YIELD AND QUALITY RESPONSE OF SPRING WHEAT CULTIVARS TO POST ANTHESIS HIGH TEMPERATURE

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Declaration

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously in its entire entity or in part submitted it at any University for a degree.

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Abstract

Knowledge of the growth, yield and quality response of spring wheat cultivars to high temperatures is important to minimise variation that often exists in yield and bread-baking quality of wheat produced in warmer regions. To achieve this, four South African spring wheat cultivars Kariega, Palmiet, SST 55 and SST 57 were grown under controlled conditions at the University of Stellenbosch during 1998 at temperature regimes of 15/10, 20/15, 25/20 and 30/25°C during grain filling. From seeding till anthesis, plants were grown at a temperature of 15/10°C. In this study, the highest temperature regime of 30/25°C affected all parameters tested, while at lower temperature regimes cultivars responded differently. The 30/25°C temperature regime caused premature senescence of the leaf area which was attributed to a decrease in relative leaf water content. Increased senescence of leaves at this temperature regime, reduced photosynthesis during grain filling, with the result that shriveled kernels with a lower mass kernel $^{-1}$ were produced and yield plant $^{-1}$ was reduced by almost 50% compared to that of the control (15/10°C). Other yield components such as kernels ear $^{-1}$ were less reduced and Kariega was less affected in comparison with the other cultivars.

High temperature regimes of 30/25°C during grain filling resulted in increased flour protein content. Mixogram peak heights increased as post-anthesis temperature regimes increased, while Palmiet also showed an increase in dough development time with increasing temperatures. At the highest temperature regime (30/25°C), the respective dough development times for SST 55 and SST 57 were well below the optimum mixing time of 2.5 to 3 minutes set by the baking industry, while the mixograph band widths of Kariega were the narrowest at all temperature regimes tested. This tendency indicated good water absorption properties. These results indicate that quality parameters of Kariega and Palmiet are less sensitive to high post-anthesis temperatures in comparison with SST 55 and SST 57. In general, it is concluded that although this study showed small differences between cultivars, Kariega was consistently different from other cultivars, indicating possible adaptation to hotter environments. However, more cultivars need to be screened before recommendations for such areas can be made.

Uittreksel

Kennis aangaande die groei-, opbrengs- en kwaliteisreaksie van lente koringcultivars teenoor hoë temperature is belangrik. Dit mag help om jaar tot variase ten opsigte van opbrengs en bakkwaliteit wat dikwels in warmer produksiegebiede voorkom, te verminder. In hierdie studie is die invloed van vier dag/nagtemperatuur-behandelings wat gedurende korrelvulling op die Suid-Afrikaanse lente koringcultivars, Karige, Palmiet, SST 55 en SST 57 toegepas is, ondersoek. Die ondersoek is gedurende 1998 onder gekontroleerde groeitoestande by die Universiteit van Stellenbosch uitgevoer. Vanaf planttyd tot antese is alle plante gegroei by 'n dag/nagtemperature van 15/10°C. Vanaf antese tot oes is die kontrole plante steeds aan hierdie temperatuur blootgestel, terwyl die ander plante aan dag/nagtemperature van onderskeidelik 20/15°C, 25/20°C en 30/25°C blootgestel is.

In hierdie studie is alle gemete eienskappe deur die hoogste dag/nag tempertaure beinvloed en het cultivars nie grooteliks verskil in hul reaksie nie. Verskille in cultivarreaksie het wel by die laer dag/nagtemperature voorgekom.

Die 30/25°C temperatuurbehandeling het blaarafsterwing versnel weens 'n verlaging in die relatiewe water inhoud van die blare. Dit het blaaroppervlakte-duurte en dus ook fotosintese gedurende korrelvulling benadeel met die gevolg dat verkrimpte, maer korrels geproduseer en opbrengs plant^{-1}, in vergelyking met die kontrole plante, met byna 50% verlaag is. Ander opbrengskomponente soos korrels aar $^{-1}$ is minder ernstig benadeel en Kariega was ietwat meer tolerant as die ander cultivars.

Hoë dag/nagtemperatuur gedurende korrelvulling het tot 'n toename in meelproteïeninhoud aanleiding gegee. Mixogram-piekhoogtes het ook toegeneem met toenemende temperature. In teenstelling met ander cultivars het Palmiet ook 'n toename in deegontwikkelingstyd getoon. By die hoogste dag/nagtemperatuur (30/25°C) was deegontwikkelingstye van die cultivars SST 55 en SST 57 betekenisvol laer as die optimum tye van 2.5 – 3.0 minute wat deur die bakbedryf vereis word. Waardes vir Kariega was meer aanvaarbaar en mixogram bandbreedtes vir kariega was ook by alle temperatuurbehandelings die smalste. Dit is ‘n aanduiding van goeie waterabsorpsie-einskappe. Hierdie resultate toon dat die bakkwaliteit van Kariega en Palmiet minder gevoelig is vir hoë temperature gedurende korrlevulling in vergelyking met SST 55 en SST 57.

In hierdie studie is gevind dat hoewel verskille in cultivareaksie oor die algemeen klein was, Kariega ietwat beter aanpassing by die hoë temperature getoon het. Meer cultivars sal egter getoets moet word alvorens aanbevelings in die warmer produksiegebiede gemaak kan word.

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List of abbreviations

ANOVA	Analysis of variance
g	Gram
cm	Centimetre
C	Cultivar
CIMMYT	International Center for Maize and Wheat
^{14}C	Carbon 14
°C	Degrees Celsius
Dev	Development
Df	Degrees of freedom
Ed	Editor
kg ha^{-1}	Kilogram per hectare
hr	Hour
LSD	Least significant difference
MDT	Mixograph Development Time
Mins	Minutes
mg	Milligram
mg g^{-1}	Milligram per gram
N.S.	Not Significant
RWC	Relative water content
SADC	Southern African Development Community
T	Temperature
%	Percentage
<	Less than
>	More than
x	By

Contents

Language and style used in this thesis are in accordance with the requirements of the *South African Journal of Plant and Soil.* This thesis represents a compilation of manuscripts where each chapter is an individual entity and some redundancy between chapters has therefore, been unavoidable.

Chapter 1

Introduction

The demand for wheat as a source of food for the developing countries increased by 73% from 1972 to 1982 (Briggle and Curtis, 1987). A recent statement by Reeves (1998) read as follows:

> *" During the next three decades, the population of the developing world will continue growing at around 200 people per minute. That staggering growth in numbers, combined with the other changes, leads us to expect that overall demand for maize and wheat will grow dramatically during the same period. By 2020 two thirds of the world's wheat and 55% of the world's maize will be consumed in developing countries ".*

This statement was therefore, a challenge to countries like Botswana which has given very little attention to wheat production in the past. At present most of the wheat milled for bread flour in Botswana is imported. Only about 80 hectares of irrigated spring type wheat is produced at a few commercial farms in the Tuli Block, situated in the eastern part of the country. Although yields range between 4 000 and 4 600 kg ha $^{-1}$ (Sims, 1981), the production is too small to satisfy the demand for wheat in the country.

The Tuli Block area has a high potential for spring type wheat produced in winter months since adequate water is available for irrigation, but several factors have played a major role in the lack of focus on wheat production. Among these were the criteria used in selecting crops for expanding production. The criteria used for selection of crops were based on their economic profitability and employment intensity. Although wheat was ranked second highest among the five crops when analysed according to economic profitability, it ranked last in terms of employment intensity. It was, therefore, not recommended for further expansion on the basis of the Government of Botswana's objective of creating employment (Edwards, Amani, Frankenberger & Jansen, 1989).

Another factor that hampered the production of wheat was the price offered by the milling companies, which farmers viewed as too low to be profitable. In spite of these limitations there is still a need for increased wheat production in Botswana to reduce wheat imports and ensure sufficient and affordable bread to all the people of Botswana. To achieve this goal it would be important to identify wheat cultivars that are well adapted to climatic conditions in Botswana. Although the climate of Botswana is characterised by high temperatures, especially during spring and summer, it is known that wheat is adapted to a broad range of environments. For instance, irrigated wheat is grown under hot subtropical conditions (Sudan, Central India), in which the mean temperature of the coolest month in the growing season exceeds 17.5°C (Fischer & Byerke, 1991 as reported by Amani, Fischer & Reynold, 1996).

Because of the reported influence of high temperature on yield and quality of wheat (Wrigley, Blumenthal, Gras, & Barlow, 1994), knowledge on the response of different cultivars to high temperatures is important before growing them in a new area.

Growth, yield and quality response of wheat to high temperatures

The effect of high temperatures on cereals at different stages of growth is well documented (Wardlaw, Dawson, Munibi & Fewster, 1989; Hunt, Van der Poorlen & Pararayasingham, 1991; Stone & Nicholas, 1994). The development of wheat can be divided into vegetative growth, ear development and grain growth (Warrington, Dunstone & Green 1977; Wardlaw, 1994). All stages are affected by both genetic and environmental factors. The most vulnerable to environmental conditions is the grain growth (grain filling) stage, which often coincides with high post-anthesis temperatures.

Growth

The growth parameters such as the leaves, stems and glumes are all chlorophyll-containing organs capable of photosynthesis. These, therefore, act as a source of carbon for the growing grain after anthesis. Their success in providing photosynthates to the growing grain depends on their ability to remain viable.

Being largely dependent on current photosynthate, the photosynthesizing leaf area is indicated to be the major contributor to grain growth. Leaf area duration is highly sensitive to high temperatures, which cause premature senescence of the leaves (Al-Khatib & Paulsen, 1984). When leaves senesce prematurely, it implies that current photosynthate is curtailed. It is known that by anthesis, all the leaves of a wheat plant, apart from those on a few tillers which may still be growing, are fully developed. This, therefore, implies that the persistence of the existing leaf area is important for continued grain filling. Spiertz (1977) observed that increasing temperatures from 10 to 25°C accelerated leaf senescence. Asana and Williams (1965) and Simpson (1968) showed that the disappearance of green leaves corresponds closely with cessation of grain filling. The rapid dessication of the leaves at elevated temperatures can also be measured by the decrease in the relative water content.

Photosynthesis also occurs in the stems of wheat plants. Stems can therefore also contribute towards grain growth (Davidson & Chevalier, 1992). Variable estimates, depending on growth conditions, of the contribution of pre-anthesis assimilate from the stem for grain growth have been reported, but could be in the order of 10% under normal conditions. This contribution is increased with high temperatures during the grain filling stage, due to an increase in the mobilisation of photosynthate (Fokar, Blum & Nguyen, 1998). Davidson and Chevalier (1992) showed a reduction of water soluble carbohydrates in the stems of wheat plants from 380 mg g^{-1} to 50 mg g^{-1} as a result of remobilisation during stress conditions. The magnitude of remobilisation may however, also differ between cultivars (Austin, Edrich, Ford & Blackwell, 1977). During stress conditions, large contributions of as much as 30% of the total grain assimilate may come from the ear itself (Duffus & Slaughter, 1980). This is especially true for awned wheat, but the pericarp may also contribute to grain dry matter since it contains chloroplasts that are active in photosynthesis.

Grain yield

Grain yield is the result of several yield components, namely ears $plant^{-1}$, kernel number ear^{-1} and mass $kernel^{-1}$.

High temperatures encountered by the crop after anthesis may limit grain yield, but reports indicate a temperature of 30/25°C as still not extreme for grain filling, particularly in subtropical wheat growing areas (Slafer & Rawson, 1994). However, the same temperatures may cause large reductions in grain weight, depending on the cultivar. Hunt, Van der Poorlen & Pararayasingham (1991) studied temperatures ranging from 15/10°C to 30/25°C and showed that genotypes clearly differ in sensitivity to high temperatures. For maximum kernel weight, however, the optimum temperature is indicated to be in the range of 15 - 18°C. The relation between grain yield and growth of a particular yield component will vary greatly depending on the sequence of environmental conditions during the grain filling period. Elevated temperatures during grain filling have a detrimental effect on kernel weight and subsequently on grain yield due to the shortening of the grain filling period (Asana & Williams, 1965). At high temperatures above 35°C during grain filling, individual kernel mass was found to decrease by as much as 23%, depending on cultivar (Stone & Nicholas, 1994). The period of grain filling consists of two components: the rate and duration of grain filling. Genetic factors (cultivar) dominate the rate of grain filling while environment (temperature) dominates the duration of grain filling (Hunt, Van der Poorlen & Pararayasingham, 1991). The rate reflects the biochemical reactions, involved in the starch and protein synthesis and is indicated to be favoured as temperature rises from 15/10°C to 21/16°C (Jenner, 1994). With a further increase in temperature to 30/25°C, rate of grain filling reaches a plateau with the result that final grain weight is substantially reduced at temperatures above 30°C (Chowdry & Wardlaw, 1978). This is due to a rapid increase in ear respiration at increasing temperatures (Evans, Wardlaw & Fischer, 1975).

Duration of grain filling also has an effect on kernel mass and is shown to decline with each incremental increase in temperature from 15/10°C to 30/25°C as a result of accelerated grain development (Sofield, Evans, Cook & Wardlaw, 1977). Reduced grain mass at high temperature is therefore the result of a decrease in the duration of grain filling combined with the inability of the rate of dry matter accumulation to compensate.

The failure of starch deposition in the endosperm is one of the major factors contributing to the reduction in final grain yield at high temperatures (Bhullar & Jenner, 1985, 1986; MacLeod & Duffus, 1988). Kernels that result from reduced starch deposition are often deformed (shriveled) (Arnon, 1972) and with a low test weight which may be considered undesirable for milling purposes. Researchers seem to have different viewpoints regarding starch deposition, which ultimately affects single grain weight. Some indicate direct effects due to the reduction in starch deposition which decrease grain weight as a result of a limited supply of assimilate to the grain. However, Bhullar and Jenner, (1986); Hawker and Jenner, (1993) and Jenner, (1994) link reduction in starch deposition with a subsequent decrease in grain weight as a result of inactivation of soluble starch synthase (an enzyme involved in the synthesis of starch). It is well known that enzymes operate at certain temperature optima, such that any temperature below or above will terminate the processes. Reduced activity in the conversion of starch can terminate grain filling (Lingle & Chevalier, 1985). According to Rijven (1986) the grains of wheat plants grown at 21°C lose more than 50% of the extractable activity of soluble starch synthase within 30 minutes after their transfer to a temperature of 37°C.

Wheat quality

Quality in wheat is very important for both milling and baking processes. Quality consists of a variety of characteristics. However, in simple terms, quality can be defined as the suitability of the wheat grain for the intended processing and product manufacture (Zeleny, 1978). Wheat which is suitable for one type of food product may be quite unsuitable for another.

Realising the importance of quality, various efforts were taken by both the milling and baking industries in setting standards for various quality parameters to ensure a wheat product of desirable quality. Any wheat flour that does not meet the set standards for these parameters is considered to be unsuitable for bread making.

