THE INFLUENCE OF SEEDING DENSITY AND ENVIRONMENTAL FACTORS ON GRAIN QUALITY OF MAIN STEMS AND TILLERS OF WHEAT IN SOUTH AUSTRALIA

(WITH SPECIAL REFERENCE TO

PRIME HARD QUALITY WHEAT)

A thesis submitted for the degree of Doctor of Philosophy

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ABSTRACT

Prime Hard wheat, a high protein hard wheat classification of the Australian Wheat Board, has traditionally been grown in Queensland and the northern areas of New South Wales. Recently there have been moves to extend this area into the more southern regions of the wheat belt, to expand production of this grain and for greater reliability of supply. The emphasis of this thesis is on the opportunities and constraints to Prime Hard wheat production in South Australia. The environmental factors affecting wheat crops in South Australia are different to those in the traditional Prime Hard producing areas, with heat and moisture stress likely to be the most important climatic influences. Management practices such as the recent trends towards higher seeding densities could also be important (influencing main stem and tiller ratios).

An experiment using controlled temperature and moisture conditions showed that main stems and tillers differed in their responses to post-anthesis heat and drought. A field experiment with moisture stress as the only treatment also showed differences in harvest parameters and grain quality between main stems and tillers.

Grain produced from field plots at different plant densities showed significant differences in a number of quality measurements, the most important being 1000-grain weight and flour colour. Less screenings and higher 1000-grain weights were obtained from plots with higher seeding rates. However, flour from plots with higher seeding rates had slightly more yellow colour.

When main stems and tillers from these plots were tested separately, using small-scale equipment, grain weight and flour colour also differed between main stems and tillers. Main stems produced larger grains than tillers, as expected, and tillers

produced grains with yellower flour. The smaller grain size and yellower flour of the tillers is attributed to the higher degree of stress likely to be experienced by tillers, as they have later anthesis dates and are more likely to experience moisture, and/or heat stress at a critical stage of grain filling. Plants with more tillers, such as those grown in a low-density crop, have a later average anthesis date than an equivalent crop of higher seeding density, with more main stems. Therefore it is likely that increasing seeding density will give a shorter crop ripening period and a more uniform seed quality. However, care must be taken not to exceed the optimum plant population density.

In conclusion, the experiments showed that tillers are more sensitive to conditions of moisture or heat stress than main stems, and that they make a measurable contribution to the quality of a wheat crop. Increasing the crop density decreased the proportion of tillers present, leading to a more uniform crop and less screenings at harvest. Increased competition in high-density crops may result in slightly more yellow flour, but dough and loaf quality were not affected.

DECLARATION

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

I give consent to this copy of my thesis, when deposited in the University Library, being available for loan and photocopying.

Rebecca E. Tonkin

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CHAPTER 1 GENERAL INTRODUCTION

Wheat is a highly important crop in Australia, and most of this crop is used for human consumption. Various grades of wheat are used for different end-products – for example, Prime Hard quality wheat is the highest protein hard-grained wheat classification in Australia. For wheat to be classified Prime Hard, it must meet stringent quality specifications for kernel size, weight, cleanliness, and protein content, and be grown in a specific area. The end uses of this grade of wheat vary from bread and noodle production to frozen dough products or blending with poorer grades to improve their quality. These different products also vary in their dough quality requirements. Noodle production requires wheats with good colour and colour stability, and the right starch characteristics, while for blending for breadmaking, the correct protein types and high dough strength is of high importance Recently, wheat marketers have been examining the possibility of extending the areas that can grow Prime Hard wheat beyond the traditional Queensland and northern New South Wales areas. Southern New South Wales has been incorporated into the Prime Hard wheat growing area, and it remains to be seen whether other southern wheat growing areas such as South Australia can produce grain of the correct type for the class.

The growth environment for wheat differs considerably in South Australia from that of the more traditional Prime Hard wheat growing areas. In SA, wheat plants fill the grains under ever increasing conditions of moisture and heat stress – unlike Queensland and northern New South Wales, for example, where the rainy season commences as grains fill. Moisture and heat stress play an important role in determining the yield and physical characteristics of the grain. While moisture stress

can improve dough quality by reducing starch production relative to protein production (Sofield *et al.*, 1977(a)) thus increasing protein percentage, the lower starch amounts in the grain can result in small and shrivelled seeds. Small seed size and high screenings percentages, caused by drought during grain filling, are a major obstacle to producing high protein wheat of the correct Prime Hard specifications. Heat shock, caused by daily maximum temperatures greater than 35° C (Stone and Nicolas, 1995, 1996) can have unexpected and dramatic effects on protein quality. However, warm temperatures below the heat shock threshold can improve dough strength (Randall and Moss, 1990).

Other environmental conditions, such as crop density, are controlled by the grower. Higher crop densities are becoming more common in South Australia as growers seek to smother weeds and make the best use of the resources available. This increased competition between plants further contributes to moisture and nutrient stresses during grain filling. The effects that higher density crops have on the end-use quality of the grain produced have not been researched. Work by Turner *et al.* (1994) indicated that plant density can affect the quality of the crop as seed size is affected by the differing competition for resources.

An understanding of the impact that moisture and heat stress has on the end-use quality of grain grown under such conditions is helpful when seeking to market the crop. Further, it is necessary to know what quality changes, if any, are the result of increasing seeding rates when producing high protein wheat.

A search of available literature found that, although much work has been done in Australia experimenting with yield and/or protein responses to heat and moisture stress, very few experiments have gone on to examine the effects of both factors on the dough quality of the grain produced. Although the effects on quality of drought

and heat stress have been well examined separately by such experiments as those of Blum (1986); Gusta *et al.* (1987); Corbellini *et al.* (1997); Blumenthal *et al.* (1998); Stone and Nicolas (1998) and Duggan *et al.* (2000), only one experiment could be found that examined the interaction between drought and heat stress (Randall and Moss, 1990). Further, many experiments in controlled conditions (such as those by Stone and Nicolas (1995)) used plants with some or all tillers removed. As tillers may make up a large proportion of the crop in the field, it is necessary to check whether tillers respond to stresses in the same way as main stems.

It is important to understand the effects of high density in high protein wheat crops, and associated factors such as moisture stress and higher temperatures on all crop components in high protein wheat varieties. As a way to understanding these effects, the study reported in this thesis examines:

1) the effects of water stress and temperature on main stem and tiller stems and grains under controlled conditions

2) the effect of water stress on main stem and tiller grain quality in the field,

3) the effect of crop density on main stem and tiller production, crop yield, protein, and physical, milling and dough quality parameters, and

4) the differences in quality of the grain produced from main stems and tillers in the field when tested using small-scale techniques.

CHAPTER 2 LITERATURE REVIEW

2.1 INTRODUCTION

Wheat is recognised as one of the world's most important food crops, with annual production of approximately 580 million metric tons (MMT) of which nearly 95 MMT is traded on the world market (International Grains Council, 1999). It is a major source of energy, protein and dietary fibre in the human diet, due to its unique properties that allow it to be used for bread, noodles, biscuits or pasta.

Australia is a relatively small grain producer, accounting for about 3 % of world wheat production (Australian Wheat Board, 1999). However, since domestic requirements are small, exports of wheat are a large part of the economy and are worth more than half of the total value of grain production in Australia.

The quality of Australian wheat is extremely important in maintaining and developing export markets. These markets differ in their quality specifications and it is necessary to produce wheats that are suitable for these products. One of the classifications of Australian wheat is Prime Hard, a high protein hard wheat suitable for bread and high protein noodle production.

There are many factors that affect quality, both genetic and environmental. This review covers the definition of quality, ways in which quality is assessed, and the physiological processes of the wheat plant and their implications for the end product quality of the grain. Finally, the review will focus on some current trends in wheat production methods in South Australia, such as the use of high seeding rates, and the potential implications of these methods for the quality of the grain produced - the specific area of the study reported in this thesis.

2.2 WHEAT QUALITY

Quality can be defined as “the degree of excellence of a thing... a distinctive attribute or faculty; a characteristic trait” (*Australian Concise Oxford Dictionary*, 1992). Wheat quality combines these definitions, so that a class of wheat carries the idea of a distinctive product which excels in the purpose for which it is grown. For example, the Australian Wheat Board classification of Prime Hard wheat is distinctive high protein hard wheat varieties which are excellent for the production of bread or high protein noodles. Australian Soft wheats, in contrast, are low protein, soft wheat varieties which are very good for the production of biscuits, cakes or pastries. Due to this idea of excellence in a particular end use, it can be said that grain quality is also the suitability of the grain for a particular purpose.

Grain quality of wheat is assessed under 3 different categories, physical, milling and dough. The quality requirements for grain with different end uses vary, so wheats are placed into different categories according to the main wheat quality classification guidelines issued by the Australian Wheat Board.

2.2.1 Physical Quality.

Physical qualities of grain are those which describe in some way the physical attributes of the grain itself. They may or may not be related to aspects of milling or baking quality. They are often the first factors that can be evaluated by a buyer. The usual physical qualities assessed are moisture content, appearance, weather damage, contamination (weeds, insects, disease, chemicals, inert matter), test weight and 1000-grain weight.

2.2.1.1 Moisture content

Moisture content is an important quality due to the fact that all grain is stored in some way before use. Grain with a high moisture content is difficult to store safely since it is liable to heat damage during storage (due to respiration) and is also more attractive to pests and diseases. On the other hand, extremely dry grain produced by oven-drying in areas where the grain cannot dry naturally may have damaged proteins (Gooding and Davies, 1997).

The amount of moisture that grain can safely contain for storage changes with the length of storage and the temperature at which it is to be stored (Brooker *et al.*, 1981), quoted in Gooding and Davies (1997). Receival standards from the Australian Wheat Board (AWB) state that the maximum moisture content for wheat is usually 12.5 %, although in some years this may be increased slightly.

Moisture content can be measured by oven drying (gravimetrically), but the more common method is to use a calibrated infra-red spectrophotometer (NIR) machine which gives rapid accurate measurement using a few grains (AusBulk, 2001, pers comm.).

2.2.1.2 Appearance

Grain should appear desirable to the consumer, clean, bright, gold-white in colour and with well filled grains. Red grained wheat varieties are not permitted to be sold for milling in Australia. Other quality characteristics which are visually assessed are damage (eg. cracked, broken or frosted grains) and contamination.

2.2.1.3 Damage

Weather damage can be caused by a number of factors both during grain filling and after maturity. Water damage occurs when the grain is wet during grain filling,

maturation or prior to harvest. In mild cases, only discolouration of the grain may be apparent. In more severe cases, the grain begins to germinate and quality deteriorates. Sprouted grain can only be used for feed. There is a dye test available for detecting the early stages of germination, as well as the Rapid Viscosity Analyser and the Hagberg Falling Number tests.

The appearance of frost damage is variable and may result in discolouration of the grain, with the tips stained brown or black, and the grain may also appear shrivelled and shrunken. Damage resulting from dry conditions is generally classed under small shrivelled grains, pinched grains or high chaff content. There is a sliding scale of discounts for screenings content in most wheat grades. Greenish grains signify immature grains and there is a limit to the amount that may be present in a sample. Incorrect harvesting methods may produce grains that are excessively skinned, cracked or broken. These grains are more prone to insect infestation or disease, and so only small numbers are permitted in sound samples.

2.2.1.4 Contamination

Wheat may be contaminated with a variety of substances. Chaff, awns and parts of the wheat plant that have escaped threshing are included as well as weeds, pests, diseases, chemicals and inert matter.

Grain needs to be primarily weed free; different countries have different standards and there is a maximum tolerance for weed seeds of different species. This will be nil weed seeds per sample for noxious weeds, or seeds that will taint the flour eg. wild garlic (*Allium vineale*). Seeds of other crops such as barley or oats are counted as foreign grains. Australian wheat is almost all white wheat, and the presence of red wheat grains in a sample will mean that that grain can only be used for feed.

Insects and other creatures are also possible contaminants of grain. The most damaging are borers and weevils, which live on the grain in storage and severely affect quality by eating the endosperm. Others such as spiders or snails can increase moisture content and allow the growth of pathogens. Australia has a nil tolerance of live insects in exported grain.

Diseases such as moulds, smuts and ergot can be present in grain. Moulds directly affect the quality of wheat by destroying the grain and imparting an unpleasant flavour to flour. They may also produce aflatoxins which possess both acute and chronic toxicity to humans and animals (Simmonds, 1989). Other toxic pathogens include some *Fusarium* species which occur when grain is harvested under wet conditions, and ergot sclerotia (*Claviceps purpurea*). Ergot is highly toxic but easily recognised as a hard black mass in place of a grain, while *Fusarium* infected grains may have a pink discolouration and greyish flour. Smut, also known as bunt, is not toxic but severely affects quality as the spores impart a fishy odour and contaminate the flour (Gooding and Davies, 1997). Other fungal diseases such as Black Point or field mould will cause the grain to be downgraded, as will fungal staining.

Grain must also be free of chemicals such as insect poisons or repellents. Chemical dyes are included in this category. Contamination with chemicals will cause the grain to be rejected at the receival point.

Other matter includes inert objects such as twigs, stones, sand, glass, metal and any other unmillable material.

2.2.1.5 Test weight

Test weight is obtained by weighing a fixed volume of grain using a chondrometer. It is expressed as a number of kg per hectolitre, eg. the minimum for wheat of Prime Hard quality is 74 kg/hl. As test weight measures weight per volume, it provides a

gauge of the bulk density of the sample. Wheat grain density is often affected by water damage or shrivelling, so test weight may be used as a measure of the soundness of the grain and as a predictor of the likely milling yield. However, results by this method are variable. Hook (1984) conducted a study of UK winter and spring wheats and concluded that correlations between specific (test) weight and flour yield were poor and that test weight could not be used as a predictor of flour yield. Marshall *et al.* (1986) found that the relationship between test weight and milling yield was dependent on both the site and variety used, and therefore was not a reliable predictor of milling yield. Schuler *et al.* (1995) found that test weight was not related to flour yield in soft red winter wheats, although it was related to protein content and hence quality.

2.2.1.6 Thousand grain weight

Thousand grain weight is the weight in grams of 1000 kernels of wheat. Since it is not volume based it is independent of some factors affecting bulk density, and may be preferred as a measure of grain quality. However it is still affected by other factors such as moisture content. Studies by Schuler *et al.* (1995) showed that 1000-kernel weight had no relation to milling qualities of soft red winter wheats. This agrees with the results of Hook (1984), who examined UK varieties of winter and spring wheats, and the results of Marshall *et al.* (1986), who examined Australian spring wheat varieties.

2.2.2 Milling and Flour Quality

Milling quality of a wheat sample describes the attributes of the grain during and after the milling process.

2.2.2.1 Flour extraction

Flour extraction is simply measured by milling a known quantity of wheat at a standard water content through a standard type of mill and measuring the amounts of the various products, ie. sieved flour, bran and pollard. This is of importance to millers since low flour extraction rates are less economical. Marshall *et al.* (1986), calculated that a 1% change in milling yield was worth approximately two dollars per tonne depending on the relative returns for flour and mill offal (bran and pollard).

2.2.2.2 Hardness

Wheats can be classified into two basic types - hard and soft - depending on their endosperm and starch structure (Simmonds, 1989). Hard wheats have a compact endosperm with the starch granules held tightly together by a continuous matrix of protein. The endosperm separates easily from the bran when milled, giving high flour extraction with low levels of bran contamination. The protein-starch matrix breaks cleanly along the cell walls and across cells to yield coarse, gritty flour granules that flow and sieve easily and pack well. The greater starch damage caused in milling to granules from hard wheats allows greater water absorption, which is of importance in bread making (Gooding and Davies, 1997).

Soft wheats have a less compact structure and it is more difficult to separate the flour and the bran cleanly. The endosperm cells break across as easily as apart, and form small fine angular particles which do not flow or pack as easily as the coarse particles from hard wheats. Flour from soft wheat does not absorb water well and must be used for lower water content articles such as biscuits, cakes or pastries.

A common measure of hardness is Particle Size Index (PSI), which is obtained by milling a sample of wheat finely and sifting it for two minutes over a silk screen. The

percentage of flour that falls through the screen is known as the PSI. Soft flours have a higher PSI than hard ones.

2.2.2.3 Colour

Flour colour has two main sources: those due to natural components of the flour itself, such as xanthophylls, carotenoids and flavones (Gooding and Davies, 1997), and those resulting from contamination. Carotenoids tend to give the flour a yellowish colour, which is desirable in products such as Yellow Alkaline Noodles (YAN) or in pasta, but not desired in most breads.

Contamination mostly results from bran, although if mouldy or smutty grain is milled fungal spores can appear in the flour as black specks. Red wheats milled with white wheats also cause changes in flour colour.

Colour is usually measured using a colorimeter. Stability of colour is also important for some wheat products.

2.2.2.4 Falling number

Falling number (also known as Hagberg falling number) is an indicator of enzyme (α-amylase) activity within the grain. α-amylase breaks down starch to produce sugars, and is normally part of the germination process. Grain that has been weather damaged or stored at high moisture levels is most likely to be affected. Some α-amylase activity is desirable during bread production (Gooding and Davies, 1997) but too much activity results in weak sticky crumbs with poor texture and brown colour throughout the loaf. Hagberg falling number is measured by stirring a mixture of water and ground wheat in a cylinder which is placed in a water bath at 100°C. The time taken in seconds for the mixture to be stirred (60 seconds) added to the time for a weight to reach the bottom of the cylinder under gravity is the falling number.

As α-amylase breaks down starch to sugars, viscosity of the mixture will be reduced. However, the relationship between falling number and α-amylase activity is not linear (Perten, 1964).

2.2.3 Dough and Baking Quality

Dough and baking quality tests have been developed to allow small scale testing of parameters that are important for bread production. They include the farinogram, extensogram, water absorption measure, dough development time, dough stability, viscosity, loaf volume and baking score.

A farinogram is an instrument designed to measure (for a given quantity of flour and water) dough mixing characteristics such as water absorption, dough development time, stability and variations in dough consistency. The extensogram uses this information to test the dough produced for elasticity and strength (resistance).

Viscosity is measured by forming a paste of flour and water and slowly heating this while recording the slurry attributes using a pin sensor and a rotating bowl.

