Sour rot *Geotrichum citri-aurantii*) - the incidence of sour rot was determined by counting the fruits with this type of decay irrespective of the size of the lesion.

Rind disorders were separated by type:

- Rind pitting – the incidence of rind pitting was determined by counting the number of fruits with the disorder irrespective of severity.
- Rind breakdown - the incidence of rind breakdown was determined by counting the number of fruits with the disorder irrespective of the severity

Results

The total soluble solids of different citrus varieties showed a slight increasing trend over the period of observation (Figure 1). Between 2013 and 2021 the total soluble solids increased by 4.6%. The average titratable acid of different citrus varieties did not show a major change over time (Figure 2). In 2013 the average acidity of fruit was 1.1% and in 2021 the acidity was slightly lower at 1.0%. Oleocellosis, decay, red scale and sunburn on fruit did not show a trend of increasing or decreasing over the period of monitoring (Figure 3).

When citrus fruit quality was monitored on arrival in the market, some varieties, Satsuma and Clementine, stood out with poor quality in the market (Figure 4). The Satsuma in some years recorded up to 45% out of grade fruit. However, the loss in quality did not show a definite trend that could be linked to climate change. The main reasons for poor quality in the market was decay and rind disorders. In isolated cases it was cubing, which occurred because of soft fruit.

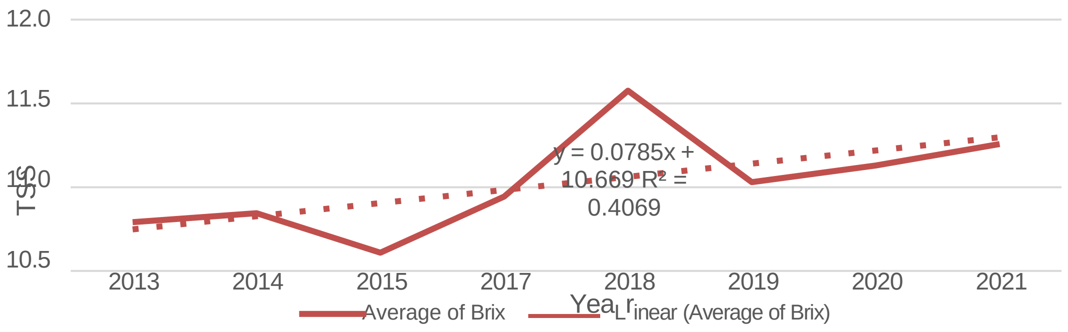

Figure 4: Average total soluble solids of different citrus varieties in the Western Cape monitored between 2013 and 2021.