Temperature is one of the factors that influence quality of wheat. The effect of high temperatures on wheat quality can be measured by, among others, the infralyser to obtain protein content and the mixograph to determine dough development characteristics (Finney & Shogren, 1972). Most researchers have reported the effect of high temperatures as either detrimental or in some cases having beneficial effects. Prolonged temperature in the range of 30 - 35°C may result in dough strengthening in both durum and bread wheat (Borghi, Corbellini, Ciaffi, Lafiandra, De Stefanis, Sgrulletta, Bogginni & Di Fonzo, 1995). Positive effects are particularly noted when wheat is used for pasta making (Borghi *et al.*, 1995). On the other hand, high dough strength is associated with a long dough development time, a slow rate of breakdown and a high resistance to extension (Hemmingway, 1993). Previously the demand was for strong wheats with long development times and strong dough characteristics because baking units were small and equipped with slow mixers which required long fermentation times (Hemingway, 1993). At present high to semi-high speed mixers require optimum mixing times of 2.5 - 3.0 minutes. Wheat flour that is either below or above these standards is considered to be of poor quality.

Protein content gives a reliable indication of flour quality. A good quality or strong wheat is not good by commercial standards unless it has a sufficient quantity of protein (Blackman & Payne, 1980). Protein content in wheat commonly varies between 6% and 20% (Zeleny, 1978), but values of 25% are not exceptional (Blackman & Payne, 1980) depending on cultivar and environmental conditions during growth. The length of the ripening period may also affect protein in the way that shorter grain filling periods normally result in higher percentages of protein (Arnon, 1972). The semi-arid regions may therefore be beneficial in improving the protein content, but at the expense of grain size and grain yield.

Research concerning wheat quality in South Africa

The seasonal variation and differences in climate and growing conditions often affect wheat quality and end-use properties of South African cultivars. It is noted that variation in protein quantity and quality are at least partly responsible for the general inferior quality of bread. Variations in protein content ranging from between 8 to 15% within one season frequently occur (Fowler, 1978). Van Lill, Purchase, Smith, Agenbag & De Villiers (1995a, 1995b) observed the major impact of environmental factors on South African wheat quality due to variation in protein content. They further noted that this variation in protein content contributed to an increase in the level of dough strength beyond the capability of Chorleywood Bread- making Process (CBP) technology which needs flour protein levels of optimum of 10%. Variation in protein content of wheat grown at different locations was found to be attributable to genotype and genotype x environment interaction (Stander & Louw, 1978). Van der Mey (1979) found the greatest environmental effect on mixograph peak height, while flour protein content remained constant. Recent investigations by Nel, Agenbag and Purchase (1998) reported instability in protein content of spring wheat cultivars Palmiet, Nantes, SST 16 and to a lesser extent Adam Tas, as largely due to environmental conditions. Working with temperature, Van Lill (1992) found that increasing temperature above 35°C neither reduced the mixograph mixing requirement, nor increased average gliadin content of winter wheat cultivars. But the combination of heat and water stress reduced the mixograph mixing requirement of Betta, Scheepers 69 and Riemland.

Although these investigations have clearly proved environment as largely responsible for the variation in quality of wheat, environment is a broad aspect which entails a number of factors. Little is known on how specific environmental factors, such as high temperature, affect quality of wheat. Although Van Lill (1992) studied high temperatures on winter wheat, an understanding of how spring wheat responds to high temperatures is important.

The aims of the study were to determine:

- The effect of high temperature on growth processes of different spring wheat cultivars.
- The effect of high temperature on the grain yield of different spring wheat cultivars
- The effect of high temperature on the quality of different spring wheat cultivars.

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Chapter 2

Growth response of spring wheat (*Triticum aestivum* L.) cultivars to post - anthesis high temperatures.

Abstract

High post-anthesis temperatures limit the growth of wheat (*Triticum aestivum L.*). However, the impact of these temperatures is dependent on cultivar response. To study the growth response of wheat to post-anthesis temperatures, four South African spring wheat cultivars (Kariega, Palmiet, SST 55 and SST 57) were initially grown at a temperature regime of 15/10°C day/night until anthesis. At 50% anthesis they were subjected to temperature regimes of 15/10, 20/15, 25/20 and 30/25°C till harvest. The results have showed that a high temperature regime of 30/25°C during grain filling accounted for a decrease in leaf area, leaf mass, stem and ear mass of all cultivars. The leaf area proved to be the most sensitive as showed by premature senescence which was associated with reduced relative water content due to water loss from the leaves. Despite sensitivity shown by the leaf area at temperature regimes of 20/15°C and 25/20°C, this did not, however, prevent the continued increase of both stem and ear mass. All cultivars showed little tolerance at post-anthesis temperature of 30/25°C, but differed in their response to temperature regimes of 25/20°C and 20/15°C. At these temperatures, Palmiet and SST 55 were more affected compared to Kariega and SST 57. These results may indicate that Kariega and SST 57 will be better adapted to areas with high post-anthesis temperature regimes.

Introduction

The expansion of wheat cultivation beyond its boundaries since its domestication 5000 years ago, has meant that both high and low temperature extremes have become important factors limiting the production of this cereal in many parts of the world (Wardlaw & Wrigley, 1994). Although optimum temperatures for spring wheat are in the order of 18°C at day and 13°C at night (Wardlaw, Dawson & Munibi, 1989), wheat is often grown in areas where temperatures as high as 35°C commonly occur late in the developmental stage of the crop (Stone & Nicholas, 1994). In South Africa, approximately 50% of the total wheat crop of the country is produced in the Free State, which is characterised by low rainfall, high temperatures and high evaporation during early summer, which coincides with the grain filling stage of wheat (Purchase, Maritz, Hatting, Du Plessis, Rautenbauch & Botha, 1995). These unfavourable climatic conditions are likely to be enhanced by the projected rise in both global mean temperature and frequency of droughts, as part of the greenhouse effect (Conroy, Senerweera & Basra, 1994). Understanding how high temperatures are likely to influence the growth of different wheat cultivars may assist agronomists, physiologists and breeders in developing strategies towards better wheat cultivation.

Several studies have concentrated on the effect of high temperatures on wheat yield (Moffat, Sears, Cox, & Paulsen, 1990; Shanahan, Edwards, Quick & Fenwich, 1990; Jenner, 1991a, 1991b; Hawker & Jenner, 1993) and quality (Blumenthal, Batey, Bekes, Wrigley & Barlo; 1990, Stone & Nicholas, 1994, 1995). However, high temperatures also influence physiological attributes, such as the leaf area duration, the relative water content of the leaves, as well as stem growth, which eventually may affect grain filling. The effect of high temperatures proved to be most detrimental if it occurs during the post-anthesis grain filling stage (Stone & Nicholas, 1994). According to these researchers, the effects are cultivar dependent.

Under non-stress conditions, the rate of kernel growth correlates with the rate of photosynthesis. In this regard Stoy, (1963); Rawson and Hofstra, (1969) and Kobza and Edwards, (1987) illustrated the importance of the flag leaf area as source of assimilates for the growing grain. However, its performance is often subjected to fluctuation by environment factors such as high temperatures (Spiertz, 1977; Wardlaw, Sofield & Cartwright, 1980; Vos, 1981). Van Lill (1992) showed a rapid decrease of relative water content of the flag leaf with time when subjected to a temperature of 35°C. This response, however, differed between cultivars.

Although remobilization of carbohydrates from the stems could support grain filling of wheat under heat stress (Wardlaw & Porter, 1967; Blum, 1986; Stoy & Berholdsson, 1986; Davidson & Chevalier, 1992), leaf area duration after anthesis proved to be the single most important factor determining grain yield under such conditions (Fischer & Kohn, 1966; Ford, Pearman & Thorne, 1976). Leaf senescence was shown to be enhanced by high temperatures (Spiertz, 1977; Al - Khatib & Paulsen, 1984; Harding, Guikema & Paulsen, 1990), but these effects are also cultivar dependent (Rawson & Evans, 1971; Austin, Edrich, Ford & Blackwell, 1977).

Although Van Lill (1992) studied the response of some winter wheat cultivars to high temperatures, this study was limited to a temperature regime of 35°C. Little is, however, known about the effects of temperatures less than 35°C on South African cultivars.

This study was conducted with the objective of determining the effects of post-anthesis high temperatures on the growth of four South African wheat spring cultivars.

Materials and Methods

Plant material

The experiment was conducted in 4 growth chambers at the Department of Agronomy and Pastures of the University of Stellenbosch in 1998. Plants were grown in 2.0 litre pots filled with coarse sand. Three seeds were sown per pot and seedlings were thinned to two plants per pot at the two-leaf stage. From seeding till anthesis all plants were subjected to a 15/10°C day/night temperature regime and a day length of 12 hours. Plants were irrigated with a balanced nutrient solution 2-times daily throughout the duration of the experiment to prevent any water stress.

Treatments and experimental layout

Four spring wheat cultivars, namely Kariega, Palmiet, SST 55 and SST 57 were used. As soon as 50% anthesis were reached, plants in different growth chambers were subjected to different day/night temperature regimes, namely, 15/10°C; 20/15°C; 25/20°C; and 30/25°C. These temperature regimes were maintained till harvest. Enough pots were initially sown to provide four replications for each cultivar x temperature combination for each sampling date as well as for the final harvest. Within each growth chamber all cultivars and replications were fully randomised. All data were subjected to an analysis of variance (ANOVA), while Tukey' s studentized Range values (Snedecor & Cochran, 1967) were used to compare treatment means.

Emphasis was, however, placed on cultivar differences within each temperature regime, due to pre-anthesis differences in growth between growth chambers.

Measurements

For each treatment, sampling was done at anthesis (0 days), 21 days and 42 days after anthesis. At each sampling date, four plants for each treatment were harvested and the leaves, ears and stem were separated. The total leaf areas of all green leaves were determined by passing the leaves through a LI - 300 leaf area meter (LI - COR). The leaves, ears and stems were thereafter dried separately at 70°C for two days and then weighed to determine leaf, stem and ear mass. Flag leaves of the main stems were kept separately to determine their relative water content as described by Matin, Brown & Ferguson, (1989). In the end, the leaf area and dry mass of flag leaves were added to that obtained from the rest of the plant. The relative water content was calculated as:

$$RWC = \frac{FW - DW}{TW - DW} \times 100$$

FW = Fresh weight immediately after sampling

TW = Turgid weight after cut ends leaves were submerged in a test tube filled with water for 24 hours.

DW = Dry weight after drying for 24 hours.

Results and discussion

Relative water content

The analysis of variance (ANOVA) for the relative water content of the flag leaves on the main stems (Table 1) showed no significant differences due to temperature treatment (T), cultivars (C) or T x C interaction at anthesis (0 days). This is an indication that water supply during the pre-anthesis growth stages, were sufficient to prevent any water stress during these stages.

Table 1 Analysis of variance (ANOVA) for flag leaf relative water content of 4 cultivars subjected to a range of post-anthesis temperatures

Sources of	**df**	**Mean square**		
Variation		0	21	42
T	3	0.0104^{NS}	29.74**	6.3190**
C	3	0.0179^{NS}	1.3310^{NS}	2.0174^{NS}
T x C	9	0.0072^{NS}	1.5859**	2.5804*
Error	45	0.0101	0.5110	0.8913
Total	63			

*, ** F - test significant at the 5 and 1% levels of probability, respectively.

In spite of the fact that plants were watered twice daily, increased temperatures after anthesis resulted in significant reductions in relative water contents of the flag leaves during samplings at 21 and 42 days after anthesis. These results supported the findings with South African winter wheat cultivars (Van Lill, 1992) and may indicate enhanced desiccation of flag leaves when exposed to high temperature regimes. This is probably due to a rapid increase in the rate of respiration at higher temperatures (Manunta & Kirkham, 1996).

Although cultivar main effect was not affected by temperature regimes at 21 and 42 days after anthesis, significant temperature x cultivar interactions were found at both sampling dates (Table 1). All cultivars were therefore not affected to the same extent by increasing temperatures during the grain filling stage. From Figure 1, it is clear that all cultivars maintained relative water content of about 98% in their flag leaves till

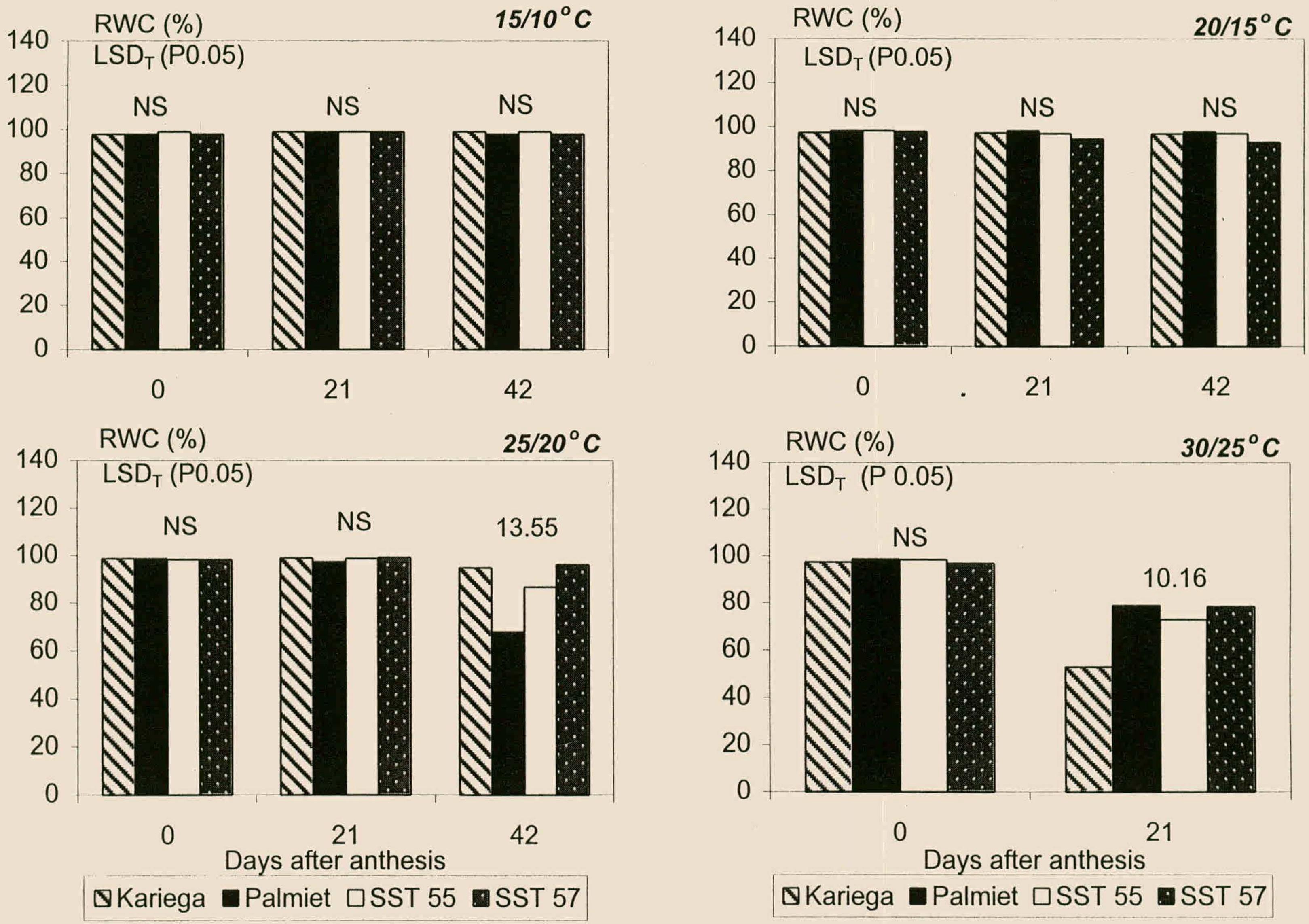

Figure 1 Effect of temperature on the relative water content (RWC) of the flag leaf of spring wheat cultivars.