Loaf volume and baking score are obtained by baking small test loaves of bread. Volume is measured by rape seed displacement while the baking score is a combined score from the loaf volume, appearance, crumb texture and crumb colour.

2.2.4 Other Quality Tests

There are other quality tests that are specifically designed for particular end uses. These include colour, colour stability and sheeting tests for noodles, cookie tests for biscuit flours, flat bread baking for flat breads and other product testing (Henry and Kettlewell, 1996).

2.3 GROWTH PROCESSES THAT DETERMINE SEED SIZE AND QUALITY

2.3.1 Vegetative growth

The growth of the wheat plant begins with germination. Moisture, oxygen and suitable temperatures are needed to activate the processes of germination in the seed. Large seeds with high nutrient levels produce plants with better emergence and early vigour than small seeds with low nutrient levels (De Marco, 1990). Other factors affecting plant emergence include soil structure, nutrition, seed bed preparation, seeding depth, presence or absence of pests and diseases, and the age of the seed. The radicle (first root) of the plant emerges from the seed first, followed by the seminal roots and then the coleoptile containing a single shoot. The coleoptile is a specialised structure that protects the new leaf from soil damage and directs it towards the surface. The shoot grows out of the coleoptile after the coleoptile reaches a certain length or reaches the surface. Wheat varieties differ in the length of the coleoptile produced (Bhatt and Sheedi, 1986).

The growing point of the shoot forms new structures by cell division. Between 5 and 20 leaf primordia may be formed before development of the ear begins (Perry and Belford, 1991). Development of leaves follows a set rate largely determined by temperature. The rate of leaf emergence can be measured in degree days, and there is a constant period of thermal time between the appearance of one leaf and the next (called a phyllochron), depending upon the sowing date. For example, wheat crops sown in southern Australia in June have an interval of approximately 100 degree days between the emergence of one leaf and the next (Perry and Belford, 1991). Tillers develop from buds formed in the axils (bases) of the leaves, eg. leaf 1 has a bud that may form tiller 1 etc (Williams *et al.*, 1975). The tillers are similar in

structure to the main stem, producing leaf buds from the growing point within the shoot. Tillers are produced on the main stem between limited time intervals, and if the window of development is missed then that tiller will not form. Once a tiller has emerged it produces leaves at the same rate as the main stem provided it is not under stress. The total number of tiller buds produced by a plant may be genetically determined (eg. limited tillering varieties) (Yunusa and Sedgley, 1992; Uddin, 1993). It is possible for sub-tillers to form from the tillers (Perry and Belford, 1991).

Tiller production and growth is highly sensitive to environmental and management conditions. Stresses delay tiller emergence and reduce growth rates, sometimes reducing tiller numbers (Williams and Langer, 1975; Stark and Longley, 1986). Competition for resources between plants causes stress within the plant, eg. less tillers are produced in dense crops than in sparse ones (Anderson and Barclay, 1991). Competition within the plant for resources can also reduce growth and development of later formed tillers (Palta *et al.*, 1994). Conversely, tillering may be encouraged by plentiful resources, eg. water, space, and nutrients (Power and Alessi, 1978).

Most wheat crops produce more tillers than survive to form heads. Tiller bud production occurs up until the start of stem elongation, at which point potential tiller numbers are at a maximum. The numbers usually then decline until the plant reaches anthesis, when the remaining tillers are likely to be those that have developed their own roots and can survive and set grain (Perry and Belford, 1991).

The root system of the wheat plant grows rapidly during the period from emergence through tillering to anthesis. Both seminal roots and crown roots (from the main stem and tillers) provide water and nutrients to the plant from the soil. Seminal roots are the first roots formed from the seed and can reach to at least 150 cm depth at anthesis

in well structured soils. Crown (nodal) roots are shallower and branching, exploiting soil resources nearer the surface.

2.3.2 Reproductive growth

Reproductive growth begins when the shoot apex ceases to form leaves and begins the formation of the ear. The timing of ear initiation in relation to the number of leaves produced determines whether the variety is a short (early), mid or late season cultivar (Setter and Carlton, 2000). Ear initiation begins on the main stem first, followed by the tillers in order of their production. However, ear primordia are always preceded by the formation of the correct number of leaf primordia, ie. if the variety is an early season variety that produces 8 leaf buds on the main stem before ear initiation, then its tillers must also have 8 leaves initiated before tiller ear initiation can begin (Perry and Belford, 1991). Ear initiation ends when the terminal spikelet is formed. It should be noted that this process takes place in the crown of the plant, and the later structures initiated may still be in an embryonic state as leaves emerge and grow.

This phase is followed by stem elongation, when the plant grows rapidly and florets are formed within the spikelet. This is the time of greatest dry matter increase and nutrient uptake, however competition within the plant leads to some tillers and ears (as buds or as more advanced structures) dying due to the competition for resources (Kirby, 1988). The main stems and tillers elongate as the internodes expand, lengthening the stem and moving the wheat ear upward, eventually breaking the flag leaf sheath and emerging above the crop canopy. Dwarf and semi-dwarf varieties have shorter stems, and take less time and plant resources to accomplish this phase than long-stemmed wheats (Rebetzke and Richards, 2000).

Wheat is self fertilising, and after anthesis the glumes on the spikelet part and show the empty anthers on the outside of the ear. If the plant is water stressed stem elongation may be slowed and anthesis takes place before the ear has emerged from the flag leaf.

As the tillers develop later than the main stem they are more likely to experience stress during stem elongation due to less water or nutrient availability (Turner *et al.*, 1994), leading to lower fertility, smaller grain numbers per ear and smaller grain sizes. Tillers have later anthesis dates than main stems, but can complete grain filling in a shorter time interval than the main stems when under moisture stress, although they still finish after the main stem heads. Most research has focused on the results of stress on the main stem or on the total plant components, with less research conducted on the tillers. For example, Langer and Ampong (1970); Williams and Langer (1975); Barlow *et al.* (1980); Brooks *et al.* (1982); Nicolas *et al.* (1985); Stark and Longley (1986), Entz and Fowler (1988); Virgona and Barlow (1991); and Ciaffi *et al.* (1996). Further, this research has mostly focused on physiological effects, or yield, yield components, and a few quality traits such as protein and 1000 grain weight (eg. Turner *et al.*. (1994)), with relatively little work fully examining the quality of the grain produced.

Development of the wheat seed commences at anthesis and is divided into 2 stages (Jenner *et al.*, 1991). The first stage, grain enlargement, (also known as the “lag phase”) is followed by a second stage known as grain filling.

2.3.3 Grain Enlargement

Grain enlargement begins with the formation of cells from the fertilised ova. It lasts typically between 10 and 14 days, proceeding rapidly at first, but becoming slower

until it stops altogether (Jenner *et al.*, 1991). A typical number of endosperm cells is about 100, 000.

At about 3-4 days after anthesis (DAA) amyloplasts are initiated in the cells. Amyloplasts are the locations in the cell where starch can be deposited. The amyloplasts initiated during the grain enlargement phase are designated A-type amyloplasts, and initiation ceases before cell division ceases. Thus, cells formed later have less A-type amyloplasts than those formed earlier. Not all amyloplasts formed have starch deposited in them (Jenner *et al.*, 1991).

2.3.4 Grain Filling

Grain filling commences 10 -15 DAA and overlaps the grain enlargement phase for a short time. The rate and duration of grain filling are variable, and the two components are thought to be quite distinct. Rate of grain filling is dependent on temperature and light intensity (Sofield *et al.*, 1974), which affect the biochemical reactions involved in starch and protein synthesis (Jenner *et al.*, 1991). Duration of grain filling is dependent on temperature, which strongly affects the developmental program of the grain.

In the period of grain filling, starch is deposited in the A-type amyloplasts and also in B-types, which arise from constrictions of the walls of existing amyloplasts. B-type amyloplasts are much smaller than the A-type, but increase in number rapidly and outnumber the A-type by about 10 to 1 at maturity. They may account for as much as 30 % of the final weight of the grain.

The starch deposited in the grain under ideal conditions is mostly derived from CO_2 fixed by the plant during grain filling (Stoy, 1980). Under conditions of stress, eg. drought, soluble (non-structural) carbohydrate reserves from the stems of the plant

are mobilised to sustain growth (Pheloung and Siddique, 1991; Blum *et al.*, 1994; Blum *et al.*, 1997).

Protein first appears in the developing wheat grain at about 10 DAA and is deposited inside spherical membranes derived from the Golgi apparatus. At maturity, many of these membranes fuse to form a continuous matrix of protein surrounding the starch granules (Jenner *et al.*, 1991). Rate and duration of protein deposition are much more influenced by supply factors than starch. Protein synthesis is particularly dependent on nitrogen supply. Large amounts of nitrogen are supplied from the leaves and stems of the plant. A greater amount of nitrogen available for use during grain filling will result in a higher amount of protein being deposited in the grain. Other environmental factors include temperature and moisture stress, which can affect the rate of protein deposition and also the types of proteins stored. This has important implications for grain quality.

2.3.5 Protein Content

Protein quality and content of the grain determines many of the characteristics of the dough and therefore is of high importance. The genetic and environmental influences on the properties of wheat protein are complex, and there are many factors to be considered.

2.3.5.1 Genetic factors

The genetic basis for quality characters in wheat is extremely complex. However, one of the most important factors influencing wheat quality is the presence of the gluten-production genes. There are several variations of these which differ in quality and may have different responses to various environmental stresses (Lawrence *et al.*, 1988).

2.3.5.2 Environmental factors

The protein content of the grain is partly determined by the amount of nitrogen available to the plant, and nitrogen deficiency is commonly a limiting factor to achieving high protein levels. The amount of N that is sufficient for plant growth and maximum yield does not produce grain with maximum protein levels. Management practices such as rotations and fertiliser regimes influence the amount of N available to the plant and have a large influence on protein percentage and hence the end-use quality of the crop (Anderson *et al.*, 1996).

Moisture conditions throughout the growing season also influence protein content. Abundant water allows crops to grow more heads and fill more grain, producing the "dilution effect" commonly seen with high yielding crops. Water stress during grain filling slows the rate of starch deposition relative to protein deposition and may produce lower yields or small or shrivelled grains with higher protein percentages.

Temperature during grain filling is also of importance. Studies have shown that protein components are severely affected by sudden periods of high temperature, and that this can lead to changes in the expected characteristics of the dough (Randall and Moss, 1990; Wrigley *et al.*, 1994(a)).

Weeds compete with wheat plants for nitrogen but there is so far no evidence to suggest that there are any other effects caused by weeds on protein quality. It is theoretically possible that some weed control methods, eg. hormone-based herbicides, could affect protein properties in some way, but no research is known to have been done in this area.

Pests, such as nematodes, can affect the root systems of plants to the extent that nitrogen supply is limited and protein content is low. In other circumstances however it may be that moisture is more limited than nitrogen and the protein percentage of

the grain is increased as a result. It is also possible for diseases of the roots or foliage to cause similar phenomena. It is not known whether protein produced under these circumstances is significantly different in quality from that produced by healthy plants. A study by O' Brien *et al.* (1990) showed that grain produced from plants infected with stripe rust had higher protein percentages than grain from rust free plants.

2.4 ENVIRONMENTAL EFFECTS ON SEED SIZE AND QUALITY

There are many factors in the environment of the wheat plant which directly or indirectly affect the grain quality. Some of these can be controlled by the producer (management effects), others not (seasonal effects).

2.4.1 Seasonal effects on quality

Many of these (such as weather damage) have already been discussed in sections 2.2.1.3 and 2.2.1.4. However, the effects of water availability, temperature and light intensity are of importance and will be covered here.

2.4.1.1 The effect of water availability on seed size and dough quality.

With water in abundance, and sufficient starch produced to fill the grain, a plump well-filled grain will result. However, if water is a limiting factor, the number of cells produced during grain enlargement will be less (Jenner *et al.*, 1991). This reduces the potential size of the grain. If there is no moisture stress while the grain fills after this stage, the result is a small but well-filled grain. If water is plentiful during grain enlargement but limiting during grain filling, there is not enough starch

deposited in the grain to fill out the walls of the seed and they collapse, producing a large, shrivelled grain. Finally, if water is limiting throughout seed production, a small and shrivelled grain is the outcome (Gaines *et al.*, 1997).

Although water stress has direct effects on quality, eg. it may in some circumstances improve it by increasing the proportion of protein within the grain, moisture stress interacts with other environmental factors to produce varying results on seed size and quality (Lopez-Bellido *et al.*, 1998; Johansson and Svensson, 1999).

The effect of high nitrogen and water stress combined results in the "haying off" phenomenon, which affects crops with high vegetative growth and/or nitrogen nutrition when water becomes limiting (van Herwaarden, 1996(a); van Herwaarden *et al.*, 1998(a); van Herwaarden *et al.*, 1998(b); van Herwaarden *et al.*, 1998(c)). Commonly the seed produced is small and shrivelled with high N content but low quality due to low flour extraction rates. Temperature and water stress also interact to change seed size and quality. Little work has been done in this area (Davidson and Birch, 1978; Randall and Moss, 1990). Panozzo and Eagles (1999) investigated effects of moisture and temperature on aspects of wheat grain filling, including protein. Pal (1992) and Shah (1992) both looked at the effects of moisture and temperature stress on the physiology and yield of wheat. However it is difficult to find work that has gone beyond yield and protein and fully investigated effects of stresses on the dough or end-use quality of the grain produced in these conditions.

2.4.1.2 The effect of temperature on seed size and quality

Temperature during grain filling is an environmental factor of great importance in wheat producing areas of Australia due to its effect on dough strength. Low temperatures rarely affect quality or seed size except in cases of frost. However, high temperatures (maximum over 35° C or daily mean over 30° C) occur during grain

filling reasonably often and can produce a heat shock response which reduces dough strength dramatically (Stone and Nicolas, 1995, 1996; Blumenthal *et al.*, 1998). Warm temperatures below this threshold however have the opposite effect, improving dough strength and quality (Randall and Moss, 1990).

2.4.1.3 The effect of illuminance on seed size and quality

Light intensity affects seed size and quality indirectly by influencing photosynthesis, supply of assimilates and growth within the plant. Work by Sofield *et al.* (1977(a); 1977(b)) showed that under controlled conditions, illuminance affected the number of grains per ear, grain growth rate and the percentage of nitrogen within the mature grain.

2.4.2 Management effects on quality

Management effects are those which can be controlled by the grain producer. They include nutrition, impact of pests and diseases and cultural practices.

2.4.2.1 Nutrition

Correct nutrition to produce a healthy crop is necessary to result in large well-filled high protein grains. The major nutrients phosphorus, potassium and calcium are necessary for plant health and as long as they are not limiting do not influence grain size or quality. The effect of nitrogen on grain protein and hence quality is well known, and the necessity of sulphur for dough strength and elasticity has been documented (Wrigley *et al.*, 1980; Randall *et al.*, 1990). The minor nutrients also affect grain quality characteristics through general plant health. Toxicities such as boron toxicity are included in this category.

Recently due to increasing profitability of cropping over other enterprises producers have been moving towards longer cropping periods, often with higher inputs of N-fertiliser to compensate for the increased use of soil resources. Due to the higher prices paid for high protein wheats such as Prime Hard and Hard types, growers are looking for ways to increase the protein content of their grain, such as heavy N-fertiliser applications, and use of legume crops, pastures or green manures. Problems with producing wheat of the desired protein and quality characteristics associated with high input of N-fertiliser commonly include high screenings and low grain weights, and haying-off is a danger in some areas (van Herwaarden *et al.*, 1998(a); Reimers *et al.*, 2001). Little research has been conducted into other quality traits such as flour colour or dough characteristics which may also be affected by these growing conditions.

2.4.2.2 Pests and Diseases

Pests and diseases in the crop generally affect seed size and quality through their effects on supply of water or nutrients and hence plant health. Section 2.3.3.2 details effects of these factors on protein. Very little work has been done in this area to investigate effects on quality, however a study by O'Brien *et al.* (1990) found that stripe rust infestation affected dough properties in ways that were not accounted for simply by the changes in grain protein content.

2.4.2.3 Cultural Practices

Cultural practices include management aspects such as time of sowing, plant density, fertiliser regimes, crop rotations, soil conservation efforts and tillage types. Those that most influence seed size and quality are those that maximise the water use

efficiency (WUE) of the crop while maintaining high protein levels. An early sowing time is important to maximise yield (Coventry *et al.*, 1993; Anderson *et al.*, 1995) and later sowing times can produce grain with high amounts of screenings in drier years (Anderson *et al.*, 1995). Adding nitrogen to the crop will increase grain nitrogen levels and therefore quality as long as there is already sufficient nitrogen for high yield. The use of legumes in rotation with wheat crops will also accomplish this. Anderson *et al.* (1995) found that in low rainfall areas of Western Australia wheat planted after a legume crop or pasture could achieve greater than 13 % protein regardless of whether nitrogen was added as fertiliser or not. Rowland *et al.* (1994) found that wheat after field peas had superior yield and protein to wheat after wheat. Another recent trend in wheat production in South Australia is the move towards high density crops in an effort to minimise tillering and ensure that all substrates produced are used to fill a single ear on the main stem, maximising the efficiency of the plant. Experiments in the area of wheat physiology indicate that the ear on the main stem usually produces the highest number of grains and the heaviest grains on the plant (Fraser and Dougherty, 1978; Darwinkel, 1979; Whingwiri and Kemp, 1980; Hucl and Baker, 1989, 1990; Turner *et al.*, 1994; Metho and Hammes, 2000). High density crops are also used in an effort to reduce weed numbers in the crop due to the increased competitive effect (Sykes *et al.*, 1990; Zaicou and Gill, 1992; Lemerle *et al.*, 1996). However, little research has been conducted on the effects that changing densities have on the quality of the wheat crop, or on the effects of related environmental stresses on the main stems and tillers in the crop and their qualities. No publications could be found between 1972 and July 2001 using standard bibliographical methods on the impact of changes in wheat crop density in Australia on the quality of the grain produced.