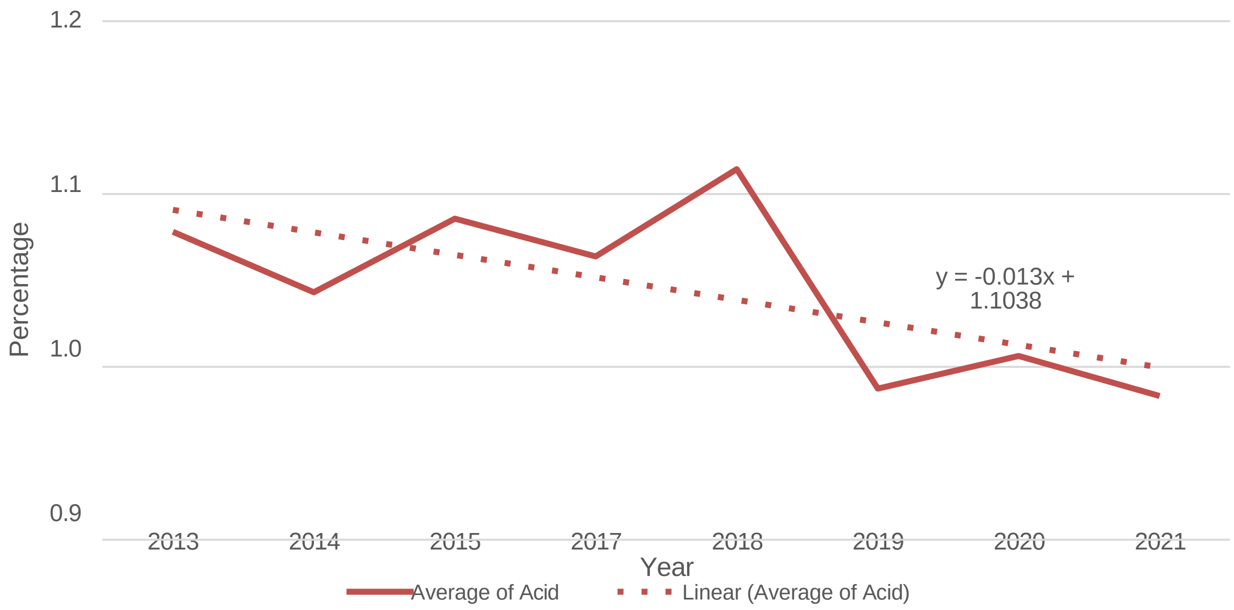

Figure 5: Average titratable acidity of different citrus varieties in the Western Cape.

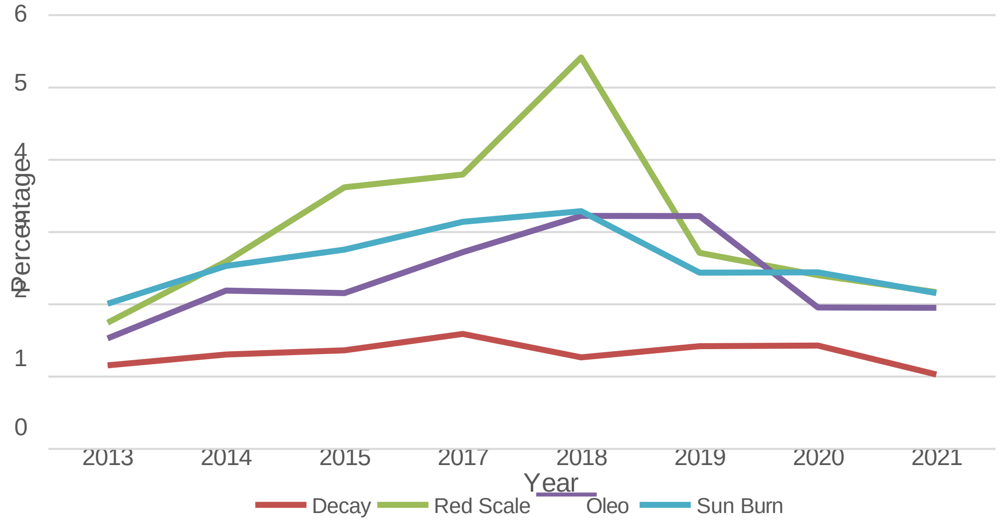

Figure 6: Development of selected disorders on different citrus varieties in the Western Cape monitored between 2013 and 2021.