42 days after anthesis if the pre-anthesis temperature regime of 15/10°C was maintained during this period. A temperature regime of 20/15°C during the post-anthesis period also had little effect, except for cultivar SST 57 that was slightly reduced at 21 and 42 days after anthesis. At a temperature regime of 25/20°C, the relative water content of cultivar Palmiet decreased markedly at 42 days after anthesis, followed by SST 55, while that of Kariega and SST 57 still showed little effect. At a post-anthesis temperature regime of 30/25°C, all cultivars showed a reduction in relative water content of their flag leaves at 21 days after anthesis, but the effect was more pronounced on Kariega in comparison to other cultivars tested. Due to early desiccation of flag leaves, no measurement could be done at 42 days after anthesis for this temperature regime.

Leaf area

The analysis of variance (ANOVA) for leaf area (Table 2) showed significant differences due to post-anthesis temperatures at all three sampling dates.

Table 2 Analysis of variance (ANOVA) for leaf area of 4 cultivars subjected to a range of post-anthesis temperature and sampled at 0, 21 and 42 days after anthesis

Sources of Variation	**df**		**Mean square**	
		0	21	42
T	3	846343.1**	389168.1**	90727.8**
C	3	201048.7**	35089.9^{NS}	98797.6^{NS}
T x C	9	21717.0^{NS}	61675.4**	50290.1^{NS}
Error	45	40303.0	22184.8	35045.8
Total	63			

*, ** F - test significant at the 5 and 1% levels of probability, respectively

These results indicated that plant development must be affected by pre-anthesis growing conditions. Significant differences between cultivars were only found at anthesis (0 days), but not at 21 and 42 days after anthesis, while significant temperature treatment x cultivar interactions were only found at 21 days after anthesis.

Because of significant differences at the start of the different temperature treatments at anthesis, leaf areas for different cultivars at samplings after anthesis were calculated as percentages of their respective leaf areas at anthesis (0 days). The response of different cultivars to post-anthesis temperature regimes could thus be measured by the percentage change of their leaf area during the grain filling stage.

From Figure 2, it is clear that leaf senescence is accelerated by high post-anthesis temperature regimes.

At a post-anthesis temperature regime of 15/10°C the leaf area of all four cultivars tested showed a slight increase till 42 days after anthesis. This is probably due to leaves on late developing tillers that continue growing after the ear on the main stem had reached anthesis.

At a temperature regime of 20/15°C, leaf area of cultivar Kariega still increased till 21 days after anthesis, while leaf area of Palmiet, SST 55 and SST 57 stayed the same or decreased slightly.

At temperature regimes of 25/20°C and 30/25°C the leaf area of all cultivars tested decreased after anthesis. At 25/20°C Kariega was less affected than other cultivars, which may be an indication of some tolerance to high post-anthesis temperatures. At 30/25°C all cultivars were severely affected with the result that all leaves died within 42 days after anthesis.

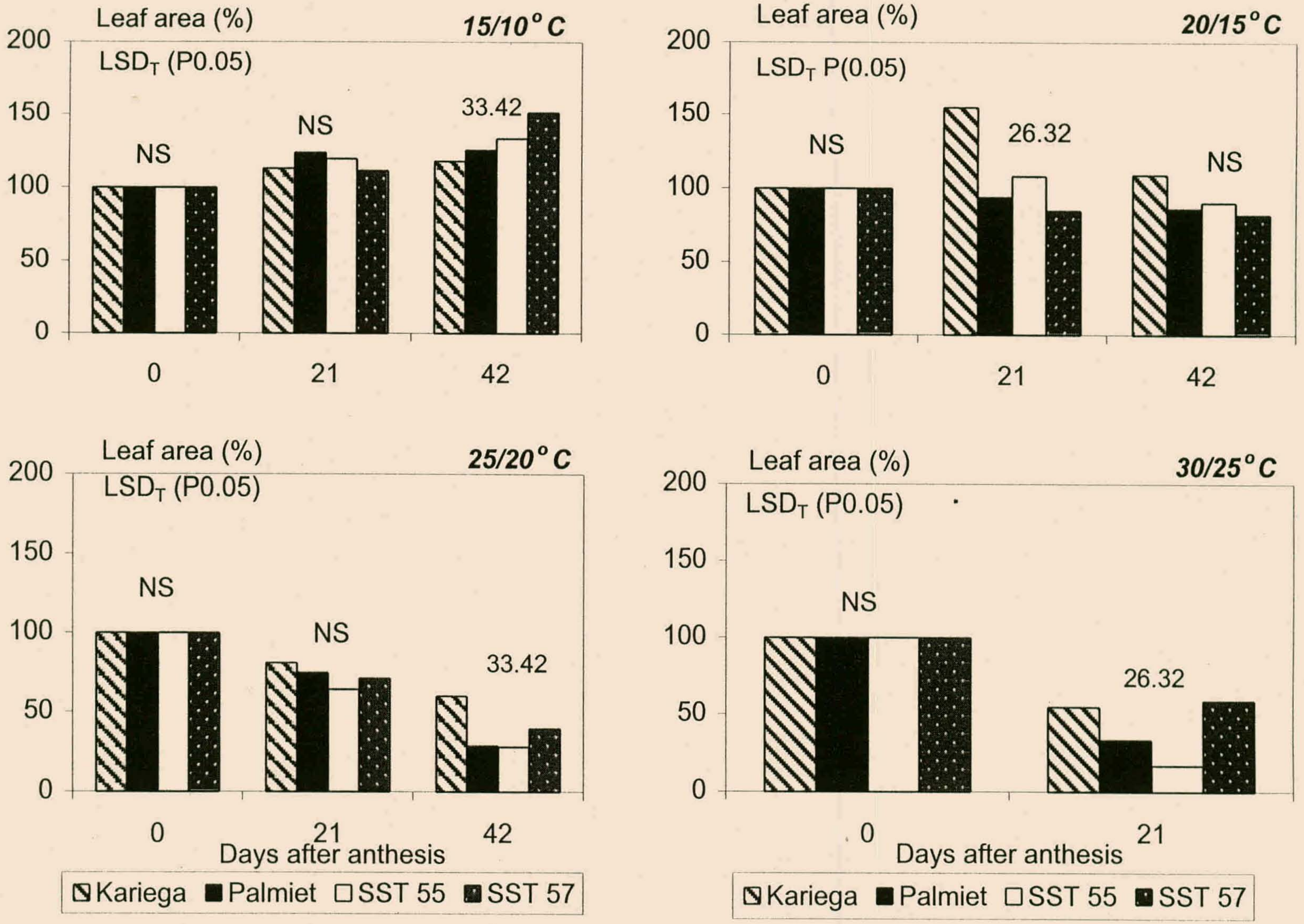

Figure 2 Effect of four different temperature regimes on the leaf area of spring wheat cultivars expressed as a percentage of their values at anthesis.

Leaf mass

Analysis of variance for leaf mass showed that post-anthesis temperature significantly affected the leaf mass from anthesis (0 days) till 42 days after anthesis (Table 3). Cultivar influenced leaf mass at anthesis (0 days) and 42 days after anthesis. The significant differences at anthesis (0 days) were not expected as it was at the onset of the treatment. Temperature x cultivar interaction was significant only at 42 days after anthesis.

Table 3 Analysis of variance (ANOVA) for leaf mass of 4 cultivars subjected to a range of post-anthesis temperature and sampled at 0, 21 and 42 days after anthesis

Sources of variation	**df**	**Mean square** **0**	**21**	**42**
T	3	26.3**	3.3**	5.6**
C	3	2.8*	1.0^{NS}	0.7*
T x C	9	0.3^{NS}	0.8^{NS}	0.5*
Error	45	0.7	0.7	0.2
Total	63			

*, ** F - test significant at the 5 and 1% levels of probability, respectively

The differences found at anthesis (0 days) were adjusted by calculating leaf mass at samplings after anthesis as a percentage of that cultivar 's leaf mass at anthesis. This meant that the response of the different cultivars to temperature regimes could be interpreted as percentage change from the measurements at anthesis (0 days). The decline in leaf mass after anthesis reflected inefficient functioning of the photosynthetic system (Figure 3).

At temperature regimes of 15/10°C and 20/15°C, mean leaf mass increased up to 42 days and 21 days after anthesis, respectively. As this tendency was also observed

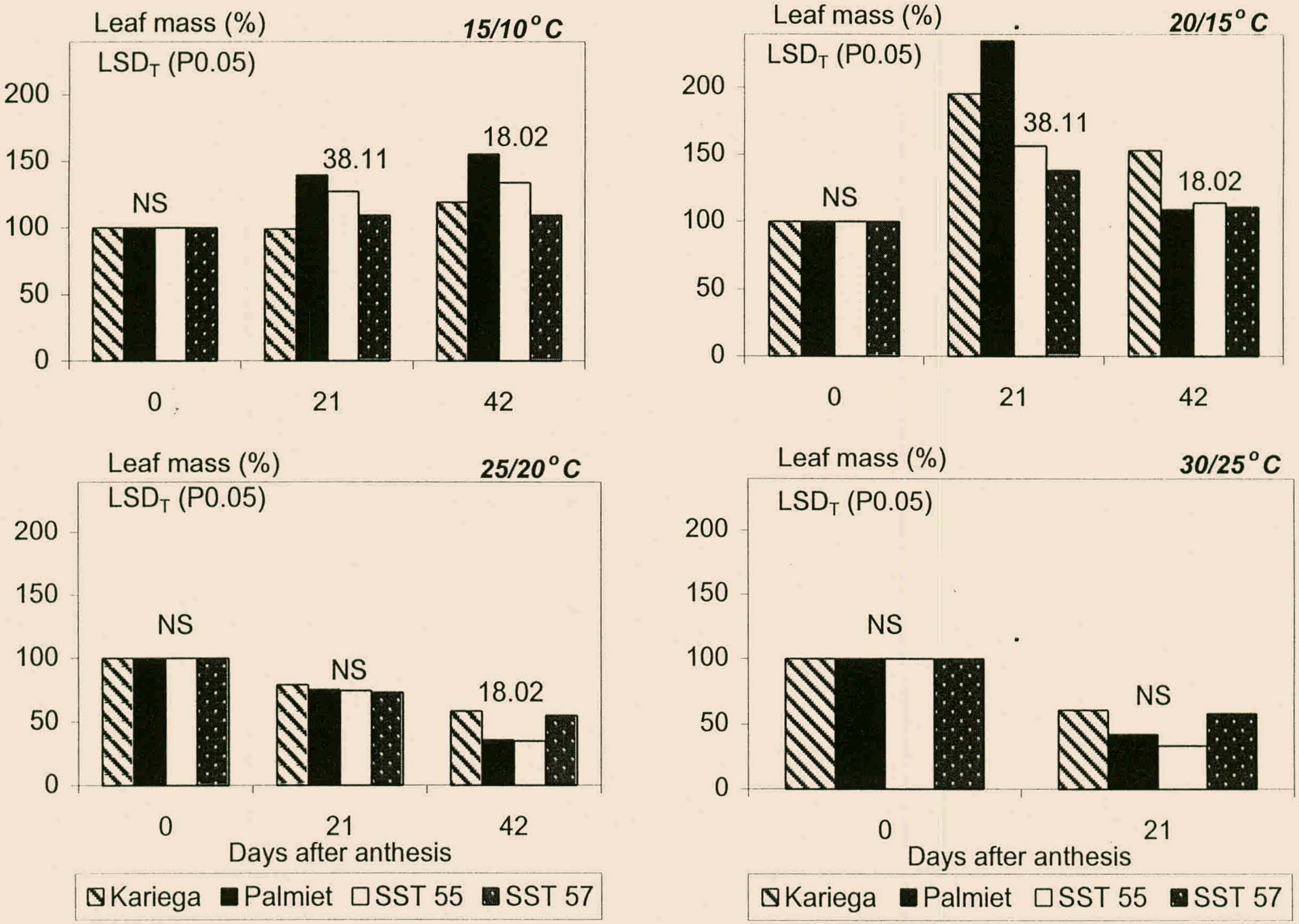

Figure 3 Effect of four different temperature regimes on the leaf mass of spring wheat cultivars expressed as a percentage of their values at anthesis (0 days).

with the leaf area this increase is attributed to leaves from secondary tillers that were still growing at anthesis. The leaves of main stems could not have contributed to the increase as they were already fully expanded at anthesis.

The leaf mass of all cultivars declined at a temperature regime of 25/20°C from anthesis till 42 days after anthesis. It appears that Palmiet and SST 55 seem to be more susceptible at this temperature regime compared to Kariega and SST 57. The reason for the decline, according to Ford *et al.* (1976), is the rapid remobilization of carbon and nitrogen from the leaves with increasing temperatures, resulting in decreased weight of leaves. At the highest temperature regime of 30/25°C all cultivars were affected to such an extent that all leaves had died within 42 days after anthesis. Even at this high temperature regime, as was observed at 25/20°C, cultivar Palmiet and SST 55 were more affected than Kariega and SST 57 at 21 days after anthesis. This tendency indicated the sensitivity of the leaves to these high temperature regimes.

Stem mass

Analysis of variance (ANOVA) in Table 4 revealed significant differences in stem mass at anthesis (0 days), 21 and 42 days after anthesis, due to post-anthesis temperature treatments. These differences observed at anthesis (0 days) probably resulted from pre-treatment conditions such as light intensity because temperature regimes were the same till anthesis. Cultivar as a main effect showed significant differences at both 21 and 42 days after anthesis. Significant differences between temperature x cultivar interaction were found at 21 and 42 days after anthesis.

Table 4 Analysis of variance (ANOVA) for stem mass of 4 cultivars subjected to a range of post-anthesis temperature and sampled at 0, 21 and 42 days after anthesis

Sources of Variation	**df**	**Mean square** 0	21	42
T	3	171.4**	230.1**	141.1**
C	3	7.9^{NS}	51.0**	22.8**
T x C	9	2.3^{NS}	11.1**	11.8**
Error	45	4.1	2.3	1.8
Total	63			

*, ** F - test significant at the 5 and 1% levels of probability, respectively

Due to the abovementioned differences at anthesis, values for different treatments were adjusted by calculating the stem mass at 21 and 42 days after anthesis as a percentage of stem mass at anthesis (0 days). The percentage change in stem mass from anthesis is thus an indication of the response of different cultivars to the temperature treatment. From Figure 4, it is clear that stem mass tended to increase after anthesis. This tendency is most probably due to growth of secondary tillers. These results agreed with the findings that increase in stem mass may occur till 10 - 11 days (Kiniry, 1993) or even 2 to 3 weeks after anthesis (Judel & Mengel, 1982; McCaig & Clarke, 1982; Duboid, Winzeler & Nosberger, 1990). Significant cultivar x temperature interaction at 42 days after anthesis, however, indicated that the different cultivars differed in their response. This may be an indication of tolerance to high temperatures shown by some cultivars (Al-Khatib & Paulsen, 1990). From Figure 4, it is however clear that the response of individual cultivars varied at different temperature regimes. At low temperature regimes (15/10°C), SST 57 and to a lesser extent Palmiet, showed the smallest increases in leaf mass at 42 days after anthesis.