2.5 THE POTENTIAL FOR HIGH PROTEIN WHEAT IN SOUTH AUSTRALIA

Early researchers and marketers recorded that the South Australian environment was capable of producing high protein bread wheats (Guthrie, 1907). However, emphasis on achieving high yields was often made without maintaining the protein content and quality of the grain and average protein throughout the 1970-1980s declined (Reuter and Dyson, 1990). The AWB has worked to arrest this trend by introducing payment incentives for higher protein wheat and this has largely been successful.

In recent years, some growers have been able to consistently produce high protein hard and durum wheats in SA. Work by Reimers *et al.* (1998) has shown that it is possible to produce Prime Hard wheat varieties with the required protein levels in SA. Producers would benefit from the higher prices paid for the high protein wheat. However, grain weights have been close to the minimum specified by the AWB and screenings percentages have been high.

At present many high protein wheats are sourced from restricted areas in New South Wales and southern Queensland. It is desirable to grow high protein wheat in South Australia to spread the production areas and ensure continuity of supply (Reimers *et al.*, 2001).

As farmers move towards high density, high input crops to achieve premium prices for high protein wheat, research needs to be conducted into the effects that changing densities and related stress factors have on the physical, milling and end-use qualities of crops grown in these conditions. Reimers *et al.* (1998) found that small grain size and high screenings were the most common problems associated with high protein wheat production, particularly in areas with a short growing season and hence subject to higher temperatures and moisture stress during grain filling. Similar results were

obtained by Anderson *et al.* (1995) in low rainfall areas of Western Australia. Van Herwaarden *et al.* (1996(a); 1998(a)) pointed out that haying off (premature senescence of the crop with small grains and low yields) was associated with high nitrogen crops under moisture stress during grain filling, but did not investigate quality. Pal (1992), and Shah (1992), investigated effects of temperature and water stresses on the yield and physiology of wheat plants, but did not investigate effects on quality. Lopez-Bellido *et al* (1998) studied the effects of tillage, crop rotation and nitrogen fertilisation on the quality of wheat in southern Spain, but did not investigate density or water stress. There is a lack of knowledge in the area of the effects (if any) that different densities and associated stresses have on the quality of high protein wheat.

2.6 PROBLEMS WITH SMALL GRAINS

Small grain size in high protein wheat for human consumption is defined as grain that has a mass of less than 30 milligrams, ie. the 1000 grain weight of such a sample is less than 30 g (Australian Wheat Board 1999, pers. comm.). This is moderately small for breadmaking wheats, which can range in size from 15 - 70 mg. A more usual average grain size under southern Australian conditions would be approximately 35 mg, while in the northern wheat growing areas of New South Wales and Queensland grain size may average 40 mg (Howes 1999, pers. comm.). Apart from the genetic constraints to achieving large grains, which may be present in the variety sown, small grains are commonly caused by a lack of water or nutrients at some stage in the growth cycle. Section 2.4.1.1 gives details of this. A restriction in water availability during early grain growth can lead to small but plump grains where

the potential grain size is small but grain filling has occurred without stress. In other circumstances, where stress is placed on the plants at a later stage, the plants may not be able to fill the potential grain and the seed is shrivelled. Tillers are more susceptible to stress than main stems, as they develop later in the season when stress due to increased temperatures and less water availability is more likely. Also, competition within the plant for nutrients often allows the main stem to develop at the expense of the later tillers. This may lead to differences in potential grain size or degree of shrivelling between grains from main stems and tillers. It is also possible that differences in substrate availability to main stems and tillers could lead to differences in other grain quality attributes as well. Most research conducted to examine the grain filling processes has focused on grains from the main stems of wheat plants, frequently with the tillers removed (Langer and Ampong, 1970; Sofield *et al.*, 1977(a); Brooks *et al.*, 1982; Nicolas *et al.*, 1985; Virgona and Barlow, 1991; Panozzo and Eagles, 1999; Panozzo *et al.*, 2001).

Further, it has been shown that small plump grains may have different quality characteristics from small shrivelled grains or large shrivelled grains. Research in this area is limited, but a study by Gaines *et al.* (1997) on soft wheats concluded that milling qualities and cookie test results differed between large and small and shrivelled and non-shrivelled wheat grains.

Work using bread wheats in this area has given varying results. Contrasting results have been found in experiments where quality has been examined with respect to grain size, weight, shrivelling or test weight. Bayles (1977) found that the degree of grain shrivelling in three British wheat varieties grown under varying nitrogen regimes did not significantly affect flour yields. Marshall *et al.* (1986) found that grain size was correlated with milling yield within cultivars on a single site, but not

across cultivars or sites. An Australian study conducted to investigate changes in the attributes of wheat populations that were mass selected for seed size found that the expression of quality characters was independent of the expression of seed size in all the crosses studied (Bhatt, 1973). However, none of these studies differentiated between main stem grains and tiller grains.

2.7 SUMMARY

The quality of wheat is determined by its suitability for use in a particular product, eg. bread, biscuits, noodles or pastries. There are many measures of quality, including physical tests (moisture content, appearance, damage, contamination and weight), milling and flour tests (flour extraction, hardness, colour and falling number), dough and baking tests (extensibility, strength, loaf volume and loaf score) and other product tests such as cookies, noodles and flat breads.

Factors that affect quality often occur during the grain enlargement and grain filling stages of the growth cycle. Of particular importance are those that influence seed size and protein. These factors may be seasonal environmental factors, such as water availability, temperature and light intensity, or management factors such as nutrition, pests or cultural practices. Recent trends in wheat management practices lean towards producing high value, high protein crops by using high fertiliser inputs and/or using legumes in the rotation. Producers also increase crop densities to suppress tillering, and as part of weed control practices.

As producers move towards high density, high input cropping regimes, research needs to be conducted to investigate the effects of these systems on the quality of the grain produced. Most research into the effects of stress on the wheat grain have

focused on the main stems of wheat plants, although tillers can contribute between 10 % (McMaster *et al.*, 1994) to 75 % of the grain harvested in a crop (Clements *et al.*, 1974; Metho *et al.*, 1998).

It is important to understand the effects of high plant density and associated factors such as moisture stress and higher temperatures on tillers as well as main stems in high protein wheat varieties. As a way to understanding these effects, the study reported in this thesis examines:

1) the effects of water stress and temperature on main stem and tiller shoot and grain characteristics under controlled conditions

2) the effect of water stress on main stem and tiller grain quality in the field,

3) the effect of crop density on main stem and tiller production, crop yield, protein, and physical, milling and dough quality parameters, and

4) the differences between main stems and tillers produced in the field when tested for selected quality parameters.

The main hypothesis of the study is that there are measurable differences in the quality of the grain produced by main stems and tillers in crops grown at different densities.

The three associated hypotheses of this study are:

1) tillers have a measurable contribution to the overall quality of the wheat in a crop

2) the smaller grains and fewer grains per head produced by tillers have higher protein and differing quality when compared with grains from the heads of main stems

3) tillers are more severely affected than main stems by water stress or changes in temperature, thus stresses produce greater changes in quality of grain from tillers than from main stems.

CHAPTER 3 GENERAL METHODS AND INFORMATION

3.1 EXPERIMENT DESIGN

The project was designed to test the responses of main stems and tillers to various stresses commonly encountered in high protein wheat growing areas in South Australia, with particular focus on the quality of the grain produced.

The first experiment examined the effect of drought and associated temperatures on main stem and tiller production and some grain qualities of the wheat plant under controlled environment conditions (Chapter 4).

Moisture stress is a common factor in high protein wheat producing areas, so the second experiment was devised to investigate the effect of drought on the quality of grain produced from the main stems and tillers in the field (also Chapter 4).

The third experiment examined the effect of different planting densities on the physiology, yield and quality of the crops over three years (Chapter 5).

Grain from the main stems and tillers of these crops was collected every year and tested in a further experiment using small scale equipment to more closely examine their properties (Chapter 6).

Full details of experiment treatments and measurements taken are given in the relevant chapters.

3.2 ENVIRONMENT

Experiments 1, 3 and 4 were carried out at the University of Adelaide's Roseworthy Agricultural Campus, South Australia (34° 32' S, 138° 42' E). The area has a Mediterranean climate, with cool wet winters and hot dry summers. Table 1, Table 2 and Table 3 show the rainfall, daily minimum and maximum temperatures and evaporation data in the years of the study, and the long term averages of those measurements.

Table 1: Monthly rainfall (mm) data recorded for Roseworthy, SA in 1998, 1999 and 2000 compared to the average monthly totals (1883 – 1997).

Month	1998	1999	2000	108-year average [A]
January	43.2	3.0	0.8	21.4
February	2.6	0.0	73.5	19.3
March	9.4	5.0	21.6	20.3
April	58.6	9.2	34.0	37.0
May	10.0	61.6	39.9	46.8
June	58.4	34.6	57.0	52.5
July	54.8	33.0	50.0	49.9
August	15.4	24.0	67.0	52.8
September	44.4	35.6	47.4	46.8
October	38.6	46.8	57.4	43.0
November	35.8	55.4	21.8	27.7
December	0.0	22.4	11.4	22.9
Total	*371.2*	*330.6*	*481.8*	*440.4*
April-October	*280.2*	*244.8*	*352.7*	*328.8*
[A] Roseworthy Agricultural College Weather Station				

Table 2: Mean daily maximum and minimum temperatures (°C) at Roseworthy, SA in 1998, 1999 and 2000 compared to the average mean daily temperatures (1917 – 1997).

Year	1998		1999		2000		Long-term average	
Month	Mean daily maximum	Mean daily minimum	Mean daily maximum	Mean daily minimum	Mean daily maximum	Mean daily minimum	80-year mean daily maximum [A]	80-year mean daily minimum [A]
January	30.5	14.7	33.3	16.1	30.3	14.9	29.9	14.9
February	30.0	13.2	32.2	16.0	33.8	18.4	29.7	15.2
March	28.1	12.3	26.0	12.9	27.5	13.7	27.2	13.5
April	21.0	9.2	22.2	6.6	23.7	11.0	22.8	11.0
May	20.1	7.8	20.2	9.7	17.8	8.0	18.8	8.9
June	15.7	6.3	16.3	6.0	15.4	6.7	15.7	6.8
July	13.8	4.6	16.0	6.0	15.5	6.3	14.9	6.0
August	16.3	6.2	17.5	4.5	15.9	5.8	16.1	6.3
September	20.8	6.6	21.0	8.0	19.3	7.6	18.7	7.2
October	22.7	7.6	23.9	9.6	22.0	7.9	22.0	9.1
November	26.2	9.7	24.3	9.6	29.4	13.2	25.4	11.6
December	29.4	12.8	28.1	13.0	30.2	11.6	27.8	13.6
Average	22.9	9.2	23.4	9.8	23.4	10.4	22.4	10.3
April-October	18.6	6.9	19.6	7.2	18.5	7.6	18.4	7.9
[A] Roseworthy Agricultural College Weather Station								

Table 3: Monthly evaporation (mm) recorded for Roseworthy, SA in 1998, 1999 and 2000 compared to the average monthly totals (1967 – 1997).

Month	1998	1999	2000	30-year average [A]
January	246.6	295.0	302.2	272.8
February	218.4	233.6	298.4	234.5
March	189.2	175.6	220.8	195.3
April	102.8	103.8	133.4	123.0
May	68.4	91.6	77.2	74.4
June	48.8	50.6	59.4	54.0
July	41.6	49.6	63.3	55.8
August	63.6	75.2	83.8	71.3
September	102.6	122.4	112.3	96.0
October	141.2	151.6	146.0	142.6
November	202.6	177.2	231.4	201.0
December	254.0	230.2	286.4	244.0
Total	*1679.8*	*1756.4*	*2014.6*	*1764.7*
April-October	*569.0*	*644.8*	*675.4*	*617.1*
[A] Roseworthy Agricultural College Weather Station				

Experiment 2 was conducted on the property of Mr Robin Manley near Avon, South Australia (approximately 34°14’ S, 138°19’ E). The area has a Mediterranean climate, however it has a lower annual rainfall and higher average daily temperatures than Roseworthy. Only rainfall data were available for the site (Table 4).

Table 4: Rainfall data for the Avon experiment site.

Month	1999	2000	30-year average [A]
January	6.3	0.0	12.0
February	6.6	73.9	14.0
March	30.5	22.1	14.0
April	5.1	32.8	22.0
May	35.6	47.5	30.0
June	30.2	54.1	40.0
July	26.9	63.1	40.0
August	18.0	29.3	36.0
September	40.2	31.5	40.0
October	41.4	47.5	34.0
November	0.0	22.7	26.0
December	0.0	6.4	19.0
Total	*240.8*	*430.9*	*327.0*
April-October	*197.4*	*305.8*	*242.0*
[A] Readings taken on property.			

3.3 SITE INFORMATION

Experiment 1 was conducted at the Roseworthy Campus using an evaporatively cooled glasshouse for the first stage of the experiment, and 2 controlled environment chambers for the second.

The site of Experiment 2 at Avon had a slight slope to the south. Soil was a Hypervescent Petrocalcic Calcic Calcarosol (medium, slightly gravely, loamy, loamy, moderate) (Isbell, 1996). The Northcote (1984) classification categorized it as

an alkaline calcareous sandy loam (Gc1.12). The soil had a pH of 8.3 in water (1:5) and 1.6 % organic carbon (0-10 cm depth).

The site in 1999 had been a weedy fallow for some years, with dominant species Great brome (*Bromus diandrus*), annual rye-grass (*Lolium rigidum*), turnip weed, (*Raphanistrum rugosum*), barley grass (*Hordeum leporinum*), flax-leaf fleabane (*Erigeron bonariensis*), roly poly (*Salsola kali*), medic (*Medicago spp*) and Paterson's Curse (salvation Jane) (*Echium plantaginum*). In 2000 a site with similar characteristics close to the previous one was used.

The soil type at the site of experiments 3 and 4 (Roseworthy Campus) was a Mottled Supracalcic Red Chromosol (medium, non-gravelly, loamy, clayey, deep) (Isbell, 1996). It had a pH of 7.5 (1:5 soil:water) and organic C content 1.5 % (0-10 cm depth).

Previous to the first year of the experiment the area had grown field peas (*Pisum sativum*), however in the 2nd and 3rd years oats had been grown on those areas the year before. Each year experiments were grown on new ground close to the last year's experiment.

3.4 WHEAT CULTIVARS

Experiments 1 and 2 used the cultivar Janz, a widely grown Prime Hard quality variety. Experiment 3 (and therefore also 4) used Janz as before, and Kukri, a recently released high protein wheat with very strong dough characteristics .

The two varieties differ at 4 of the 6 glutenin allele loci (Cornish 2002, pers. comm.) (Table 5), which control the types of glutenin proteins produced. These proteins are important in determining the end-use quality of the grain, as proteins with inadequate

dough strength mean that the variety cannot be used for bread making and other end-uses requiring good dough strength.

Table 5: Glutenin alleles of Janz and Kukri

	Glu-A1	***Glu-B1***	***Glu-D1***	***Glu-A3***	***Glu-B3***	***Glu-D3***
Janz	1	7*+8	2+12	b	b	b
Kukri	1	7+8*	5+10	d	h	b

Janz has a combination of alleles that produce dough with adequate strength for Prime Hard, and flour with a good white colour. The variety also is widely adapted to a range of environments, and is widely grown in the accepted Prime Hard wheat areas (Johnson and Hall, 1999). It produces many tillers, and therefore can produce high yields in good seasons. However, in the harsher grain filling environment of southern Australia, this is not always utilised.

Kukri has an allele combination that produces very high strength doughs, more suited to blending or specialty products such as frozen doughs. The 5+10 allele in particular is known to carry this characteristic (Payne *et al.*, 1987). Kukri has wider leavers and thicker stems than Janz, and purple coloured auricles. It tillers less, but does produce larger grains than Janz, and more consistently.

3.5 DETAILS OF PHYSIOLOGICAL DATA COLLECTION

All counts of emergence and population density were made by a single person. Plant samples were taken using a 0.25 m^2 quadrat randomly placed within the boundaries of the chosen plot. Growth stages were defined using Zadok's standardised growth scale (quoted in Perry and Belford (1986)), which assigns a number from 1 to 9 to each growth stage. The 10 principal stages in the Zadok's scale are listed in Table 6.

Table 6: Ten principal stages in Zadok's growth scale.

0	Germination	5	Ear emergence
1	Seedling growth	6	Flowering
2	Tillering	7	Milk development
3	Stem elongation	8	Dough development
4	Booting	9	Ripening

3.6 DETAILS OF QUALITY TESTS

3.6.1 Standard Quality Testing Procedures

3.6.1.1 Physical

Moisture and protein content were determined using a Leco unit and the Dumas method (RACI CCD Method 02-03, 2003). Thousand-grain weights were determined by counting a pre-determined number of seeds (usually 500, but in the case of the smaller samples, 100), weighing and multiplying to obtain the 1000-grain weight. Samples were screened over a 2mm slotted screen to obtain screenings percentages.

3.6.1.2 Milling and Flour Quality

Experiment 3 used a Buhler mill to mill the flour and obtain flour yield data. All grain was tempered to 16 % moisture content by adding sufficient distilled water to the grain 24 hours before milling. The grain was rotated regularly until milling to ensure uniformity of the sample. A control sample of wheat was milled each morning before the experimental samples as a check for uniformity.

Experiments 2 & 4 utilised a Quadrumat mill, with samples also tempered to 16 %. Hardness was measured using whole-wheat samples ground in a Falling Number mill and a calibrated NIR machine. Flour colour was measured using a Minolta colour meter, which measures the brightness (L value, 100-0), yellow-blue value (positive

values indicate yellowness, negative blueness), and red-green value (positive values indicate redness, negative green-ness).

3.6.1.3 Dough and Baking Quality

The Farinograph method used for Experiment 3 was that given by the American Association of Cereal Chemists (AACC) Method 54-21, and also by the Royal Australian Chemistry Institute (RACI) Cereal Chemistry Determinations (CCD) Method (Farinograph Testing). The Farinograph measures the resistance of the dough to mixing over time, using a chart and balanced pen which is attached through gears to the blades which mix the dough. Fifty grams of flour (on a 14% moisture basis) is used for each sample, and sufficient water is added to form a dough that at mean maximum strength is centred on the centre line of the chart (500 Buhler Units – BU). Figure 1 shows the measurements taken from the farinograph.