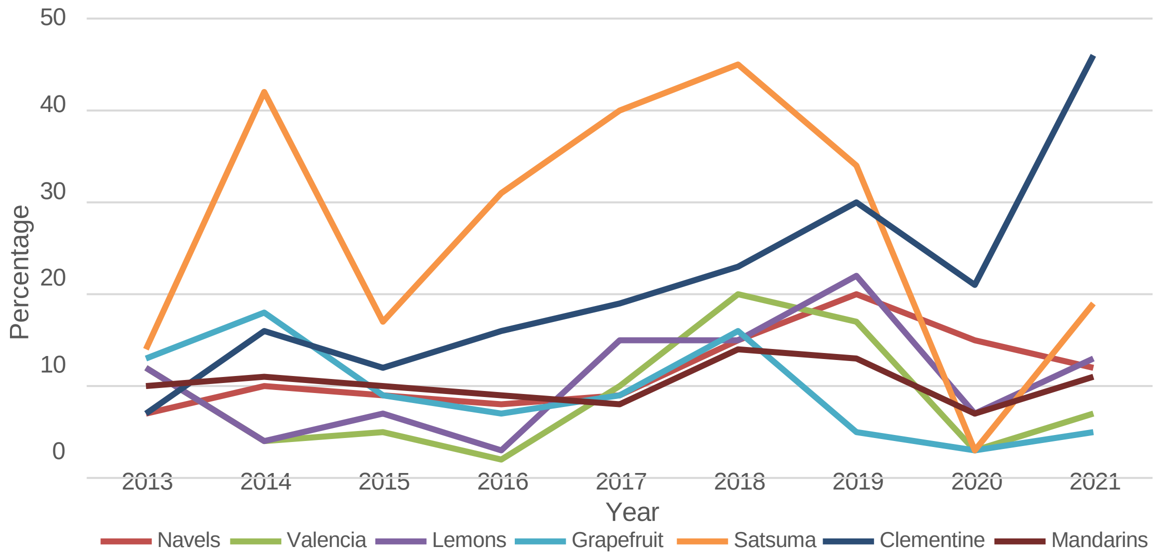

Figure 7: Out of grade fruit on arrival in the market, monitored between 2013 and 2021**.**

Creasing on retention samples showed an increasing trend from 2010 to 2016 (Figure 5). However, after 2016, the levels dropped, and fluctuations thereafter did not show a definite trend of increasing or decreasing.

Rind breakdown spiked in 2011, then decreased drastically in 2012 (Figure 6). From 2012 to 2020, the occurrence and fluctuation of all rind breakdown did not show a definite trend except for a spike in rind breakdown in the 2020 season. Rind pitting showed little fluctuation, hovering between 8 and 10%, for the period of observation.

Sunburn on fruit showed a general upward trend over the twelve-year period of observation (Figure 7). The 2016 season had uncharacteristically high levels of sunburn, which were about three to six times higher than the other season where the disorder was measured. The incidence of Alternaria rot (*Alternaria citri*) fluctuated over the years but did not show a definite trend (Figure 8). Anthracnose (*Colletotrichum gloeosporioides*) reached a peak in the early years, 2013, thereafter it decreased and remained low, especially from 2016 where it has remained close to 0%. The incidence of brown rot (*Phytophthora citrophthora)* also had an early peak, 2011, thereafter decreased and remained relatively low for most of the seasons under observation. Stem end rot (*Lasiodiplodia theobromae*) showed an erratic trend through the observation period that wasn't definite.

Blue mould (*Penicillium italicum*) incidence on fruit showed an upward trend for a few seasons, peaking in 2016, then began decreasing thereafter (Figure 9). Green mould (*Penicillium digitatum*) infection on fruits showed seasonal variation but no definite trend of increasing or decreasing over the years. The incidence of sour rot (*Geotrichum citri-aurantii*) showed seasonal fluctuation until 2015, thereafter decreasing for the rest of the observation period.

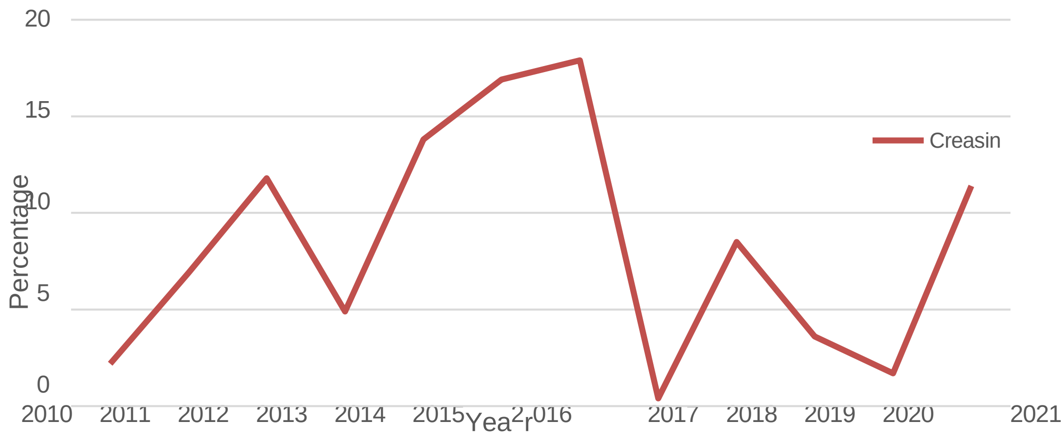

Figure 8: Development of creasing on different citrus varieties in the Eastern Cape monitored between 2010 and 2021.