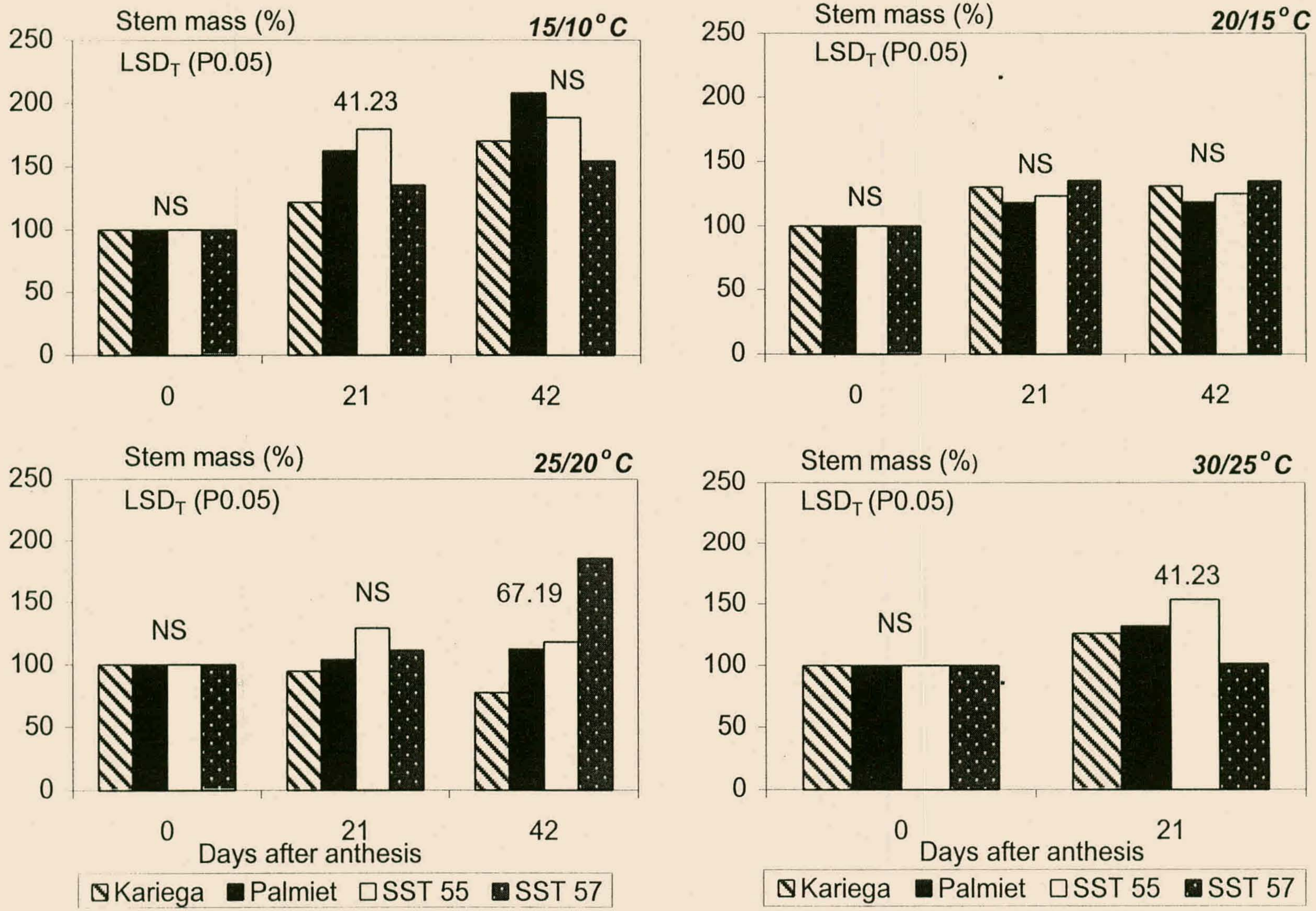

Figure 4 Effect of four different temperature regimes on the stem mass of spring wheat cultivars expressed as a percentage of their values at anthesis (0 days).

At intermediate temperature regimes (20/15°C) increases in stem mass for different cultivars at 42 days after anthesis were more or less the same, while SST 57 showed the highest increase in stem mass at a temperature regime of 25/20°C. Unfortunately no results could be obtained at a temperature regime of 30/25°C, because all plants died within 42 days after anthesis. These results may indicate that SST 57 is less affected by higher temperatures, while Palmiet and to a lesser extent SST 55, on the other hand, perform well at lower temperature regimes.

Ear mass

Temperature as a main effect showed significant differences at anthesis (0 days), 21 and 42 days after anthesis (Table 5). Cultivar as a main effect showed significant differences at 21 and 42 days after anthesis, while the temperature x cultivar interactions were only significant at 42 days after anthesis.

Table 5 Analysis of variance (ANOVA) for ear mass of 4 cultivars subjected to a range of post-anthesis temperature and sampled at 0, 21 and 42 days after anthesis

Sources of Variation	**df**	**Mean square**		
		0	21	42
T	3	52.4**	289.5**	259.6**
C	3	3.0^{NS}	36.2*	29.2*
T x C	9	0.6^{NS}	11.0^{NS}	34.1**
Error	45	2.1	8.9	8.1
Total	63			

*, ** F – test significant at the 5 and 1% levels of probability, respectively

Because of significant differences at the start of the temperature treatments at anthesis (0 days), ear mass at 21 and 42 days after anthesis were expressed as a percentage of that cultivar' s ear mass at anthesis. The percentage change is thus an indication of how cultivars responded after exposure to different post-anthesis temperature regimes.

As expected, ear mass generally increased after anthesis for all cultivars (Figure 5). At high temperature regimes (25/20°C and 30/25°C) ear mass increases after anthesis were, however, much less when compared to lower temperature regimes. At a temperature regime of 30/25°C all plants died within 42 days after anthesis. As shown for ear mass, percentage increase at 42 days after anthesis at low temperature regimes (15/10°C) were the highest for SST 55. At temperature regimes of 20/15°C and 25/20°C, SST 57 showed the highest percentage increase in ear mass at 42 days after anthesis, while no differences were found between cultivars even at 21 days after anthesis at a temperature regime of 30/25°C. In comparison to other cultivars tested, post-anthesis ear growth of SST 57 therefore seemed to be more tolerant to higher temperature regimes

Conclusion

This study has shown that high temperatures applied after anthesis accounted for most of the variation in the relative water content of the leaves, leaf area, as well as leaf, stem and ear mass. All parameters of cultivars tested were significantly reduced before 42 days after subjection to the highest temperature regime of 30/25°C. The most sensitive parameter was the leaf area which senesced prematurely as a result of the high temperatures and this was associated with reduced relative water content.

This is an indication that exposure of these wheat cultivars to areas with post-anthesis temperatures of 30°C may affect grain growth through reduction in viable

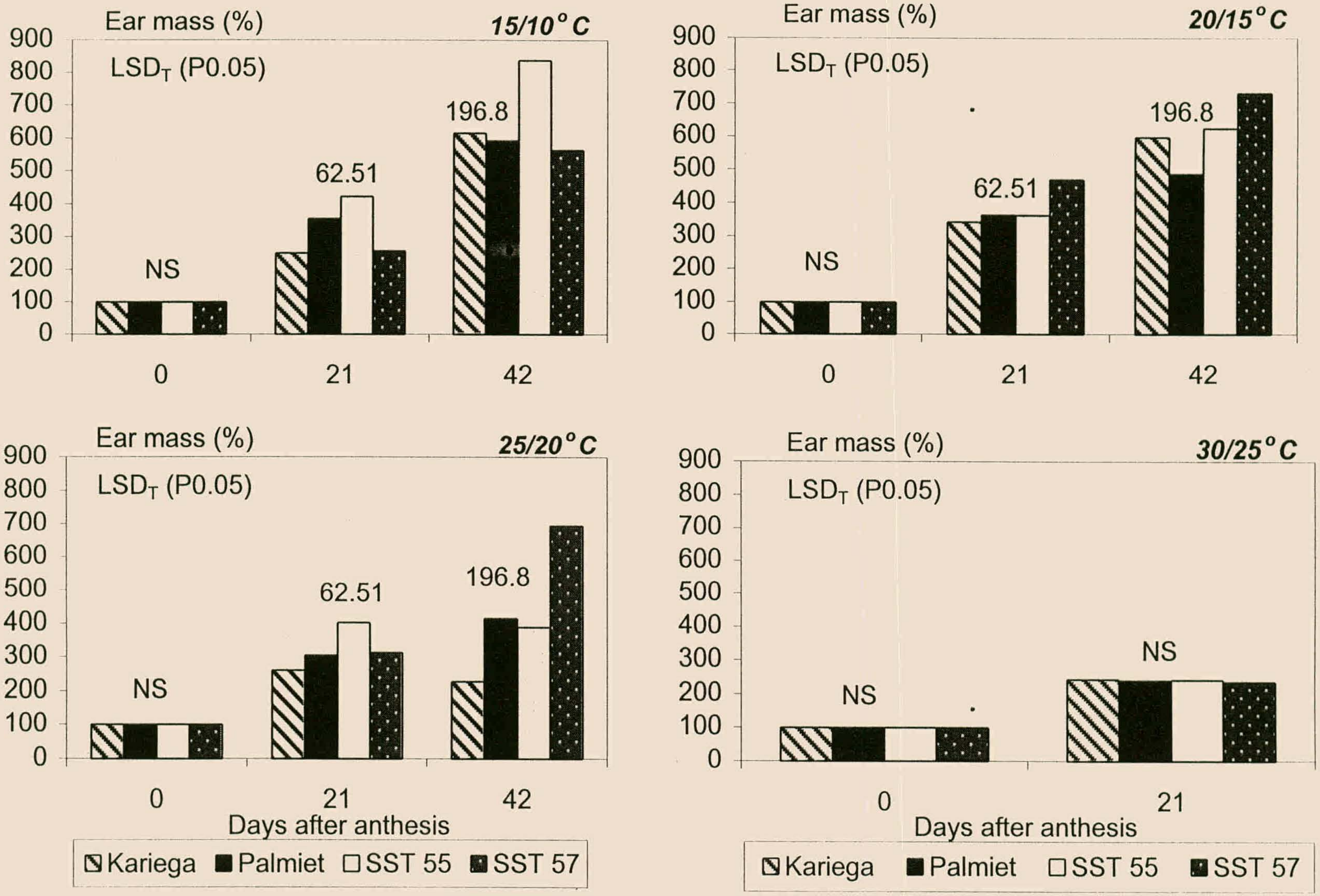

Figure 5 Effect of four different temperature regimes on the ear mass of spring wheat cultivars expressed as a percentage of their values at anthesis (0 days).

leaf area. Although all cultivars tested showed little tolerance to a post-anthesis temperature regime of 30/25°C, cultivars did differ in their response to lower temperature regimes. When post-anthesis temperature regimes were increased from 15/10°C to 25/20°C, SST 57 and to a lesser extent Kariega were not affected to the same extent as were Palmiet and SST 55. These results may indicate that SST 57 and Kariega will be better adapted to hotter areas, but the effect on grain yield and quality will also need to be considered.

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Chapter 3

Yield response of spring wheat (*Triticum aestivum* L) cultivars to post-anthesis high temperatures

Abstract

The grain yield of wheat is often low when grown in warm environments. High temperature effects on the grain yield of four spring wheat cultivars (Kariega, Palmiet, SST 55 and SST 57) were studied in controlled environmental conditions under four day/night temperature regimes (15/10, 20/15, 25/20 and 30/25°C) at the University of Stellenbosch in 1998. The study revealed that a temperature regime of 30/25°C after anthesis reduced the yield plant $^{-1}$ to almost 50% to that of the control (15/10°C) on all cultivars tested. Kernels were shriveled which resulted in low test weights accounting for the reduced yield plant $^{-1}$. As a result, kernel mass ear $^{-1}$ was also drastically reduced at this temperature regime (30/25°C). Although grain yield of all cultivars tested was severely reduced, individual components of yield did show some differences. When post-anthesis temperatures were increased from 15/10°C to 30/25°C, Palmiet and SST 57 showed the largest reductions in kernels ear $^{-1}$, while mass kernel $^{-1}$ of Kariega was the least affected due to increasing temperatures. As a result Kariega produced slightly higher yields at the temperature regime of 30/25°C when compared to other cultivars tested. Although not significant these results may indicate that Kariega is slightly more tolerant to high post-anthesis temperature regimes.

Introduction

The grain yield of wheat is often low when grown under field conditions in semi-arid environments. These environments are characterised by high temperatures that prevail during the grain filling period and tend to be detrimental to processes that contribute towards endosperm production and subsequently reduce grain yield.

It is known that grain yield of wheat depends on several yield components, such as kernel number ear $^{-1}$ which in turn is interrelated to mass kernel $^{-1}$. Under normal conditions a wheat kernel consists largely of starch ranging from 75 - 80% (Jenner, Ugalde & Aspinall, 1991). This percentage is, however, likely to be reduced under adverse conditions, such as high temperatures, because soluble starch synthase, which converts sucrose to starch, is indicated to be highly sensitive to high temperatures. This results in a reduction in starch deposition in the endosperm (Blum, Sinmena, Mayer, Golan & Shipler, 1994). Less starch deposition in the endosperm may result in a higher relative proportion of nitrogen (Arnon, 1972).

Chowdry and Wardlaw (1978) observed that the shortening of the grain filling period as a result of high temperature is the main cause which reduces mass kernel $^{-1}$. This is because, as temperature rises above 18 - 22°C, the decrease in the period of dry matter deposition is not accompanied by a compensatory increase in the rate of grain filling. Kernels produced at high temperatures are not only small, but also shriveled

(Du Plessis, 1991). A 1.04 mg decrease in kernel weight for each degree Celsius increase in temperature during grain filling for Russian wheat cultivars has been observed by Wiegand and Cuellar (1981).

Since earlier studies (Wardlaw & Wrigley, 1994; Wardlaw, Moncur & Patrick, 1995) reported differences in cultivar response to high temperatures, it is important to determine the effect of high temperatures to individual cultivars. Currently little information is available on the response of the South African spring wheat cultivars to high post - anthesis temperatures.

This study was conducted to determine the effects of post-anthesis high temperatures on grain yield of four South African spring wheat cultivars.

Materials and Methods

Plant material

The experiment was conducted in 4 growth chambers at the Department of Agronomy and Pastures of the University of Stellenbosch in 1998. Plants were grown in 2.0 litre pots filled with coarse sand. Three seeds were sown per pot and seedlings were thinned to two plants per pot at the two - leaf stage. From seeding until anthesis all plants were subjected to a 15/10°C day / night temperature regime and a day length of 12 hours. Plants were irrigated with a balanced nutrient solution twice daily throughout the duration of the experiment to prevent any water stress.

