Effect of planting density and nitrogen application rate on grain quality and yield of three barley (*Hordeum vulgare* L.) cultivars planted in the Western Cape Province of South Africa

by

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DECLARATION

I, Mholi Khumalo, declare that the contents of this dissertation/thesis represent my own unaided work, and that the dissertation/thesis has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my own opinions and not necessarily those of the Cape Peninsula University of Technology.

Signed **Date**

ABSTRACT

Grain yield and its components are very important and complicated in barley (*Hordeum vulgare* L.) and are highly influenced by environmental factors and agronomic management practices. For 2018 growing season, a study was designed under rainfed conditions to evaluate the effects of nitrogen (N) fertilizer rate (0, 10, 20, 30 and 40 kg ha^{-1} of N) and planting density (120, 140, 160, and 180 to 200 seeds m^{-2}) on the agronomic performance of three barley cultivars (Elim, Hessekwa and S16). A randomized complete block design with 3 replications was used. Combined analysis of variance showed significant ($p<0.1$) differences among cultivars, N rates and planting densities. The main objective of this study was to determine the effects of planting density and different fertilizer application strategies on barley grain yield and quality. The results showed that biggest increases on yield and yield components were observed at 180 seeds m^{-2} and 80kg ha^{-1} N rate. Higher N rates generally reduced kernel size. Kernel size was both increased and decreased by increasing planting density as well as N rate. Increasing planting density from 180 to 200 seeds m^{-2} generally provided slight reductions in grain N concentration and reduced kernel size. The three cultivars expressed a significant effect on kernel plumpness and N content of grain. The most beneficial agronomic practices for malting barley production in Western Cape were application of N fertilizer at optimum rate depending on cultivar, locality and rainfall and planting seeds at a rate of 160-180 seeds m^{-2} depending on cultivar. A planting density of 160-180 seeds m^{-2} at a rate of 80 kg N ha^{-1} is recommended for planting barley under dry land in the Western Cape.

Key words: planting density, kernels, plumpness, nitrogen rate

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DEDICATION

I dedicate this thesis to three beloved people who have meant and continue to mean so much to me. Although one is no longer in this world, his memories continue to regulate my life. First and foremost, to my biological father Mvuselelo Khumalo whose love for me knew no bounds and, who taught me the value of hard work. Thank you so much "Mzilikazi", I will never forget you.

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LIST OF ABBREVIATIONS

ARC	Agricultural Research Council
CV	Coefficient of variance
cm	Centimetre
DAFF	Department of Agriculture, Forestry and Fishery
g	Gram
ha	Hectare
ha^{-1}	Per hectare
K	Potassium
kg	Kilogram
m	Meter
m^2	Square metre
m^{-2}	Per square metre
ml	Millilitre
N	Nitrogen
Ns	Non-significant
P	Phosphorous
SABBI	South African Barley Breeding Institute
SAS	Statistical Analysis System
%	Percentage

CHAPTER ONE

INTRODUCTION AND BACKGROUND

1.1 Introduction

Barley (*Hordeum vulgare* L.) is probably the fourth most important cereal crop after maize (*Zea mays* L.), wheat (*Triticum aestivum* and rice (*Oryza sativa*) worldwide (Alam *et al*., 2007). In South Africa, barley is the third most important grain crop after wheat and maize, and is the second most important small grain after wheat (DAFF, 2013). In South Africa barley is widely grown in the dryland areas of the arid and semi-arid regions where nitrogen (N) and water are the main limiting factors affecting agricultural production (Mohammad *et al*., 1999).

In South Africa, barley production is limited to specific areas in the Northern and Southern Cape as well as the North West Province (DAFF, 2017). In the Southern Cape barley is grown in areas surrounding Bredasdorp, Caledon, Napier, Riviersonderend and Swellendam where it is grown under dryland conditions, while in the Northern Cape it is grown under irrigation (DAFF, 2017). Barley is also grown by some emerging farmers in the North West Province (DAFF, 2010). In the Northern Cape and North West Provinces, barley production takes place close to stable water sources namely the Harts River, Vaal River, Vaalharts and the Orange River Irrigation scheme (DAFF, 2013).

For the 2016 season, the Western Cape Province was the largest producer of barley in South Africa with a contribution of 89%, followed by the Northern Cape and North West Provinces with contributions of 6% and 3%, respectively (DAFF, 2017). Extensive barley production in the Western Cape can be ascribed to the fact that the province is a winter rainfall area, making it a suitable location for production of barley and other winter cereals (DAFF, 2013), and also due to fewer competing crops such as maize and vegetables.

Barley can grow in a broad range of environmental conditions and can even grow in semi-arid areas with annual rainfall as low as 200–350 mm (Munir, 2002). The cultivation area for malting barley under rainfed conditions is at present confined to a very particular region, namely the Southern Cape, stretching from Bot River in the west to Heidelberg in the east (DAFF, 2013). However, the risk of unpredictable weather conditions in the Southern Cape has resulted in barley production being introduced to the cooler central areas of the Northern Cape Province where the crop is grown under irrigation. Barley requires far less water than other cereal crops (e.g. maize, oats and wheat) and can be produced in areas where water for irrigation is less easily obtainable (Alam *et al*., 2017).

Abiotic stresses such as nutrients, water and temperature are contribute to the low yields of malting barley (Fekadu and Skjelvåg, 2002). Sinebo *et al*. (2003) reported that about 65% of grain yield variability in barley was ascribed to N stress. Poor soil fertility is another major factor limiting the production and production stability of barley (Fekadu and Skjelvåg, 2002). Phosphorus (P) and N are among the most productivity limiting nutrients (Kho, 2000).

One of the most important crop management practices is planting density and is accorded a high research priority (Sangoi *et al*., 2002). Planting density affects yield by influencing yield components such as the number of tillers plant^{-1}, the number of kernels ear^{-1}, number of ears plant^{-1}, and individual kernel weight (Ahmadi *et al*., 1993). Under adequate water and nutrient supply, high plant density can result in an increased number of tillers unit area^{-1}, with an increase in grain yield (Bavec, 2002).

Thousand kernel mass is an important feature that determines the number of kernels kg^{-1} seed. This varies from 36 – 54 g per 1000 barley kernels, which can have a distinct influence on seeding rate, typically 130-170 plants m^{-2} (SABBI, 2013). Malting begins with the attainment of quality grain (Oser, 2015). Maltsters require barley that "malts homogeneously and modifies quickly, requires no or little cleaning and that will deliver malt of an acceptable and consistent brewing quality" (SABBI, 2013). Therefore, maltsters prescribe certain quality standards for malting barley to ensure that the malt is produced in the most economical way possible (SABBI, 2013).

1.2 Motivation of the research

Different cultivars of malting barley react differently to an increased planting density and N requirements and the timing thereof, that is, single top dressing or split applications (Paynter and Malik, 2017). The introduction of a great number of recently introduced new malting barley cultivars means that systematic research should be carried out to determine their requirements in terms of the optimal planting density and N application in relation to grain yield and ultimate quality (Oser, 2015). On the one hand, a higher concentration of N will result in higher yields along with the optimum grain quality (Overthrow, 2001). On the other hand, these higher N concentrations may create a requirement for plant growth regulators, which may themselves negatively affect yield and quality (Overthrow, 2005). Nitrogen effects are also be influenced by plant, which may influence the standing ability of the crop and therefore its requirement for plant growth regulators (Wade and Froment 2003).

While high seeding rates increase early dry matter accumulation and weed competitiveness, they may have negligible or even negative effects on grain yield because of increased inter-plant competition (Park *et al*., 2003). Optimum seeding rates for grain yield of winter cereals are bound to be higher when seeding is delayed beyond the optimum seeding date (McKenzie *et al*., 2007). The effects of planting density on barley grain yield and malting quality have also been an important variable, but results from most studies have indicated little to no improvement in yield at seed rates above 200 seeds m^{-2} (O'Donovan *et al*., 2009). O'Donovan *et al.* (2011) concluded that seeding malting barley at 400 compared with 200 seeds m^{-2} reduced kernel plumpness, but also resulted in earlier maturity, more uniform kernels, and lower protein concentration. The authors recommended that planting density for malting barley need to be defined to optimize seed uniformity and maintain a comparatively low protein without reducing kernel plumpness to unacceptable levels.

1.3 Objectives of the research

The overall aim of the research was to investigate the effects of planting density and nitrogen application on grain yield and quality of different barley cultivars planted in the Western Cape Province of South Africa. The specific objectives were:

- To establish the optimum planting density guidelines for new experimental barley cultivars, before they are commercially introduced to producers,
- To determine the relationship between planting density and different fertilizer application on barley grain yield and quality,
- To determine the effect of different N rates and planting densities across different cultivars on yield and grain quality

1.4 Chapter outline

This dissertation consists of six chapters. Chapter 1 provides the background and introduction to the study. Chapter 2 presents the general literature review of the study. Chapter 3 is the general materials and methods used. This is followed by chapter 4 which gives results and discussion on the effect of planting density and nitrogen application on grain yield of three barley (*Hordeum vulgare* L.) cultivars planted Western Cape. Chapter 5 gives results and discussion on the effect of planting density and nitrogen application on grain quality of three barley (*Hordeum vulgare* L.) cultivars planted in the Western Cape. Chapter 6 provides the conclusions and recommendations from the study.

CHAPTER TWO

GENERAL LITERATURE REVIEW

2.1 Introduction

Barley is the most important small grain in South Africa after wheat, and its main uses include production of malt, animal feed, and pearl barley (DAFF, 2016). In South Africa, barley is mainly cultivated for malting purposes because there is no significant feed market for barley due to the oversupply of maize (Van der Vyver, 2013)**.** The small part of barley crop that is less suitable for malting is used for animal feed. The average annual commercial production for barley in South Africa is about 261 000 tons while the local consumption requirements exceeds 287 000 ton per year (DAFF, 2016). Until 1997, barley was only produced in the Western Cape Province under dryland conditions with small quantity from Northern Cape, but currently it is also widely grown in the Northern Cape under irrigation (Van der Vyver, 2013).

Relationships between grain yield and quality in barley are often inconsistent and affected by cultivar, general soil fertility, soil water availability, fertiliser N management, and by patterns of pre- and post-anthesis N uptake (De Ruiter, 1999). Given that N is the most limiting nutrient for crop productivity in the major world's agricultural areas, adoption of good N management strategies often results in high economic benefits to farmer (Shafi *et al.*, 2011). Marshall1 and Ellis (1998) concluded that optimum yield is obtained by N fertilizer application at the higher end of current recommendations. In malting barley production, there is a challenge in balancing the aim of growing crops to meet the requirements of maltsters and of achieving the highest gross margin if the standard for grain N content is not met (Marshall1 and Ellis, 1998).

Plant density is an important factor in determining the competitive ability of cereals (Doll *et al.*, 1995). In Western Australia, increasing the seed rate of barley significantly decreased the quality of barley crops in medium to high rainfall areas (Trainor and Paynter, 2017). Planting density that is higher than the optimum may reduce grain size and increase lodging, especially under irrigation. Lower than optimum planting density will reduce yield potential, although lower rates should be used when there is limited subsoil moisture at sowing, and in drier areas (GRDC, 2018). High seeding rates tend to decrease individual kernel weight and increase screenings in barley (GRDC, 2018).

2.2 Nitrogen and planting density effects on barley grain yield and quality

2.2.1 Introduction

Yields of barley under each of N and P stresses are reported to be less than 50% of those of the respective non-stressed environments (Dejene and Fetien, 2014*).* An increase in N application generally increased the spike length, fertile tillers plant^{-1}, grain number spike^{-1}, spike number m^{-2}, plant height, and reduced the 1000 grain weight (Munir 2002). Increasing N concentration results in a decrease in the harvest index (Munir, 2002). Shafi *et al*. (2011) concluded that though spilt N application had little effect on yield, it resulted in decreased lodging.

Nakano and Morita (2009) reported that when the objective is to increase grain yield, N application at active tillering is more effective than that at anthesis, but that if the intention is to increase grain protein content, N application at anthesis is more effective than that at active tillering. Iwabuchi *et al*. (2007) also reported that when 4 and 2 g N m^{-2} were applied at active jointing and tillering, respectively, the grain protein content increased linearly with increased N application at anthesis at a rate of about 0.5% per 1 g N m^{-2}. On the other hand, Campbell *et al*. (1991) concluded that protein content of grain is not influenced by planting density. However, information on the interactions between planting density and N application rates at different stages on grain yield and protein content is limited. Although high seeding rates increase early dry matter accumulation and weed competitiveness, they may have negligible to negative impacts on grain yield due to increased inter-plant competition (Park *et al*., 2003).

2.2.2 Plant growth and development

One of the factors affecting crop morphology, crop growth rate and grain yield is N (Shafi *et al*., 2011). Excessive plant-available N produces barley plants that are vulnerable to lodging and pests, with resultant decreased yields and increased input costs (Alley *et al.*, 2009). On the other hand, insufficient N availability to barley plants can result in very low yields, and hence, reduced profits, compared to a well fertilized barley crop (Alley *et al.*, 2009). Nitrogen fertilizer rate and timing are the most important tools available after planting to manipulate barley to produce higher yields ha^{-1}. In barley, N is needed for early tiller development to set up the crop for a high yield potential (Shafi *et al*., 2011).

Efficient N use is important for reducing environmental contamination such as leaching of N through runoff (Scharf and Alley, 1988). Although the yield response of malting barley to N rate may be very pronounced under most circumstances, the process of malting requires grain with a N content of less than 21.6 g kg^{-1} (Baethgen *et al.*, 1995). Therefore, N fertilisation strategies must be carefully adjusted in order to balance the often-contradictory goals of maximal production with the need to achieve low N levels in grain (Baethgen *et al.*, 1995). Split application of N fertiliser in order to meet the N requirements by the crop throughout the growing season is perhaps the best strategy to achieve high grain yields while concomitantly maintaining malting quality (Baethgen *et al.*, 1995). Studies with wheat have shown that applying part of the N fertilizer in early growth stages and part at the onset of stem elongation usually results in maximum N use efficiency (Baethgen and Alley, 1989).

Gregersen *et al*. (2008) reported that water and N supply as the major environmental factors controlling plant growth, development and survival under drought stress conditions. Water deficiency has negative impacts on photosynthetic capacity and leaf elongation, causing changes in protein synthesis, cell membrane properties and N metabolism and resulting in a decline in grain yield (Gous *et al*., 2015).

2.2.3 Grain yield

Grower management strategies for malting barley production attempt to maximise grain yield and kernel plumpness, and minimize grain protein and usually, management strategies that maximise grain yield will not optimise grain protein and malting quality (Lauer and Partridge, 1990). Nitrogen fertilizer effect on grain yield can also be influenced by late planting (Weston *et al*., 1993). Planting date and N fertilizer management significantly affect barley grain yield, grain protein and kernel plumpness, and delayed planting results in decreased grain yield and kernel plumpness on the one hand, and increased grain protein content on the other hand (Lauer and Partridge, 1990).

Hochhalter (2015) observed barley grain yield reductions of 295 kg ha^{-1} when planting was delayed by two weeks, but grain yield increased with the addition of N fertilizer regardless of planting date. The study also showed that the effect of N fertilizer on barley grain yield was dependent on growing season precipitation and soil moisture. Bole and Pittman (1980) conducted research on the effect of soil moisture at planting, growing season rainfall, and N level on barley grain yields and observed that rainfall during the growing season had a three times greater effect on barley response to N than soil moisture at planting.

Baethgen *et al*. (1995) studied the effect of N fertilizer on growth, yield components and grain yield of malting barley and observed that tiller number increased when all the N was applied at sowing versus split application at mid-tillering (Z22) or end of tillering (Z30). Regardless of application timing, the number of spikes m^{-2} and the number of kernels m^{-2} increased with increasing N rates; however, there was an increase in tillers when more N was applied at sowing versus mid-tillering (Baethgen *et al*., 1995). This can possibly translate into higher grain yields when there is little or no moisture stress, but fewer fertile tillers in moisture-deficient conditions (Hochhalter, 2015).