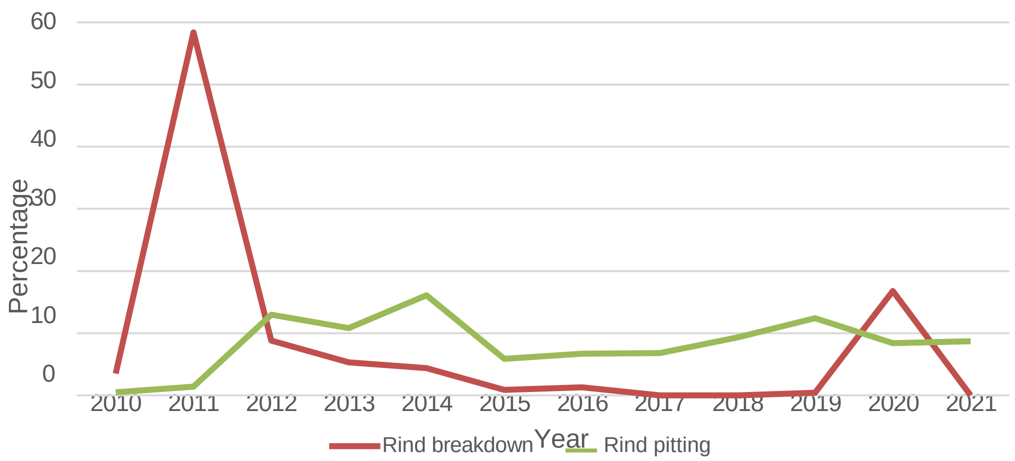

Figure 9: Development of rind breakdown and rind pitting on different citrus varieties in the Eastern Cape monitored between 2010 and 2021.

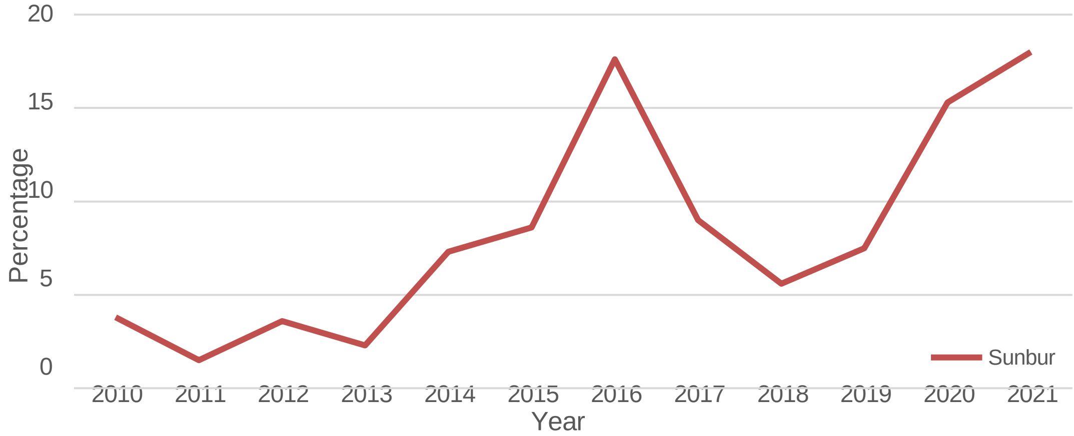

Figure 10: Development of Sunburn on different citrus varieties in the Eastern Cape monitored between 2010 and 2021.