Treatments and experimental layout

Four spring wheat cultivars, namely Kariega, Palmiet, SST 55 and SST 57, were used. As soon as 50% anthesis was reached; plants in different growth chambers were subjected to different day/night temperature regimes, namely 15/10°C; 20/15°C; 25/20°C; and 30/25°C. These temperature regimes were maintained till harvest. Within each growth chamber all cultivars and replications were fully randomised. All data were subjected to an analysis of variance (ANOVA), while Tukey's studentized range values (Snedecor & Cochran, 1967) were used to compare treatment means.

Emphasis was, however, placed on cultivar differences within each temperature regime, due to pre-anthesis differences in growth between growth chambers. Because it often happens that some comparisons comprising the main effects in a two-factor experiment have substantial interactions while the majority of the comparisons have negligible interactions, the F-test of the interaction sum of squares as a whole is not a good guide as to whether interactions can be ignored (Snedecor & Cochran, 1967). Therefore, LSD - values for treatment x cultivar interaction were calculated, although the ANOVA sometimes showed no significant interaction.

Measurements

At maturity the ears were harvested and ear number and mass were recorded for each treatment. These were then dried at 50°C for 2 hours to get rid of excess moisture and then hand threshed. After threshing the following were recorded:

kernels ear $^{-1}$, mass kernel $^{-1}$, kernel mass ear $^{-1}$, kernels plant $^{-1}$ and yield plant $^{-1}$.

Results and discussion

Yield components

Ear plant $^{-1}$

The analysis of variance (ANOVA) for ears plant $^{-1}$ revealed significant differences due to temperature and cultivars as main effects (Table 1). No significant differences were shown for temperature x cultivar interaction.

In spite of the lack of significant temperature x cultivar interaction, the mean separation test (Tukey's studentized range test) revealed significant differences

Table 1 Analysis of variance (ANOVA) for yield and yield components of 4 cultivars subjected to a range of post - anthesis temperature.

					Mean square			
Sources of variation	**df**	**Ear plant $^{-1}$**	**Kernels ear $^{-1}$**	**Mass kernel $^{-1}$**	**Kernel mass ear $^{-1}$**	**Kernels plant $^{-1}$**	**Ear mass plant $^{-1}$**	**Yield plant $^{-1}$**
T	3	67.56**	697.14**	0.00090**	4.45**	207868.63**	139.99**	138.22**
C	3	12.21**	2184.31**	0.00010*	0.39**	38564.11^{NS}	12.23^{NS}	4.97*
T x C	9	4.02^{NS}	189.58*	0.00002^{NS}	0.12^{NS}	31074.72^{NS}	12.03^{NS}	5.82*
Error	45	2.24	89.13	0.00003	0.07	20834.92	8.99	2.04
Total	63							

*, ** F test - test significant at the 5 and 1% levels of probability, respectively. NS - not significant

between cultivars at all temperature regimes (Figure 1). In general, the number of ears plant $^{-1}$ increased with increasing post-anthesis temperature regimes (Figure 1). Because the potential number of ears plant $^{-1}$ were determined prior to anthesis when temperature regimes were the same for all growth chambers, these results were difficult to explain, but indicated that in the absence of water stress, survival of secondary tillers were not affected by high post-anthesis temperatures. Although significant differences did occur between cultivars at different temperature regimes, ranking orders did not vary much (Figure 1). It must therefore, be concluded that for this parameter the cultivars tested did not differ with regard to their sensitivity toward high post-anthesis temperatures.

Ear mass plant $^{-1}$

The analysis of variance (ANOVA) showed that post-anthesis temperatures significantly influenced ear mass plant $^{-1}$ of spring wheat (Table 1).

Although the ANOVA showed no temperature x cultivar interaction, Tukey's studentized test showed significant differences between cultivars at a temperature regime of 25/20°C (Figure 2). These differences were however, not repeated at other temperature regimes and ranking orders of cultivars did not correspond to those found at other temperature regimes.

The highest ear mass plant $^{-1}$ was obtained with a temperature regime of 25/20°C. Evans, Wardlaw & Fischer (1975) found a temperature between 20 and 25°C to be the optimum during the grain filling stage of wheat. Higher temperatures (30/25°C) resulted in reduced ear mass plant $^{-1}$ in this study. This was probably due to a shorter grain filling period as the number of ears plant $^{-1}$ were not negatively affected by higher temperatures.

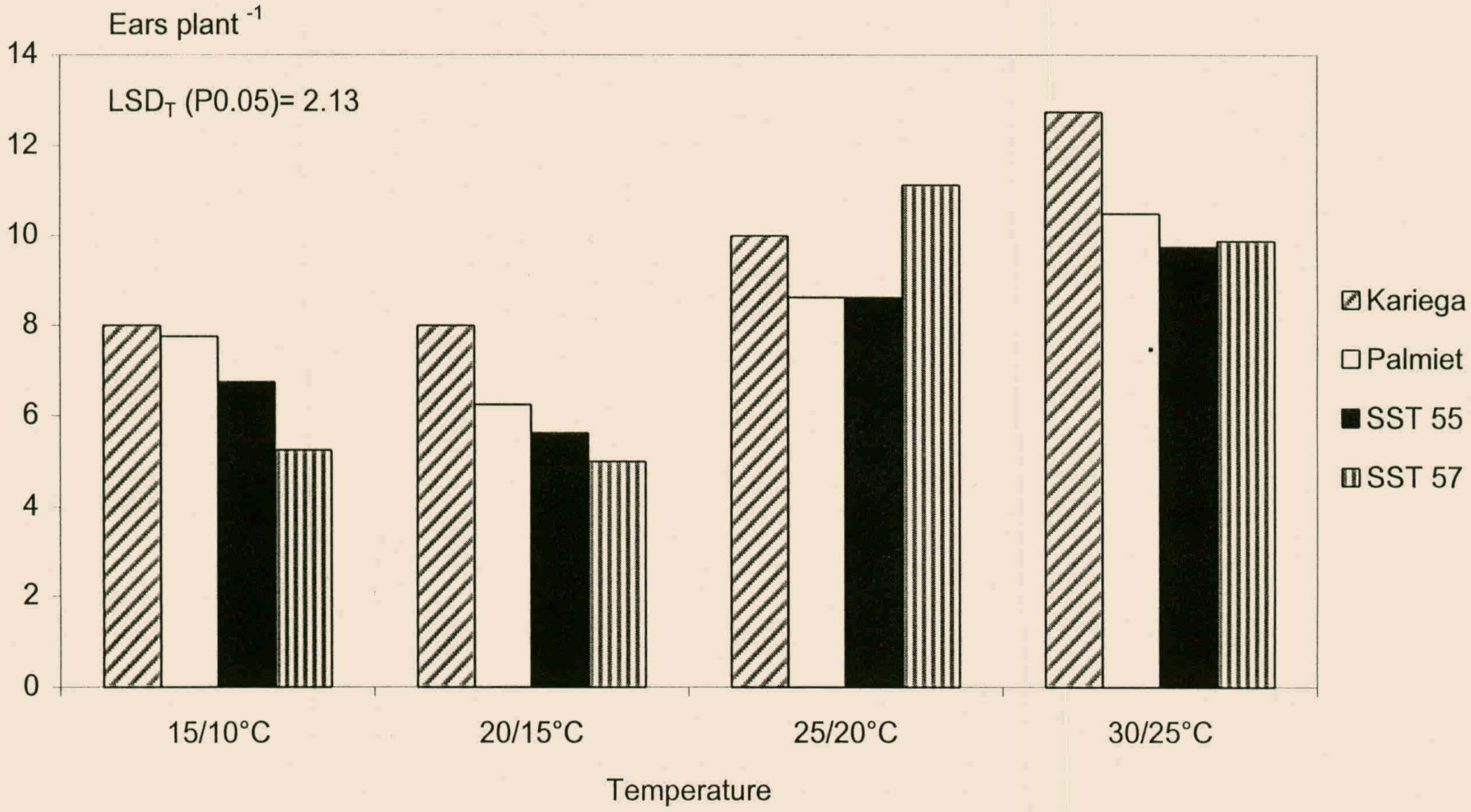

Figure 1 Effect of four different temperature regimes on ears plant $^{-1}$ of spring wheat cultivars.

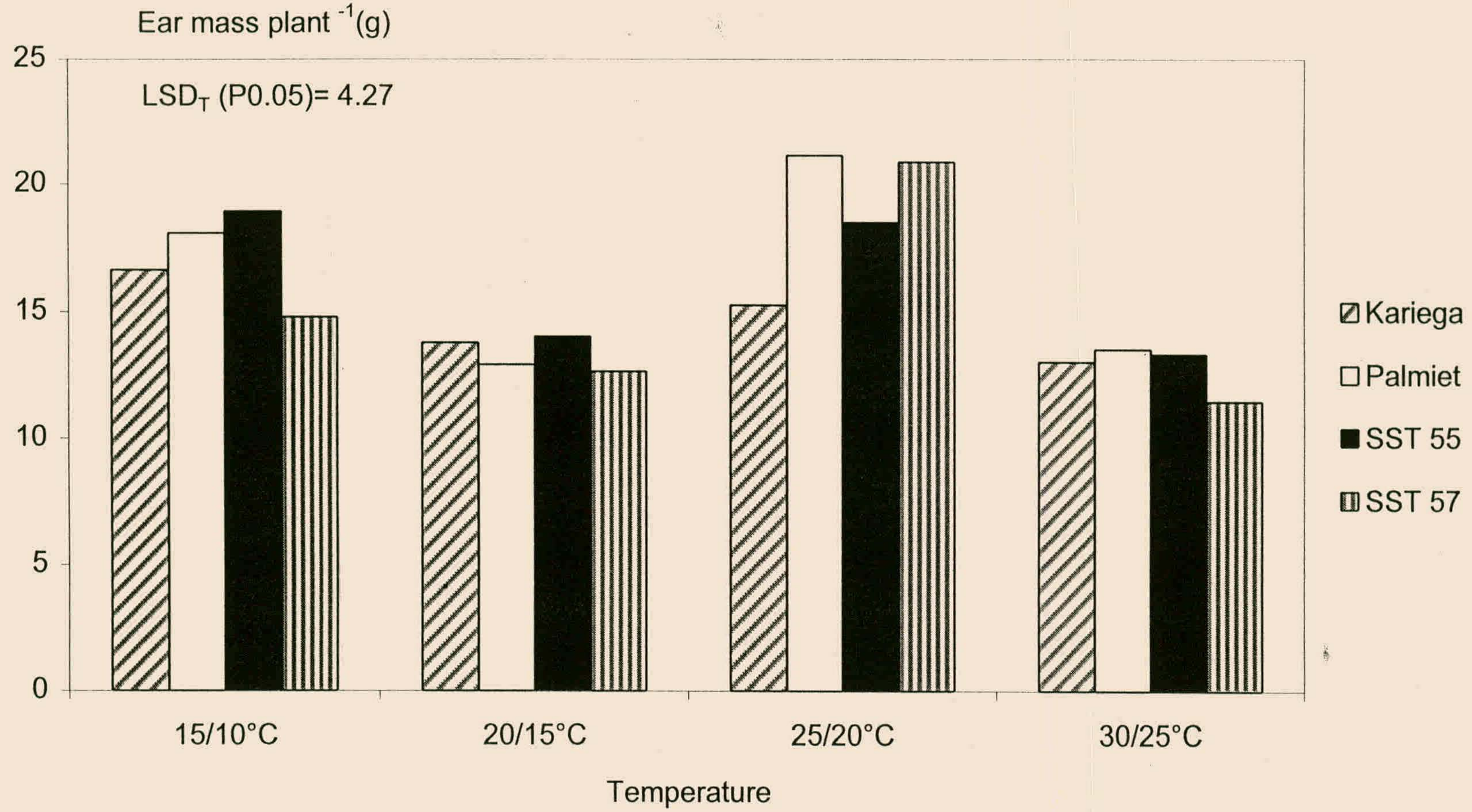

Figure 2 Effect of four different temperature regimes on ear mass plant $^{-1}$ of spring wheat cultivars.

Kernels ear $^{-1}$

Analysis of variance (ANOVA) for kernels ear $^{-1}$ showed significant effects due to post - anthesis temperatures (Table 1). Although significant differences between cultivars were found, a significant temperature x cultivar interaction indicated that the response of cultivars to the different post-anthesis temperatures were not the same.

Generally, kernels ear $^{-1}$ were reduced by increasing post-anthesis temperature regimes (Figure 3). Less kernels ear $^{-1}$ are under most instances the result of poor fertilisation of the egg cell due to very dry or wet conditions or very high temperatures (>32°C) during pollination (Evans, Wardlaw & Fischer, 1975). Although pollen quality and fertilisation are therefore not supposed to be affected by temperature regimes applied in this study, lower numbers of kernels ear $^{-1}$ for Kariega and Palmiet at the 30/25°C regime may be the result of the sudden change in temperature at anthesis.

At the lowest post - anthesis temperature regime of 15/10°C, SST 57 produced the most and Kariega the least number of kernels ear $^{-1}$ (Figure 3). At post - anthesis temperature regimes of 20/15°C, 25/20°C and 30/25°C kernels ear $^{-1}$ of Kariega stayed more or less the same, while that of SST 57 decreased from 90.3 at 15/10°C to 63.5 at 30/25°C. Kernels ear $^{-1}$ of Palmiet decreased from 79.3 at a temperature regime of 15/10°C to 57.0 at 30/25°C, while that of SST 55 showed no definite trend. It is therefore clear that kernels ear $^{-1}$ of SST 57 and Palmiet are more affected by high post - anthesis temperatures compared to Kariega and SST 55.