Hochhalter (2015) conducted a study on N effects on low-protein and semi dwarf genotypes for malting barley production and observed that increasing rates of N fertilizer delayed spike emergence by up to nine days depending on cultivar. Insufficient amounts of N, especially during plant establishment, can decrease grain yield and end-use quality below acceptable levels (Baethgen *et al.*, 1995).

2.2.4 Kernel plumpness

Kernel plumpness can be defined as the percentage weight of grains retained over a 2.5mm sieve (% w/w) (Walker et al., 2009). A uniform kernel size ensures grain modifies (absorbs water) evenly when steeped. The desirable kernel plumpness in malting barley is when it is above 90%, although in some places, the minimum recommended is 70% (Morojele1 and Kilian, 2015). Morojelel and Kilian (2015) studied optimization of N application under irrigated barley production in the Northern Cape and North West provinces of South Africa and concluded that high kernel plumpness was as a result of high amounts of photosynthates redistributed from the stem and other parts of the plant to fill the kernels. On a sliding scale, more is paid pro rata for barley with a kernel plumpness that increases from 70% to 100% (SABBI, 2009).

Because kernel plumpness is important for homogeneity during the malting process (SABBI, 2009). Thin kernels are not desirable because they take up water faster than plump kernels and have a relatively higher percentage husk, which can result in beer with an astringent taste (SABBI, 2009). This, a more uniform plumpness is desirable as it will result in better malt quality. Low kernel plumpness is caused by unfavourable conditions during the grain filling period, as late ears ripen too fast or if an initial yield potential exceeds the capacity of the environment at the grain filling stage (SABBI, 2009). In areas where soil water deficits and heat stress occur during the grain filling period and where certain plant diseases, such as *Rhynchosporium secalis* (scald), are common, significant losses could occur, resulting in the downgrading of the crop due to a low kernel plumpness percentage (Agricultural Research Council, 2015).

The kernel plumpness of all the present barley cultivars in South Africa can be described as good to very good (SABBI, 2009). Kernel plumpness determines the grade of the grain and soil water deficit and heat stress during the grain-filling period can cause considerable losses (SABBI, 2015). O'Donavan *et al.* (2011) conducted a study on the effect of seeding date and seeding rate on malting barley and found that the average plumpness at 300 seeds m^2 was 887 mg g^{-1}, which exceeds the required limit of 800 mg g^{-1} and the largest decreases in kernel plumpness tended to occur at seeding rates above 300 seeds m^{-2} with a relatively minor decline as seeding rate increased from 100 to 300 seeds m^{-2} (O'Donovan *et al.*, 2011).

CHAPTER THREE

GENERAL MATERIAL AND METHODS

As the material and methods employed at the three experimental sites (Caledon, Malmesbury and Heidelberg) were basically the same, they are presented in this chapter. Where differences occurred, they are specified in Chapters 4 and 5.

3.1 Sites and soil

Experimental field studies were conducted under dryland conditions during the 2018 growing season at three agricultural research farms in the Western Cape Province of South Africa, namely the South African Barley Breeding Institute (SABBI) at Caledon, Malmesbury and Heidelberg. The soil type for all three localities was clay loam. Selected properties of these three soils are presented in Table 3.1.

Table 3.1 Selected properties of the soils at Caledon, Heidelberg and Malmesbury experimental sites

Locality	Soil type	Stone fraction	Colour	Soil depth
Caledon	Clay loam	Medium	Light brown	15-20 cm
Heidelberg	Clay loam	Medium	Reddish	15-20 cm
Malmesbury	Clay loam	High	Brown	15-20 cm

Source: South African Barley Breeding Institute (2018)

3.2 Rainfall and temperatures

Rainfall data (Figure 3.1), and maximum and minimum temperatures (Table 3.2) recorded during the 2018 growing season were compared with the 2017 and 2016 averages at Caledon.

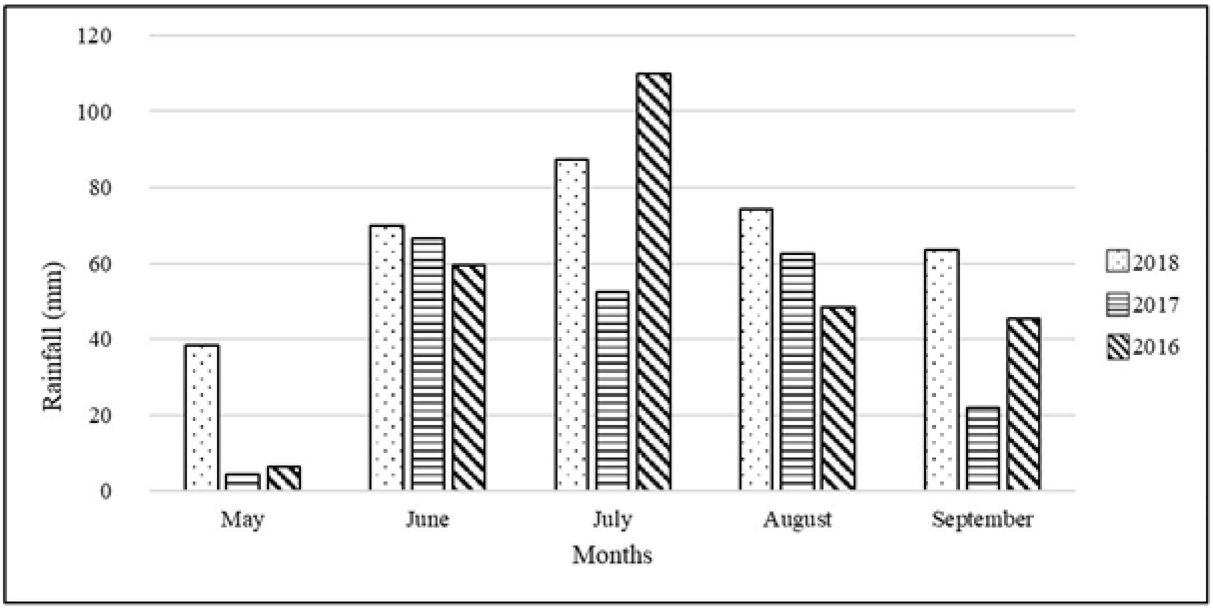

Figure 3.1 Monthly rainfall (mm) from May to December during the 2018 growing season compared with the 2017 and 2016 growing season averages at Caledon.

Table 3.2 Mean monthly maximum and minimum temperatures during the 2018 growing season compared with the 2017 and 2016 averages for Caledon.

	2018 Season		2017 Season		2016 Season	
Months	Max °C	Min °C	Max °C	Min °C	Max °C	Min °C
May	22.5	10.6	23.1	10.6	22.3	10.6
June	18.9	8.3	17.9	6.4	18.2	7.6
July	19.3	7.2	18.2	6.2	16.9	7.6
August	16.9	5.4	17.6	7.5	19.4	7.8
September	19.6	8.3	21.0	8.5	18.8	8.5
October	26.0	11.4	22.7	9.1	23.3	10.3
November	25.3	11.5	25.0	11.7	25.6	13.0
December	27.8	14.7	27.4	14.4	29.1	15.2
Averages	22.0	8.8	21.6	9.3	21.7	10.1

Rainfall data (Figure 3.2), and maximum and minimum temperatures (Table 3.3) recorded during the 2018 growing season were compared with the 2017 and 2016 averages at Malmesbury.

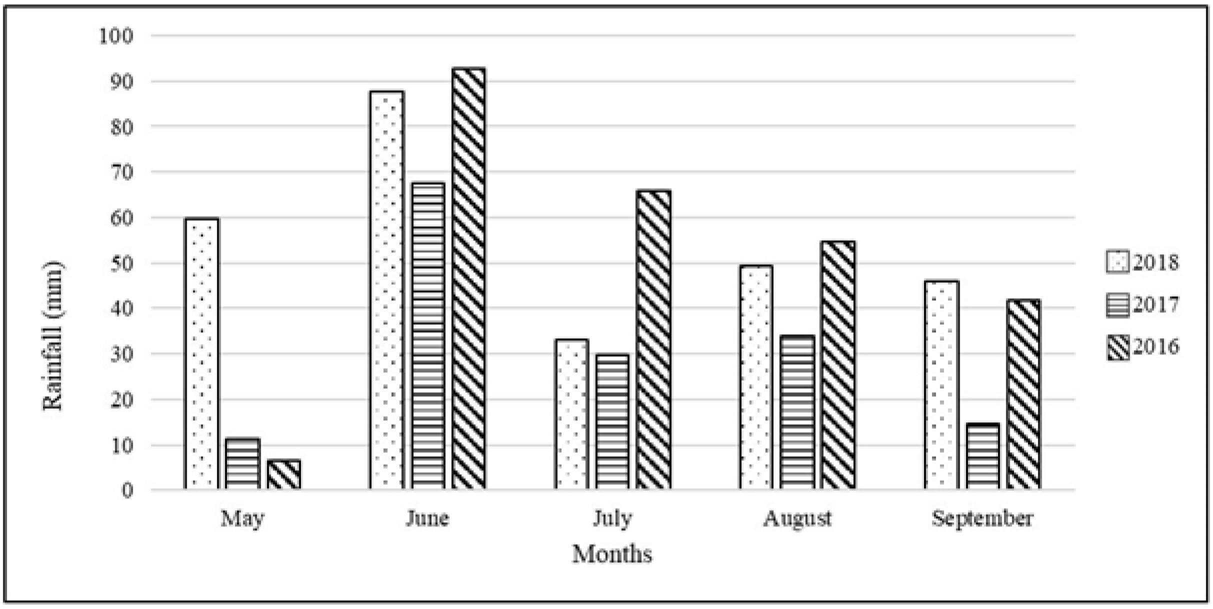

Figure 3.2 Monthly rainfall (mm) from May to December during the 2018 growing season compared with the 2017 and 2016 growing season averages at Malmesbury.

Table 3.3 Mean monthly maximum and minimum temperatures during the 2018 growing season compared with the 2017 and 2016 averages for Malmesbury.

Months	2018 Season		2017 Season		2016 Season	
	Max °C	Min °C	Max °C	Min °C	Max °C	Min °C
May	21.5	12.2	24.3	12.0	22.8	11.4
June	17.5	9.5	17.6	8.4	17.9	8.5
July	19.1	9.3	17.7	7.2	16.9	7.6
August	16.4	6.4	17.4	7.4	16.6	8.5
September	18.5	7.4	22.2	9.0	19.9	8.3
October	28.0	13.5	23.5	9.7	24.5	10.4
November	27.7	12.6	26.9	12.6	28.4	12.1
December	28.5	14.0	30.3	15.4	30.2	15.1
Averages	22.2	10.6	22.4	10.2	18.8	10.2

Rainfall data (Figure 3.3), and maximum and minimum temperatures (Table 3.4) recorded during the 2018 growing season were compared with the 2017 and 2016 averages at Heidelberg.

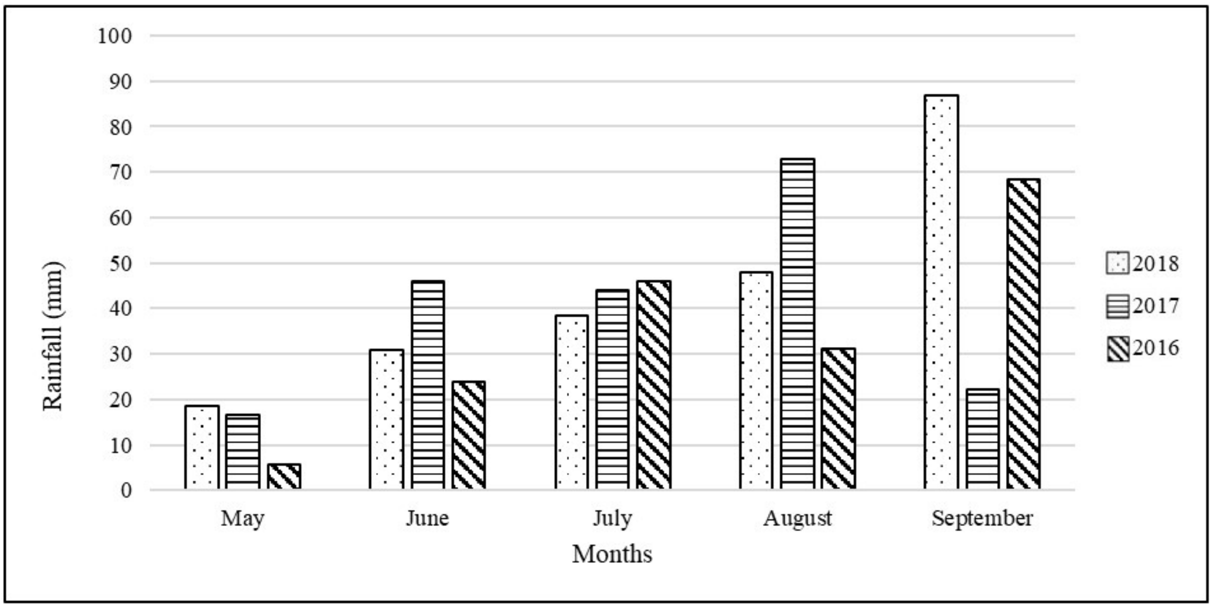

Figure 3.3. Monthly rainfall (mm) from May to December during the 2018 growing season compared with the 2017 and 2018 growing season averages at Heidelberg.

Table 3.4 Mean monthly maximum and minimum temperatures during the 2018 growing season compared with the 2017 and 2016 averages for Heidelberg.

	2018 Season		2017 Season		2016 Season	
Months	Max °C	Min °C	Max °C	Min °C	Max °C	Min °C
May	23.8	12.3	22.7	11.9	21.7	11.2
June	20.0	10.0	19.3	8.8	18.4	9.5
July	20.6	10.3	18.8	8.0	17.4	8.4
August	17.5	7.7	17.9	8.2	19.9	9.5
September	19.6	8.9	21.3	10.1	19.4	9.5
October	25.9	13.0	23.1	10.1	23.1	11.0
November	25.0	12.4	24.5	12.3	24.6	13.3
December	27.0	15.0	26.7	14.5	29.5	15.7
Average	22.4	11.2	18.7	10.5	21.8	11.0

3.3 Experimental design and treatments

All barley trials were planted under dryland conditions. Three cultivars (Hessekwa, Elim and S16) were planted at Caledon, Heidelberg and Malmesbury. The planting density range was 120, 140, 160, and 180 to 200 seeds m^{-2}, which translated to 50, 59, 67, 76 and 84 kg of seed per hectare, respectively. Specific N treatments are presented in Table 3.5. All trials were planted in three replicates using a randomised complete block design with a split plot arrangement. Individual plots were 1 m wide and 5 m in length. Thousand kernel weight (TKW) was 42.0g and kernels planted m^{-2} was 140 g for all three cultivars. All trials were planted using a Wintersteiger plot planter during optimum planting dates in May and harvested early November with a Wintersteiger Delta plot harvester. The actual planting and harvesting dates are presented in Table 3.6.

3.5 Crop protection

Weeds, insects and disease control were applied optimally as required to ensure a competition free environment for barley plants throughout the growing season. Weed control was achieved by the application before planting of Triflurilan at 2000 ml ha^{-1} and Preeglone at 1500 ml ha^{-1} followed by an application of Boxer at 3000 ml ha^{-1} and Logran at 30g ha^{-1} after planting. The first application after 8 weeks was a mixture of Abacus at 1000 ml ha^{-1} and Cyperfos at 800 ml ha^{-1} and that was followed up by a mixture of Ceriax at 800 ml ha^{-1} and Cyperfos at 800 ml ha^{-1} at flag leaf stage (Table 3.7). Maintenance of the trials i.e. spraying of alleys involved the use of Preeglone.