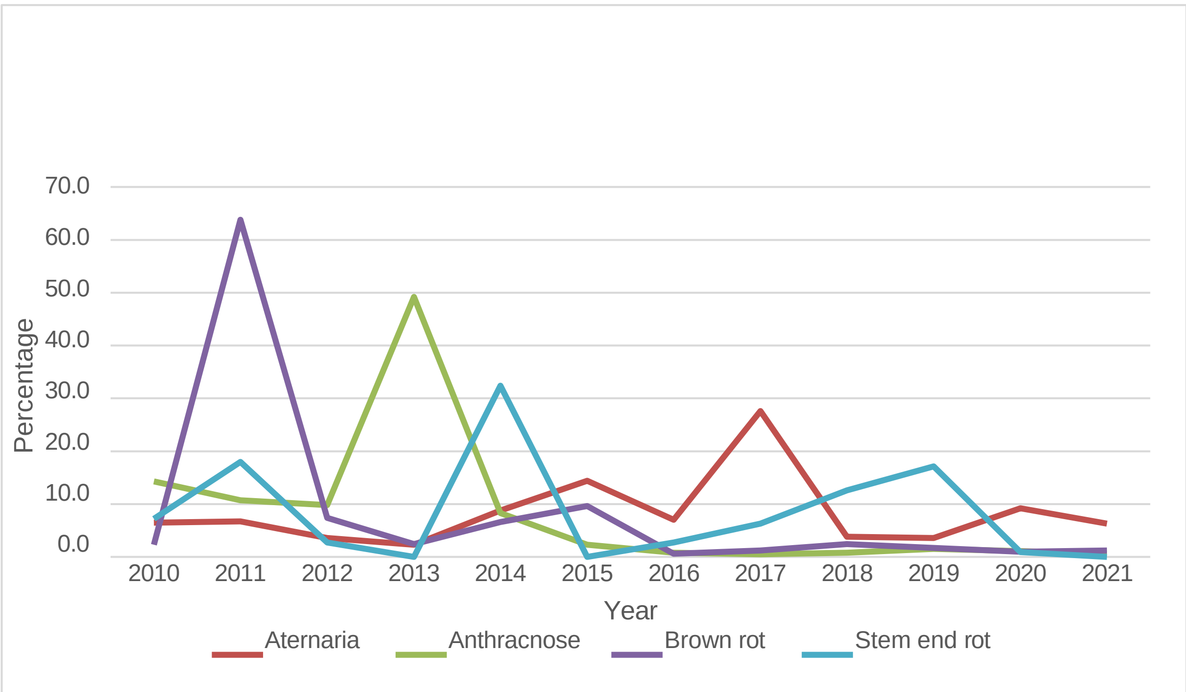

Figure 11: Development of different types of decay on citrus fruit in the Eastern Cape monitored between 2010 and 2021.

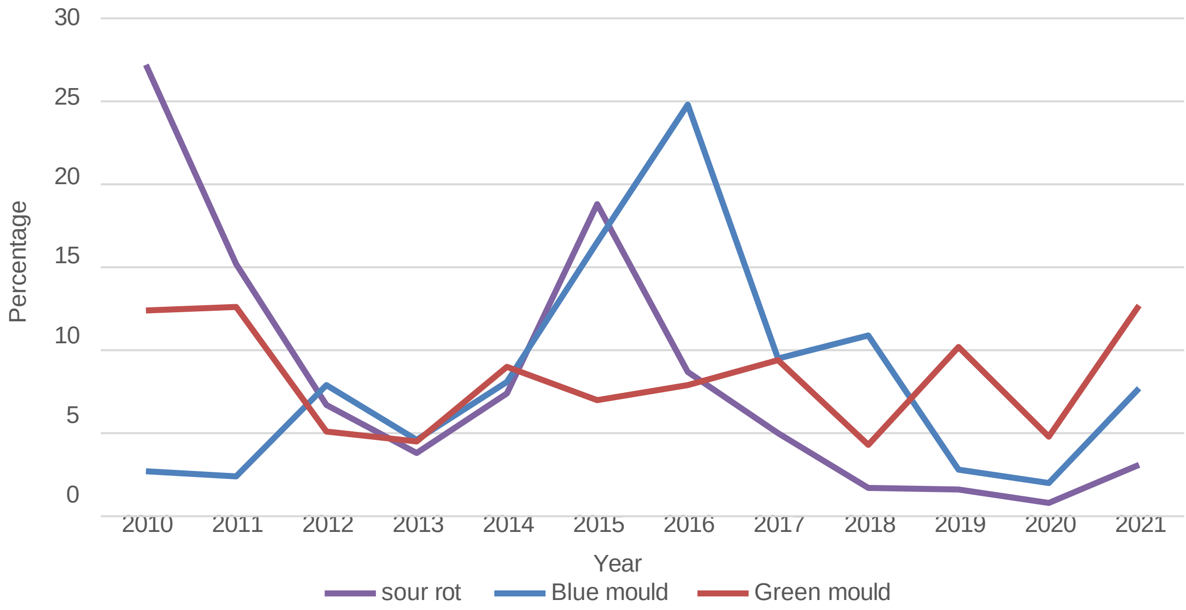

Figure 12: Development of decay, caused by wound pathogens in the, on different citrus varieties in the Eastern Cape monitored between 2010 and 2021.