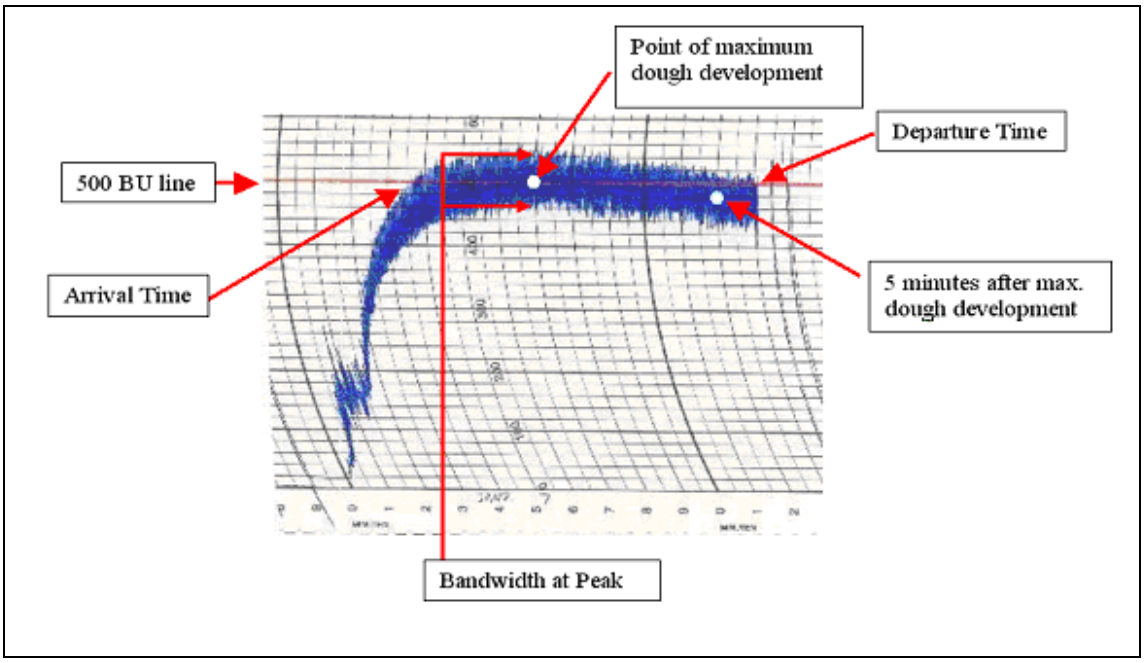

Figure 1: Some measurements taken from the farinograph.

The Extensograph method for Experiment 3 is given in AACC Method 54-10. Using a farinograph, 50 grams of flour is mixed to a dough strength of 500 BU in 5 minutes. This dough is then weighed to 75 grams, moulded into a sausage shape and

allowed to rest for 45 minutes at 30°C. It is then placed in a holding cradle and stretched to breaking point on the extensograph. A balanced pen records the dough's resistance to elongation (strength, Rmax), and the length to which the dough can be stretched (extensibility, cm). Figure 2 shows the measurements taken from the extensograph.

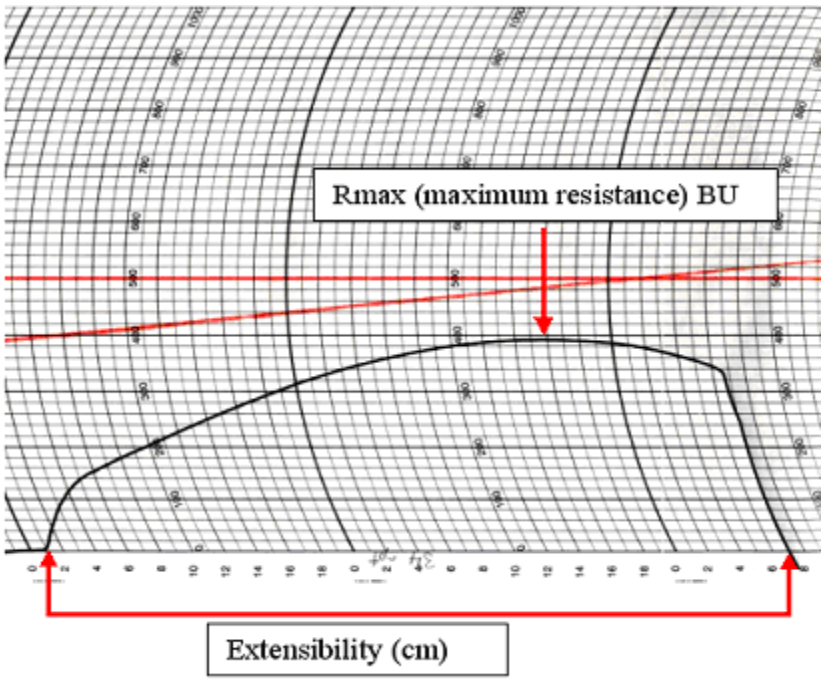

Figure 2: Measurements from the Extensograph

The loaf baking method is that given by AACC Method 10-10B. Loaf colour was measured using the Minolta colour meter, and loaf volume by rape-seed displacement.

3.6.2 Small Scale Quality Testing Procedures

3.6.2.1 2-gram Mixograph

Small scale testing of the dough properties of main stems and tillers was carried out at the CSIRO Grain Quality Research Laboratory (GQRL), North Ryde, NSW, (now

located in Canberra, ACT) using a 2-gram mixograph and the AACC method 54-40A (American Association of Cereal Chemists, 2000). All masses and volumes were adjusted to provide the same ratios of water to flour whilst producing 3.5 g of dough. The 2-gram mixograph automatically records the dough resistance while mixing every 4 seconds, and saves the data to a computer. After each sample, the relevant dough characteristics are calculated by the program.

3.6.2.2 Extension tester

The grain from 1998 was also tested using a small scale extension tester at the GQRL comprising a CSIRO instrument and the SMS TA-XT2 with Keiffer test-rig (Gras *et al.*, 1997). The instrument is made up of a vertically moving arm to which the sample holder is attached, and a platform to which the arm and a recording hook is attached. The arm moves at a constant rate from the top to the base. At the top of the instrument the recording hook is fixed and the dough sample is placed over this when fitted to the holder arm. The hook electronically records the force (Newtons) exerted by the dough on the hook as the dough is stretched downwards. Results are similar to those obtained by an extensograph.

Samples of flour were mixed to peak dough development using the method previously described for the 2-gram mixograph. The dough was removed from the mixograph bowl and divided into 2 samples of 1.5 g each. These were rolled to a small cylinder shape using a hand press, clamped at each end in a holding piece and placed in a proofing cabinet at 30 °C and 65 % humidity for 30 minutes. The samples were then fitted one at a time to the holding arm and the strength and elasticity characteristics of the dough recorded.

3.6.2.3 Thimble loaf baking

The thimble loaf baking procedure was a scaled down version of that used by MacRitchie and Gras (1973). All masses and volumes were adjusted to provide the same ratios of water to flour whilst producing 3.5 g of dough.

Flour samples were mixed with a correctly proportioned aqueous blend of brewer's yeast, sodium chloride and flour improver in water (Bread Research Institute of Australia standard) to give the ratio 100:2.5:2:0.5 for flour:yeast:salt:improver, and water was added as for the mixograph method detailed in the AACC Methods 54-40A. The composition of the improver was 0.6% potassium bromate, 1.0% ascorbic acid, 10.0% ammonium chloride, 15.0% calcium sulphate and 73.4% malt flour. The dough was mixed to peak development for each sample and then weighed to obtain 2.4 g. The sample was rolled in a wooden press as used for the extension test, and placed in a closed container in a proofing area at 35 °C and 80% humidity for 20 minutes. The sample was then re-rolled at right angles to the original direction and placed in a modified metal thimble. The thimbles had dimensions of approximately 10 mm base diameter, 15 mm rim diameter and 24 mm height, and had 5 holes drilled in the bases to allow steam to escape. The samples in the thimbles were then placed in the proofer again for 40 minutes. When this time had elapsed, they were immediately placed in an oven at 100 °C for 17 minutes to bake. After baking the loaves were allowed to cool, and then measured for height using callipers accurate to 0.01 mm. Height was measured from the base of the loaf to the highest point on the crust.

CHAPTER 4 EXPERIMENTS 1 & 2: EFFECTS OF TEMPERATURE AND DROUGHT ON MAIN STEM AND TILLER GRAIN QUALITY

4.1 INTRODUCTION

Wheat crops in South Australia reach the stage of grain filling towards the end of the growing season, as moisture levels decline and temperatures rise. It is known that moisture stress and temperature can interact to produce various effects on grain yield and quality. Randall and Moss (1990) examined records of Australian Wheat Variety trials, correlating site temperatures with quality attributes, and found that moderate increases in daily average temperature caused an increase in dough strength. However, in the same records, dough strength was decreased by drought, and when droughted plants were exposed to moderately high temperatures, lower dough strength resulted. This phenomenon was not the same as that of heat shock, as described by Stone and Nicolas (1995). Further, Davidson and Birch (1978) showed that for two different varieties of wheat, main stems and early tiller yields were much more resistant to combinations of droughting and warm temperatures than the yields of tillers formed later in the plant's development.

Although Randall and Moss (1990) looked at end-use quality parameters in their investigation, no work has been found that examined separately the responses of main stem and tiller grain quality to combinations of water stress and temperature stress.

In ideal conditions, water is not a limiting factor in the growth and development of the wheat plant. Main stems and tillers can both reach their full genetic potential

without constraint. However, these ideal conditions are not found in the field towards the end of the growing season in South Australia. Usually, decreasing water availability is apparent during grain filling. As the tillers reach anthesis later, they are usually subject to more water stress than the main stems at the same stage of growth. Moisture stress also interacts with other factors such as temperature and nutrition to produce varying results on seed size and quality (Lopez-Bellido *et al.*, 1998; Johansson and Svensson, 1999). Work by Randall and Moss (1990) and Davidson and Birch (1978) in the glasshouse found varying effects on quality of the grain, but did not examine main stems and tillers separately. Panozzo and Eagles (1999) investigated aspects of moisture stress on grain yield and protein in the field, but did not examine quality, or differentiate between stem types.

Production of high protein wheat in South Australia frequently takes place in areas where the moisture stress on the grain during filling is high. This can assist in producing high protein levels, but an unwelcome side effect may be the production of small, shrivelled grains, and occasionally, haying off of the crop (van Herwaarden *et al.*, 1998(a); van Herwaarden *et al.*, 1998(b); van Herwaarden *et al.*, 1998(c)). Varietal characteristics may play a part in the ability of a wheat crop to finish well under conditions of moisture stress. It is not known whether there are differences in end-use quality between grain from the main stems and grain from the tillers in these circumstances. This is of importance, as to understand and predict seasonal changes in wheat quality, the contribution of the tiller grains to the harvest must be accounted for. Many experiments dealing with various stresses have been conducted on the main stem alone, but very few have included the tillers.

The experiments described here were designed to:

1. closely investigate the effects that water stress and heat stress had on the quality of the main stem and tiller grains of a Prime Hard quality wheat, when grown in a controlled environment, and
2. examine the effects of water stress on the quality of high protein grain harvested from main stems and tillers, when grown in a low rainfall field environment.

4.2 MATERIALS AND METHODS:

EXPERIMENT 1: CONTROLLED ENVIRONMENT EXPERIMENT

4.2.1 Location, Soil and Environment

The experiment took place using a glasshouse and 2 similar controlled environment cabinets at the Roseworthy Campus of the University of Adelaide.

Round pots of 25 cm diameter were used, lined with plastic bags to prevent loss of water through drainage. The outside of each pot was covered with aluminium foil to reflect heat. Each pot contained 7 kg of soil mix, which contained 8.62 % water at the time the pots were filled. (Equivalent to 6.396 kg dry soil.) The soil was made up of a mix of Gawler River loam, coarse sand and organic compost in the ratio 2:2:1. The soil had water retention characteristics as shown in Table 7 and Figure 3.

Table 7: Retention of water by sandy loam.

-kPa	%water
1	16.60
10	16.60
100	10.95
500	8.25
1500	7.75

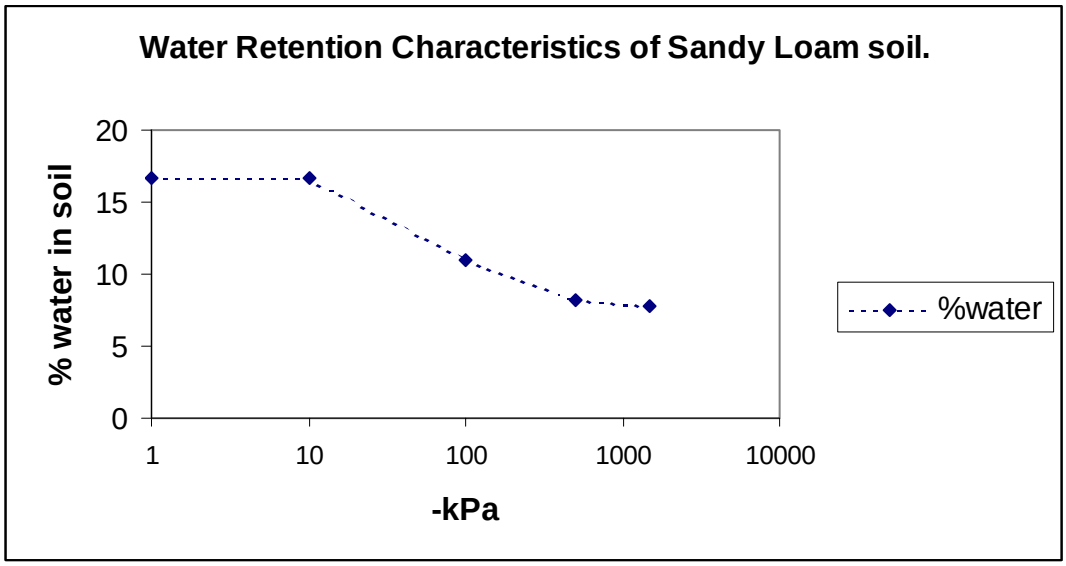

Figure 3: Water retention by sandy loam.

Water holding characteristics were measured using a pressure plate apparatus. Water content of the soil at pot filling was measured gravimetrically. The amount of water present in the soil at field capacity (FC), and the weight of each pot at FC was calculated. When watering the pots, the pots were weighed on a balance calibrated with an empty pot and plastic bag, and water added until the pots weighed the desired amount.

The pots were watered to 80 % of field capacity and left to settle in the glasshouse. The glasshouse was evaporatively cooled so that the maximum temperature was usually not more than 25 °C. During humid periods in summer however a maximum of 30 °C could be reached.

4.2.2 Experiment Design.

The experiment was a split-plot design with 4 treatments and 4 replicates. Each replicate contained 8 pots, with 2 pots per treatment, and 8 plants per pot (Table 8).

Table 8: Treatments in Experiment 1.

Wheat	Water Availability	Temperature	Treatment Name
Janz	Field Capacity	Warm	FC-W
"	"	Cool	FC-C
"	Droughted	Warm	D-W
"	"	Cool	D-C

Ten seeds per pot of Janz wheat were planted on the 23rd October and the pots were watered to field capacity. They were kept in the glasshouse and the water content maintained between 100% and 75% of field capacity using tap water. The pots were re-randomised at each watering, which was done twice weekly. One hundred ml of a complete nutrient mix (Thrive) was added to each pot at 28 DAS (20th November), at the rate of 1 g/L.

At tillering, Z23, 39 DAS (5th December) 10g of Nitrophoska (slow release complete fertiliser mix) was added to each pot.

At anthesis (Z65, 8th January, 77 DAS) the pots were randomly allocated to treatments and moved into temperature cabinets. Pots with more than 8 plants per pot were thinned to the required number. Two temperature cabinets were used, one with day/night temperatures of 19/13 °C (cool) and the other with day/night temperatures of 24/18 °C (warm). The temperatures simulated the average day/night temperatures of the Roseworthy area during October and November, the period of anthesis and grain filling.

The pots were watered every 2-3 days by slowly adding water while the pot was on a tared balance. Moisture in the FC treatments was maintained between 90 and 75 % of FC, while the pots in the droughted treatments were allowed to use water to 40 % of FC and then maintained between 40 and 60 % of FC. This was similar to the

treatments used by Langer and Ampong (1970), Brooks *et al.* (1982) and Randall and Moss (1990). The pots were re-randomised within their temperature cabinets at each watering.

4.2.3 Measurements and Procedures

From the beginning of anthesis each head was tagged with a coloured plastic strip and labelled with the date of anthesis and whether it was a main stem, first tiller, or second or third tiller.

At physiological maturity the heads were individually harvested, and the grains counted and weighed.

EXPERIMENT 2: FIELD EXPERIMENT

4.2.4 Location, Soils and Climate

This experiment took place in 1999 and 2000 on the property of Mr Robin Manley near Avon, South Australia. Climate and soil details of the site are given in the General Methodology chapter.

4.2.5 Experiment Design

4.2.5.1 Experiment 2 – 1999

The experiment was a blocked design replicated 4 times. Each replication contained three treatments (see Table 9).

Table 9: Treatments at Avon 1999

Variety	Water Available
Janz	Rain (open)
	Drought (sheltered)
	Irrigated (sheltered)

An area 20m x 35m was solidly sown to Janz at a rate of 70 kg/ha on the 28th May. Fertiliser (DAP 18:20:0:1 + 2.5% Zinc) at the rate of 20 kg N/ha was placed below the seed, and 10 kg N/ha with the seed.

Blocks 4m wide by 20m long were marked out inside the area with pegs. Three plots per block were marked out, the droughted and irrigated ones side by side (with the irrigated plots on the downhill side) and the rain watered plots at a little distance uphill so they would not be affected by runoff from the rainout shelters when they were in place.

The experiment area was sprayed with Spray.Seed® (paraquat 135 g/L + diquat 115 g/L at 2 L/Ha) on the 1st June as a pre-emergent post-sowing weed kill. The crop was sprayed on the 15th June with Glean (chlorsulfuron 750 g/kg) at 25 mL/ha and Diuron (500 g/L) at 833 mL/ha to control ryegrass, brome grass, wild radish and medic.