Table 3.5: Planting density and nitrogen treatments levels for all three localities

Treatment No.	Variety	Locality specific N-treatment		
		Caledon	Heidelberg	Malmesbury
1	Hessekwa	60:00	20:00	40:00
2	Hessekwa	60:10	20:10	40:10
3	Hessekwa	**60:20**	**30:00**	**40:20**
4	Hessekwa	60:30	30:10	40:30
5	Hessekwa	60:40	30:20	40:40
6	Elim	60:00	30:20	40:40
7	Elim	60:30	30:10	40:30
8	Elim	60:20	30:00	40:20
9	Elim	60:30	20:10	40:10
10	Elim	60:40	20:00	40:00
11	S16	60:00	20:00	40:00
12	S16	60:10	20:10	40:10
13	S16	60:20	30:00	40:20
14	S16	60:30	30:10	40:30
15	S16	60:40	30:20	40:40*

*Note: 00:00 = Application with planting: Zadok's 24-27 (4-6 Leaf stage) measured in grams m^{-2}. The numbers in bold are the recommendation from farmers in Heidelberg and Malmesbury and researchers' recommendation in Caledon.

Table 3.6: Planting and harvesting dates of the barley crop at the three localities

Localities	Planting date	Harvesting date
Caledon	24 May 2018	14 November 2018
Malmesbury	13 May 2018	16 November 2018
Heidelberg	8 May 2018	19 November 2018

Table 3.7: Pesticides used for the control of weeds, insects and fungal pathogens for all three localities

Pesticide used for control	Active ingredient
Abacus F500 (fungicide)	Pyraclostrobin-62.5 g $litre^{-1}$ Epixiconazole-62.5 g $litre^{-1}$
Cyperfos 500 EC (insecticide)	Chlorpyrifos-450 g $litre^{-1}$ Cypermethrin-50 g $litre^{-1}$
Roundup (herbicide)	Glyphosate-360 g $litre^{-1}$
Trifuralin 480 EC (herbicide)	Dinitro analine-480 g $litre^{-1}$
Preelog (herbicide)	Paraquat-135 g $litre^{-1}$
Logran 750 (herbicide)	Triasulfuron-750 g kg^{-1}

3.6 Data collection and statistical analysis

Three plants per block for each plot were hand harvested at the end of grain growth. The harvested plants were separated to enable tiller and ear counts. After harvest, the barley crop was evaluated for grain yield, grain quality, protein content and kernel plumpness. Data were analysed using Agro-base statistical software and the results were statistically evaluated using analysis of variance.

CHAPTER FOUR

EFFECT OF PLANTING DENSITY AND NITROGEN APPLICATION RATE ON GRAIN YIELD OF THREE BARLEY CULTIVARS PLANTED IN THE WESTERN CAPE PROVINCE OF SOUTH AFRICA.

4.1 Abstract

The significant expansion of the brewing industry in South Africa has increased requirements on the South African malting barley industry to supply malting barley (*Hordeum vulgare* L.) with high grain yield and quality. Published literature suggests that soil type and environmental conditions are the predominant drivers controlling production of malting barley. However, it is acknowledged that agronomic practices such as planting density and nitrogen (N) application are also important factors in determining the grain yield and grain quality of malting barley. The objectives of this study were to determine the relationship between planting density and N fertilizer application strategies on barley grain yield in order to establish the best management practices maximising yield without compromising end market objectives. The effects of N rate and planting density on grain yield of three malting barley cultivars were evaluated at three different localities during the 2018 growing season. Planting density was at five levels: 120, 140, 160, 180 and 200 seeds m^{-2}, while N levels ranged from 20 to 100 kg ha^{-1}. Plants established at 180 seeds m^{-2} attained the highest grain yield of 5.99 t ha^{-1}, while the lowest grain yield of 4.71 t ha^{-1} was attained at a planting density of 120 plants ha^{-1}. Grain yield also increased consistently with increased N rate to a maximum yield of 6.69 t ha^{-1}, with a minimum yield of 2.68 t ha^{-1}. Water stress resulted on low yield with poor kernel plumpness in Heidelberg. Cultivar S16 produced a higher yield of 6.69 t ha^{-1} when 80 kg N ha^{-1} was applied and this yield was the highest in all three localities. In all localities the 200 seeds m^{-2} had the highest plant stand count at emergence. These results suggest that a planting density of 120-140 seeds m^{-2} is the best for Heidelberg while S16 is recommended to be planted at a density of 160-180 seeds

m^{-2} at a rate of 80 kg N ha^{-1} in Caledon and Malmesbury. From the findings of this study, cultivar S16 is recommended for cultivation in Malmesbury and Caledon at a range of 160-180 seeds m^{-2} as this resulted in high yield in both locations, while Elim is recommended for cultivation in Heidelberg region.

Key words: grain yield, cultivars, planting density, kernels

4.2 Introduction

Barley yield predictions are of great interest to the growers and the malting industry in order to allow effective crop management and convenient organisation of barley grain production (Křen *et al*., 2014). Grain yield of barley cultivars varies greatly due to varying growing conditions (Janković *et al.*, 2011). The genotypic traits of a cultivar and agroclimatic conditions are the key factors influencing grain yield and its quality, and the first step to success in the growing systems of barley in a given environment is the choice of suitable cultivars (Kılıç *et al*., 2010). Barley yield reduction is primarily due to lower number of ears, lower kernel mass, fewer kernels per ear or a combination of these components (Cox, 1996).

Grain yield response to planting density is expected to vary among barley cultivars because some lodge badly at high densities (Mukai *et al*., 1990). A cultivar × density interaction for grain yield in barley may also be caused by variation in tillering pattern, as cultivars differ significantly in maximum tiller number and percentage of tillers surviving to form spikes (Mukai *et al*., 1990). A significant number of tillers die before heading in most barley cultivars, and cultivars with a large number of tillers appear to lose more, although there are generally more spikes plant^{-1} in high-tillering cultivars (Simmons *et al*., 1982).

Shirazi *et al* (2014) concluded that different N doses significantly influenced the grain yield and yield parameters, and that for the highest grain yield, doses of 100 kg N ha^{-1} were the best treatment when considering N fertilizer only. On the other hand, Narolia and Yadav (2013) concluded that increasing N levels of N 60 to 90 kg ha^{-1} significantly enhanced number of effective tillers, spike length, plant height, , number of grains $spike^{-1}$ and test weight and grain yield ha^{-1} of malting barley. Nitrogen regime may affect the number of tillers and the number of kernels ear^{-1} for barley (Anbessa and Juskiw, 2012). Nitrogen fertilizer is applied in order to increase agronomic yield and improve grain quality (Gous *et al*., 2015). The objective of this study was to evaluate the effects of planting density, N application and cultivar on yield and yield components of three malting barley cultivars planted at Caledon, Heidelberg and Malmesbury.

4.3 Materials and methods

The general materials used and the methodology employed are presented in Chapter 3. After emergence, plants were counted for planting density trials in all localities. Plants and ears per square meter were counted for all the plant density plots at all the localities. Kernels were counted per ear for all plant density trials at all localities. Samples were weighed and quality analysed by SABBI. Data were subjected to analysis of variance using Agro-base statistical software. Mean separation was done using the least significant difference (LSD) at 90% confidence level. Significant differences are represented in graphs and tables by alphabetical letters in the following order: a, b, c and d with the letter a representing highest significance, and the letter d the lowest. The means containing a similar letter, does not differ significantly. In this chapter results for grain yield and yield components from the field experiments conducted at Caledon, Malmesbury and Heidelberg are presented and discussed.

4.4 Results

4.4.1 Crop establishment

Rainfall for the 2018 growing season was below average from May to December at all three locations (Figures 3.1 to 3.3). A light rainfall averaging only 19 mm followed immediately after planting the first trial at Heidelberg. Thus, the plants of the first planting date at Heidelberg were established under dry conditions resulting in poor stand and stunted growth. However, for the other planting dates at Caledon and Malmesbury the crop establishment was good and vigorous and the localities received relatively better rainfall from planting throughout the season (Figures 3.1 and 3.2). Weather data obtained from the weather stations deployed at localities illustrated that temperatures decreased after planting and started increasing gradually towards and during harvesting season. Inversely with rainfall, there were higher amounts of rainfall at the beginning of the growing season and a gradual decrease towards harvest time in November.

4.4.2 Planting density effects on grain yield

Planting density had a significant ($p<0.1$) effect on grain yield obtained at Caledon (Table 4.1). The highest yield was obtained with Cultivar S16 when planted at 180 seeds m^{-2} or with cultivar Elim when planted at 160-200 seeds m^{-2}. Yield obtained by cultivar S16 when planted at 120-160 seeds m^{-2} had no significant difference. Cultivar Hessekwa yielded the lowest with yield of 4.72 t ha^{-1} when planted at 120 seeds m^{-2} and yield obtained between 140-200 seeds m^{-2} was not significantly different for this cultivar (Table 4.1).

Table 4.1: Effect of planting density on grain yield obtain at Caledon site (Means followed by the same letter(s) are not significantly different)

Planting density (seeds m^{-2})	Grain yield (t ha^{-1})		
	Hessekwa	Elim	S16
120	4.72e	5.75b	5.59c
140	4.92cd	5.03cd	5.68bc
160	5.20c	5.98a	5.20c
180	5.66bc	5.93a	5.99a
200	5.23c	5.97a	5.82ab
P value	0.09		
LSD	0.92		
CV (%)	8.26		

At Malmesbury, plant density had a significant effect on grain yield (Table 4.2). The highest yield was obtained from cultivar Hessekwa when planted at 180 seeds m^{-2} and with cultivar S16 when planted at 160-200 seeds m^{-2} (Table 4.2). No significant different in yield was observed when Hessekwa and Elim was planted 120-140 seeds m^{-2}. Cultivar Elim yielded the lowest with 5.35 t ha^{-1} when planted at 200 seeds m^{-2}.

At Heidelberg, planting density caused highly significant differences ($p<0.01$) in grain yield (Tables 4.3). Cultivar S16 yielded the highest of 3.26 t ha^{-1} when planted at 140 seeds m^{-2}. Elim obtained the lowest yield when planted at a density of 160-200 seeds m^{-2}. There was no significant difference for the yield obtained at a density of 160-200 seeds m^{-2} for all cultivars.

Table 4.2: Effect of planting density on grain yield obtained at Malmesbury site (Means followed by the same letter(s) are not significantly different)

Planting density (seeds m^{-2})	Grain yield (t ha^{-1})		
	Hessekwa	Elim	S16
120	5.45d	5.62d	6.01bc
140	5.65d	5.86c	5.89c
160	6.08ab	5.50d	6.12a
180	6.12a	5.76c	6.05ab
200	6.04bc	5.35de	6.08ab
P value	0.1		
LSD	0.81		
CV (%)	6.89		

Table 4.3: Effect of planting density on grain yield obtain at Heidelberg site (Means followed by the same letter(s) are not significantly different)

Planting density (seeds m^{-2})	Grain yield (t ha^{-1})		
	Hessekwa	Elim	S16
120	3.17b	2.76d	2.89cd
140	3.12bc	2.93cd	3.26a
160	2.91cd	2.68de	3.07bc
180	2.97c	2.78d	3.01c
200	2.97c	2.72de	2.91cd
P value	0.006		
LSD	0.50		
CV (%)	8.48		

4.4.3 Nitrogen application effects on grain yield

The amount of N fertilizer added had a significant effect (p = 0.036) on grain yield in Caledon (Figure 4.1). Cultivar Elim and Hessekwa yielded the highest among the three cultivars with a yield of 5.29 t ha^{-1} when 60 kg N ha^{-1} was applied at planting and 20 kg N ha^{-1} was applied as top dressing at Zadok's (Figure 4.1). Yield obtained by cultivar Hessekwa when only 60 kg N ha^{-1} was applied at planting was not significantly higher than the yield obtained by Elim [1] when 60 kg N ha^{-1} was applied at planting and 20 kg N ha^{-1} was applied as top dressing at Zadok's .Whilst cultivar S16 produced lowest yield of 4.78 t ha^{-1}when 60 kg N ha^{-1} was applied during planting and 20 kg N ha^{-1} as top dressing at Zadok's and this yield was similar to yield obtained by Hessekwa (60:20),Hessekwa (60:30) and Elim (60:40).

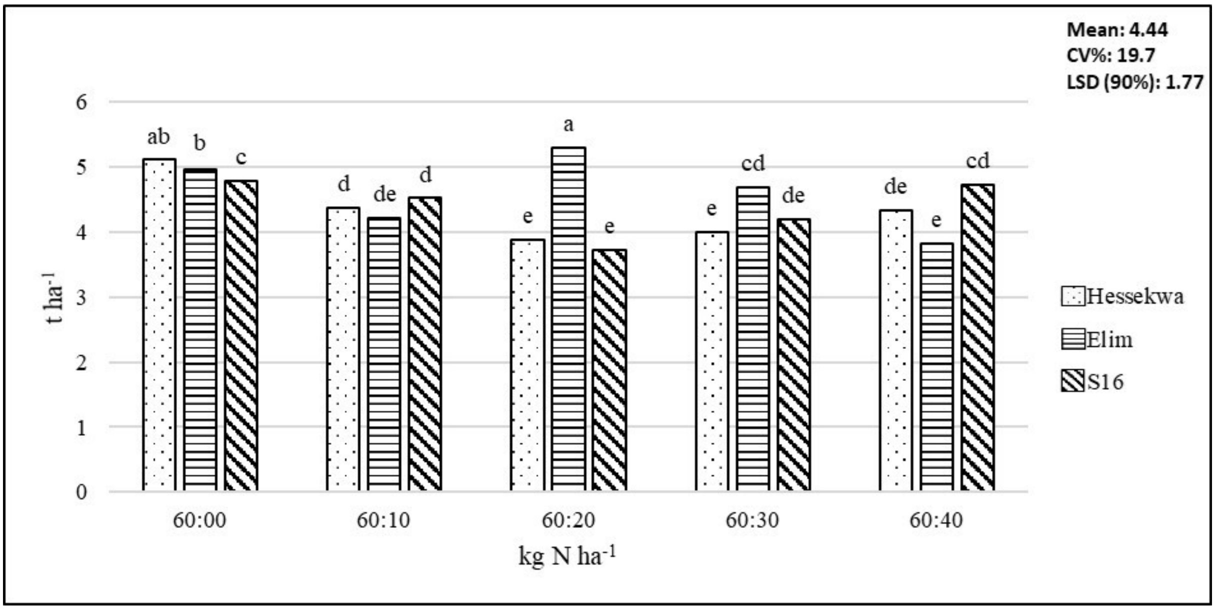

Figure 4.1. N levels effects on three different cultivars at Caledon. Columns topped by the same letter are not significantly different

Significant (p = 0.09) differences in grain yield were detected for the N treatments across the three cultivars in Malmesbury (Figure 4.2). Cultivar S16 performed best with regards to grain yield with yield of 6.69 t ha^{-1} when 40 kg N ha^{-1} was applied during planting and 40kg N ha^{-1} applied 40 as top dressing at Zadok's (Figure 4.2). Hessekwa and Elim had no significant difference in yield when 40 kg N ha^{-1} was applied during planting and 40 kg N ha^{-1} was applied as top dressing at Zadok's. All cultivars produced the lowest among the cultivars when 40kg N ha^{-1} was applied during planting and 10 kg N ha^{-1} as top dressing at Zadok's.