Discussion

With rising air temperatures and reduced precipitation in the regions, the fruit response observed was higher brix and marginal decline in acidity. This trend is not necessarily unexpected because, it has been shown in numerous studies that reduced water supply to citrus trees during the fruit maturation phase increases soluble solids and acidity in fruit (Verreynne *et al.*, 2001; Valiante and Albrigo, 2004; Treeby *et al.*, 2007; Perez-Perez *et al.*, 2009). The reduction in rainfall allows for better control and management irrigation, where farmers can implement deficit irrigation, uninterrupted by rainfall. The difference with the current result was on acidity which did not increase but showed a marginal decline. Valiante and Albrigo (2004) explained a decrease in acidity of citrus fruit with rising temperatures as the result of increased respiration which may lead to faster turnover of acidity. It is therefore suggested that the decrease in titratable acidity observed in citrus fruit from the Western Cape of South Africa could be in response to rising air temperature resulting in higher respiration and acid turnover. Although, it must be stated that the change in acidity is very small.

Other quality parameters on citrus fruit, including sunburn, decay, oleocellosis and red scale infection, did not show a response to climate change. While there are peaks and troughs in the occurrence of these quality issues, a direct association with temperature or rainfall could not be ascertained. On sunburn in particular, some farms may already be employing some climate change mitigation approaches such as netting or the use of kaoline-based spray products which are known to reduce sunburn (El-Tanany *et al.*, 2019).

The Eastern Cape, experienced drought from 2016 to 2021, therefore the creasing was expected to increase on susceptible citrus varieties. However, this was not the case in the data collected. There are two plausible reasons for this observation. The first reason has been mentioned previously which is the fact that fruit sorting may have removed most of the creasing that had developed in the field. Furthermore, since creasing does not increase in storage, the figures reported in the report are not a true reflection of the creasing levels, that may have developed on fruit in the field (Saleem *et al*., 2014; Juan and Jiezhong, 2017). Secondly, since commercial citrus plantings are irrigated, in South Africa, this could have partially negated the negative effects of the drought, resulting in creasing levels not increasing due to the drought as would be expected.

The seasonality in the occurrence of rind disorders suggests that environmental factors play a role in their development. However, the exact environmental or climatic factors exacerbating rind disorders have not been defined (Lado *et al*., 2018). Several factors, including late rains just before harvest, fruit shading, vitamin C content of fruit, have been associated with the development of rind disorders (Bassal and El-Hamahmy, 2011; Cronjé *et al*., 2011; Cronjé *et al*. 2013 Magwaza *et al*. 2019). Clearly rind disorders are influenced by multiple factors, from environmental to postharvest handling of fruit. The rind pitting trend reported on fruit from the Eastern Cape was variable but generally low during the drought years. This supports the findings by Cronjé *et al*., (2011) that late rains a few weeks before the start of the season can exacerbate the occurrence of the disorder. In this case the drought was beneficial and could have led to less rind disorders.

Sunburn is generally removed during sorting and grading of fruit, so the sunburn reported in this report is that which was missed by the sorting and grading in the packhouse. Since sunburn is photodamage on fruit, occurring in the field, and caused by excessive heat or light irradiance, it cannot develop further after harvest (Munne-Bosch and Vincent, 2019). The observed trend was for Sunburn to increase over the years of fruit quality observation. It is accepted that climate change in the Eastern Cape is associated with increasing temperatures and drier conditions as well as an increase in the number of very hot days (DEDEA, 2011; Munne-Bosch and Vincent, 2019; Ndlovu *et al.,* 2021). Therefore, the sunburn trends are in line with the trends seen in climate change.

Alternaria rot (also known as black rot of citrus) is caused by *Alternaria citri* and is a widespread postharvest disease across all citrus producing areas, particularly humid environments where it causes significant economic losses (Umer *et al*., 2021, Sardar *et al*., 2022). The pathogen affects most above ground organs of citrus trees including leaves, branches, twigs, as well as fruits (Umer *et al*., 2021). Alternaria rot can infect plant parts for a wide range of temperatures, from 15ºC to 35ºC, with the ideal being 25ºC. However, fruits are susceptible for much longer in cooler climates (Umer *et al*., 2021). In the period under study, no objective trend wasnoted with regards to the development of Alternaria rot on citrus fruit, except for the spike in prevalence in the 2017 season.