Kernels plant $^{-1}$

Kernels plant $^{-1}$ is the product of ears plant $^{-1}$ and kernels ear $^{-1}$. Trends for kernels plant $^{-1}$ should therefore correspond to those found for the abovementioned

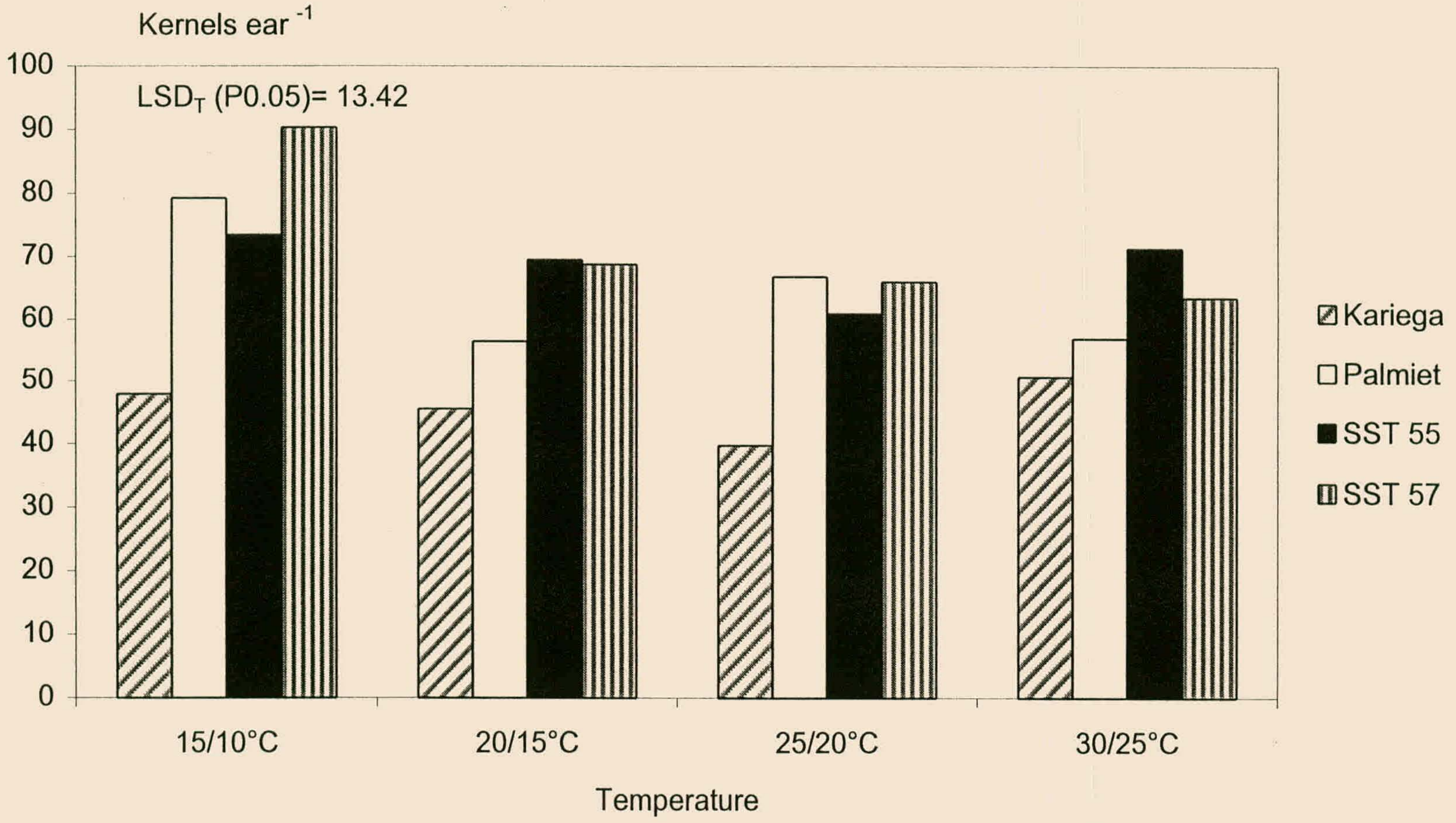

Figure 3 Effect of four different temperature regimes on kernels ear $^{-1}$ of spring wheat cultivars.

parameters. The analysis of variance (ANOVA) showed that post-anthesis temperature as a main effect significantly affected kernels plant $^{-1}$ of spring wheat (Table 1). Neither cultivar nor temperature x cultivar interaction showed any significant differences.

However, significant differences between cultivars within the same growth chamber were revealed when data were subjected to Tukey's studentized range (Figure 4). These differences were observed at both temperature regimes of 15/10°C and 25/20°C. At both temperature regimes, Kariega showed the lowest number of kernels plant $^{-1}$, which correlates with the low number of kernels ear $^{-1}$ produced by this cultivar (Figure 3). At the lowest temperature regime (15/10°C) all other cultivars tested produced more kernels plant $^{-1}$ in comparison with Kariega. At the highest temperature regime (30/25°C) Kariega did not produce less kernels plant $^{-1}$ than other cultivars tested. This tendency can be attributed to the fact that kernel number ear $^{-1}$ of Kariega (Figure 3) was found to be less sensitive to high post - anthesis temperatures since it increased marginally from 48.0 at 15/10°C to 50.8 at 30/25°C.

Mass Kernel $^{-1}$

Mass kernel $^{-1}$ is determined by growth conditions during grain filling (Evans, Wardlaw & Fischer, 1975). In this study, both cultivar and post - anthesis temperature regimes (Table 1) significantly affected mass kernel $^{-1}$. Although the analysis (ANOVA) showed no significant temperature x cultivar interaction, significant differences between cultivars were revealed at the 15/10°C temperature regime when data were subjected to Tukey's studentized range test (Figure 5). At this temperature regime Kariega produced kernels with the highest mass kernel $^{-1}$ followed by SST 55, while the lowest mass kernel $^{-1}$ was obtained from Palmiet and

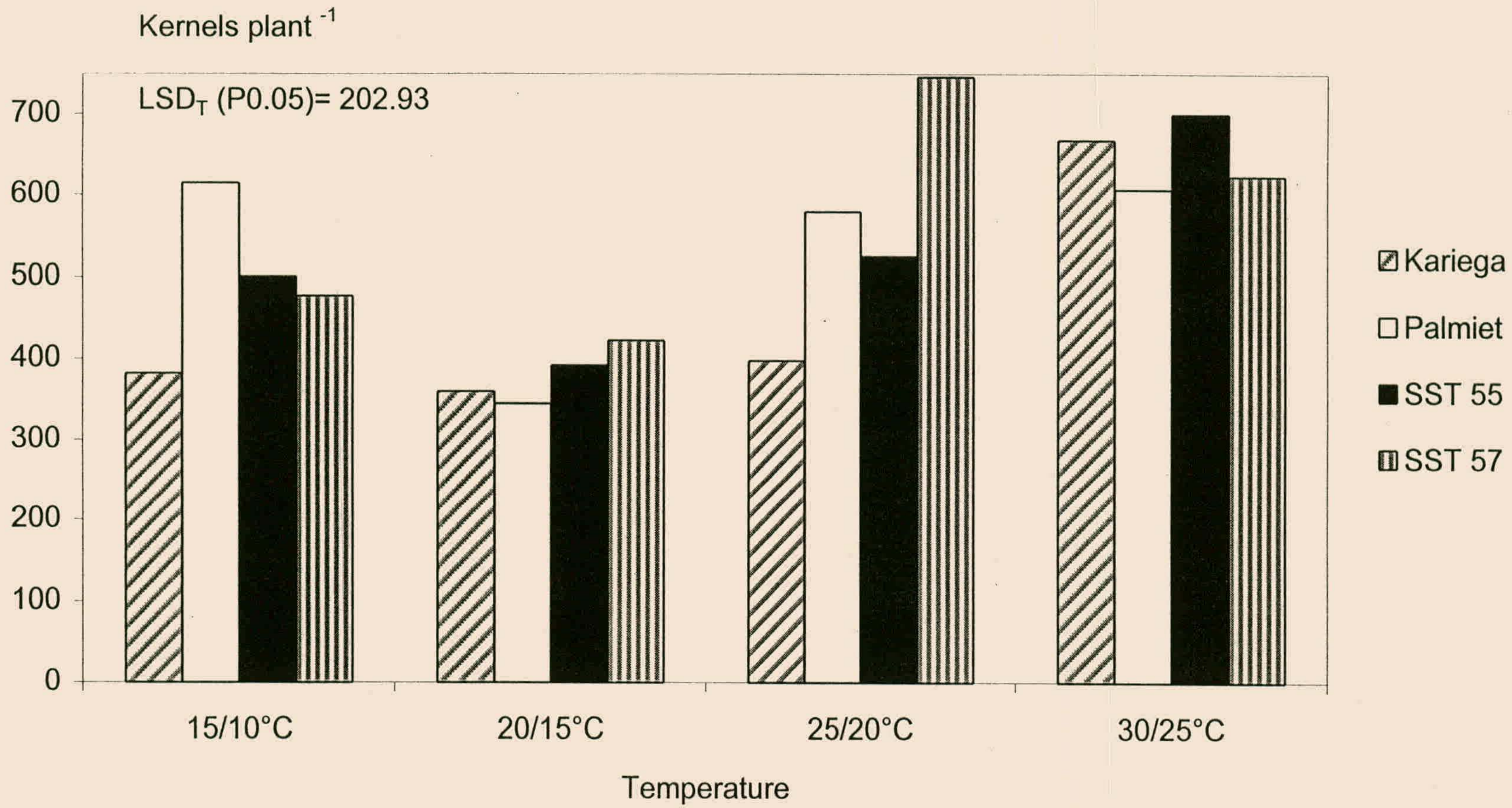

Figure 4 Effect of four different temperature regimes on kernels plant $^{-1}$ of spring wheat cultivars.

SST 57 (Figure 5). These results may indicate differences in sensitivity to suboptimum grain filling temperatures for different cultivars as this temperature was well below temperatures generally found to be optimum for kernel growth (Shi, Seib & Bernardin, 1994). Lower kernel numbers ear $^{-1}$ (Figure 3) for Kariega and SST 55 and higher kernel number ear $^{-1}$ for Palmiet and SST 57, however, strongly favoured competition for photosynthates as a possible explanation for differences in mass kernel $^{-1}$ found at low post-anthesis temperature regimes. Such competition is often found between different components of yield in wheat (Evans, Wardlaw & Fischer, 1975). Although mass kernel $^{-1}$ generally decreased with increasing temperature regimes, this effect became very large when post-anthesis temperature regimes increased from 25/20°C to 30/25°C. From Figure 5, it is clear that mass kernel $^{-1}$ of all cultivars tested were reduced by nearly 50% when temperature elevated beyond 25°C. At this temperature regime, kernels appeared shriveled with weights well below the average of 30 to 50 mg indicated for wheat (Duffus & Slaughter, 1980). Shriveled kernels may be the result of either a loss of carbohydrates due to an increased respiration rate (Asana & Williams, 1965), or a decrease in starch deposition (Keeling, Bacon & Holt, 1993; Blum *et al.*, 1994; Denyer & Hylton, 1994; Jenner, 1994) brought about by a shortened grain filling period (Arnon, 1972; Chowdry & Wardlaw, 1978). Unfortunately all cultivars tested showed the same sensitivity to higher temperatures (Figure 5).

Kernel mass ear $^{-1}$

Kernel mass ear $^{-1}$ is the product of kernels ear $^{-1}$ and mass kernel $^{-1}$. In correspondence to the results for kernels ear $^{-1}$ and mass kernel $^{-1}$, kernel mass ear $^{-1}$

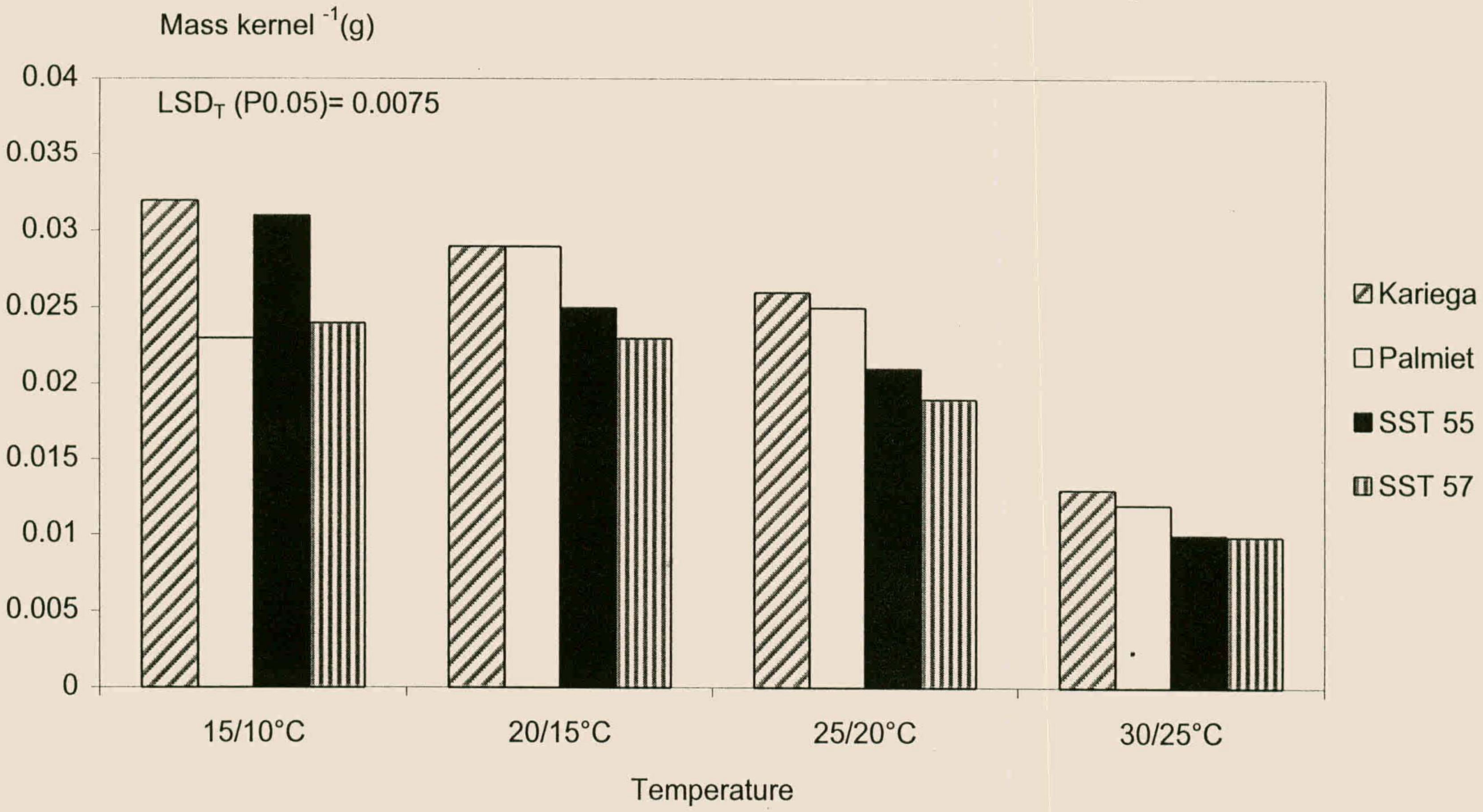

Figure 5 Effect of four different temperature regimes on mass kernel $^{-1}$ of spring wheat cultivars.

was also significantly affected by both cultivars and post-anthesis temperature regimes (Table 1). Although the analysis of variance (ANOVA) did not show significant cultivar x treatment interaction, significant differences were revealed when the data were subjected to Tukey's studentized range test (Figure 6). Results of kernel mass ear $^{-1}$ are somewhat confused by the already discussed negative relationship between kernels ear $^{-1}$ and mass kernel $^{-1}$. Kernels ear $^{-1}$, however, seemed to be the most dominant factor as Kariega which yielded the lowest number of kernels ear $^{-1}$, also yielded the lowest kernel mass ear $^{-1}$ at all temperature regimes tested. At a post-anthesis temperature regime of 15/10°C, kernel mass ear $^{-1}$ of Kariega was significantly lower than that of both SST 55 and SST 57, but no significant differences were shown at the temperature regime of 30/25°C. These results indicate that kernel mass ear $^{-1}$ of Kariega is affected to a greater degree by high post-anthesis temperatures compared to other cultivars tested. From Figure 6 it is clear that the reduction in kernel mass ear $^{-1}$ of Palmiet at 25/20°C is somewhat less than the reduction found for Kariega, SST 57 and to a lesser extent also SST 55. This may indicate that Palmiet is better adapted to a post-anthesis temperature regime of 25/20°C. As shown for mass kernel $^{-1}$, reductions in kernel mass ear $^{-1}$ became more evident when temperatures exceeded 25°C, which accentuate the problems which can be expected when these cultivars are grown in areas where high spring or early summer temperatures often prevail.