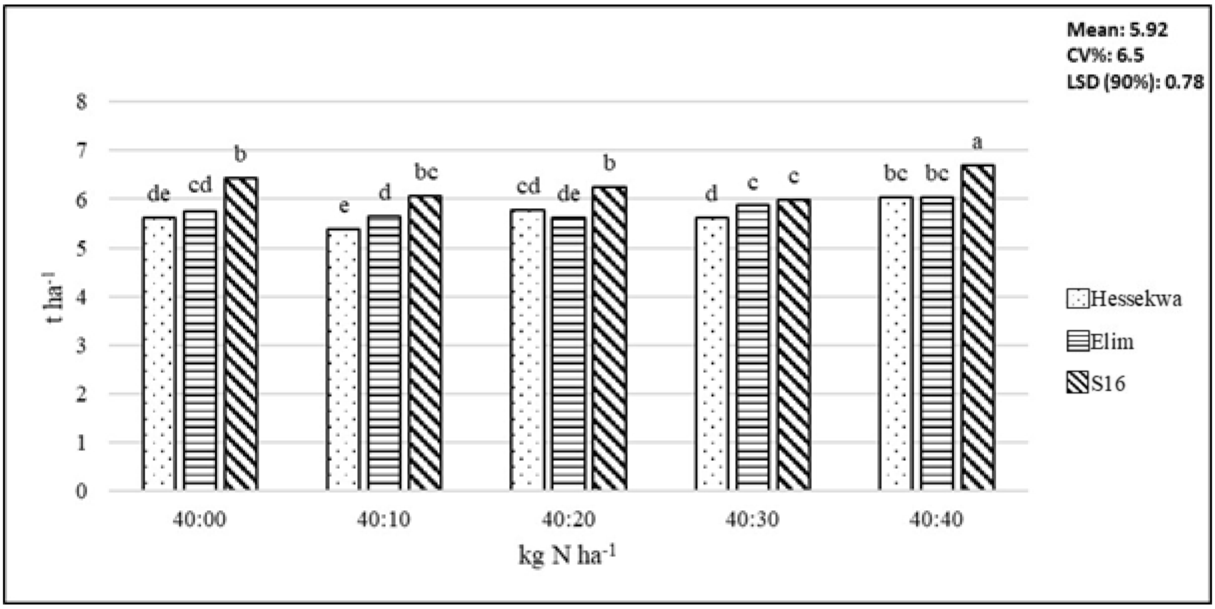

Figure 4.2. Grain yield (t ha^{-1}) and N levels effects on three different cultivars at Malmesbury. Columns topped by the same letter are not significantly different

The amount of N fertilizer applied had a significant effect ($p<0.1$) on yield in Heidelberg (Figure 4.3). Elim produced highest yield of 3.26 t ha^{-1} when 20 kg N ha^{-1} was applied at planting and 10 kg N ha^{-1} applied as top dressing at Zadok's. No significant difference was observed in grain yield for all three cultivars when 20 kg N ha^{-1} applied during planting and 0 kg N ha^{-1} applied as top dressing at Zadok's. All cultivars obtained lowest yield when 30 kg N ha^{-1} was applied at planting and 20 kg N ha^{-1} applied at Zadok's (Figure 4.3).

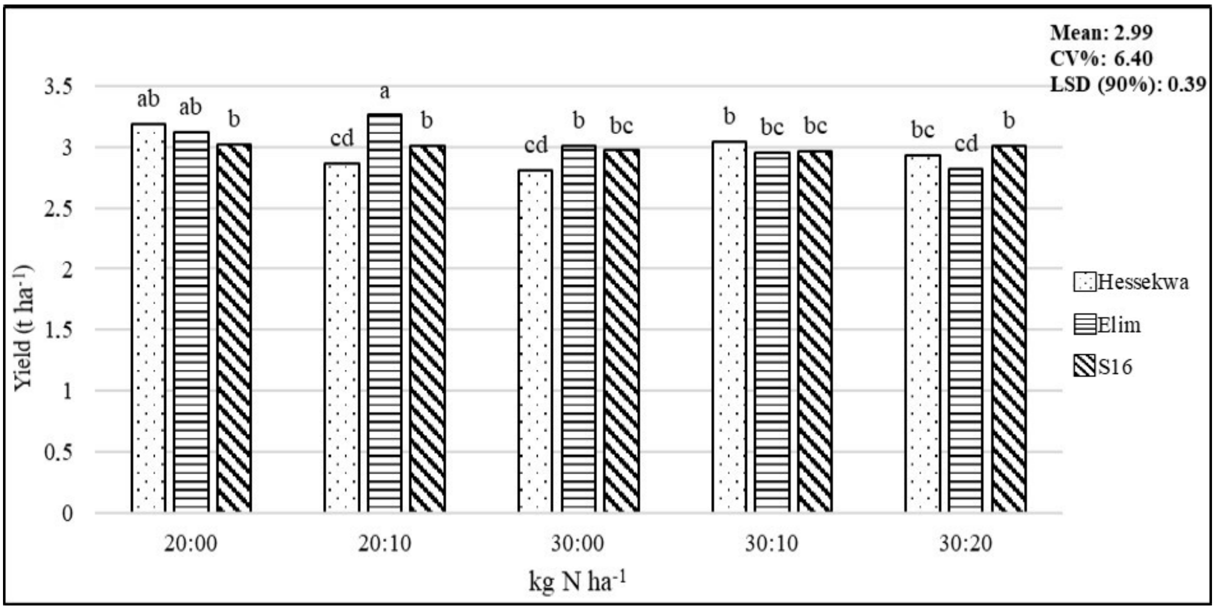

Figure 4.3. Grain yield (t ha^{-1}) and N levels effects on three different cultivars at Heidelberg. Columns topped by the same letter are not significantly different

4.4.1 Effects of planting density on plant stand

Planting density had significant effects ($p<0.1$) on plant stand (Figure 4.4). Cultivar S16 had the highest plant count among all cultivars when planted at 200 seeds m^{-2} in all three localities (Figures 4.4 and Figure 4.5). Cultivar Hessekwa produced the lowest plant count when planted at 120 seeds m^{-2} (Figure 4.5).

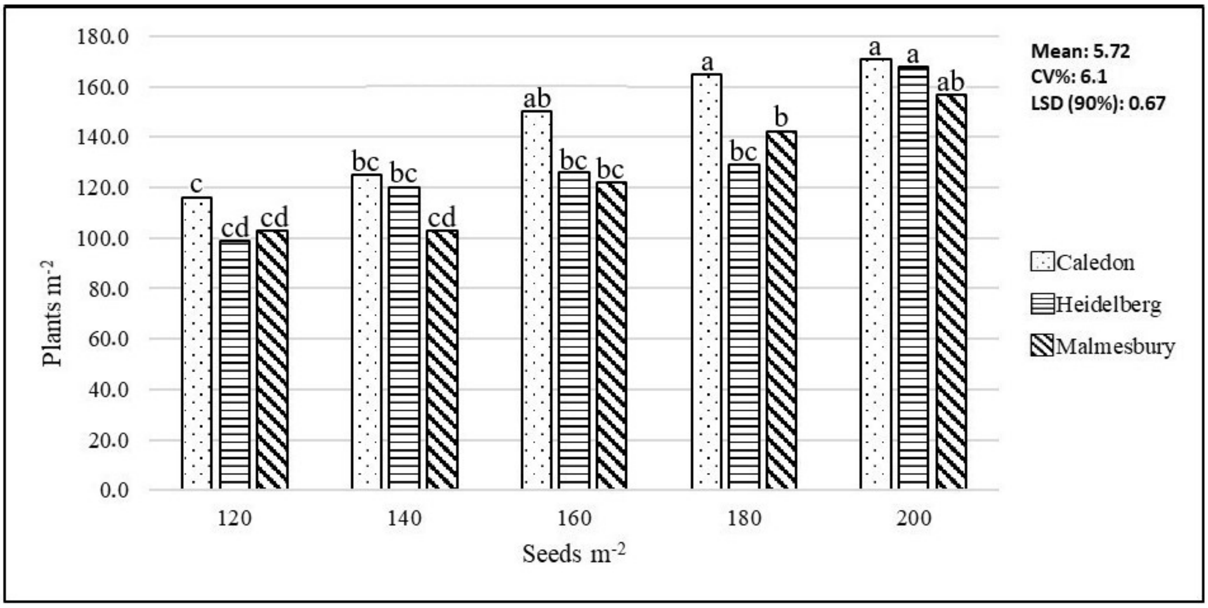

Figure 4.4. Average number of plants counted m^{-2} for 5 different levels of planting densities in all three localities

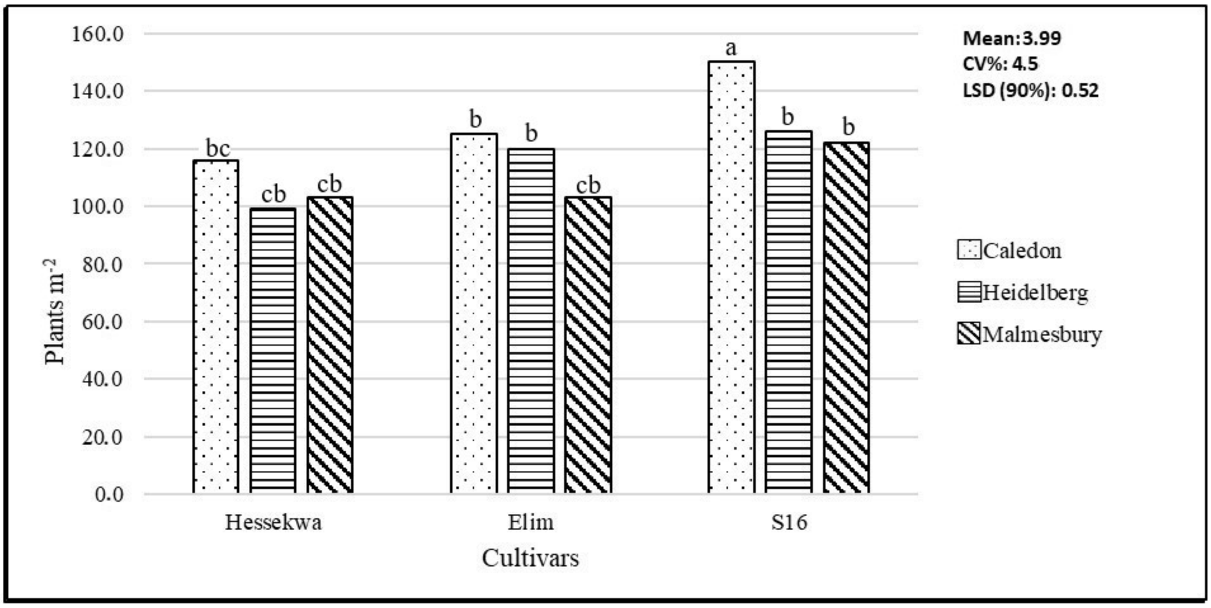

Figure 4.5. Average number of plants counted m^{-2} for all 3 cultivars in all three localities

4.4.2 Effects of planting density on number of ears per plant

In Caledon, planting density did not have a significant effect (p>0.1) on the number of ears plant^{-1}.

4.4.3 Effects of planting density on number of kernels ear^{-1}

Planting density had significant effects (p<0.1) on number of kernels ear^{-1}. At Caledon the 180 seeds m^{-2} planting density resulted in 28 kernels ear^{-1}, which was the highest and the 120,140,160 and 200 seeds m^{-2} planting densities obtained 26 kernels ear^{-1}. Hessekwa obtained 28 kernels ear^{-1}, while Elim and S16 obtained 27 kernels ear^{-1}. In Malmesbury, the 160 seeds m^{-2} planting density obtained 31 kernels and was the highest number of kernels ear^{-1} and the 120, 140, 180 and 200 seeds m^{-2} planting densities obtained 30 kernels ear^{-1}. Hessekwa obtained 31 kernels ear^{-1}, while S16 and Elim had 30 the kernels ear^{-1}. For Heidelberg, all planting densities obtained 24 kernels ear^{-1} and all cultivars obtained 24 kernels ear^{-1}.

4.5 Nitrogen application correlation analysis for the three lacalities

4.5.1 Correlation between plant counts and yield

There was a positive relationship between the number of plants counted at emergence and yield in Malmesbury (Figure 4.6). Whilst a negative relationship was observed in Caledon and Heidelberg (Figures 4.7 and 4.8)

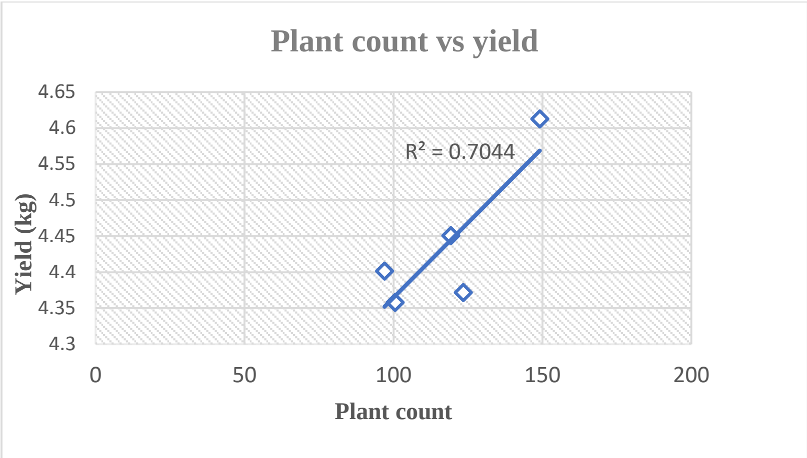

Figure 4.6. Malmesbury Correlation between plant counts and yield

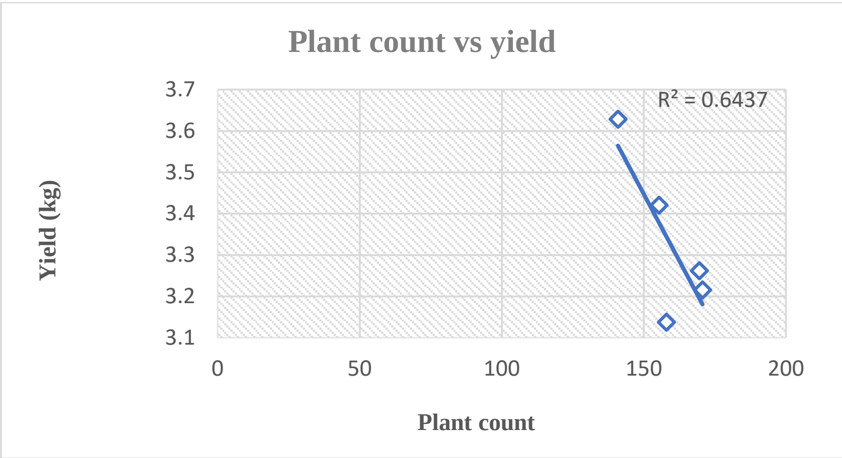

Figure 4.7. Caledon Correlation between plant counts and yield

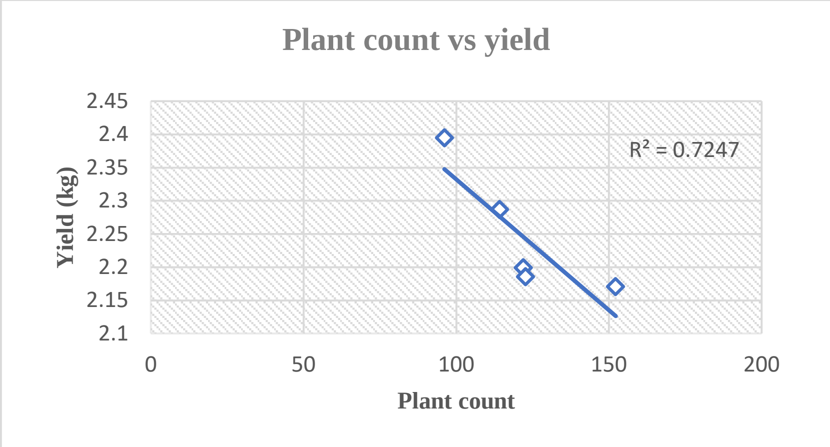

Figure 4.8. Correlation between plant counts and yield at Heidelberg

4.5.2 Correlation between ears m^{-2} and yield

There was a positive linear relationship between ears m^{-2} and yield in Caledon and Heidelberg (Figures 4.9 and 4.11). There was no discernible relationship between ears m^{-2} and yield in Malmesbury (Figure 4.10)