Anthracnose rot is a citrus disease caused by multiple species within the *Colletotrichum* genus of fungi, causing serious losses on production globally (Wang *et al.,* 2021). Anthracnose infection before harvest reduces yield, while postharvest anthracnose reduces fruit quality, negatively affecting fruit export and marketability (Phoulivong *et al*., 2012). The fungus requires humid conditions as well as a temperature range of 25 to 28ºC for infection to occur (Majune *et al*., 2018). The disease is more prevalent during springs of prolonged wet periods and seasons of most rainfall occurring late in the season than normal (Eskalen and Adaskaveg, 2019). Anthracnose has remained very low in the Eastern Cape over the last few seasons, and this was possibly due the low rainfall received in the province (Mahlalela *et al*., 2020).

Brown rot (*Phytophtora* spp.) has remained relatively low in the area, with a low number of fruits with the decay intercepted from retention samples. *Phytophtora* is a soilborne fungal disease, requiring water or rain drop splash to move from the soil to low hanging fruit

(Savage *et al.*, 2021). Furthermore, fruits need to be wet for at least three hours with a temperature range of 27 to 30°C, for spores to infect (Timmer *et al.,* 2000). With climate change causing drought conditions in the Eastern Cape, the low cases of brown rot during this period are in line with the prevailing conditions in the province.

Diplodia stem-end rot is another economically important postharvest decay caused by the pathogen *Lasiodiplodia theobromae* (synonyms: *Botryodiplodia theobromae* and *Diplodia natalensis*) (Zhang and Bautista-Baños, 2014). The disease affects all kinds of citrus fruits, and very prevalent in hot and humid climates of tropical and subtropical regions (Forehand, 2021). Infection on immature fruits in-field requires high temperature as well as high and frequent rainfall, whilst degreening as well as excess delay in processing fruits at the packhouse are ideal conditions for the development of symptoms post harvesting (Zhang and Bautista-Baños, 2014). The occurrence of stem-end rot has been low in the Eastern Cape which can be attributed to the low rainfall received in the region.

Green mould and blue mould of citrus fruit are caused by the same genus of pathogen and are considered as the most economically important postharvest diseases of citrus fruit in all production areas (Palou, 2014). Green mould did not show a definite trend with rising temperature and reduced rainfall. Sour Rot caused by *Geotrichum citri-aurantii* is the third most economically important wound pathogens of citrus (Wang *et al.*, 2020). The prevalence of sour rot has been low since the province was affected by drought from 2016, which is expected as the pathogen is most active under high rainfall conditions (François *et al.*, 2022). The result on wound pathogen could also be confounded by good post-harvest fungicide treatments, in the packhouse and good cold chain management all which can reduce the incidence of decay on citrus fruit (Njombolwana *et al.*, 2013).

There is indication that some rind disorders may be reduced in hot and dry weather conditions, as less rind disorders developed, in storage, during the drought years compared to the period before the drought. Disorders like creasing and sunburn, clearly do not develop any further in storage and are mainly determined by pre harvest conditions. The development of most types of decay seemed to reduce during the drought years. Therefore, climate change had both negative and positive effect on fruit quality. Most of the positive effects may have been due to climate change adaptation, like shade netting of orchards, use of precession farming and high-tech post-harvest handling in the packhouse.

Conclusions and recommendations

The study showed the vulnerability of citrus fruit to climate change, particularly rising temperatures and reduced precipitation. It was further shown that the effect of climate change is not only negative but can be positive in some cases. While sunburn poses a great risk, by increasing out of grade fruit, which can lead to low profitability on the farm. The positive results of climate change included improved internal quality, in terms of total soluble solids and lower incidence of decay and rind disorders under warm and dry conditions.

To remain resilient and profitable, farms have implemented and need to continue to invest in climate change adaptation measures, which significantly lessens the impact of climate change. Shade netting, climate smart precision farming, state of the art degreening chambers and packhouses with high tech equipment are some of the adaptations seen on farms. The results of the study suggest that the negative impact of climate change on citrus fruit quality is not very pronounced at this stage.

There is room for further research on this topic, where farms with climate adaptation will be separated from farms without any adaptations. Furthermore, the investigation should start on the farm and continue to the packhouse and finally to arrival in the market, to assess the effect at different levels of the value chain.

Acknowledgment

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