Grain Yield

Yield is determined by several yield components, including ears plant $^{-1}$, ear mass plant $^{-1}$, kernels ear $^{-1}$, kernels plant $^{-1}$, mass kernel $^{-1}$ and kernel mass ear $^{-1}$.

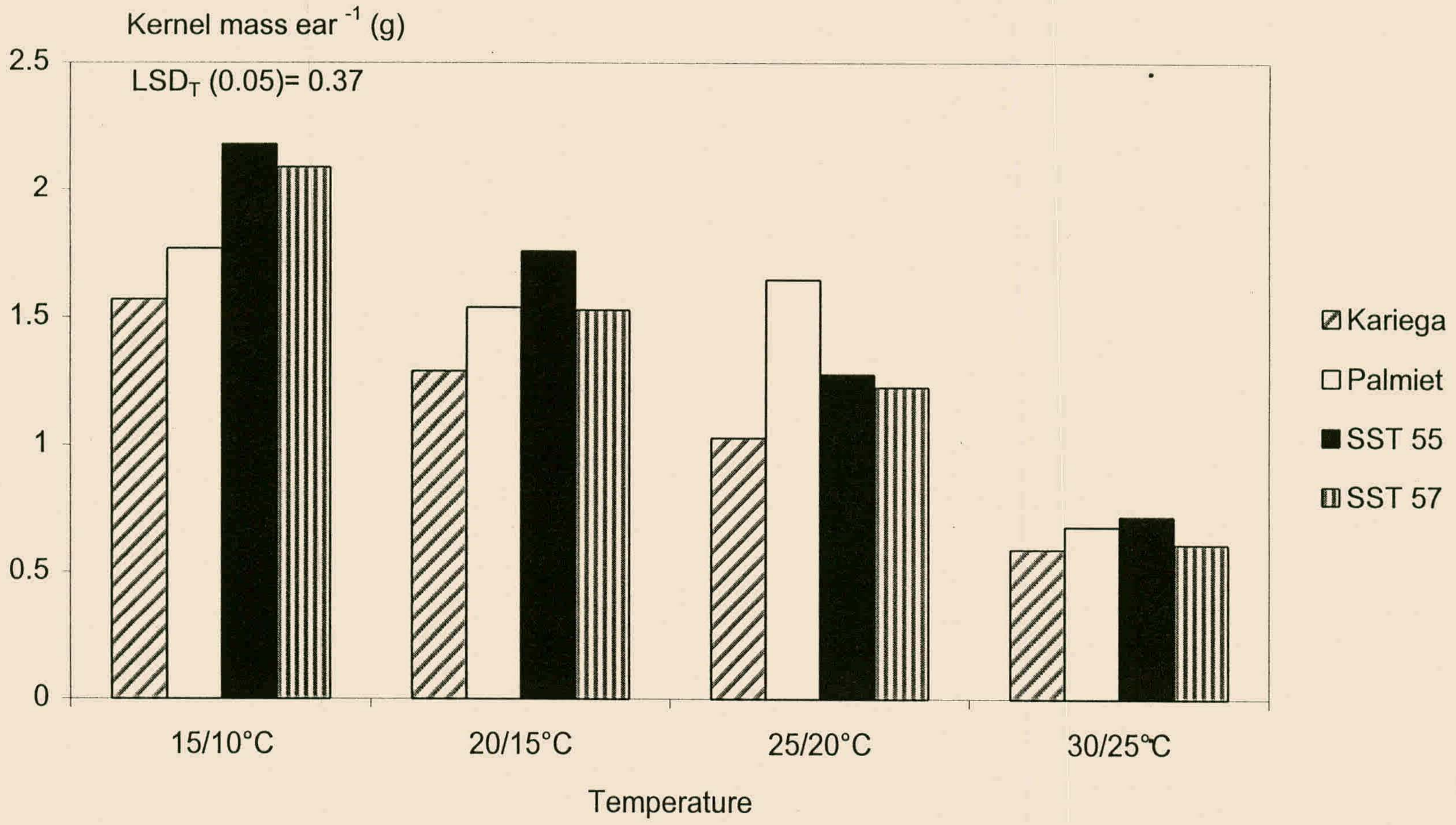

Figure 6 Effect of four different temperature regimes on kernel mass ear $^{-1}$ of spring wheat cultivars.

Between these parameters the most important ones are often found to be kernel ear^{-1} and mass kernel $^{-1}$ (Bingham, 1966, 1967).

In this study, analysis of variance (ANOVA) showed significant differences in grain yield as an effect of post-anthesis temperature regimes (Table 1). Although grain yields generally decreased with increasing post-anthesis temperature regimes, yields for different cultivars showed only small reductions and in some cases even increased when temperature was increased from 15/10°C to 25/20°C (Figure 7). When temperature was, however, increased from 25/20°C to 30/25°C, grain yield of all cultivars tested was severely reduced. Although grain yield for Kariega was marginally higher when compared to the other cultivars at the 30/25°C temperature regime, this difference was too small to be of any significance. Tukey's studentized range values did show significant differences between cultivars at lower post-anthesis temperature regimes. Differences between cultivars were, however, inconsistent and did not correlate with differences found for yield components such as kernels ear $^{-1}$ and mass kernel $^{-1}$. If anything, it could therefore be said that all cultivars are well adapted to post-anthesis temperatures ranging between 15 and 25°C, but Kariega may out yield Palmiet, SST 55 and SST 57 when day-time temperatures during this growth stage rise to levels of 30°C.

Conclusion

This study clearly revealed that a temperature regime of 30/25°C applied after anthesis severely affected the yield plant $^{-1}$ of all cultivars by almost 50% when compared to that of 15/10°C temperature regime. The reduction was primarily due to low kernel mass ear $^{-1}$ which also affected test weights. Although grain yield of all

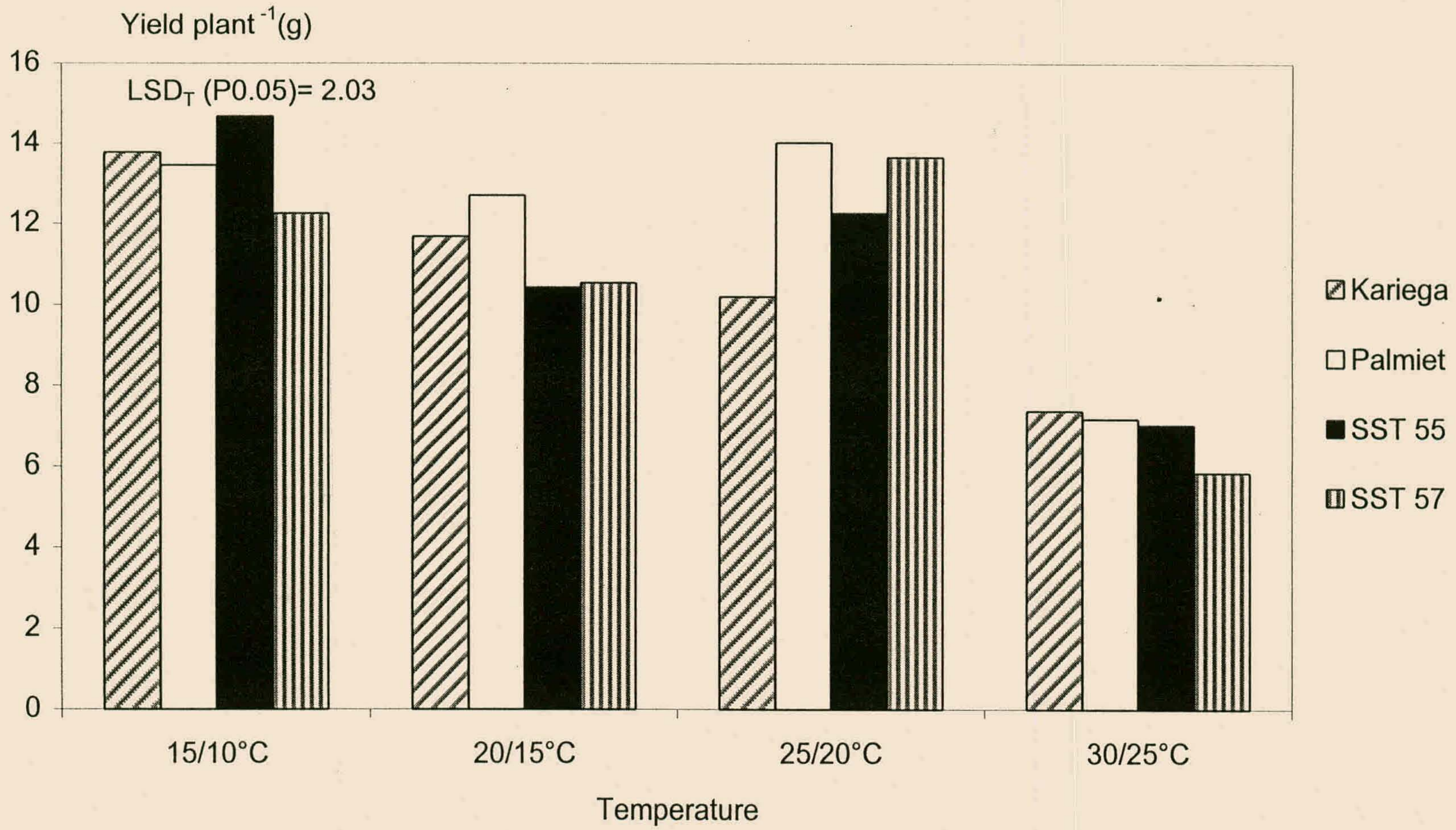

Figure 7 Effect of four different temperature regimes on yield plant $^{-1}$ of spring wheat cultivars.

cultivars was severely affected, individual components of yield did show some differences between cultivars. When comparing the values found at 15/10°C temperature regime, both kernels plant $^{-1}$ and mass kernel $^{-1}$ of Kariega were least affected by the 30/25°C temperature regime. These results may indicate that Kariega is slightly more heat tolerant than the other cultivars tested.

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Chapter 4

Quality response of spring wheat (*Triticum aestivum* L) cultivars to post-anthesis high temperatures

Abstract

Protein content is one of the major quality parameters that determines the bread-making quality of wheat. It has been noted to vary drastically with changing environmental conditions, resulting in unacceptable end products. To study the effect of post-anthesis high temperatures on wheat quality, four South African wheat cultivars, namely Kariega, Palmiet, SST 55 and SST 57, were grown in growth chambers at 15/10°C day/night until anthesis. When 50% of the plants were at anthesis they were subjected to temperature regimes of 15/10°C, 20/15°C, 25/20°C and 30/25°C till harvest. Protein content increased substantially as temperature increased. Increased temperature, in conjunction with increased protein, contributed to altered mixogram dough development time and peak height. Although a high temperature regime of 30/25°C affected quality parameters similarly, responses varied substantially between cultivars at lower temperature regimes. Palmiet at a temperature regime of 25/20°C showed tolerance as its dough development time was within the acceptable range of 2.5 to 3.0 minutes, despite a slight increase in protein content and peak height. Kariega, SST 55 and SST 57 had altered protein content and peak height at 25/20°C and 20/15°C which resulted in dough development parameters not falling within the acceptable range. These results indicate that Palmiet may be more tolerant to high post-anthesis temperatures.

Introduction

Quality characteristics of a wheat crop indicate its commercial value to the milling and baking industry (Van Lill, Purchase, Smith, Agenbag & De Villiers, 1995). Protein levels and dough development properties are the most important factors which determine the bread baking quality of wheat. Dough development properties can best be determined by the mixograph (Finney & Shogren, 1972). The mixograph parameters are in turn affected by the quantity and quality of protein in the flour. This is because protein is a major component of quality. For instance, with a protein content of 8%, dough development time was found to be long (10 minutes), while with a 11.5% protein content, dough development time was reduced to 5.37 minutes (Finney, Yamazaki, Yongs & Rubenthaler, 1987). To produce a flour of high gluten content for best bread-making quality, the protein content of the flour should be in the order of 12 - 13% (Terman, 1979; Vet, 1995). However, protein content of wheat may vary from 6% to as much as 25% (Blackman & Payne, 1987), depending on environmental conditions, especially during the kernel filling stage of wheat. Differences between cultivars of the same wheat type, but more so between hard red and soft red wheat also occur (Terman, 1979).

High temperatures during grain filling are one of the climatic conditions that affect protein content. Protein content increased when temperatures during grain filling increased from 15 to 35°C (Correl, Butler, Spouncer & Wrigley, 1994; Wardlaw & Wrigley, 1994; Wrigley, Blumenthal, Gras & Barlow, 1994; Uhlen, Hafskjold, Kalhvd, Sahlstrom, Longva & Magnus, 1998) due to the inhibition of starch synthesis in the endosperm. This resulted in more protein relative to starch accumulation (Arnon, 1972; Keeling, Bacon & Holt; 1993; Denyer & Hylton, 1994; Jenner, 1994). High temperatures during grain filling affected both protein concentration and dough properties associated with baking quality (Randal & Moss 1990; Blumenthal, Bekes, Batey, Wrigley, Moss, Mares & Barlow 1991). Although the increase in grain filling temperatures to 30°C may result in stronger dough, this may enhance energy demands in mixing processes (Blackman & Payne, 1987). Dough development time may also be increased as a result of high temperatures. Cultivars may, however, differ in their response to adverse temperature conditions during grain filling (Williams, 1966; Uhlen *et al.*, 1998).

From the literature, it is clear that high temperatures during grain filling have a variable effect on quality of wheat, depending on cultivar. It is therefore important to know what response could be expected when a new cultivar is to be introduced into a production area. Tests must therefore be done to determine its quality response to climatic conditions that prevail in that area. So far few studies have been done to determine the effect of post-anthesis temperatures on baking quality of South African spring wheat cultivars.

This study was conducted to determine the effects of post-anthesis high temperatures on baking quality of four South African wheat cultivars.

Materials and Methods

Plant material

The experiment was conducted during 1998 in 4 growth chambers of the Department of Agronomy and Pastures of the University of Stellenbosch. Plants were grown in 2.0 litre pots filled with coarse sand. Three seeds were sown per pot and seedlings were thinned to two plants per pot at the two - leaf stage. From seeding until anthesis all plants were subjected to a 15/10°C day / night temperature regime and a day length of 12 hours. Plants were irrigated with a balanced nutrient solution twice daily throughout the duration of the experiment to prevent any water stress.