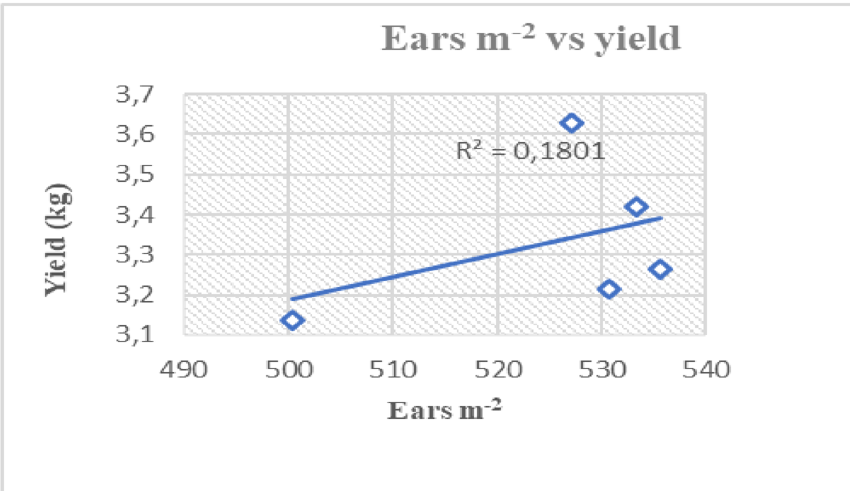

Figure 4.9. Correlation analysis for ears m^{-2} and yield of Caledon

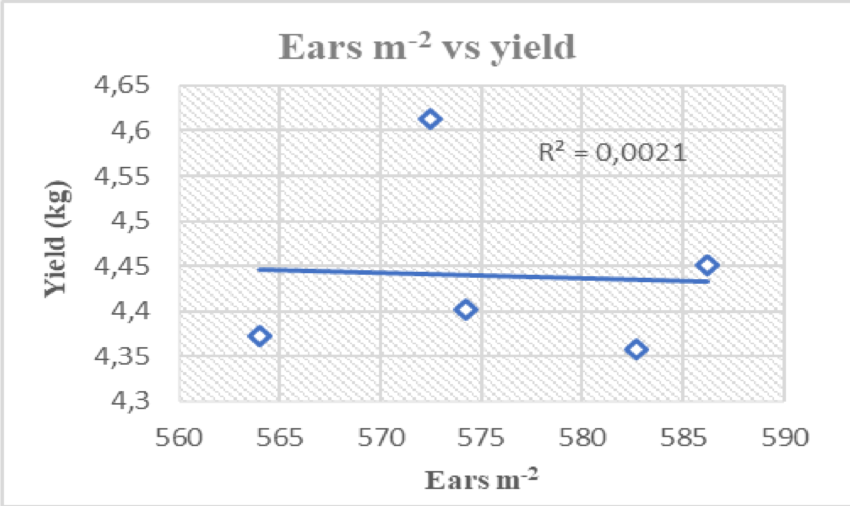

Figure 4.10. Malmesbury correlation analysis for ears m^{-2} and yield

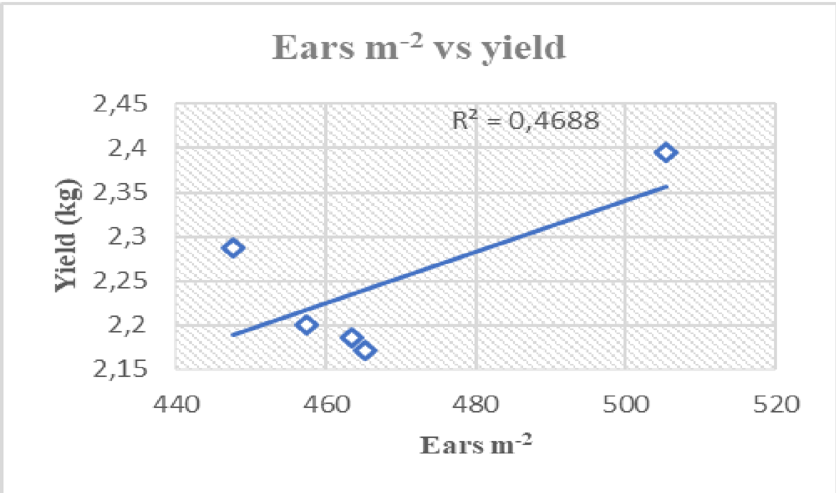

Figure 4.11. Heidelberg correlation analysis for ears m^{-2} and yield

4.5.3 Correlation between kernels ear^{-1} and yield

There was a negative relationship between kernels ear^{-1} and yield at all sites (Figures 4.13 and 4.14)

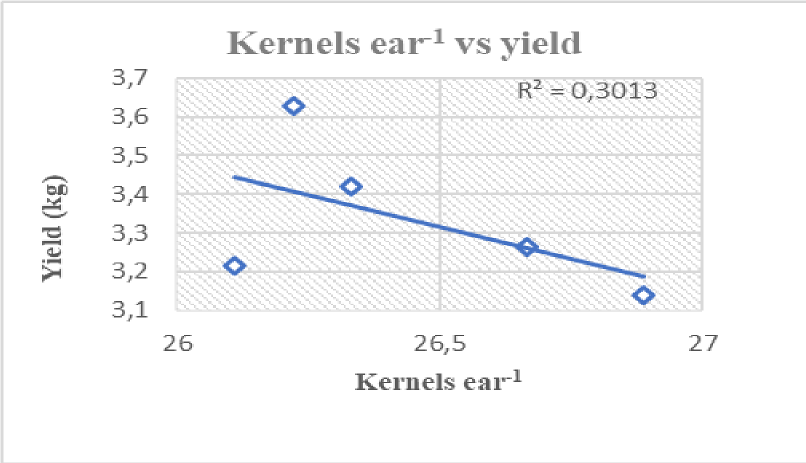

Figure 4.12. Caledon correlation analysis for kernels ear^{-1} and yield

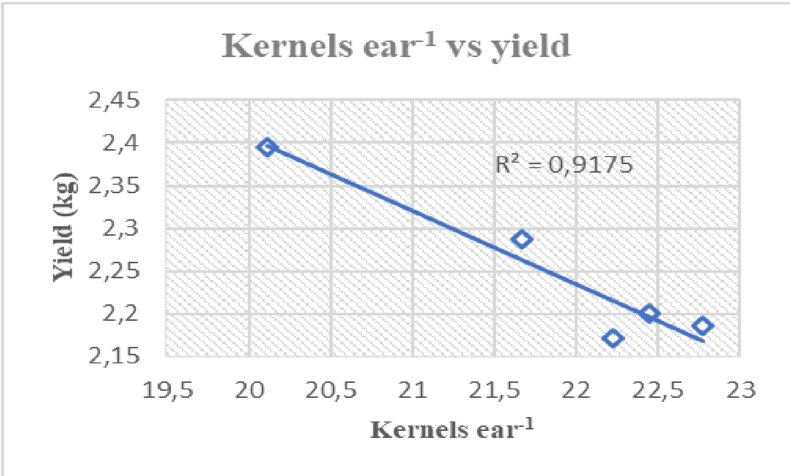

Figure 4.13. Malmesbury correlation analysis for kernels ear^{-1} and yield

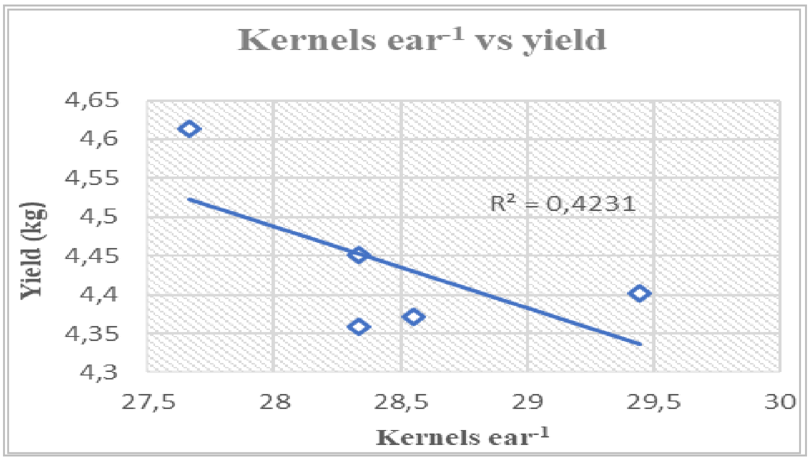

Figure 4.14. Heidelberg correlation analysis for kernels ear^{-1} and yield

4.6 Discussion

4.6.1 Effect of weather conditions on grain yield

Different weather conditions were encountered in the season during which the trials were conducted. In Heidelberg there was a very severe drought during June to November when only 22 mm rain fell (Figure 3.3). This restricted tiller vigour, reduced ear size, and caused below average yields. Despite variable weather, good barley yields were harvested in Caledon and Malmesbury. Although very dry weather was experienced immediately after the trial was planted in Caledon and Malmesbury, ample rain fell in July-September (Figures 3.1 and 3.2) to ensure excellent vegetative and reproductive growth. At the same time 3 months of warm, sunny weather favoured high yields of well-filled, good quality grain. Weather fluctuations caused wide variations in barley yields. For example, a planting density of 120 seeds m^{-2} yielded 2.41 t ha^{-1} of grain in the drought of Heidelberg, whereas the same rate of seeding on the same soil type (sandy loam), also on drought-prone downs, yielded 4.71 t ha^{-1} in Malmesbury where growing conditions were more favourable.

4.6.2 Planting density effects on grain yield

Different barley cultivars react differently to planting density due to different characteristics of those cultivars were found also in field experiments in Poland (Noworolnik, 2010). In this study the 160, 180 and 200 seeds m^{-2} planting densities had the highest effect on the yield and the 120 and 140 seeds m^{-2} planting density had the least impact on the yield. Noworolnik, (2010) on similar study reported that the increase in planting density resulted in an increase in yield in all four the cultivars evaluated. From the results of this study, the 160-180 seeds m^2 treatment is recommended for Caledon and Malmesbury because both areas receives enough rainfall for plant growth and development while on the other hand 120-140 treatments is best for Heidelberg because the area has drought problems and too high planting density can result in moisture competition. These results confirm those of Hajighasemi *et al*. (2016) who reported higher grain yield of dual-purpose barley at higher planting density in Iran. These results also suggest that different planting densities must be used for different cultivars as the cultivars react differently to treatments.

In contrast, some other studies have reported very little to no barley effects on yield, especially at rates above 200 seeds m^{-2} (McKenzie *et al*., 2005; O'Donovan *et al*., 2008). In this study, the highest yield was obtained from a planting density of 180 seeds m^{-2}. This was however not significantly higher than the yield obtained with the 160 and 200 kernels m^{-2}. Noworolnik (2010), recorded the same results during 2006-2007 season testing four different cultivars established at different planting densities. In that study, grain yield increased with increasing sowing rate to 450 seed m^{-2}, but in the 2004–2005 season yield increase (averaged across cultivars) at the 450 seeds m^{-2} sowing rate compared to the 350 seed m^{-2} sawing rate was more like a tendency and higher yield increase at high sowing rate compared to 350 seeds m^{-2} medium sowing rate were found for the four cultivars tested. (Noworolnik, 2010).

4.6.3 Nitrogen application effects on grain yield

The N fertilizer effects on grain yield differs among varieties and production systems (Hajighasemi *et al.,* 2016) and grain yield of cultivars is more depend on genetic of cultivars (Oral *et al*., 2018). In Malmesbury, the S16 variety had the highest yield of 6.69 t ha^{-1} at a treatment of 80 kg N ha^{-1} and this was significantly higher than the other cultivars. In Caledon, the highest yield was from the Elim variety which was 5.2 t ha^{-1} at a treatment of 80 kg N ha^{-1}. These results indicate that the N treatment of 80 kg N ha^{-1} did not result in yield disadvantage at Malmesbury and Caledon and confirms that grain yield was significantly influenced by N fertilizer application in this experiment. The results suggest that 80 kg N ha^{-1} is best treatment for Caledon and Malmesbury. At Heidelberg, the highest yield from the Elim variety was 3.2 t ha^{-1} at a treatment of 30 kg N ha^{-1} and this yield was significantly lower than yield obtained from Caledon and Malmesbury due to poor rainfall received during growing period. N rate is important agronomic factor in enabling the production of high yielding malting barley with excellent grain quality (Potterton and McCabe, 2018).

Results indicated that for all cultivars, grain yield was numerically higher when N fertilizer was applied during planting versus the 0 kg N ha^{-1} treatment. This means N should be applied in split applications when planting barley at Caledon, Malmesbury and Heidelberg in order to maximize yield. The grain yield response of barley cultivars to N fertilizer has been extensively researched and is known to increase with increasing application rates of N fertilizer (O'Donovan, 2011).

4.6.3 Yield components effects on yield

The increase in yield due to planting density was primarily a result of more ears m^{-2} being produced. The number of kernels ear^{-1} decreased with increasing planting density, whereas ears density increased with increase in planting density. In this study there were no interactions between cultivars and planting density. A cultivar and density interaction for grain yield in barley may also be caused by variation in tillering pattern, as cultivars differ greatly in maximum tiller number and percentage of tillers surviving to form ears (Fukai *et al.,* 1990).

A large number of tillers die before heading in most barley cultivars, and cultivars with a large number of tillers appear to lose more, although there are generally more ears per plant in high-tillering cultivars (Simmons *et al*., 1982). In Heidelberg, the 30 kg N ha^{-1} treatment and the 40 kg N ha^{-1} treatment had the highest number of ears $plant^{-1}$. At Heidelberg Elim had the highest ears $plants^{-1}$.while on the other hand S16 produced highest ears $plant^{-1}$ for Caledon and Malmesbury. This results suggest that the number of ears to be produced per unit area depends on cultivar and location where the cultivar is planted. At Heidelberg the 20 kg N ha^{-1} treatment had the highest number of kernels ear^{-1} and Elim had the highest number of kernels ear^{-1}. At Caledon and Malmesbury the 80 kg N ha^{-1} treatments had the highest number of ears m^{-2} and S16 and Elim had the highest number of ears m^{-2}. These results suggest that number of kernels ear^{-1} and ears m^{-2} both depend on cultivar selected in specific localities and cultivars react different to different N treatments in different localities.

Ears production was affected by plant density and cultivar, but there was no significant interaction between them. In the high density treatments of 180-200 seeds m^{-2}, ears number per unit area (mean of all cultivars) increased rapidly, whereas in the low density treatments of 120 seeds m^{-2} it decreased gradually. The number of ears^{-2} number did not change in the low planting density, while it declined gradually in the high planting density (Fukai *et al.*, 1990). The high planting density treatments always had the largest number of ears^{-2} and the low density the smallest, in all localities**.**

4.6.4 Conclusions

The highest yield was obtained by all cultivars tested with a planting density of 180 seeds m^{-2}. This planting density's yield were significantly higher, than the yield obtained by the 120 and 140 seeds m^{-2}, but not significantly higher than that of the 160 and 200 seeds m^{-2} planting densities. This also indicates that current recommended planting density of 160-180 seeds m^{-2} for barley grown under rainfed are still on target. At Caledon and Malmesbury the 80 kg N ha^{-1} treatment produced the highest yield of 5.29 and 6.69 t ha^{-1}, respectively, while at Heidelberg the 20 kg N ha^{-1} treatment produced the highest yield of 3.26 t ha^{-1}.This indicates that yield depends on the amount of N applied as well as the amount of rainfall received during the growing season. With adequate rainfall, high N rates are expected to result in better yields, while lower rates are favourable under drier conditions.

CHAPTER FIVE

EFFECT OF PLANTING DENSITY AND NITROGEN APPLICATION ON GRAIN QUALITY OF THREE BARLEY CULTIVARS PLANTED IN THE WESTERN CAPE PROVINCE OF SOUTH AFRICA.

5.1 Abstract

Weather conditions are often unfavourable for malting barley production in the Western Cape Province of South Africa, but agronomic practices may improve the probability of attaining acceptable quality. The objective of this study was to determine the effects of N application and planting density on the quality of malting barley cultivated in the Western Cape. Field trials were conducted at three dryland sites during the 2018-2019 season. At each site, experiments were conducted with the following treatments: planting density range was 120 to 200 seeds m^{-2}, which translated to 50 to 84 kg of seed per hectare. Three cultivars (Hessekwa, Elim and S16) were tested in the experiment. Higher N rates of 80-100 kg N ha^{-1} reduced kernel size. Cultivar differences in N response were negligible and cultivars were not significantly different in grain quality. Kernel size was increased up to 97.8 % when planted at 200 seeds m^{-2}. Increasing planting density from 180 to 200 seeds m^{-2} resulted in a reduction of 0.1% in grain N concentration and reduced kernel size by 2.13%. Screenings percentage was more than 80% for all treatments and did not affect the grain quality in all localities. The most beneficial agronomic practices for malt barley production in Western Cape was application of N fertilizer at rates of 40 to 80 kg N ha^{-1} and planting seeds at a rate of 140-180 seeds m^{-2} depending on cultivar.