The experiment was sprayed with Achieve (Tralkoxydim 400g/kg) at 1.5 L/ha on the 29th July to control brome grass.

On the 23rd August, large amounts of brome grass and barley grass that the sprays did not control were hoed out by hand.

At anthesis, (15th September, 110 DAS, Z65) a rainout shelter was placed over the lower end of each plot (so any run-off from the roof would flow away from the experiment area). The rainout shelters measured 4m wide by 6m long, with one of the shelters extended to 4 x 8m. The roofing material was clear corrugated

polycarbonate, allowing light through, and extending over the sides for approximately 10 cm. The sides were left open and were 1m from the ground to the roof, while the ends were also open with the peak height 2m.

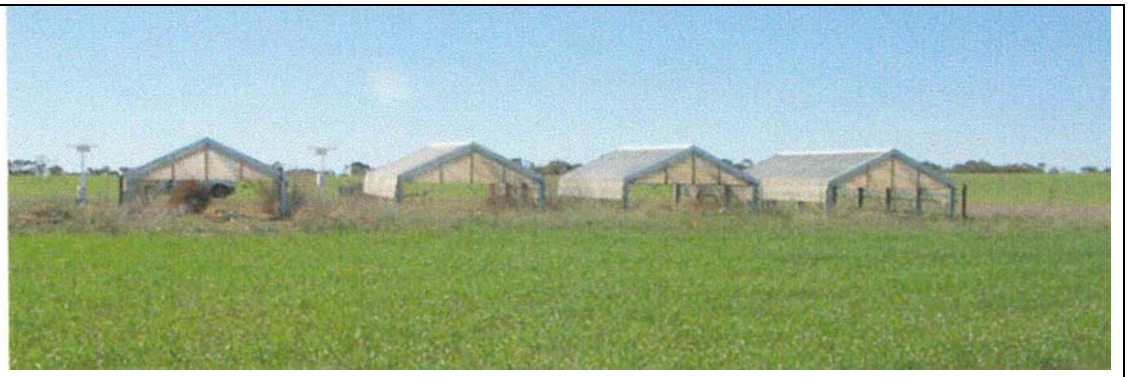

Figure 4: Rain-out shelters used in Experiment 2 at Avon.

Also at anthesis, T-tape irrigation lines were placed through the lower half of each rainout shelter on the irrigated treatments. The tape used was type 510-10-750, which supplied water at the rate of 750 L/hr for every 100m of tape at the optimum pressure of between 50 and 70 kPa. The tape was spaced in approximately 35cm wide rows, following every second row in the crop. This ensured each plant had equal access to the irrigation water. From anthesis onwards, the irrigated plots received water equivalent to that received by the rain-watered plot, as measured by the farm weather station. The water was applied to the plots within 48 hours of a rainfall event. This was to attempt to provide a control in case the atmosphere inside the shelter affected the experiment as well as the lack of water.

Also at anthesis, 30 plants were randomly chosen in each treatment, and tagged with a coloured plastic strip on the main stem, and on a tiller. The plants were randomly located within a 2 m^2 area within each plot, and those inside the rainout shelters were far enough from the sides of the shelters to avoid edge effects. Overall, the tagged plants were evenly distributed within the 2 m^2 area.

Soon after the rainout shelters were in place, problems with birds eating the crop were apparent. The shelters were covered with plastic netting, however it was not possible to make them fully bird-proof. Many heads were partially eaten, and others had the stems broken, affecting the final grain filling process. This affected all the plots inside the shelters. Not all plants were affected, however birds destroyed some tagged heads in the shelters, so others of a corresponding type were found to replace them whenever possible.

The tagged heads were harvested by hand on the 10th November. The plots were also reaped with a KEW harvester.

4.2.5.2 Experiment 2 – 2000

In 2000 the plots were moved to an adjacent area to avoid disease carryover and avoid the brome grass. Due to the shape of the area available, a completely random design was used. The irrigation treatment was not included to expand the area under the drought treatment, as yields the previous year were very low. Further, the irrigation treatment in 1999 showed that the presence of the rain-out shelter (apart from the effect of drought) did not appear to affect the quality of the grain in any other way.

The experiment was sown on the 12th May. An area of land 8m x 45 m was solidly sown to Janz at the rate of 70 kg/ha, while 10 kg N/ha as DAP + 2.5%Zn was placed with the seed and 20 kg N/ha under the seed. Additional N (DAP + 2.5% Zn) was supplied to the crop at 10 kg N/ha at booting (Z43, 95 DAS) on the 15th of September.

The area was sprayed with a mixture of Jaguar (bromoxynil 250 g/L and diflufenican 25 g/L at 500 mL/Ha) and Nugrass (diclofop-methyl 375 g/L at 1 L/Ha) to control ryegrass, barley grass and brome on 31st July (80 DAS).

The rainout shelters were moved over the droughted treatment plots at anthesis on the 28th September. Fifty main stems and 50 tillers in each treatment were tagged at this time, to ensure sufficient grain in case of repeated quality testing.

4.2.6 Measurements and Procedures

4.2.6.1 Experiment 2 - 1999

An emergence count was taken on the 2nd July of six randomly selected areas of 0.25 m^2 each. Six dry matter (DM) cuts of 0.25 m^2 each were taken randomly throughout the area using a quadrat on the 23rd August (Z23, 87 DAS). A dry matter cut was also taken at anthesis in each of the treatments. Thirty heads each of main stems and tillers were tagged on the 1st October (Z69, 126 DAS and 15 DAA).

The tagged heads and the plots were harvested on the 10th November (Z92, 169 DAS & 42 DAA) and stored. The sheltered plots had a buffer zone surrounding them, which protected them from the edge effect of rain runoff. Therefore, the final size of the plots under shelter was only 2 x 1m^2. Not enough grain was collected to do full scale quality testing on the plots.

The main stem and tiller heads were treated as those in section 6.2.3, 1999.

4.2.6.2 Experiment 2 - 2000

A dry matter cut was taken on the 13th July at tillering (Z23, 32 DAS) as detailed for 1999. A dry matter cut was also taken at anthesis (Z65, 136 DAS) on the 27th September as in 1999.

The sheltered tagged heads were collected at maturity (Z93) on the 17th November, 189 DAS and 51 DAA, however the heads in the open plots were unable to be harvested until the 21st November due to rainy weather. The whole plots were harvested with the KEW plot harvester on the 22nd November. Again, however, not enough grain was available from the plots for full scale quality testing.

Birds caused few problems in 2000 as the nests were removed from the shelters weekly.

4.2.7 Statistical Analysis

The greenhouse experiment data were analysed using a 3-way analysis of variance. For the second experiment, data were analysed using a 2-way analysis of variance in both years.

4.3 RESULTS: EXPERIMENT 1

Due to the low yields, quality measurements were unable to be carried out beyond the 1000-grain weight stage, with sufficient grain available only from the main stems and the first tillers.

Table 10 shows the numbers of stems of each type that were present for each of the treatments. Most plants survived, however not all produced tillers. Tiller survival was strongly affected by water availability, and to a lesser extent by temperature.

Table 10: Number of observations made for each treatment in Experiment 1.

Treatment:	Cool Dry	Cool Wet	Hot Dry	Hot Wet
Main Stem	61	64	64	64
Tiller 1	18	36	7	23

The harvest and physical quality results are summarised in Table 11. Overall, the Cool Wet treatment had the highest yield, due to the high 1000-grain weight and highest number of grains per ear. This treatment also had the lowest screenings. The Hot Dry treatment had the lowest yield, and the highest screenings. Tillers had lower yields and higher screenings than main stems for all treatments. The Cool Dry and Hot Wet treatments were similar in results for all parameters measured.

Table 11: Harvest and physical quality results from Experiment 1 .

Stem Type	*Treatment*	Yield (g/ear)	Grains per ear	Screenings %	1000-grain weight
Main Stem	Cool Dry	0.65	15.5	1.0	41.74
	Cool Wet	0.87	20.1	0.7	43.46
	Hot Dry	0.50	14.2	9.8	35.30
	Hot Wet	0.72	18.0	3.6	39.18
Tiller 1	Cool Dry	0.32	10.1	15.0	28.26
	Cool Wet	0.52	14.8	12.8	34.85
	Hot Dry	0.14	4.6	34.3	17.00
	Hot Wet	0.34	11.0	16.6	29.95
lsd (*P=0.05*)	Temperature	0.10	2.6	10.7	3.92
	Water	0.10	2.6	10.7	3.92
	Stem Type	0.10	2.6	10.7	3.92
	Temp *x* Water	0.14	3.7	15.1	5.54
	Temp *x* Stem	0.14	3.7	15.1	5.54
	Water *x* Stem	0.14	3.7	15.1	5.54
	Temp *x* Water *x* Stem	0.20	5.2	21.3	7.83

4.3.1 Harvest

The yields (grams per ear) were low, however there were still significant differences apparent between stem types (*P<0.001*), temperature treatments (*P=0.002*) and water availability (*P<0.001*). No interactions were present. Main stems (mean yield 0.68 g/ear) yielded higher than tillers (mean yield 0.33 g/ear), cool temperature treatments (mean yield 0.59 g/ear) yielded higher than high temperature treatments (mean yield 0.43 g/ear) and high water availability treatments (mean yield 0.61 g/ear) yielded higher than droughted treatments (mean yield 0.40 g/ear).

The numbers of grains per head results were also low, but ranked as expected, with main stems having higher numbers of grains (mean 16.9) than tillers (mean 10.1,

P<0.001), cool treatments having higher numbers of grains (mean 15.1) than the warm treatments (mean 11.9, *P=0.017*) and wet treatments higher numbers of grains (mean 16.0) than dry treatments (mean 11.1, *P<0.001*).

There was a large significant difference (*P=0.004*) apparent between main stem screenings (mean 3.8 %) and first tiller screenings (mean 19.7 %). Temperature and water availability did not affect screenings percentage in this experiment.

4.3.2 Physical Quality

There were independent significant effects of stem type (*P<0.001*), temperature (*P=0.001*) and water availability (*P=0.002*) on 1000-grain weight in the experiment. Main stems had higher 1000-grain weights (mean 39.9) than first tillers (mean 27.5), cooler temperatures produced higher 1000-grain weights (mean 37.1) than warm temperatures (mean 30.4), and wet conditions produced higher 1000-grain weights (mean 36.9) than dry conditions (mean 30.6).

4.4 RESULTS: EXPERIMENT 2

In 1999, results showed that both water availability and stem type had a strong main effect on yield and the yield components grains per ear and 1000-grain weight. Water availability and stem type interacted to affect screenings percentage. Protein was affected by water availability, but stem type and the interaction were not significant at the *P=0.05* level.

In 2000, yield, grains per ear and screenings percentage were affected by a water availability x stem type interaction, protein was only affected by water availability and 1000-grain weights were only significantly affected by stem type.

Table 12 and Table 13 show the summarised results of the harvest and preliminary quality data from 1999 and 2000 respectively.

Table 12: Harvest and physical quality results from Experiment 2 at Avon, 1999.

Year	Stem Type	Treatment	Yield (g/ear)	Grains per ear	Screenings %	Protein %	1000-grain weight
1999	Main Stem	Rain	1.00	31.5	7.0	14.3	32.2
		Droughted	0.59	23.9	19.9	14.0	24.9
		Irrigated	0.74	23.3	8.9	12.9	32.7
	Tiller	Rain	0.42	16.1	7.7	14.2	26.2
		Droughted	0.28	13.2	35.2	15.1	21.1
		Irrigated	0.33	11.0	5.2	13.1	29.7
lsd (*P=0.05)*		Stem Type	0.09	2.9	4.0	0.4	1.8
		Water	0.11	3.6	4.9	0.5	2.3
		Stem Type *x* Water	0.16	5.1	6.9	0.7	3.2

Table 13: Harvest and physical quality results from Experiment 2 at Avon, 2000.

Year	Stem Type	Treatment	Yield (g/ear)	Grains per ear	Screenings %	Protein %	1000-grain weight
2000	Main Stem	Rain	1.09	43.1	30.7	10.5	25.5
		Droughted	1.20	48.5	38.4	10.8	25.2
	Tiller	Rain	0.58	24.6	28.4	10.5	23.4
		Droughted	0.50	25.4	59.9	11.8	20.2
lsd *(P=0.05)*		Stem Type	0.05	1.9	11.3	0.7	1.8
		Water	0.05	1.9	11.3	0.7	1.8
		Stem Type *x* Water	0.06	2.8	16.0	1.0	2.5

4.4.1 Harvest

4.4.1.1 Yield (g/ear)

The results of the measure of yield per ear in 1999 showed significant main effects (*P<0.001*) of stem type and water availability. Main stems produced a mean yield of 0.78 g per ear, almost twice the amount that tillers (0.34 g/ear) did, while the rain fed control plots had higher yields per ear (0.71 g) than either the droughted (0.43 g/ear) or the irrigated (0.53 g/ear) plots.

In 2000, there was a significant interaction between water availability and stem type (*P=0.001*). Droughted main stem ears yielded highest (1.20 g/ear), followed by rain-fed main stem ears (1.10 g/ear). Rain fed tiller ears (0.58 g/ear) yielded lower than all main stems but higher than droughted tiller ears (0.50 g/ear), which yielded lowest. Over the 2 years of the experiment, the interaction of stem type and water availability was significant in 1999 and close to significant in 2000. Stem type was significant in both years.

4.4.1.2 Grains per ear

The results of the measure of grains per ear in 1999 showed significant main effects of stem type (*P<0.001*) and water availability (*P=0.003*), but no significant interaction. Main stems produced more grains per ear (mean 26.2) than tillers (mean 13.4), and the rain-fed treatment produced more grains per ear (mean 23.8) than either the irrigated (mean 17.1) or droughted (mean 18.5) treatments.

In 2000, there was a significant interaction between stem type and water availability (*P=0.029*). Droughted main stems produced the highest number of grains per ear (mean 48.46), followed by rain fed main stems (mean 43.14). Tillers of both water regimes were not significantly different from each other but had significantly lower grains per ear than the main stems (mean figures 24.55 and 25.41 grains per ear for rain fed tillers and droughted tillers respectively).

Both stem type and water availability significantly affected the number of grains per head in both years, however the interaction was only significant in 2000.

4.4.1.3 Screenings (%)

In 1999, there was a significant interaction of stem type and water availability (*P=0.002*) affecting screenings %. The droughted tillers had significantly higher screenings (mean 35.15 %) than droughted main stems (mean 19.87 %), which were also significantly higher than all other treatments. All the other treatments were not significantly different from each other, averaging 7.2 % screenings.

In 2000, there was also a significant interaction of stem type and water availability (*P=0.041*). Screenings were significantly higher in the droughted tiller heads (mean 59.9 %) than in any other treatment.

There was a significant interaction of water availability and stem type present in both years.

4.4.1.4 Protein content (%)

In 1999 protein levels showed a significant main effect of water availability (*P<0.001*), with the interaction close to significance at *P = 0.075*. The irrigated treatment had significantly lower protein levels (mean 13.02%) than the rain-fed (mean 14.22) or droughted (mean 14.56 %) treatments.

Protein levels in 2000 showed a significant main effect of water availability (*P=0.043*), with droughted grain averaging 11.29 % protein compared to rain fed grain at 10.53 %.

Water availability significantly affected protein levels in both years of the experiment, possibly interacting with stem type in 1999 and as a main effect in 2000.

4.4.2 Physical Quality

4.4.2.1 1000-grain weight

In 1999 there were significant main effects of stem type (*P<0.001*) and water availability (*P<0.001*) on 1000-grain weights. Main stems produced significantly higher 1000-grain weights (mean 29.92) than tillers (mean 25.63), and the rain-fed (mean 29.15) and irrigated (mean 31.18) treatments produced significantly higher 1000-grain weights than the droughted treatment (mean 23.01).

In 2000, there was a significant main effect of stem type (*P=0.001)*, while water availability was almost significant (*P=0.056*). Main stems (mean 25.38) had significantly higher 1000-grain weights than tillers (mean 21.77). The rain-fed treatment had slightly higher 1000-grain weights (mean 24.44) than the droughted treatment (mean 22.71).

Overall, stem type had a significant main effect in both years while water availability was significant in 1999 and close to significant in 2000. There was no significant interaction in both years.

4.4.3 Milling and Flour Quality

Quadrumat flour yield was not significantly affected in either year. All Minolta colour parameters were significantly affected by a stem type x water availability interaction in 1999, and by water availability in 2000. Conversely, in 1999, all 2g-mixograph measurements were affected by water availability alone, while in 2000 they were affected by the water availability *x* stem type interaction.

4.4.3.1 Flour yield (%)

Flour yield showed no significant differences between treatments in both years.

4.4.3.2 Flour colour

In 1999 there were significant differences between treatments affecting all the measured components of flour colour (L, a, b and L-b).

“L” flour colour showed a significant interaction of stem type and water availability, with brightness higher for droughted main stems. There were significant differences between droughted main stems and tillers, and between droughted and irrigated main stems (see Table 14).

Table 14: Mean "L" Minolta flour colour Experiment 2, 1999.

Stem Type	Water Availability		
	Rain (Control)	Droughted	Irrigated
Main Stems	90.43^{AB}	90.68^{A}	90.20^{B}
Tillers	90.31^{B}	90.27^{B}	90.52^{AB}

LSD *(P=0.05)*		
Stem Type	n.s.	*(P = 0.488)*
Water	n.s.	*(P = 0.559)*
Water x Stem Type	0.36	*(P = 0.022)*

The "a" flour colour in 1999 also showed a significant interaction of stem type and water availability (Table 15). Irrigated main stems had significantly higher "a" values (more green flour) than all other treatments except droughted tillers.

Table 15: Mean "a" Minolta flour colour Experiment 2, 1999.

Stem Type	Water Availability		
	Rain (Control)	Droughted	Irrigated
Main Stems	0.003^{B}	-0.037^{B}	0.138^{A}
Tillers	0.015^{B}	0.058^{AB}	0.018^{B}

LSD *(P=0.05)*		
Stem Type	n.s.	*(P = 0.882)*
Water	n.s.	*(P = 0.099)*
Water x Stem Type	0.109	*(P = 0.020)*

The flour "b" values in 1999 showed a similar significant interaction of stem type and water availability (Table 16). There were significant differences apparent between irrigated main stems and irrigated tillers. Rain-fed main stems were

significantly different (less yellow) to both droughted and irrigated main stems, while irrigated tillers were significantly lower in value (less yellow) than all other treatments except rain-fed main stems.