Treatments and experimental layout

Four spring wheat cultivars, namely Kariega, Palmiet, SST 55 and SST 57, were used. As soon as 50% anthesis were reached, plants in different growth chambers were subjected to different day/night temperature regimes, namely 15/10°C; 20/15°C; 25/20°C; and 30/25°C. These temperature regimes were maintained till harvest. Within each growth chamber all cultivars and replications were fully randomised. All data were subjected to an analysis of variance (ANOVA), while Tukey's studentized range values (Snedecor & Cochran, 1965) were used to compare treatment means. Emphasis was, however, placed on cultivar differences within each temperature regime, due to pre - anthesis differences in growth between growth chambers. Since it often happens that some comparisons comprising the main effects in a two-factor experiment have substantial interactions, while the majority of the comparisons have negligible interactions, the F-test of the interaction sum of squares as a whole is not a good guide as to whether interactions can be ignored (Snedecor & Cochran, 1965). Therefore, LSD values for treatment x cultivar interaction were calculated, although the ANOVA sometimes showed no significant interaction.

Quality analysis

After maturity the ears were harvested, hand threshed and cleaned. The grain was then milled into flour to determine protein content, mixograph dough development time, peak height and bandwidth. Unfortunately, flour samples were too small to conduct a baking test to determine loaf volume.

The flour protein content was determined with near infra-red spectroscopy (Technicon Infra Alyser Model 400). The mixograph dough development time (MDT min), peak height and bandwidth were determined with a 10 g National Mixograph (Finney & Shogrey, 1972).

Results and discussion

Flour protein content

Flour protein content ranging between 12 to 13% is preferred for production of standard loaf volume (Vet, 1995). However, protein content is often influenced by the environmental conditions under which wheat is produced. In this study, temperature as a main effect significantly influenced the flour protein content, as shown by the analysis of variance (ANOVA) (Table 1). Cultivar as a main effect also showed significant differences. Significant Temperature (T) x Cultivar (C) interaction was also observed which indicated differences in cultivar response to temperature during the kernel filling stage. Generally, also as found by Uhlen *et al.*, (1998), flour protein content increased with increasing post-anthesis temperature regimes in this study (Table 2). At a temperature regime of 15/10°C, flour protein content of different cultivars did not show any significant differences. At a temperature regime of 20/15°C, flour protein content for SST 55 and SST 57 were significantly higher in comparison with Kariega and Palmiet. At temperature regime 25/20°C, flour protein of Palmiet was still the lowest, with no significant differences between the other

Table 1 Analysis of variance (ANOVA) of flour protein content, dough development time, peak height and band width of 4 cultivars subjected to a range of post-anthesis temperature regimes

		Mean square			
Sources of Variation	df	Flour Protein content	Dough dev. time	Peak height	Bandwidth
T	3	287.78**	0.41**	2.70**	6.65**
C	3	10.88**	1.92**	0.45^{NS}	0.75*
T x C	9	9.12**	0.25**	0.70^{NS}	0.43^{NS}
Error	45	0.60	0.08	0.46	0.25
Total	63				

*, ** F test - test significant at the 5 and 1% levels of probability, respectively. NS - not significant. Dev. - development

Table 2 Means of flour protein content and mixograph parameters of 4 cultivars subjected to a range of post-anthesis high temperature regimes

		Parameters			
Temperature Treatment (°C)	Cultivar	Protein content (%)	Dough dev. time (min)	Peak height (cm)	Band width (cm)
15/10	Kariega	11.68	2.55	7.98	5.0
15/10	Palmiet	12.8	2.52	7.65	5.58
15/10	SST 55	12.0	2.48	7.90	5.63
15/10	SST 57	12.43	2.08	7.70	5.33
20/15	Kariega	11.93	2.13	8.58	4.22
20/15	Palmiet	12.88	3.00	7.48	5.23
20/15	SST 55	16.98	2.10	8.38	4.40
20/15	SST 57	16.93	2.13	8.18	5.00
25/20	Kariega	16.68	3.23	7.40	4.63
25/20	Palmiet	14.83	3.00	8.22	4.38
25/20	SST 55	17.43	3.07	8.05	5.20
25/20	SST 57	17.68	2.30	8.43	4.95
30/25	Kariega	21.8	2.35	9.53	3.6
30/25	Palmiet	23.33	3.40	8.60	3.68
30/25	SST 55	22.03	2.20	8.93	4.18
30/25	SST 57	21.6	2.15	8.60	3.83
LSD_T (0.05)		**1.09**	**0.08**	**0.96**	**0.70**

cultivars. In contrast to that, Palmiet showed the highest protein content at a temperature regime of 30/25°C. Flour protein content of Palmiet and to a lesser extent Kariega were therefore less affected compared to SST 55 and SST 57 when post-anthesis temperatures were increased from 15/10°C to 25/20°C. This may indicate that SST 57 and SST 55 are more sensitive to high post-anthesis temperatures. At a temperature regime of 30/25°C, all cultivars tested were however severely affected. At this temperature regime flour protein content of all cultivars tested were in excess of 20%, which may result in undesirable dough development and baking characteristics. From these results it became clear that SST 57 and SST 55 will be less suitable for production in warmer regions compared to Palmiet and to a lesser extent Kariega.

Mixograph dough development properties

The mixograph determines the physical dough properties of wheat and are represented as mixograms. In this study, some mixograms were characterised by wild swings and unclear peaks which were difficult to read.

Mixograph dough development time

Mixograph dough development time (minutes) relates to the rate at which flour and water are converted into a dough by blending and distributing the flour ingredients and developing gluten into a continuous phase (Hoseney & Finney, 1974). Mixograph dough development time values that are below or above 2.5 to 3.0 minutes set by the baking industry indicate a dough that is either very sensitive to overmixing or will require too much mixing to develop to the optimum.

The mixograph dough development time in this study was significantly influenced by post-anthesis temperature regime as a main effect as revealed by the analysis of variance (ANOVA) (Table 1). Cultivar as a main effect also revealed significant differences, while a significant Temperature (T) x Cultivar (C) interaction showed that cultivars responded differently to increasing temperature regimes. Hoseney and Finney (1974) found that high temperatures reduced dough development time. In this study, dough development time for Kariega and SST 55 were also significantly reduced when post-anthesis temperature regimes were increased from 15/10°C to 20/15°C (Table 2). Dough development time for SST 57 were not significantly affected, while that of Palmiet was significantly increased. With the exception of Palmiet, which showed an increasing tendency, tendencies for all other cutlivars became unclear with further increases in post-anthesis temperature regimes. This was probably due to the very high flour protein content found at these temperature regimes which resulted in excessive wild swings and no definite peaks in the mixograms. It was therefore very difficult to take an accurate reading. At a post-anthesis temperature regime of 15/10°C, dough development time for SST 57 (2.08 mins) was found to be both significantly lower than that for other cultivars tested and below the optimum of 2.5 to 3 minutes set by the baking industry. At this temperature regime, dough development time for SST 55, Palmiet and Kariega varied between 2.48 and 2.55 minutes. At a temperature of 20/15°C, dough development times for all cultivars, except Palmiet, were reduced to values between 2.10 and 2.13 minutes, which were below the minimum values set by the baking industry. Although it is unlikely that heat shock proteins would be produced at a temperature regime of 20/15°C, the sudden change from 15/10°C to 20/15°C experienced in this study may have altered the protein composition in the cultivars Kariega, SST 55 and SST 57, as suggested by Blumenthal, Barlow and Wrigley (1993) to happen during heat stress conditions. These results again indicated that Palmiet may be better suited for production in hotter areas.

Mixograph peak height

The mixograph peak height (cm) is correlated with protein content. The optimum peak height is achieved when all the flour protein is hydrated (Faubion & Hoseney, 1990). Uhlen *et al.* (1998) observed that high temperatures affect peak height, and this was confirmed by a significant temperature effect shown by the ANOVA (Table 1) in this study. The ANOVA, however, showed no significant effect due to cultivar or any significant temperature (T) x cultivar (C) interaction. In spite of this, further subjection to Tukey's studentized test revealed significant differences between cultivars at the 20/15°C and 25/20°C temperature regimes (Table 2). In general, peak height increased as post-anthesis temperature increased from 15/10°C to 30/25°C (Table 2). Although the highest peak heights were observed at the highest temperature regime of 30/25°C, the differences between cultivars were not significant, indicating similar cultivar sensitivity at this temperature regime. No significant differences were also found at the lowest temperature regime (15/10°C). Generally, increased peak heights correlated with high protein content (Table 2), which confirms findings by Finney and Shogren (1972). Although significant differences between cultivars did occur at the post-anthesis temperature regimes of 20/15°C and 25/20°C, ranking orders of cultivars did not show any meaningful trend. With the exception of the 25/20°C regime, ranking order of cultivars stayed the same. It can therefore be concluded that although mixograph peak height generally increases with increasing post-anthesis temperatures, spring wheat cultivars did not differ significantly in their response.

Mixogram bandwidth

Bandwidth (cm) is an indicator of the status of water absorption by dough. Poor water absorption is reflected by a wider bandwidth, while narrow bands are typical of well optimised water absorption.

In this study, the analysis of variance (ANOVA) for bandwidth showed significant differences between temperature and cultivar as main effects, but no significant Temperature (T) x Cultivar (C) interaction. In spite of the lack of significant interaction, Tukey's studentized test showed differences between cultivars at temperature regimes of 20/15°C and 25/20°C (Table 2). Generally, bandwidths decreased with increasing post-anthesis temperature regimes (Table 2). Although the broadest bandwidth was obtained with SST 55 and the narrowest with Kariega at both the 15/10°C and 30/25°C post-anthesis temperature regimes, these differences were not significant. Significant differences in bandwidth did occur at the 20/15°C and 25/20°C post-anthesis temperature regimes. Ranking order of Kariega and SST 57 to some extent corresponded to those obtained at the 15/10°C and 30/25°C temperature regimes, but this was not the case for Palmiet and SST 55, at the 20/15°C regime. At the 25/20°C regime, the broadest bandwidth was obtained by SST 55, followed by SST 57, Kariega and Palmiet. These ranking orders showed some similarities with the ranking orders for different cultivars at the 15/10°C and 30/25°C post-anthesis temperature regimes, which indicated that different cultivars did not show any differences in their response to increasing post-anthesis temperature regimes. On average it is, however, obvious that Kariega showed the narrowest bandwidth, which is an indication of a good water absorption. Cultivar SST 55, on the other hand, showed the broadest bandwidth at most of the temperature regimes tested, which may indicate inferior water absorption.

Conclusion

It is clear from this study that increasing post-anthesis temperature regimes affected flour quality of all cultivars tested. Flour protein content of all cultivars was increased, but Palmiet and to a lesser extent Kariega were less affected in comparison to SST 55 and SST 57. At a post-anthesis temperature regime of 30/25°C, dough development time of Kariega, SST 55 and SST 57 were reduced to less than 2.5 minutes, which is the minimum value set by the baking industry. Palmiet on the other hand showed an increase in dough development time with increasing temperature regimes, which indicates that this cultivar may be less sensitive to high post-anthesis temperature regimes. Although mixogram peak height generally increases with increasing temperature regimes, cultivar responses did not differ significantly. Cultivar responses with regard to mixogram bandwidth also did not differ significantly, but on average Kariega showed the narrowest and SST 55 the broadest bandwidth. Although differences in quality responses of different cultivars to increasing post-anthesis temperature regimes were generally small, the results indicated that Palmiet and Kariega may be better suited for production in hotter areas compared to SST 55 and SST 57.

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Chapter 5

General conclusions

The economic feasibility of bread wheat production in specific production areas depends on both yield potential and the possibility to produce grain with an acceptable quality as determined by the milling and baking industries. Both grain yield and quality are affected by post-anthesis temperature regimes. Environments characterised by hot climatic conditions, such as those prevailing in Botswana, may therefore encounter problems for cultivars that are not adapted to such conditions. At present little is known regarding to the response of South African spring wheat cultivars to high temperatures.

The aim of this study was to examine the growth, yield and quality response of spring wheat cultivars, to a range of post-anthesis high temperatures during grain filling. To achieve this, four cultivars, namely Kariega, Palmiet, SST 55 and SST 57, were subjected to day/night temperature regimes of 15/10°C, 20/15°C, 25/20°C and 30/25°C from anthesis until harvest. From seeding to anthesis all plants were grown at a day/night temperature regime of 15/10°C.

In this study it was established that a high temperature regime of 30/25°C applied during grain filling significantly affected all parameters tested on all cultivars. The largest impact by this temperature regime was on the leaf area which senesced prematurely as a result of decreased relative water content. Because the growing grain depends largely on products of photosynthesis from the leaves during the grain filling period, the premature loss of the leaf area resulted in the inadequate supply of photosynthate, lower yields and grain quality, which was not within the standards set by the milling and baking industry. At lower temperature regimes, the impact of temperature was less pronounced and cultivars responded differently. The relative water content of Kariega and SST 57 were less affected by a temperature regime of 25/20°C in comparison with other cultivars, while the leaf area of Kariega was also found to be less sensitive than the other cultivars. This ability to sustain a high relative water content by Kariega and SST 57 at high temperatures is an indication that viable leaf area could be prolonged for provision of photosynthate to the growing grain. Although results of stem and ear mass did not provide strong evidence with regard to differences in cultivar responses, mentioned differences in the response of relative water content and leaf area may indicate that the growth of Kariega and to a lesser extent SST 57 will be less affected by high post-anthesis temperatures than that of Palmiet and SST 55.

High post-anthesis temperatures (30/25°C) reduced the yield plant $^{-1}$ to almost 50% of that of the control (15/10°C). This resulted from a decrease in major yield components such as mass kernel $^{-1}$ and kernel number plant $^{-1}$. Lower mass kernel $^{-1}$ was found to be the major reason for the reduction in yield plant $^{-1}$ because of shriveled kernels with low test weights. Although grain yield of all cultivars tested was severely reduced, individual components of yield for different cultivars did show some differences in response to the increasing post-anthesis temperature regimes. When post-anthesis temperature regimes were increased from 15/10°C to 30/25°C, Palmiet and SST 57 showed the largest and Kariega the smallest reductions in kernels ear $^{-1}$. As a result Kariega produced slightly higher yields at a temperature regime of 30/25°C. Although not significant, these results confirm the findings with regard to relative water content and leaf area which indicate that Kariega may be slightly more tolerant to high post - anthesis temperatures in comparison to Palmiet, SST 55 and SST 57.

Bread baking quality determines the economic value of wheat. Earlier studies showed that bread baking quality is highly correlated with flour protein content. In this study, flour protein content showed an increasing tendency with increasing post-anthesis temperature regimes, but all values were generally high (>12.0%) even at the lowest temperature regime. Although all cultivars tested were severely affected by a post-anthesis temperature regime of 30/25°C, Palmiet was less affected at lower temperatures in comparison with the other cultivars. Dough development time of Palmiet was also found to be less affected by increasing temperatures. Mixogram peak heights for all cultivars increased with increasing temperature regimes due to the reported higher protein contents. Wild swings of the mixogram at high protein contents, however, made it difficult to obtain accurate readings. Mixogram bandwidth for Kariega, on the other hand, was found to be the narrowest at all temperature regimes which indicated good water absorption properties. These results indicate that, although Palmiet is known for inferior bread baking quality, the quality of Palmiet and Kariega may be less affected by high temperatures in comparison to SST 55 and SST 57.

In general, it can be concluded that although differences between cultivars are small, Kariega may be slightly more tolerant to high post-anthesis temperatures than Palmiet, SST 55 and SST 57. The full range of spring wheat cultivars should however be tested before specific cultivar recommendations for warmer regions like Botswana can be made.