Key words: kernel size, screenings, grain quality, planting density

5.2 Introduction

Barley (*Hordeum vulgare* L.) is an important cereal crop grown worldwide not only for food and feed, but also for the provision of raw material for the malting process to produce beer and other alcoholic beverages (Celus *et al*., 2006). The grain quality and productivity of malting barley are affected by cultivation practices and the weather conditions during planting and growing season (Holm *et al*., 2018). When producing malting barley, it is important to use management practices that can support good early growth in order to attain both high grain yield and the target quality traits (Holm *et al*., 2018).

Relatively low protein (<125 g kg^{-1}) and relatively large plump kernels (>800 g kg^{-1}) of uniform size are the requirements for good quality malting barley include (O'Donovan *et al.*, 2011). Therrien *et al*. (1994) showed that malting quality was affected more by environmental and genetic factors than fertilizer management. McKenzie *et al*. (2005) found that the most beneficial agronomic practice for malting barley production was the application of N fertilizer at rates appropriate to the expected availability of moisture and soil N. Wade and Froment (2003) found that agronomic management of barley in the field was the main factor influencing malting quality, while different treatments in the commercial malting plant had much less influence on quality. Their study also indicated that grain size distribution was very important with more uniform seed resulting in a more homogeneous malt.

O'Donavan *et al*. (2011) found that kernel weight and diameter and seed plumpness were lower at the higher seeding rate of 400 seeds m^{-2}, while protein was also lower and seed maturity occurred sooner. McKenzie *et al.* (2005) also found that higher seeding rates of 400 seeds m^{-2} reduced protein levels, but suggested that relatively small reductions in protein (4 g kg^{-1}) due to increased planting density were likely to have less impact than changes in plumpness and kernel size. Maltsters take both criteria into account when assessing malting barley quality. The relative importance of lower protein compared to reduced plumpness is difficult to determine (O'Donavan *et al*., 2011).

5.3 Materials and Methods

The general materials used and the methodology employed are presented in Chapter 3. The kernel plumpness, foreign matter and screenings in a consignment of barley was determined by taking working sample of 100 g of rubbed and un-screened barley from which stones, if present, were removed by hand. The sample was placed on the standard barley sieve and the sample was screened by moving the sieve 50 strokes to and from, alternately away from and towards the operator of the sieve, in the same direction as the long axes of the slots of the sieve. Analyses of variance were performed on a least significant difference (LSD) level of 90% confidence. Alphabetical letters, i.e. a, b, c and d were used to denote significant differences in graphs and tables, whereby the letter a represented the highest significance and the letter d represented the lowest significant difference.

5.4 Results

5.4.1 Effects of N fertilizer application on grain N content

At Malmesbury, the rate of N fertiliser applied had a significant ($p = 0.084$) effect on grain N content (Figure 5.1). The highest grain N content of 1.59% was obtained from Hessekwa or S16 cultivar when 40 kg N ha^{-1} was applied at planting and when 30-40 kg N ha^{-1} was applied as top dressing at Zadok's (Figure 5.1).There was no significant difference in grain N content for all cultivars when 40 kg N ha^{-1} was applied at planting and 20 kg N ha^{-1} was applied as top dressing at Zadok's. The lowest grain N content of 1.47% was obtained by cultivar Elim when 40 kg N ha^{-1} was applied at planting and 40 kg N ha^{-1} was applied as top dressing at Zadok's (4-6 leaf stage) (Figure 5.1).

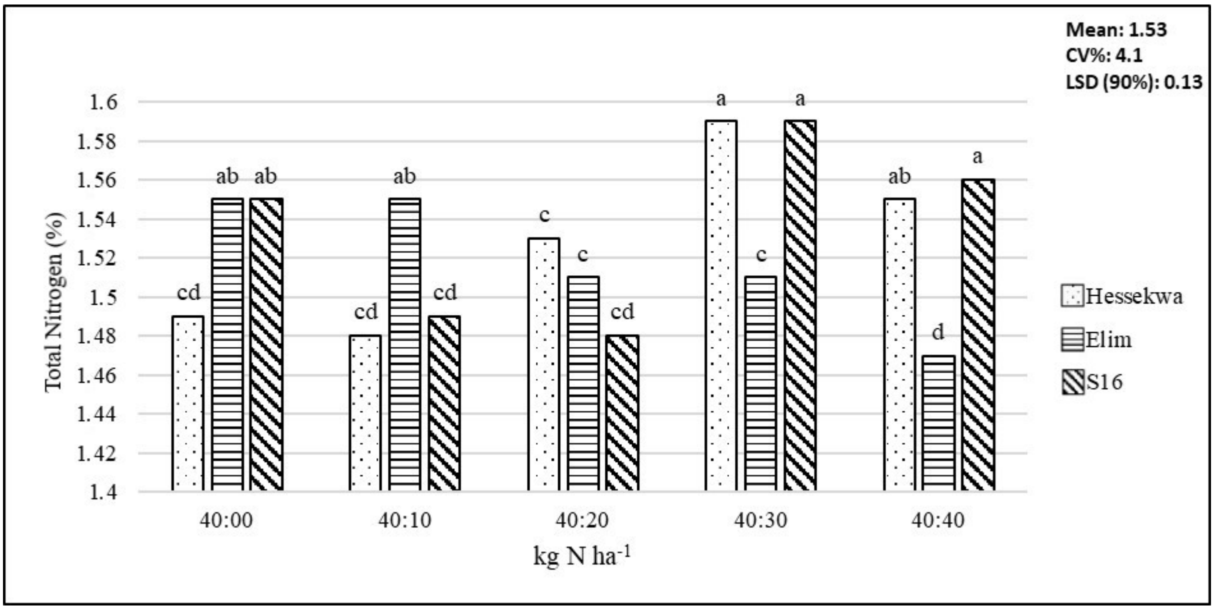

Figure 5.1 Effects of N applied on grain total nitrogen content for cultivars Hessekwa, Elim and S16 in Malmesbury

For Caledon, N rate had a significant (p = 0.01) effect on grain N content (Figure 5.2). The highest grain N content of 1.7% was obtained by all three cultivars when 60 kg N ha^{-1} was applied at planting (Figure 5.2). There was no significant difference in grain N content for all three cultivars when 60 kg N ha^{-1} was applied at planting and 0 kg N ha^{-1} was applied at Zadok's. The lowest N content of 1.41% was obtained by Elim when 60 kg N ha^{-1} was applied at planting and when 10 kg N ha^{-1} was applied as top dressing at Zadok's (Figure 5.2).

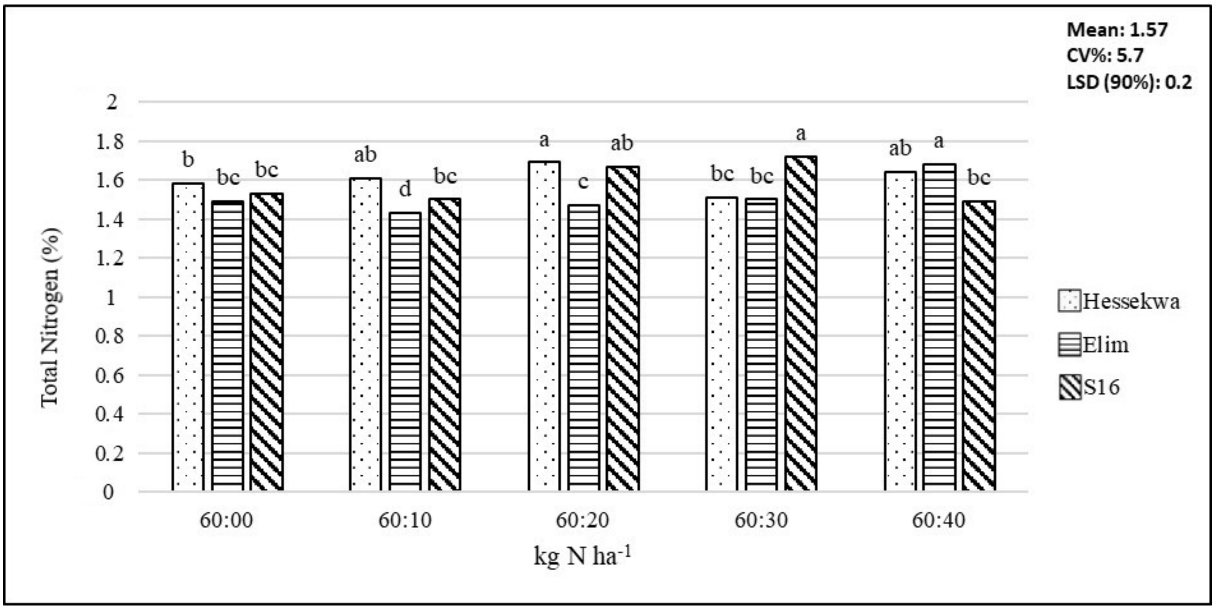

Figure 5.2 Effects of N applied on rain total nitrogen content for cultivars Hessekwa, Elim and S16 in Caledon

N rate had a significant ($p<0.1$) effect on grain N content at Heidelberg. The highest grain N content of 2.27% was obtained by all cultivars when 30 kg N ha^{-1} was applied at planting and when 0 kg N ha^{-1} was applied as top dressing at Zadok's (Figure 5.3). There was no significant difference in N content for all three cultivars when 20 kg N ha^{-1} was applied at planting and 0 kg N ha^{-1} was applied at Zadok's. The lowest N content of 2.05 % was obtained when 20 kg N ha^{-1} was applied at planting and when 10 kg N ha^{-1} was applied as top dressing at Zadok's (Figure 5.3).

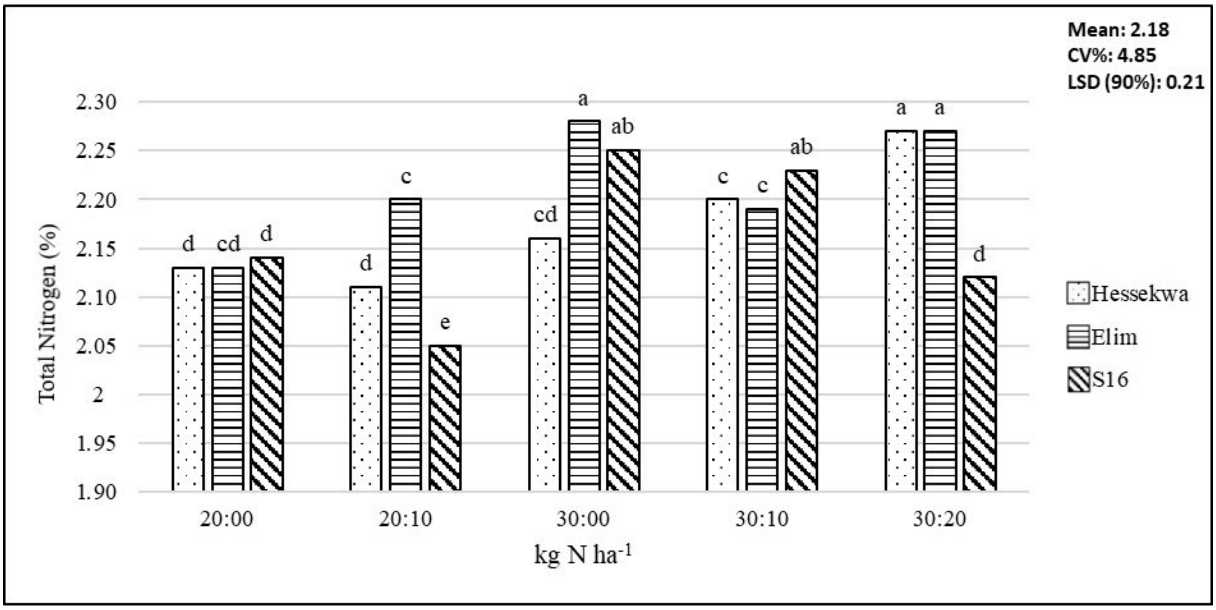

Figure 5.3 Effects of N applied on grain total nitrogen content for cultivars Hessekwa, Elim and S16 in Heidelberg

5.4.2 Planting density effects on grain N content

In Malmesbury, planting density had a significant effect ($p<0.05$) on grain N content. The highest N content of 1.62% was obtained by Hessekwa when planted at density of 120 seeds m^{-2} (Table 5.1). There was no significant difference in grain N content obtained by cultivar Elim at all planting densities. The lowest N content of 1.42% was obtained by S16 when planted at a density of 140 seeds m^{-2} (Table 5.1).

Planting density had a highly significant ($p<0.01$) effect on grain N content in Caledon. The Hessekwa variety had the highest N content of 1.84% planted at 120 seeds m^{-2}, which was significantly higher than other treatments except for Elim, which had a kernel N content of 1.82 % at 120 seeds m^{-2} (Table 5.2).

Table 5.1: Effect of planting density on N content obtain at Malmesbury site (Means followed by the same letter(s) are not significantly different)

Planting density (seeds m^{-2})	Kernel N content (%)		
	Hessekwa	Elim	S16
120	1.62a	1.54b	1.54b
140	1.56ab	1.54b	1.42c
160	1.59ab	1.54b	1.58ab
180	1.62a	1.52ab	1.54b
200	1.51ab	1.50ab	1.61a
P value	0.01		
LSD	0.14		
CV (%)	0.44		

Table 5.2: Effect of planting density on N content obtain at Caledon site (Means followed by the same letter(s) are not significantly different)

Planting density (seeds m^{-2})	Kernel N content (%)		
	Hessekwa	Elim	S16
120	1.84a	1.82a	1.72b
140	1.76ab	1.58d	1.69bc
160	1.70bc	1.67c	1.67bc
180	1.61cd	1.63cd	1.60cd
200	1.60cd	1.58d	1.71bc
P value	0.009		
LSD	0.24		
CV (%)	7.1		

In Heidelberg, planting density had a highly significant ($p<0.01$) effect on grain N content (Table 5.3). The highest N content of 2.50% was with cultivar Hessekwa when planted at a density of 120 seeds m^{-2} (Table 5.3). There was no significant difference for the yield obtained by Hessekwa and S16 when both cultivars were planted at 160-200 seeds m^{-2}. The lowest N content was of 2.24 % obtained with cultivar S16 at a planting density of 140 seeds m^{-2}. There was no significant difference in N content for cultivar Elim when it was planted at 140-180 seeds m^{-2} (Table 5.3).

Table 5.3: Effect of planting density on grain quality obtain at Heidelberg site (Means followed by the same letter(s) are not significantly different)

Planting density (seeds m^{-2})	Kernel N content (%)		
	Hessekwa	Elim	S16
120	2.50a	2.28cd	2.49a
140	2.25cd	2.45ab	2.24d
160	2.44ab	2.46ab	2.31c
180	2.40bc	2.41bc	2.39bc
200	2.40bc	2.33c	2.39bc
P value	0.003		
LSD	0.28		
CV (%)	5.8		

5.4.3 Effects of nitrogen application on kernel plumpness

At Malmesbury application of N fertilizer applied had no significant effect ($p>0.1$) on kernel plumpness (Figure 5.4).