Table 16: Mean "b" Minolta flour colour Experiment 2, 1999.

Stem Type	Water Availability		
	Rain (Control)	Droughted	Irrigated
Main Stems	9.25^{BC}	9.69^{A}	9.65^{A}
Tillers	9.34^{AB}	9.63^{AB}	8.96^{C}

LSD *(P=0.05)*		
Stem Type	0.22	*(P = 0.048)*
Water	0.27	*(P = 0.016)*
Water x Stem Type	0.38	*(P = 0.017)*

In 1999 flour "L-b" values also showed the significant stem type and water availability interaction (Table 17). Irrigated main stems and tillers were significantly different to each other, as were droughted and irrigated tillers, but other treatments were not significantly different.

Table 17: Mean "L-b" Minolta flour colour Experiment 2, 1999.

Stem Type	Water Availability		
	Rain (Control)	Droughted	Irrigated
Main Stems	81.17^{AB}	80.99^{AB}	80.55^{B}
Tillers	80.97^{AB}	80.64^{B}	81.56^{A}

LSD *(P=0.05)*		
Stem Type	n.s.	*(P = 0.405)*
Water	n.s.	*(P = 0.442)*
Water x Stem Type	0.65	*(P = 0.012)*

In 2000, water availability significantly affected all flour colour parameters measured.

"L" flour colour was significantly higher (hence brighter) in the rain-fed control treatment than in the droughted treatment (Table 18).

Table 18: Mean "L" Minolta flour colour Experiment 2, 2000.

Water Availability	
Rain (Control)	Droughted
90.35^{A}	89.35^{B}

LSD *(P=0.05)*		
Stem Type	n.s.	*(P = 0.266)*
Water	0.73	*(P = 0.013)*
Water x Stem Type	n.s.	*(P = 0.376)*

The "a" values for 2000 showed a significant difference between the rain-fed treatment (more red) and the droughted treatment (more green) (Table 19).

Table 19: Mean "a" Minolta flour colour Experiment 2, 2000.

	Water Availability	
	Rain (Control)	Droughted
	-0.26[A]	0.20[B]

LSD *(P=0.05)*		
Stem Type	n.s.	*(P = 0.547)*
Water	0.26	*(P = 0.003)*
Water x Stem Type	n.s.	*(P = 0.758)*

Flour "b" values in 2000 also showed a significant main effect of water availability (Table 20). Droughted grains had flour of higher "b" values (more yellow) than the rain-fed grains.

Table 20: Mean "b" Minolta flour colour Experiment 2, 2000.

	Water Availability	
	Rain (Control)	Droughted
	11.02[A]	11.46[B]

LSD *(P=0.05)*		
Stem Type	n.s.	*(P = 0.117)*
Water	0.18	*(P < 0.001)*
Water x Stem Type	n.s.	*(P = 0.396)*

"L-b" values in 2000 also showed a significant main effect of water availability (Table 21). The rain-fed treatment had significantly higher "L-b" values than the droughted treatment.

Table 21: Mean "L-b" Minolta flour colour Experiment 2, 2000.

	Water Availability	
	Rain (Control)	Droughted
	79.33[A]	77.88[B]

LSD *(P=0.05)*		
Stem Type	n.s.	*(P = 0.202)*
Water	0.86	*(P = 0.004)*
Water x Stem Type	n.s.	*(P = 0.560)*

Overall, water availability was a significant common factor affecting all the flour colour parameters in both years, interacting with stem type in 1999, and as a main effect in 2000.

4.4.4 Dough Quality – 2-gram Mixograph

Water availability affected mix times in both years of the experiment, as a main effect in 1999 and interacting with stem type in 2000. It also had a significant main effect on peak resistance in both years of the experiment. There was a significant interaction of water availability and stem type affecting maximum bandwidth in both years of the experiment.

Water availability significantly affected resistance breakdown in both years of the experiment, as a main effect in 1999 and interacting with stem type in 2000. Bandwidth breakdown was significantly affected by water availability in both years. Stem type had a significant main effect in 2000 but not 1999.

4.4.4.1 Mix time (s)

There was a significant main effect of water availability on mix time in 1999 (Table 22). The droughted treatment had the longest mix time, followed by the rain-fed treatment, and then the irrigated treatment. All treatments were significantly different from each other.

Table 22: Mean mix time (s) Experiment 2, 1999.

	Water Availability		
	Rain (Control)	Droughted	Irrigated
	172.3^{B}	199.4^{A}	159.8^{C}

LSD *(P=0.05)*		
Stem Type	n.s.	*(P = 0.089)*
Water	8.4	*(P < 0.001)*
Water x Stem Type	n.s.	*(P = 0.289)*

In 2000 there was a significant interaction of water availability and stem type (Table 23). Main stems had lower mix times than tillers, with the rain-fed treatment having the lowest mix time. Both the droughted treatments had higher mix times than the rain-fed treatments, with the droughted tillers having the highest mix times overall.

Table 23: Mean mix time (s) Experiment 2, 2000.

Stem Type	Water Availability	
	Rain (Control)	Droughted
Main Stems	133.1^{C}	143.1^{B}
Tillers	145.9^{B}	171.1^{A}

LSD *(P=0.05)*		
Stem Type	5.3	*(P < 0.001)*
Water	5.3	*(P < 0.001)*
Water x Stem Type	7.5	*(P = 0.007)*

4.4.4.2 Peak Resistance (MU)

Peak resistance showed a significant main effect of water availability in 1999 (Table 24). All treatments were significantly different from each other, with the droughted treatment having the highest resistance and the irrigated treatment the lowest.

Table 24: Peak Resistance (MU) in Experiment 2, 1999.

Water Availability		
Rain (Control)	Droughted	Irrigated
401.4^{B}	421.2^{A}	369.1^{C}

LSD *(P=0.05)*		
Stem Type	n.s.	*(P = 0.533)*
Water	14.9	*(P < 0.001)*
Water x Stem Type	n.s.	*(P = 0.720)*

In 2000, there was a significant interaction of water availability and stem type (Table 25). Droughted main stems were significantly different to all other treatments, with low peak resistance.

Table 25: Peak Resistance (MU) in Experiment 2, 2000.

Stem Type	Water Availability	
	Rain (Control)	Droughted
Main Stems	348.9[A]	313.8[B]
Tillers	335.6[A]	338.6[A]

LSD *(P=0.05)*		
Stem Type	n.s.	*(P = 0.224)*
Water	9.6	*(P = 0.002)*
Water x Stem Type	13.6	*(P < 0.001)*

4.4.4.3 Maximum bandwidth (MU)

In 1999 there was a significant interaction of water availability and stem type (Table 26). The irrigated treatment was significantly different to both the other treatments in the experiment, and irrigated main stems were significantly different to irrigated tillers.

Table 26: Mean maximum bandwidth Experiment 2, 1999.

Stem Type	Water Availability		
	Rain (Control)	Droughted	Irrigated
Main Stems	259.3^{A}	257.8^{A}	227.3^{C}
Tillers	252^{A}	261.4^{A}	237.5^{B}

LSD *(P=0.05)*		
Stem Type	n.s.	*(P = 0.437)*
Water	7.0	*(P < 0.001)*
Water x Stem Type	9.9	*(P = 0.048)*

The results in 2000 showed another significant interaction of water availability and stem type (Table 27). Droughted main stems were significantly different from all other treatments. Droughted and rain-fed tillers were significantly different from each other, but not from rain-fed main stems.

Table 27: Mean maximum bandwidth Experiment 2, 2000.

Stem Type	Water Availability	
	Rain (Control)	Droughted
Main Stems	205.8^{AB}	186.3^{C}
Tillers	203.1^{B}	213.4^{A}

LSD *(P=0.05)*		
Stem Type	6.1	*(P < 0.001)*
Water	n.s.	*(P = 0.129)*
Water x Stem Type	8.6	*(P < 0.001)*

4.4.4.4 Resistance Breakdown (%)

In 1999 there was a significant main effect of water availability on resistance breakdown (Table 28). The irrigated treatment had higher breakdown percentage than both the rain-fed and droughted treatments.

Table 28: Resistance breakdown Experiment 2, 1999.

	Water Availability		
	Rain (Control)	Droughted	Irrigated
	17.3[B]	17.7[B]	19.1[A]

LSD *(P=0.05)*		
Stem Type	n.s.	*(P = 0.884)*
Water	1.4	*(P = 0.031)*
Water x Stem Type	n.s.	*(P = 0.903)*

In 2000, there was a significant interaction of water availability and stem type affecting resistance breakdown (Table 29). Main stems had greater resistance breakdown than tillers for both water availabilities, but droughted tillers had the lowest percentage breakdown. The droughted treatments had lower resistance breakdown values than the rain-fed treatments for both main stems and tillers.

Table 29: Resistance breakdown Experiment 2, 2000.

Stem Type	Water Availability	
	Rain (Control)	Droughted
Main Stems	23.9^{A}	21.8^{B}
Tillers	21.0^{B}	16.0^{C}

LSD *(P=0.05)*		
Stem Type	0.7	*(P < 0.001)*
Water	0.7	*(P < 0.001)*
Water x Stem Type	1.0	*(P < 0.001)*

4.4.4.5 Bandwidth breakdown (%)

There was a significant main effect of water availability in 1999 (Table 30). The droughted treatment was significantly different to both the rain-fed and irrigated treatments, with a higher bandwidth breakdown percentage.

Table 30: Bandwidth breakdown Experiment 2, 1999.

Water Availability		
Rain (Control)	Droughted	Irrigated
46.7^{B}	52.8^{A}	43.4^{B}

LSD *(P=0.05)*		
Stem Type	n.s.	*(P = 0.355)*
Water	5.9	*(P = 0.008)*
Water x Stem Type	n.s.	*(P = 0.148)*

In 2000, there were significant main effects of water availability and stem type on bandwidth breakdown (Table 31). Main stems had greater bandwidth breakdown

than tillers, and rain-fed treatments greater bandwidth breakdown than droughted ones.

Table 31: Bandwidth breakdown Experiment 2, 2000.

Stem Type	
Main Stems	Tillers
43. 6[A]	39.7[B]

Water Availability	
Rain (Control)	Droughted
45.1[A]	38.1[B]

LSD *(P=0.05)*		
Stem Type	2.3	*(P = 0.002)*
Water	2.3	*(P < 0.001)*
Water x Stem Type	n.s.	*(P = 0.319)*

4.5 DISCUSSION

4.5.1 Harvest

In Experiment 1, dough quality measurements could not be carried out on the material due to the low amount of grain obtained. The only quality measurements which were collected were those for yield parameters, screenings and 1000-grain weights.

Similar experiments by Langer and Ampong (1970), Davidson and Birch (1978), Brooks *et al.* (1982), Nicolas *et al.* (1985) and Randall and Moss (1990) resulted in production of up to 4 tillers per plant, with about 1 gram of grain per head. The low yields in this experiment may have been caused by a nutrient deficiency, or by localised waterlogging in the sealed pots.

There were significant differences between main stems and tillers, cool and hot treatments and droughted and wet treatments. This agreed with work by Davidson and Birch (1978) when comparing two wheat varieties stressed by heat and drought, and with the results of Randall and Moss (1990) in a glasshouse experiment using similar conditions.

In Experiment 2, (in the field), 1999, the yields although low (1999 was a low rainfall year) were much as expected, with lower yields for the droughted treatments and higher for those with irrigation and rainfall. The longer filling times available for the rain-fed treatment, combined with larger amounts of substrate produced by the plant in this period, allowed both higher numbers of grains, and heavier grains. However, in 2000, higher yields were obtained for the droughted treatment than for the rain-fed one. The increased yield in the droughted treatment was due primarily to

the higher numbers of grains per ear, as seen in Table 13. Frosty conditions were apparent at the time of anthesis in this area, and it is known that frost can severely affect yield by reducing seed set in the ear. It is possible that this was the case in 2000. In support of this, the flour colour Minolta "a" readings from 2000 showed that flour from the rain-fed treatments tended to show slightly greener readings, whereas the droughted treatments showed the more usual reddish reflectance.

Protein levels decreased with increasing water availability, as expected. When the probable effects of frost are taken into account, this experiment agrees with previous experiments such as those by Barlow *et al* (1980).

Yield differences between droughted and wet treatments can easily be explained by the well known facts that substrate production is dependent on water supply, and when this is withdrawn smaller grains, and less grains, are the result (Sofield *et al.*, 1977(a); Singh and Jenner, 1982). This is further apparent in the experiment results for the numbers and sizes of grains.

Also well known is the fact that hot conditions speed the rate at which grains mature, but also shorten the time in which they can store starch and protein, usually resulting in higher protein but lower yields of grain and lower 1000-grain weights (Sofield *et al.*, 1977(b); Correll *et al.*, 1994; Wardlaw and Moncur, 1995). This was confirmed by Experiment 1, as yields from the hot treatments were lower and had lower 1000-grain weights than yields from the cool treatments. Similar results were obtained by Wardlaw (1994) and Tashiro & Wardlaw (1990). An experiment by Panozzo *et al* (1999) in which actual ear temperatures were compared to ambient temperatures in the field showed considerable differences between the two measurements. However, this should not have been a problem in the growth cabinet.

The results from the increased temperature in Experiment 1 differ from the type of response that occurs when wheat is exposed to a “heat shock” – a brief period (several days) of high temperatures (daily maxima > 35 °C) - during grain filling. This type of shock may cause changes in the types of proteins produced and hence impact on grain quality (Blumenthal *et al.*, 1994; Stone and Nicolas, 1995, 1996).

The main stems in Experiment 2 had higher yields than the first tillers, as expected, since the main stem both reaches anthesis earlier and is better supplied with water and nutrients. Experiments by Panozzo and Eagles (1998) showed that rates of grain filling and nitrogen accumulation in wheat were strongly affected by increased temperatures and water stress, and that this translated into lower yields where both those factors were present. The results of Experiment 1 agree with this, however, the experiment by Panozzo and Eagles did not investigate any differences between the main stems and tillers. Work by Sarvestani (1995) also investigated water stress and nitrogen relations in wheat, but only looked at the effects on the main stem. It is common in these types of experiments for researchers to focus on single stems, with all others removed. This causes a different scenario from that of a field situation, when tillers are an important factor in the growth and yield of the crop.

Numbers of seeds were higher on the main stems than on the first tillers in both parts of Experiment 2. This agrees with other experiments both in pots and in the field (Sims and Aitken, 1979).

Screenings also followed the expected pattern, with main stems having a much lower percentage of screenings than first tillers.

4.5.2 Physical Quality

In the greenhouse experiment, 1000-grain weights were highest on the main stems, as expected from the work of Sims and Aitken (1979). Wet conditions also allowed larger grains, as the plant could produce more substrate for a longer period of time. Cooler temperatures produced larger grains, as the rate at which the plants senesced was slower, again allowing higher substrate production.

In the field, 1000-grain weights were low for both rain fed and droughted treatments, in both years. This is due to the effects of the low rainfall site, and also because the variety Janz has a tendency towards lower grain weights in these conditions (Reimers *et al.*, 1999). It is of concern to growers that Janz produces small grain size in low rainfall conditions, as Janz is the most widely grown and accepted Prime Hard and Hard quality wheat.

4.5.3 Milling and Flour Quality

Flour yield was unaffected by the treatments. This agrees with the work of Marshall *et al.* (1986), who found that flour yield was not affected by seed size or test weight. However, it contrasts with the work of Oliver *et al.* (1996), who when investigating the potential of Prime Hard wheat in non-traditional areas of New South Wales found that small seed size and low test weight was associated with lower flour yields.

Flour colour was affected by water availability in all 4 components (L, a, b and L-b) in both years. In 1999, this occurred in interaction with stem type, however in 2000, stem type did not affect colour.

Decreased water availability increased the measure of colour for Minolta “a” (+ is green, - is red) and Minolta “b” (yellowness). Minolta “L” values were not consistent

in their response. Seasonal variation may play more of a part here, for example frosted grain tends to have a more green colour than ordinary grain.

The Minolta “a” and “b” responses show that in droughted grain, there is more likely to be yellower flour. The green/red reflectance values are low, close to zero, and are unlikely to cause any quality changes. However the yellowness of the flour is already a serious issue in some varieties, and market demand is for very white flour for bread. Increased yellowness of flour due to drought conditions could cause marketing problems in some years. This is an issue of which breeders need to be aware, and select for colour stable varieties that do not change when stressed. If the higher yellow colour in droughted grain is due to greater amounts of xanthopyll or carotenoid compounds in the protein matrix surrounding the starch granules, then better milling techniques will not remove this. With expanding markets for yellow noodles, it is possible that high protein grain from droughted areas, which are likely to have more yellow flour, could be diverted into a high protein noodle wheat pool with no loss of payments.

4.5.4 Dough Quality

Dough quality tests over the whole experiment showed that stem type and water availability either had no effect, or an inconsistent effect, showing one result in 1999 but a different one in 2000. An exception was the mixing time, where droughted treatments consistently showed longer mixing times than rain-fed treatments. This is probably related to the higher protein percentage of the droughted treatments. Peak resistance, while performing as expected in 1999 with higher resistance in the droughted treatments, showed an unexpected result in 2000 when droughted main stems had much lower peak resistance than all other treatments.

It is likely that generally, dough mixing properties are resistant to change due to stress as seen in Experiment 2, apart from the effects of changing protein levels or extreme stress events such as heat shock, and possibly frost. Little research appears to have been done on the effects of cold damage on wheat quality in Australia, as heat shock damage is much more common. Yield losses due to frost are well known; however changes in quality of grain exposed to severe cold events could also occur.

Water availability was the most common factor affecting quality parameters. 1000-grain weight, flour colour and mix time were most consistently affected. This is in accord with results from the literature (Davidson and Birch, 1978; Randall and Moss, 1990). Stem type however was also seen to affect these quality parameters, either as a main effect or interacting with water availability. The effects of stem type on 1000-grain weights have been documented by Turner *et al.* (1994), but the implications of stem type for flour colour, or for any dough quality parameters, have not been assessed. To examine whether stem type has an effect on the end-product quality of wheat grown in the field, further experimentation with differing crop densities was undertaken.