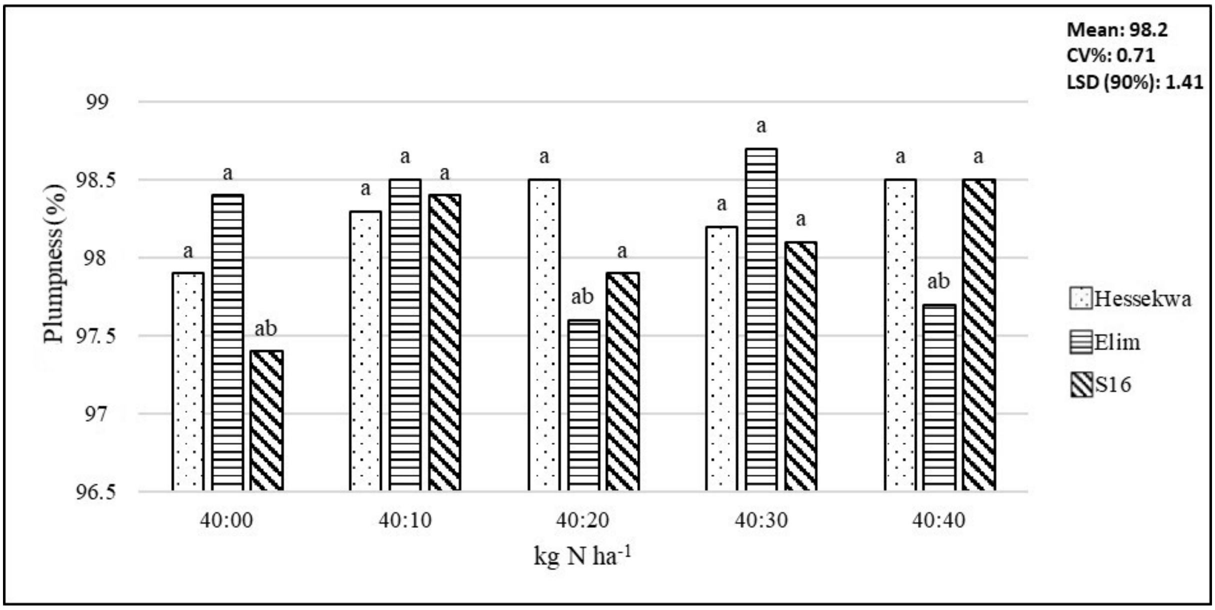

Figure 5.4: A comparative analysis on the effects of N applied to kernel plumpness for cultivars Hessekwa, Elim and S16 in Malmesbury

For Caledon N fertilizer application had a highly significant effect (p = 0.002) on kernel plumpness (Figure 5.5). Elim had the highest plumpness percentage of 97.4% when 60 kg N ha^{-1} was applied at planting and 20 kg N ha^{-1} was applied as top dressing at Zadok's (Figure 5.5). There was no significant difference in kernel plumpness among the three cultivars when 60 kg N ha^{-1} was applied at planting and 30 kg N ha^{-1} was applied as top dressing at Zadok's. The lowest plumpness percentage of 90% was obtained with cultivar Elim when 60 kg N ha^{-1} was applied at planting and 40 kg N ha^{-1} was applied as top dressing at Zadok's (Figure 5.5). There was no significant difference in kernel plumpness for Hessekwa when 60 kg N ha^{-1} was applied at planting and 10-40 kg N ha^{-1} was applied as top dressing at Zadok's.

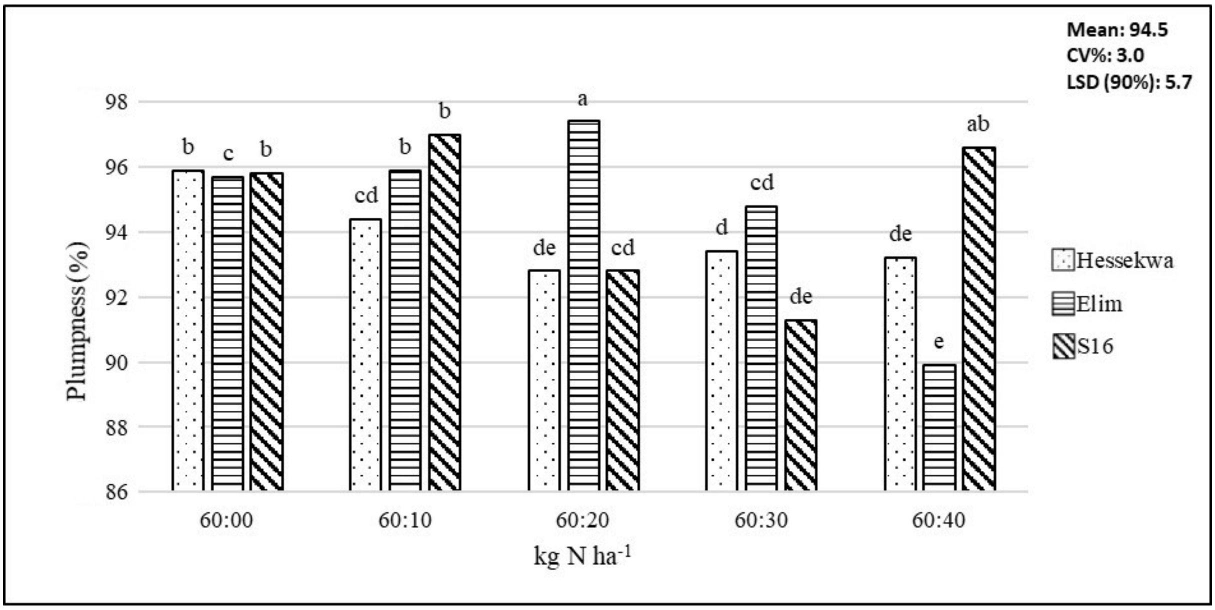

Figure 5.5: A comparative analysis on the effects of N applied to kernel plumpness for cultivars Hessekwa, Elim and S16 in Caledon

In Heidelberg, N application had a significant effect ($p = 0.01$) on kernel plumpness. (Figure 5.6) Elim had the highest plumpness percentage of 91% when 20 kg N ha^{-1} was applied at planting and 0 kg N ha^{-1} was applied as top dressing at Zadok's (Figure 5.6). The lowest kernel plumpness percentage of 81.8% was obtained with cultivar Hessekwa when 30 kg N ha^{-1} was applied at planting and 10 kg N ha^{-1} was applied as top dressing at Zadok's (Figure 5.6). Cultivars S16 and Elim had no significant difference in plumpness percentage when 30 kg N ha^{-1} was applied at planting and 10 kg N ha^{-1} was applied as top dressing at Zadok's.

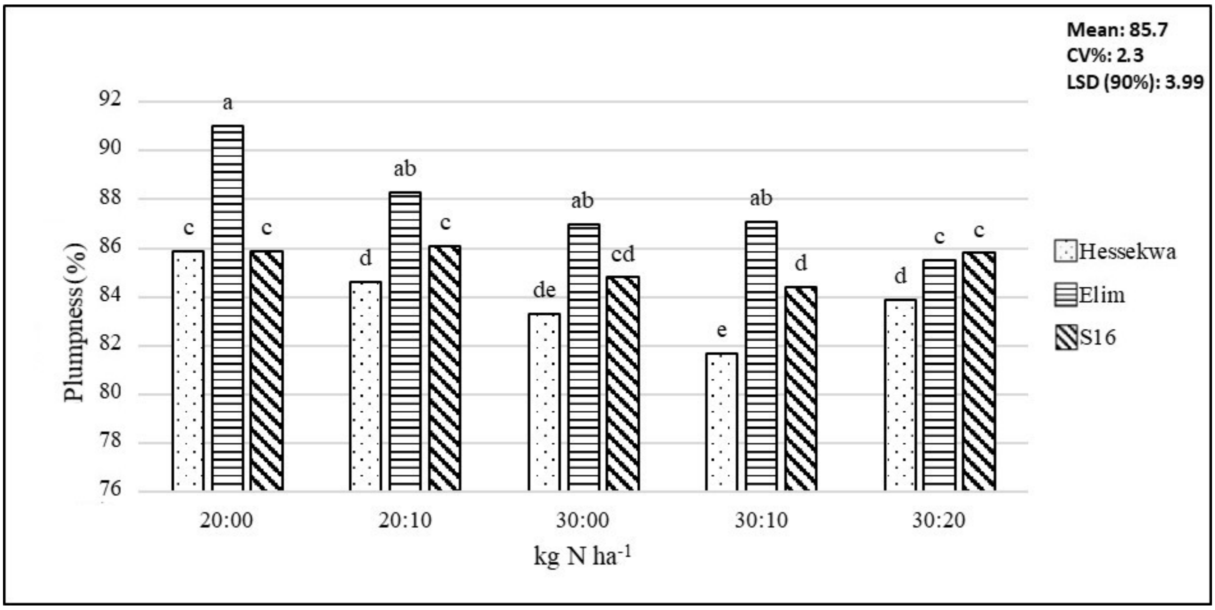

Figure 5.6 A comparative analysis on the effects of N applied to kernel plumpness for cultivars Hessekwa, Elim and S16 in Heidelberg

5.4.4 Effects of planting density on kernel plumpness

In Malmesbury planting density had no significant (p>0.1) effect on kernel plumpness (Table 5.4).

Table 5.4: Effect of planting density on grain quality obtain at Malmesbury site (Means followed by the same letter(s) are not significantly different)

Planting density (seeds m^{-2})	Kernel plumpness (%)		
	Hessekwa	Elim	S16
120	98.0a	98.7a	97.6a
140	98.1a	98.5a	97.9a
160	98.4a	98.1a	98.3a
180	98.6a	98.2a	98.1a
200	98.5a	99.3a	97.7a
P value	0.68		
LSD	1.52		
CV (%)	0.8		

Planting density had a significant ($p<0.05$) effect in kernel plumpness in Caledon (Table 5.5). The highest percentage of plumpness of 97.8% was obtained from the Hessekwa cultivar at 200 seeds m^{-2} planting density (Table 5.5). For cultivar Elim, planting density did not result in any significant differences in kernel plumpness. Cultivar S16 had no significant effects when planted at 120-140 seeds m^{-2}. The Hessekwa cultivar had the lowest kernel plumpness of 84.6% at planting density of 120 seeds m^{-2} (Table 5.5).

Table 5.5: Effect of planting density on grain quality obtain at Caledon site (Means followed by the same letter(s) are not significantly different)

Planting density (seeds m^{-2})	Kernel plumpness (%)		
	Hessekwa	Elim	S16
120	84.6e	94.0b	95.4ab
140	94.0b	92.9bc	93.8b
160	86.5d	92.9bc	91.3c
180	95.7ab	94.4b	93.7b
200	97.8a	96.4ab	90.3cd
P value	0.023		
LSD	6.6		
CV (%)	12.4		

At Heidelberg, planting density had significant effects ($p<0.05$) in kernel plumpness (Table 5.6). The highest kernel plumpness percentage of 94.2% was obtained when Hessekwa was planted at 200 seeds m^{-2} (Table 5.6). There was no significant difference in plumpness for cultivar S16 when planted at 140-200 seeds m^{-2}. The lowest plumpness percentage of 88% was with cultivar Hessekwa at a planting density of 140 seeds m^{-2}. The S16 variety had the highest percentage of plumpness of 93.8 % at 200 seeds m^{-2} and the lowest was 90 % at 120 seeds m^{-2}.

Table 5.6: Effect of planting density on grain quality obtain at Heidelberg site (Means followed by the same letter(s) are not significantly different)

Planting density (seeds m^{-2})	Plumpness (%)		
	Hessekwa	Elim	S16
120	86.1c	85.6c	90.0b
140	88.0c	92.2ab	93.7a
160	88.9b	88.0bc	90.8ab
180	90.9ab	89.9b	93.2a
200	94.2a	84.7cd	93.8a
P value	0.013		
LSD	6.24		
CV (%)	11.3		

5.4.5 Effects of nitrogen application on grain screenings

In Malmesbury N fertilizer had a significant (p = 0.046) effect on screenings (Figure 5.7). The highest screenings percentage of 0.9% was obtained by Elim or S16 when 40 kg N ha^{-1} was applied at planting and 10-30 kg N ha^{-1} was applied at Zadok's as top dressing (Figure 5.7). There was no significant difference for all three cultivars when 40 kg N ha^{-1} was applied at planting and 0-10 kg N ha^{-1} was applied as top dressing at Zadok's.

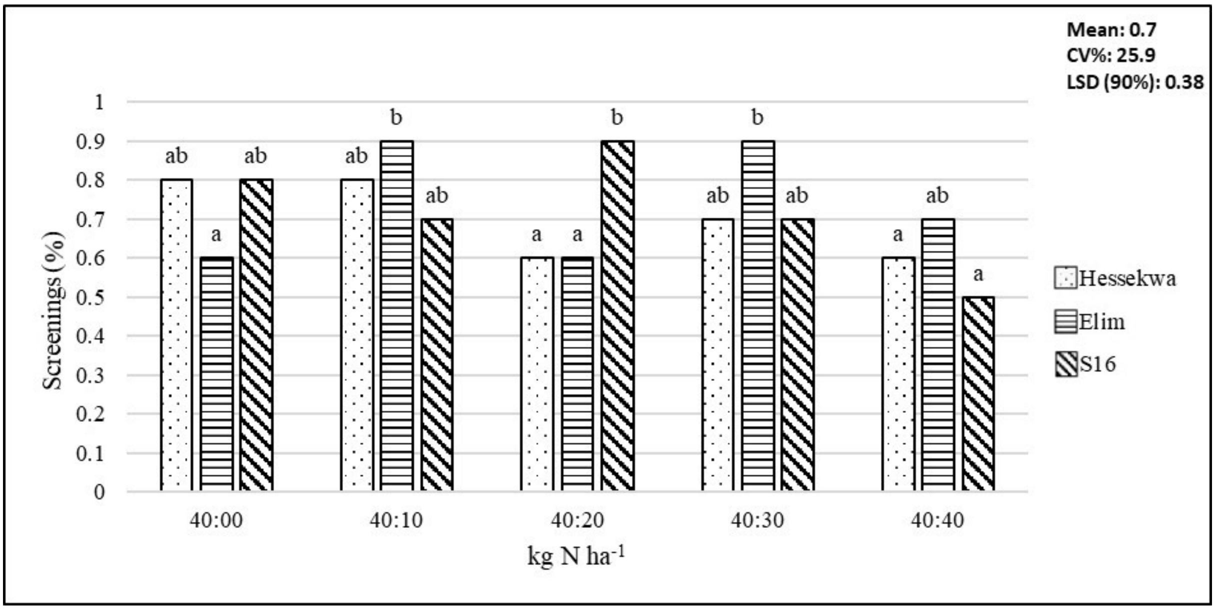

Figure 5.7: A comparative analysis of Hessekwa, Elim and S16 screenings % in Malmesbury

The N fertilizer had a significant (p = 0.032) effect on screenings percentage in Caledon (Figure 5.8). The highest screenings percentage of 4.8% was obtained from cultivar S16 when 60 kg N ha^{-1} was applied at planting and 30 kg N ha^{-1} was applied as top dressing at Zadok's (Figure 5.8). The lowest screenings percentage of 0.3% was also obtained from S16 when 60 kg N ha^{-1} was applied at planting and 20. There was no significant difference in all cultivars when 60 kg N ha^{-1} was applied at planting and 0 kg N ha^{-1} was applied at Zadok's (Figure 5.8).