CHAPTER 5 EXPERIMENT 3: EFFECT OF CROP DENSITY ON THE GROWTH AND QUALITY OF WHEAT.

5.1 INTRODUCTION

Previous experiments examining environmental effects on wheat quality in either the field or laboratory have tended to focus on either all the harvested grain, or grain from single heads of wheat, where the plant has been kept to a single stem throughout it's growth. As the tillers of the wheat plant are highly sensitive to environmental and/or management conditions (Williams and Langer, 1975; Anderson, 1986; Palta and Fillery, 1995(a), 1995(b)), it is possible that stress at grain filling affects tillers more than main heads, or in different ways (Turner *et al.*, 1994). Although many experiments have analysed the physiology of tiller growth, very few have gone on to test the quality of the grain produced.

Increased planting density (a recent trend in South Australian agriculture) changes the environmental stresses placed on the wheat crop, and also changes the proportions of main stems to tillers within the crop. Work by Turner *et al.* (1994) showed that changes in crop density resulted in differences in yield and 1000-grain weight between different densities. However, dough or baking qualities were not investigated.

The purpose of Experiment 3 was to examine the hypothesis that changes in seed rate, and therefore changes in plant density, would result in differences in the growth of the plants and the quality of the grain produced. It was expected that as plant

density increased, these changes would include a decrease in the ratio of tillers to main stems, increases in dry matter weights and higher yields at higher densities.

5.2 MATERIALS AND METHODS

5.2.1 Location, Soil & Climate

This experiment was carried out at the University of Adelaide's Roseworthy Agricultural Campus, South Australia. The area has a Mediterranean climate, with cool wet winters and hot dry summers. (For site details, see General Methods and Information.)

The experiment was carried out over 3 years, however minor changes were made in each year due to changes in the site area, availability of materials and the previous year's results.

5.2.2 Experiment Design

5.2.2.1 Experiment 3 - 1998

The experiment was set out as a randomised complete block design (RCBD), with 2 varieties and 5 seeding rates. The varieties were Janz (a Queensland bred Prime Hard Quality wheat with a tendency towards small grain size in SA conditions) and Kukri (a recent release SA bred Prime Hard quality wheat with high protein potential and larger grain size). The seeding rates were designed to give plant densities of 65, 190, 260, 320 and 450 plants per square metre when different grain sizes and germination percentages were taken into account (see Table 32). When "seed rate" is referred to in this document it means viable (germinable) seeds per m^2.

The experiment was replicated 4 times. The seeding rates were chosen to represent low, district average, and high rates.

The seed was treated with Vincit® pickle (cypermethrin 4g/L + flutriafol 25 g/L) to prevent fungal disease affecting the plant in the early stages.

Table 32: Treatments in Experiment 3 - 1998

Variety	Seed Rate (viable seeds/m^2)				
Janz	65	190	260	320	450
Kukri	65	190	260	320	450

The crop was sown on May 25th 1998 with a cone seeder, and 50 kg/ha triple superphosphate + 5% Zinc (0:19:0 + 5%Zn) was banded below the seed. The fertiliser was placed at a depth of 8 cm below the surface first, and the seed sown over the top at a depth of 3 cm. Press wheels were used to ensure good soil-seed contact. Plots were 28 m long and 1.45 m wide. The area was sprayed the next day with Treflan® (trifluralin 400 g/L at 1.5 L/Ha) and rolled to incorporate the herbicide.

Nitrogen was supplied as ammonium nitrate (NH_4NO_3), at the rate of 30 kg N/ha, 32 days after sowing (DAS) and at growth stage Z21 (Zadok's growth scale, as quoted in (Perry and Belford, 1991)) on the 26th of June. The nitrogen was broadcast by hand to minimise disturbance to the crop.

The plots were sprayed with Broadstrike® (flumetsulan 800g/kg at 1 L/Ha) on the 7th August to control broad-leaved weeds including nettle (*Urtica urens*), medic (*Medicago spp.*), field peas (*Pisum sativum*), 3-corner-Jack (*Emex australis*), Indian hedge mustard (*Sisymbrium orientale*), capeweed (*Arctotheca calendula*), soursob

(*Oxalis pes-caprae*), wild turnip (*Brassica tournefortii*) and cleavers (*Galium tricornutum*).

A further 30 kg N/ha (NH_4NO_3) was applied to the plot on the 26th August (Z23 - Z24), 93 DAS, and an additional 30 kg N/ha was supplied at anthesis (Z65, 30th September) 128 DAS to ensure a high protein crop.

The crop was harvested at maturity (Z93, 184 DAS and 56 DAA) with a KEW plot harvester on the 25th November.

5.2.2.2 Experiment 3 – 1999

The experiment was also set out as a RCBD, however only one variety (Kukri) was used to more fully investigate the results of the previous year. Kukri was used as it had previously shown greater variation in response to the previous year's treatments. Six seeding rates were used (see Table 33) to more closely investigate the variation in seed size that was apparent from the 1998 results. A new site was used close to the previous location so that diseases from last year's wheat would not be a problem. The soil type and situation of the plots was similar, and the crop grown on that area in 1998 was oats. Buffer plots were sown either side of the area to protect the experimental plots from edge effects.

Table 33: Treatments in Experiment 3 - 1999

Variety	Seed Rate (viable seeds/m^2)					
Kukri	260	280	300	320	350	380

As the 28m plots the previous year had supplied more than enough grain for testing, it was decided to use shorter plots and increase replication. Therefore plot length was

12 m, with the same width of 1.45m. The experiment was replicated 5 times (RCBD).

The experiment was sown on the 17th June 1999 using the same cone seeder as the previous year. The experiment was sown later due to rain and wet soil conditions in late May. Di-ammonium phosphate (DAP) + 5%Zn (18:20:0:1 + 5% Zn) at the rate of 20 kg N/ha was placed 5cm below the seed, and 20 kg N/ha (DAP) with the seed at sowing.

At booting (Z43) 30 kg N/ha (DAP) was applied to the crop to boost protein levels. At maturity plots were trimmed to 10 m in length and the grain was harvested and treated as in 1998.

5.2.2.3 Experiment 3 – 2000

In 2000 the experiment returned to the 2 varieties – 5 seeding rates format (Table 34). To better examine the changes in quality as plant density was varied, the plant densities used were similar to 1998. Slightly longer plots of 15 m were used, and the experiment was replicated 5 times. A buffer to eliminate edge effects surrounded the experiment.

Table 34: Treatments used in 2000.

Variety	Seed Rate (viable seeds/m^2)				
Janz	230	260	290	320	350
Kukri	230	260	290	320	350

The experiment was sown on 19th May. DAP + 5% Zn (18:20:0:1 + 5% Zn) was placed 5cm below the seed at the rate of 20kg N/ha and 20kg N/ha (DAP) with the seed at sowing, as per the previous year.

The plots were sprayed with Broadstrike® at the recommended rate to control broadleaved weeds on the 3rd July.

30 kg N/ha was applied to the crop at booting (Z43) to boost protein levels.

The plots were harvested on December 2nd.

5.2.3 Measurements

5.2.3.1 Experiment 3 - 1998

An emergence count to establish the actual crop density was conducted 13 DAS on the 11th of June, using a 0.25m^2 quadrat placed randomly 10 times inside the plot and counting all plants. The results were averaged and converted to plants per square metre.

Dry matter cuts were taken at tillering (Z23, 84 & 85 DAS) on the 17th and 18th August. Two cuts of 0.25 m^2 each, using a quadrat, were taken per plot. The plant material was dried at 80 °C for at least 48 hours and then weighed. At anthesis (Z65, 122 DAS) on the 24th September, the plants were not cut but pulled from the ground with the roots, to enable the identification of main stems and tillers. Again 2 quadrats each of 0.25m^2 were taken from each plot. The plants were separated, the main stems, tillers, main stem heads and tiller heads were counted and then the roots were removed and the remaining material dried and weighed as per the previous dry matter measurement. As the samples were large, they were confined in fine netting to dry to allow better ventilation.

Also at anthesis, 25 heads on main stems and 25 heads on tillers were tagged in each plot with different coloured plastic strips so that they could be readily identified for hand harvest. (See Chapter 6 for details.)

The tagged heads were hand harvested on the 20th November (Z92, 179 DAS and 27 days after anthesis (DAA)).

The plots were trimmed to 22 m in length on the 23rd November and harvested with a KEW plot harvester on the 25th November. The grain was not screened at harvest. After harvest, the grain was weighed and cleaned with a Kamas Westrup seed cleaner. Grain with a diameter of less than 2 mm was screened out and the clean grain, screenings and chaff were weighed. Fifty gram sub-samples of the cleaned grain were taken, and a 2 kg sample stored in a cool-room at 4 °C until sent to Wagga Wagga (NSW) for full grain quality testing.

At the Grain Quality Laboratory at Wagga Wagga the grain was tested for test weight, 1000-grain weight, hardness, moisture, protein, flour extraction, flour colour, farinograph and extensograph, RVA (rapid viscosity analysis), baking (loaf) score and loaf colour. The methods used were those outlined in General Methodology .

5.2.3.2 Experiment 3 – 1999

Dry matter cuts were taken as per the previous year at tillering (Z23, 87 DAS) and anthesis (Z65, 106 DAS). Plant densities were obtained from the anthesis pull data. Thirty main stem and tiller heads per plot were tagged at random at anthesis for hand harvest. The extra number allowed for a few tags being lost.

The grain was harvested and treated as in 1998.

5.2.3.3 Experiment 3 - 2000

A dry matter cut was taken in the same way as previous years at tillering (Z23, 89 DAS), and another at anthesis (Z65, 124 DAS), counting main stems and tillers as

before. An emergence count was not done as plant densities could be obtained from the anthesis pull data. In this year, 50 main stems and 50 tillers were tagged in each plot at anthesis as it had been found that 25 heads did not provide enough flour to allow repeated testing if extra tests were necessary.

The plots were harvested on December 2nd and the grain cleaned and weighed as in the previous years. Due to time and financial constraints, the quality testing was done at the Waite Grain Quality Research Laboratory, SA. The same tests were done in the same way; however there could be slight variations between machines in the different laboratories.

5.2.4 Statistical Analysis

All experiments were analysed using the statistical package Genstat 5.

In 2000 the results from the initial 1000-grain weight tests showed that one of the replicates was affecting the results; therefore this replicate was removed from the analysis.

5.3 RESULTS

5.3.1 Physiological data

5.3.1.1 Emergence

An emergence count was only conducted in 1998. The first shoots emerged on June 4th, 10 DAS.

The results from the emergence count are summarized in Table 35. The emergence count showed that there were significant differences between all the seeding rate treatments. Kukri was generally lower in density than Janz, and the two varieties were significantly different in density.

Table 35: Mean emergence count (seedlings/m^2) in Experiment 3, 1998.

	Variety	
	Janz	Kukri
	244[A]	233[B]

Seed Rate				
65	190	260	320	450
60[A]	175[B]	234[C]	297[D]	428[E]

LSD *(P=0.05)*		
Variety	8	*(P = 0.004)*
Seed Rate	13	*(P < 0.001)*
Variety x Seed Rate	n.s.	*(P = 0.421)*

5.3.1.2 Tillering data

In 1998 the dry matter cut at tillering showed significant differences in dry matter production between both seeding rates and varieties, but with no significant interaction (Table 36 and Figure 5). Kukri produced more dry matter than Janz at all seeding rates, while for both varieties greater amounts of biomass were produced with higher density crops.

Tillering dry matter weight results showed no significant differences between seed rates in 1999.

In 2000 tillering dry matter weight results showed significant differences between varieties and seed rates but no interaction (Table 36 and Figure 5). Kukri had greater dry matter weight than Janz, and dry matter weight increased as seed rate increased.

Table 36: Mean tiller dry matter weights grouped by variety in Experiment 3 (all years).

Variety	Mean Dry Matter (g/m^2)		
	1998	*1999*	*2000*
Janz	198	-	195
Kukri	239	186	247
LSD	15	-	11

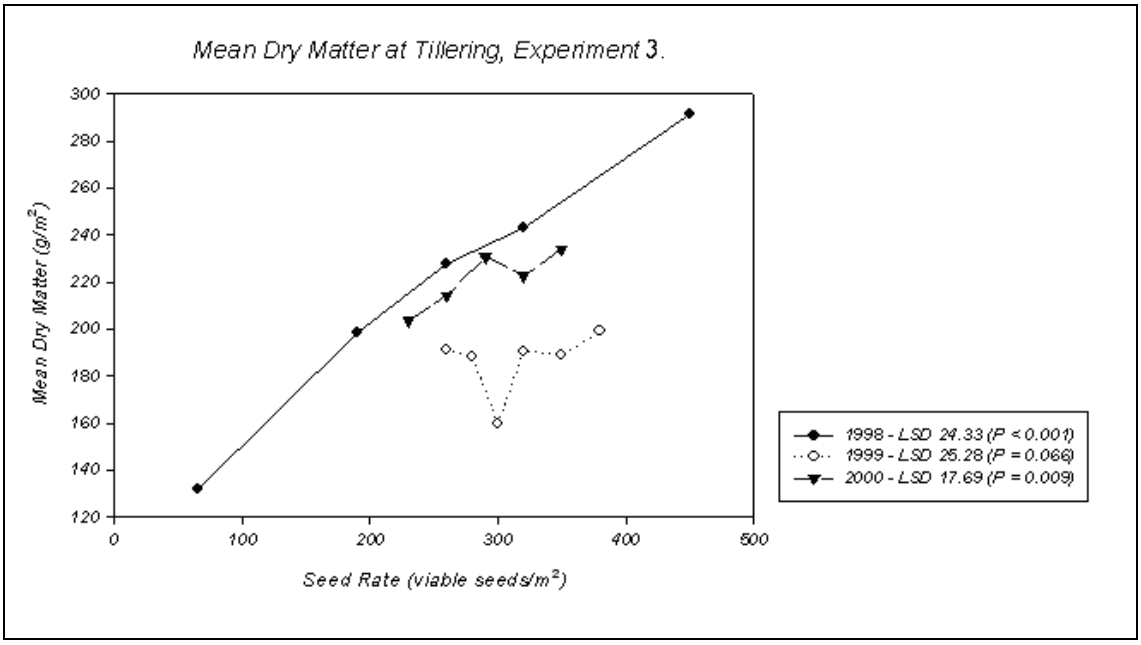

Figure 5: Mean dry matter production vs. seed rate, at tillering, for Experiment 3 (all years).

Overall, seed rate affected tillering dry matter production in 2 of the 3 years, and variety affected dry matter production in all years when there were more than 2 varieties.

In 1998 the two middle blocks were affected by waterlogging during July and August. This prevented these blocks being sprayed, and the low density plots in particular were affected by weeds. This may have affected growth and yield of the plots.

5.3.1.3 Anthesis data

5.3.1.3.1 Mean dry matter

The results of the dry matter cuts at anthesis are shown in Table 37 and Figure 6 below. In 1998 Kukri produced significantly more dry matter than Janz overall, and significantly greater amounts of dry matter were produced by both varieties at higher seeding rates. There was no significant interaction.

Mean total dry matter weights at anthesis were not significantly different in 1999 (Table 37 and Figure 6).

Total dry matter weight at anthesis in 2000 showed only a variety effect (Table 37 and Figure 6).

Table 37: Dry Matter Production at anthesis by each variety in Experiment 3 (all years).

Variety	Mean Dry Matter (g/m^2)		
	1998	*1999*	*2000*
Janz	637	-	796
Kukri	679	551	852
LSD	39	-	47

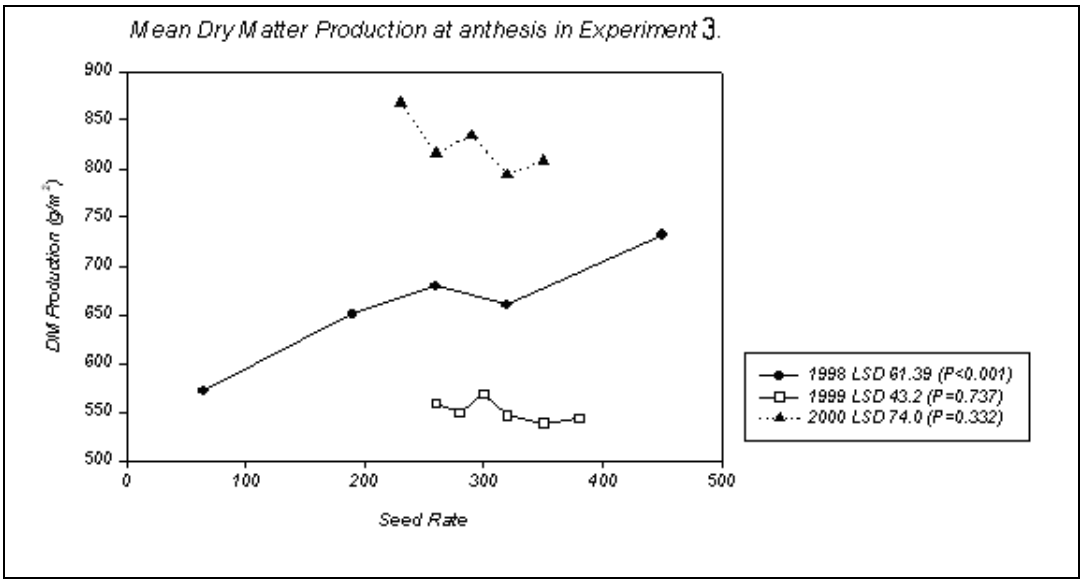

Figure 6: Dry Matter Production at anthesis, Experiment 3 (all years).

There was no consistent significant effect of seed rate on dry matter production at anthesis over the 3 years.

5.3.1.3.2 Main stem and tiller numbers

The numbers of main stems and tillers, and dry matter production of main stems and tillers were also measured at anthesis. The analysis of the data showed that in 1998 there was a significant 3-way interaction between variety, seed rate and stem type for the numbers of main stems and tillers (Table 38).