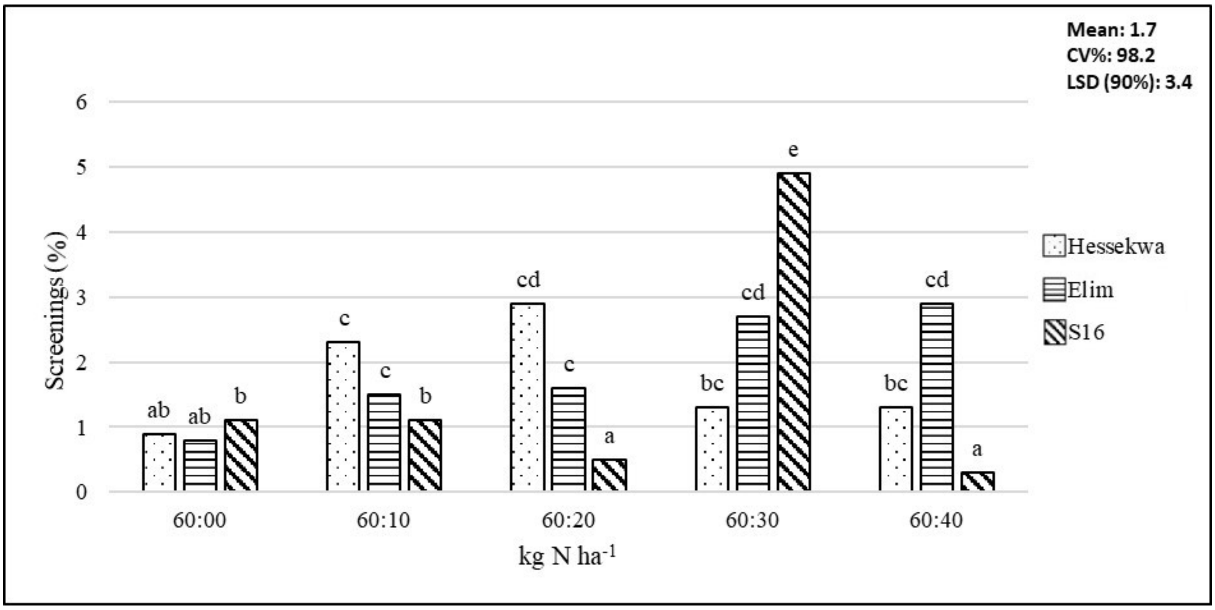

Figure 5.8: A comparative analysis of Hessekwa, Elim and S16 % screenings in Caledon

At Heidelberg, N applied had a highly significant ($p = 0.0012$) effect on screenings. Elim obtained the lowest screenings percentage of 7% when 20 kg N ha^{-1} was applied at planting and when 10-20 kg N ha^{-1} was applied as top dressing at Zadok's (Figure 5.9). There was no significant difference among all cultivars when 30 kg N ha^{-1} was applied at planting and 20 kg N ha^{-1} was applied at Zadok's as top dressing. S16 obtained the highest screenings percentage of 18% when 30 kg N ha^{-1} was applied at planting and 0 kg N ha^{-1} was applied as top dressing at Zadok's (Figure 5.9).

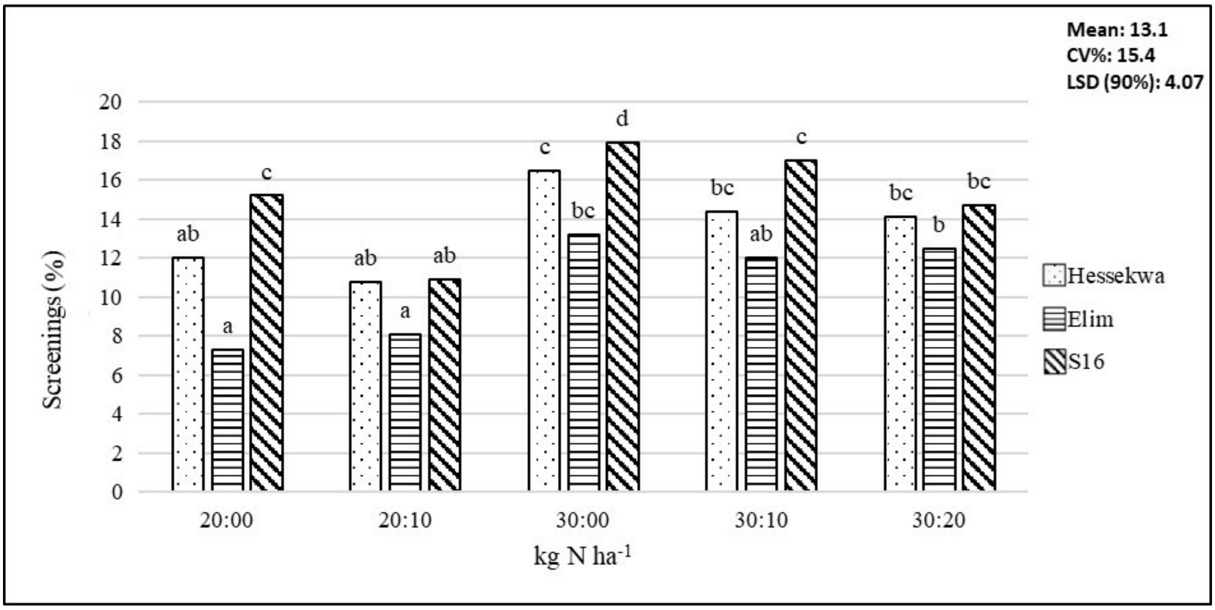

Figure 5.9: A comparative analysis of Hessekwa, Elim and S16 screenings % in Heidelberg

5.4.6 Effects of planting density on grain screenings

At Malmesbury planting density had a significant ($p<0.1$) effect on screenings. (Table 5.7) The lowest percentage of screening of 1.2% was obtained with the Hessekwa or S16 cultivar planted at 160 or 180 seeds m^{-2} (Table 5.7). The highest screenings percentage of 2.2% was obtained with S16 cultivar at planting density of 140 seeds m^{-2} .There was no significant difference in screenings percentage for Elim when planted at 120-180 seeds m^{-2} (Table 5.7).

Table 5.7: Effect of planting density on grain quality obtain at Malmesbury site (Means followed by the same letter(s) are not significantly different)

Planting density (seeds m^{-2})	Screenings (%)		
	Hessekwa	Elim	S16
120	2.0c	1.4a	2.0c
140	1.6ab	1.2a	2.2c
160	1.2a	1.5ab	2.0c
180	1.5ab	1.2a	1.3a
200	1.2a	1.4c	2.1c
P value	0.05		
LSD	28.6		
CV (%)	0.91		

For Caledon planting density had a significant effect ($p<0.05$) on screenings. The Hessekwa cultivar had the highest screenings 15.2% at a planting density of 120, but this was not significantly different from that obtained at and 160 seeds m^{-2} (Table 5.8). The lowest screenings percentage of 1.5% was obtained with Hessekwa at a planting density of 200 seeds m^{-2}.

Table 5.8: Effect of planting density on grain quality obtain at Caledon site (Means followed by the same letter(s) are not significantly different)

Planting density (seeds m^{-2})	Screenings (%)		
	Hessekwa	Elim	S16
120	15.2e	6.8cd	4.2bc
140	4.8bc	3.4b	5.9c
160	12.3e	7.6cd	8.6d
180	3.0ab	4.4bc	5.8c
200	1.5a	3.9b	9.3de
P value	0.019		
LSD	11.32		
CV (%)	86.9		

Planting density had a significant effect ($p<0.1$) on screenings in Heidelberg. The Elim cultivar had the highest screenings of 9.7% at a planting density of 180 seeds m^{-2} (Table 5.9). The lowest screenings of percentage of 5.1% was obtained with Hessekwa at a planting density of 120 seeds m^{-2}.

Table 5.9: Effect of planting density on grain quality obtain at Heidelberg site (Means followed by the same letter(s) are not significantly different)

Planting density (seeds m^{-2})	Screenings (%)		
	Hessekwa	Elim	S16
120	5.1a	6.1ab	8.7e
140	7.3c	7.5cd	6.7bc
160	7.4cd	8.0de	7.5cd
180	7.2c	9.7f	8.1de
200	7.4cd	9.2e	7.8de
P value	0.09		
LSD	3.3		
CV (%)	21.4		

5.5 Discussion

5.5.1 Effects of N rate on grain N content

The prescribed malting barley standards for grain N content are between 1.5 and 2.1 % for delivery as malt, but a premium is paid when the N content is between 1.7 and 1.99% (SABBI, 2012). When N rates were above the recommended rates, grain N content increased in all localities. A study conducted in Western Canada showed that the way barley was treated in the field (e.g., N rate and cultivar) was the main factor influencing malting barley quality (O'Donovan *et al*., 2011).

McKenzie *et al*. (2005) found that the most beneficial agronomic practice for malting barley production in Southern Alberta was application of N fertilizer at rates appropriate to the moisture and soil N available. The grain N content obtained ranged from 1.43% to 2.28%. This suggests that there may be less risk of unacceptably high grain N levels when relatively high N rates are applied as top-dressing at the end of tillering to achieve malting barley standards for grain nitrogen content. Therefore, fertilizer recommendations may need to be cultivar specific.

O'Donovan *et al* (2011) reported that prediction of optimum rates of N fertilizer for malting barley production and quality can be difficult due to uncertainty in estimating available soil N and the N demand of the crop. This is as a result of the difficulty associated with trying to balance maximum yields with relatively low levels of N content. Baethgen *et al*. (1995) suggested that limiting N application at planting with additional topdressing applications at the end of tillering based on the requirements of the crop as a way of addressing this dilemma.

5.5.2 Planting density effects on grain N content

The 120 seeds m^{-2} had the highest effect on N content at Heidelberg. Increased planting density significantly affected total N content. These findings are similar to those of McKenzie *et al*. (2005) where the authors found that high planting density were more likely to reduce malt quality than increase it, although effects were mixed and relatively weak.

5.5.3 Effects of N rate on kernel plumpness

Previous studies (Clancy *et al*., 1991; Baethgen *et al*., 1995) showed that the variable response of barley kernel plumpness to N addition was consistent and showed occasional small negative effects of N addition on kernel size. The plumpness percentage in Malmesbury and Caledon was between 95.4 - 98.5% with Hessekwa having the highest plumpness percentage of 98.5 % at treatments of 60 kg N $ha^{-1.}$ Nitrogen demand varies widely from year to year, depending primarily on available moisture (McKenzie *et al*., 2005). In Heidelberg, the plumpness was between 81.9 – 85.9% and this low kernel plumpness could be attributed to the low rainfall received during growing season. Hessekwa had the highest plumpness percentage of 85.9 % at treatments of 20 kg N ha^{-1}. The proportion of kernels that were plump was reduced by the addition of N fertilizer most strongly at sites with good early-season moisture and late-season drought (e.g. Heidelberg). A similar study of Baethgen *et al*. (1995) confirms that the negative effect of improved N fertility on kernel plumpness can be attributed to the increase in tiller and ears number during early growth due to N addition, which increased the number of kernels beyond what could be supported during the grain-filling stage. Nitrogen application had a significant effect on kernel plumpness in all localities.

5.5.4 Effects of planting density on kernel plumpness

A previous study by Lafond (1994) showed that increased planting density reduce kernel size. In Caledon, the plumpness percentage was between 84.6 and 97.8% with Hessekwa having the highest plumpness percentage. The 200 seeds m^{-2} planting density had the highest effect on plumpness. In Heidelberg, the plumpness percentage was between 86% - 93.8% with S16 having the highest plumpness of 93.8%. The 140, 180 and 200 seeds m^{-2} planting densities having the highest effect on plumpness. The plumpness percentage in Malmesbury was not significant. These result indicates that increasing planting density beyond the optimum results in increased intraspecific competition for resources, leading to reduced kernel plumpness.

5.6 Conclusion

The three cultivars of barley examined expressed a significant effect on kernel plumpness and N content of grain harvested during the research. The highest planting density of 200 seeds m^{-2} resulted in the lowest kernel plumpness in all three localities. Increased N rates resulted in high kernel plumpness and grain N content increased in Caledon and Malmesbury. In contrast increased N rate resulted in kernel plumpness and N content reduction in Heidelberg. This might be as a result of differences in heat units and rainfall distribution between the three localities. Therefore, these environmental factors should be investigated and compared before any recommendations can be made to farmers in particular areas. Screenings did not affect the grain quality in all localities.

CHAPTER SIX

GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

6.1 Discussion

In Malmesbury, the total rainfall in the growing season was 206 mm with the highest rainfall recorded on the 1 June 2018 of 27 mm. Caledon had a higher rainfall throughout the season when compared to Malmesbury with a total rainfall of 364 mm recorded in the growing season. Heidelberg recorded the lowest rainfall throughout the season when compared to the other localities with a total seasonal rainfall of 179 mm. Caledon and Malmesbury obtained higher yield compared to yield obtained at Heidelberg due to low rainfall received in this area during the 2018 growing season. Baethgen *et al*., (1995) found that N rates above 100 kg N ha^{-1} could be used if available soil water was greater than 150 mm, but only 20 to 50 kg N ha^{-1} could be applied if available soil water was less than 100 mm due to excessive protein. These results indicates that in areas where poor rainfall is received, less plants should be planted to reduce moisture and nutrients stress and increase chances of obtaining high yield.

Cultivars differ in the amount of N needed to achieve optimum yields (Lauer and Partridge, 1990). The highest yield was obtained of 6.1 t ha^{-1} by Hessekwa cultivar with a planting density of 180 seeds m^{-2}. This planting density's yield were significantly higher, than the yield obtained by the 120 and 140 seeds m^{-2}, but not significantly higher than that of the 160 and 200 seeds m^{-2}. This indicates that the current recommendations for barley grown under rainfed conditions in the Western Cape South Africa of between 160– 180 seeds m^{-2} are still on target. Insufficient N reduce grain yield and quality below acceptable levels, while excessive N usually produces undesirable high protein levels (Lauer and Partridge, 1990). S16 variety had the highest yield of 6.69 t ha^{-1} at a treatment of 80 kg N ha^{-1} and this was significantly higher than yield obtained by Hessekwa and Elim cultivars. This suggest that the current recommendation of planting at N rate between 40-80 kg N ha^{-1} under rainfed conditions is still recommended.

O'Donovan *et al*. (2011) concluded that seeding malting barley at 400 compared with 200 seeds m^2 reduced kernel plumpness, but also resulted in earlier maturity, lower protein concentration and more uniform kernels. Therefore, the authors recommended that planting density for malting barley need to be defined to optimize seed uniformity and maintaining a relatively low protein without reducing kernel plumpness to unacceptable levels. Plumpness decreased with an increase in planting density for S16 cultivar and increased with an increase in planting density for Hessekwa and Elim cultivar. Increasing N application resulted in a decrease in kernel plumpness in all cultivars planted. These results indicates that N rates should not be applied above recommended as this results in poor quality. Significant differences were observed in percentage plumpness between planting density treatments. These results suggest that cultivar S16 cannot be planted in high planting densities of between 180-200 seeds m^{-2} as this resulted in reduced kernel plumpness in all localities. On the other hand cultivars Hessekwa and Elim can be planted at high planting density of between 180-200 seeds m^{-2} and still produce acceptably plump kernels for all localities.

6.2 Conclusions

- Yield generally increased with increased planting density across the three cultivars, with a clear optimum planting density at 160 seeds m^{-2} at Caledon and Malmesbury.
- Planting density showed very little effect on plumpness and grain N content across the three cultivars. Only the lower 120 m^{-2} seeds planting density showed a higher grain N content all localities.
- Kernel plumpness was not affected by planting density for all the three cultivars.
- Grain N content decreased with an increase in planting density for all cultivars.

- The 80 kg N ha^{-1} treatment resulted in high yield and acceptable quality at Caledon and Malmesbury, while 30 kg N ha^{-1} resulted in high yield at Heidelberg location.
- Cultivar Elim was the most suitable cultivar yielding optimally when planted at Heidelberg which was a very dry area compared to Caledon and Malmesbury.
- The results provided substantial evidence that seeding barley at approximately 180 seed m^{-2} has the potential to optimize yield and important malting barley parameters such as protein concentration and kernel uniformity without significantly compromising kernel plumpness. In addition, seeding at 180 seeds m^{-2} resulted in less plant stand variability due to site or environmental factors.

6.3 Recommendations

Two significant recommendations resulted from the study. First, planting malting barley at density of 160 seeds m^{-2} at Caledon and Malmesbury should result in less screenings, greater plumpness and thus improving the likelihood of obtaining malting grade. The results provided substantial evidence that seeding barley at approximately 180 seed m^{-2} (compared with lower rates) has the potential to optimize yield and important malting barley parameters such as N content and kernel uniformity without significantly compromising kernel plumpness. In addition, planting at 160 seeds m^{-2} resulted in less plant stand variability due to site or environmental factors. Planting above 180 seeds m^{-2} should be avoided since it increased the risk of a decline in yield and plumpness, and did not provide significant improvements in N content or grain uniformity. Second, applying approximately 80 kg N ha^{-1} at Caledon has a potential of increasing yield and improving quality parameters such as grain N content and plumpness. Applying 60 kg N ha^{-1} at Malmesbury can improve grain yield and improve quality paremeters.

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