Main stem numbers increased at higher seeding rates for both varieties. Janz tended to have higher numbers of main stems than Kukri but this was found to be insignificant. Tiller numbers initially increased then decreased for the variety Janz as seed rate increased. Tiller numbers for Kukri increased at first and then remained steady, ie. not significantly different from each other as seed rate increased. Tiller numbers were greater than main stem numbers until 320 s/m^2 for the variety Janz, then not significantly different at 320 s/m^2 and the number of tillers was significantly lower at a seed rate of 350 s/m^2. Tiller numbers increased with seeding rate until a

rate of 320 s/m^2 for the variety Kukri, and were not significantly different from main stem numbers at 320 and 450 s/m^2.

Table 38: Mean number and type of stems/m^2 at anthesis in Experiment 3, 1998.

Variety	Stem Type	Seed Rate				
		65	190	260	320	450
Janz	Main Stems	72^{A}	154^{BC}	212^{DE}	224^{DEF}	348^{JK}
	Tillers	254^{DEFG}	322^{HIJK}	367^{K}	333^{IJK}	269^{FGH}
Kukri	Main Stems	60^{A}	146^{B}	207^{CD}	250^{DEFG}	312^{HIJ}
	Tillers	247^{DEFG}	319^{HIJK}	291^{GHI}	276^{FGH}	323^{HIJK}

LSD *(P=0.05)*		
Variety	n.s.	*(P = 0.145)*
Seed Rate	27	*(P < 0.001)*
Stem	17.	*(P < 0.001)*
Variety.Seed Rate	n.s.	*(P = 0.488)*
Variety.Stem	n.s.	*(P = 0.518)*
Seed Rate.Stem	39	*(P < 0.001)*
Variety.Seed Rate.Stem	55	*(P = 0.015)*

In 1999 there was a significant interaction between stem type and seed rate at anthesis influencing the density of main stems and tillers (Table 39). Main stem numbers were not significantly different between 260 and 350 s/m^2, but different at the highest rate (380 s/m^2). Tiller stem numbers were similar between 260 and 320 s/m^2 then declined significantly.

Table 39: Mean number and type of stems/m^2 at anthesis in Experiment 3, 1999.

Stem Type	Seed Rate					
	260	280	300	320	350	380
Main Stem	300^{B}	293^{B}	302^{B}	304^{B}	335^{AB}	354^{A}
Tiller	157^{C}	162^{C}	192^{C}	153^{C}	107^{D}	102^{D}

LSD *(P=0.05)*		
Stem Type	18	*(P < 0.001)*
Seed Rate	n.s.	*(P = 0.671)*
Stem Type x Seed Rate	43	*(P < 0.001)*

Stem numbers per m^2 showed a significant variety-stem type interaction and a significant independent effect of seed rate in 2000 (Table 40).

Main stem numbers were not significantly different between the 2 varieties, however Janz had more tillers than Kukri. There were greater numbers of tillers than main stems for both varieties.

Stem numbers were lowest at 260 s/m^2 (not significantly different from 230 s/m^2) and highest at 320 s/m^2 (not significantly different from 350 or 290 s/m^2).

Table 40: Mean number and type of stems per m^2 at anthesis in Experiment 3, 2000.

Seed Rate				
230	260	290	320	350
225^{AB}	213^{B}	229^{AB}	241^{A}	234^{A}

Variety	Stem Type	
	Main Stem	Tillers
Janz	154^{C}	319^{A}
Kukri	160^{C}	280^{B}

LSD *(P=0.05)*		
Variety	12	*(P = 0.007)*
Seed Rate	19	*(P = 0.044)*
Stem	12	*(P < 0.001)*
Variety.Seed Rate	n.s.	*(P = 0.507)*
Variety.Stem	17	*(P < 0.001)*
Seed Rate.Stem	n.s.	*(P = 0.731)*
Variety.Seed Rate.Stem	n.s.	*(P = 0.433)*

All factors in the experiment (seed rate, stem type and variety) significantly affected the numbers and types of stems in all the years they were present.

5.3.1.3.3 Ears apparent at anthesis

The numbers of ears were also counted, this being more relevant to the final yield. In 1998 (see Table 41) there were interactions between seed rate and stem type, and variety and stem type. Main stem ear numbers increased as seed rate increased as expected, although numbers at higher seed rates reflected the increased mortality rates of the plants due to competition. Tiller numbers were stable at the lower seed rates, showing that maximum tiller ear numbers had been produced with the available resources, but decreased at the higher seed rates at a result of further competition.

While Janz did not significantly differ in ear numbers between main stems and tillers, Kukri had on average, lower numbers of tiller ears than main stem ears.

Table 41: Mean ears per m^2 in Experiment 3, 1998.

Stem Type	Seed Rate				
	65	190	260	320	450
Main Stems	66^{A}	149^{BC}	204^{EF}	225^{F}	300^{G}
Tillers	188^{DE}	188^{DE}	168^{CD}	151^{BC}	125^{B}

Stem Type	Variety	
	Janz	Kukri
Main Stems	192^{B}	185^{B}
Tillers	184^{B}	145^{A}

LSD *(P=0.05)*		
Variety	15	*(P = 0.003)*
Seed Rate	24	*(P < 0.001)*
Stem	15	*(P = 0.001)*
Variety.Seed Rate	n.s.	*(P = 0.882)*
Variety.Stem	21	*(P = 0.035)*
Seed Rate.Stem	33	*(P < 0.001)*
Variety.Seed Rate.Stem	n.s.	*(P = 0.140)*

In 1999, there was a much more marked difference discernible between the numbers of ears produced by the two stem types (Table 42). Main stems produced much more ears than the tillers. Seed rate did not affect the final ear numbers.

Table 42: Mean ear numbers in 1999.

	Stem Type	
	Main Stems	Tillers
	304[A]	50[B]

LSD *(P=0.05)*		
Stem	13	*(P < 0.001)*
Seed Rate	n.s.	*(P = 0.662)*
Stem x Seed Rate	n.s.	*(P = 0.115)*

In 2000, ear numbers showed a variety-stem type interaction (see Table 43). However there was no seed rate-stem type interaction, probably due to the lesser difference between the seed rates. The results differed from those in 1998, with tiller ears much more abundant than in 1998.

Both Janz and Kukri had significantly more tiller ears than main stem ears, however Janz produced significantly more tiller ears than Kukri.

Table 43: Mean ear numbers per m^2 in 2000.

Stem Type	Variety	
	Janz	Kukri
Main Stems	154[A]	161[A]
Tillers	315[C]	280[B]

LSD *(P=0.05)*		
Variety	14	*(P = 0.037)*
Seed Rate	n.s.	*(P = 0.191)*
Stem	14	*(P < 0.001)*
Variety.Seed Rate	n.s.	*(P = 0.531)*
Variety.Stem	19	*(P = 0.003)*
Seed Rate.Stem	n.s.	*(P = 0.653)*
Variety.Seed Rate.Stem	n.s.	*(P = 0.562)*

5.3.1.3.4 Mean stem dry matter weights at anthesis

In 1998 stem dry matter weight measurements produced a significant interaction between seed rate and stem type (Table 44). Variety had no significant effect. The amount of dry matter produced by main stems increased as seed rate increased, whereas tiller dry matter production decreased.

Table 44: Mean stem dry matter weights (g/m^2) at anthesis, Experiment 3, 1998.

Stem Type	Seed Rate				
	65	190	260	320	450
Main Stems	172^{A}	312^{D}	390^{F}	405^{F}	516^{G}
Tillers	387^{EF}	338^{DE}	289^{CD}	255^{BC}	216^{AB}

LSD *(P=0.05)*		
Variety	n.s.	*(P = 0.104)*
Seed Rate	35	*(P < 0.001)*
Stem	22	*(P < 0.001)*
Variety.Seed Rate	n.s.	*(P = 0.363)*
Variety.Stem	n.s.	*(P = 0.195)*
Seed Rate.Stem	50	*(P < 0.001)*
Variety.Seed Rate.Stem	n.s.	*(P = 0.325)*

In 1999 there was also a significant interaction between stem type and seed rate (Table 45).

Main stems had higher total dry matter weights than tillers for all seeding rates. There were no significant differences in dry matter weight for main stems until the highest seed rate (380 s/m^2) when dry matter weight increased. Tiller total dry matter weights showed no significant difference until 350 s/m^2, when dry matter weights decreased.

Table 45: Mean stem dry matter weights (g/m^2) at anthesis, Experiment 3, 1999.

Stem Type	Seed Rate					
	260	280	300	320	350	380
Main Stem	442^{AB}	435^{B}	442^{AB}	434^{B}	438^{AB}	466^{A}
Tiller	118^{CD}	115^{CD}	127^{C}	113^{CD}	90^{D}	90^{D}

LSD *(P=0.05)*		
Stem Type	12	*(P < 0.001)*
Seed Rate	n.s.	*(P = 0.488)*
Stem Type x Seed Rate	30	*(P = 0.035)*

Anthesis dry matter weight in 2000 when separated by stem type did not have a 3-way interaction. There was a significant variety-seed rate interaction and a significant seed rate-stem type interaction (Table 46).

The variety-seed rate interaction showed that the dry matter weight of all tillers was greater than the dry matter weight of all main stems for both varieties. Kukri had higher total main stem weights than Janz, but total tiller weights between the varieties were not significantly different.

The seed rate-stem type interaction showed that total main stem dry matter weights were not significantly different at all seed rates, however total tiller dry matter weights decreased at higher seed rates. Tiller weights were greater than main stem weights for all seed rates.

Table 46: Mean stem dry matter weight at anthesis (g/m^2) Experiment 3, 2000.

Variety	Stem Type	
	Main Stem	Tillers
Janz	331^{C}	465^{A}
Kukri	389^{B}	466^{A}

Stem Type	Seed Rate				
	230	260	290	320	350
Main Stem	363^{E}	340^{E}	350^{E}	369^{E}	378DE
Tiller	505^{A}	476^{AB}	483^{AB}	426^{CD}	438^{BC}

LSD *(P=0.05)*		
Variety	22	*(P = 0.007)*
Seed Rate	n.s.	*(P = 0.290)*
Stem	22	*(P < 0.001)*
Variety.Seed Rate	n.s.	*(P = 0.141)*
Variety.Stem	31	*(P = 0.009)*
Seed Rate.Stem	48	*(P = 0.017)*
Variety.Seed Rate.Stem	n.s.	*(P = 0.669)*

Seed rate and stem type showed significant interactions in all years.

5.3.1.3.5 Mean dry matter weight per stem

The data were further examined by calculating the mean dry matter weight per stem. This showed that in 1998 there was a significant interaction of variety and stem type, accompanied by an independent effect of seed rate (Table 47).

Kukri had higher dry matter weights per stem than Janz for main stems but tiller dry matter weights were not significantly different between the varieties. Main stems had higher dry matter weights per stem than tillers in both varieties.

Mean stem weights were significantly different at all seeding rates, with stem weight decreasing as seed rate increased.

Table 47: Mean dry matter weight (g) per stem at anthesis in Experiment 1, 1998.

Variety	Stem Type	
	Main Stem	Tillers
Janz	1.89[B]	0.98[C]
Kukri	2.11[A]	1.05[C]

	Seed Rate				
	65	190	260	320	450
Mean	2.11[A]	1.60[B]	1.39[C]	1.28[D]	1.17[E]

LSD *(P=0.05)*		
Variety	0.06	*(P < 0.001)*
Seed Rate	0.09	*(P < 0.001)*
Stem	0.06	*(P < 0.001)*
Variety.Seed Rate	n.s.	*(P = 0.722)*
Variety.Stem	0.08	*(P = 0.012)*
Seed Rate.Stem	n.s.	*(P = 0.277)*
Variety.Seed Rate.Stem	n.s.	*(P = 0.444)*

In 1999 dry matter weight per stem showed a significant interaction of seed rate and stem type (Table 48).

Main stems had greater values than tillers for all seed rates measured. Dry matter weight of main stems was maintained until 320 s/m^2, and then decreased although the differences were not significant until 380 s/m^2. Tiller dry matter weights were not significantly different between 260 and 350 s/m^2, and increased significantly at 380 s/m^2.

Table 48: Mean dry matter weight (g) per stem 1999.

Stem Type	Seed Rate					
	260	280	300	320	350	380
Main Stem	1.48^{A}	1.50^{A}	1.47^{A}	1.45^{AB}	1.34^{AB}	1.29^{B}
Tiller	0.77^{DE}	0.79^{DE}	0.72^{E}	0.78^{DE}	0.93^{CD}	1.00^{C}

LSD *(P=0.05)*		
Stem Type	0.07	*(P < 0.001)*
Seed Rate	n.s.	*(P = 0.959)*
Stem Type x Seed Rate	0.18	*(P < 0.001)*

In 2000 the analysis of dry matter weight per stem showed independent effects of variety, seed rate and stem type with no interactions (Table 49).

Kukri had higher dry matter weights per stem than Janz. Stem weight showed no significant differences between 230 and 260 s/m^2, a drop in stem weight at 290 s/m^2 and a further drop in stem weight at 320 s/m^2. 320 and 350 s/m^2 were not significantly different. Main stems had greater dry matter weights than tillers.

Table 49: Mean dry matter weight (g) per stem at anthesis 2000.

Variety	
Janz	Kukri
1.84^{B}	2.06^{A}

Seed Rate				
230	260	290	320	350
2.05^{AB}	2.09^{A}	1.96^{B}	1.83^{C}	1.83^{C}

Stem Type	
Main Stem	Tillers
2.32^{A}	1.58^{B}

LSD *(P=0.05)*		
Variety	0.06	*(P < 0.001)*
Seed Rate	0.09	*(P < 0.001)*
Stem	0.06	*(P < 0.001)*
Variety.Seed Rate	n.s.	*(P = 0.155)*
Variety.Stem	n.s.	*(P = 0.095)*
Seed Rate.Stem	n.s.	*(P = 0.875)*
Variety.Seed Rate.Stem	n.s.	*(P = 0.614)*

Overall, each of the factors had a significant effect on the results in all 3 years, however not in the same way, as interactions were present in some years but not others.

In 1998, hot winds during October caused some premature senescence in the crop.

5.3.2 Harvest

5.3.2.1 Grain yields

There were independent effects of variety and seed rate on total grain yield but no interaction in 1998 (Table 50). Yield increased initially, but was not significantly different from 190 to 450 s/m^2. Janz yielded significantly more than Kukri.

Table 50: Mean total harvested grain (g/m^2) for each treatment in Experiment 3, 1998.

Variety	
Janz	Kukri
344^A	311^B

Seed Rate				
65	190	260	320	450
237^A	346^B	348^B	348^B	359^B

LSD *(P=0.05)*		
Variety	12	*(P < 0.001)*
Seed Rate	19	*(P < 0.001)*
Variety x Seed Rate	n.s.	*(P = 0.409)*

Yields in 1999 were not significantly different between treatments.

The total yields (g/m^2) from 2000 are contained in Table 51. There was an interaction between variety and seed rate. One outlier was removed due to heavy weed infestation.

Janz had higher yield than Kukri at higher seed rates but there was no significant difference between the varieties at lower rates. Kukri showed no significant differences in yield as seed rate increased. Janz showed significant differences in yield, with 260 s/m^2 having the lowest yield and 290 s/m^2 the highest.

Table 51: Mean total grain harvested (g/m^2) 2000

Variety	Seed Rate				
	230	260	290	320	350
Janz	462^{AB}	410^{C}	481^{A}	448^{B}	455^{AB}
Kukri	421^{BC}	425^{BC}	421^{BC}	410^{C}	401^{C}

LSD *(P=0.05)*		
Variety	12	*(P < 0.001)*
Seed Rate	20	*(P = 0.015)*
Variety x Seed Rate	28	*(P = 0.004)*

Variety had a significant effect in all years that it was a factor, and seed rate had a significant effect in 2 of the 3 years of the experiment.

5.3.2.2 Clean grain

In 1998 after cleaning (removal of screenings and any other non-millable product), the grain yields differed little to the results from the unscreened grain. There were significant main effects of variety and seed rate (see Table 52).

The highest cleaned grain yield was achieved by the highest seed rate (450 s/m^2), however this was not significantly different from any other value except that at 65 s/m^2. The lowest yield was measured at the low seed rate of 65 s/m^2. Janz yielded significantly higher then Kukri.

Table 52: Mean weight of clean grain (g/m^2) in Experiment 3, 1998.

Variety	
Janz	Kukri
327^{A}	291^{B}

Seed Rate				
65	190	260	320	450
220^{A}	330^{B}	327^{B}	327^{B}	341^{B}

LSD *(P=0.05)*		
Variety	13	*(P < 0.001)*
Seed Rate	20	*(P < 0.001)*
Variety x Seed Rate	n.s.	*(P = 0.225)*

The results of the total harvested grain and cleaned grain weight measurements were not significantly different in 1999.

The clean grain measurements in 2000 showed a significant variety-seed rate interaction (Table 53) with similar results to the results of total grain harvested. A single outlier was removed from the results. This plot had been badly affected by weeds.

Table 53: Mean clean grain (g/m^2) 2000

Variety	Seed Rate				
	230	260	290	320	350
Janz	440^{AB}	389^{CD}	457^{A}	426^{BC}	432^{AB}
Kukri	402^{CD}	408^{BC}	404^{CD}	394^{CD}	383^{D}

LSD *(P=0.05)*		
Variety	12	*(P < 0.001)*
Seed Rate	19	*(P = 0.020)*
Variety x Seed Rate	27	*(P = 0.004)*

Clean grain weight results over the 3 years of the experiment showed similar results to those of the harvest weights.

5.3.2.3 Screenings

There were no significant effects on the amount of screenings found per m^2 in 1998. There was a significant effect of seed rate in 1999 (Table 54). The amount of screened grain at 350 s/m^2 was significantly lower than all other results except that of 300 s/m^2.

Table 54: Mean screened grain weight (g/m^2) Experiment 3, 1999

Seed Rate					
260	280	300	320	350	380
14.0^{A}	14.4^{A}	13.3^{AB}	14.3^{A}	12.4^{B}	14.0^{A}

LSD *(P=0.05)*		
Seed Rate	1.3	*(P = 0.044)*

There was a varietal effect only on screenings in 2000 (Table 55). Janz had more screened grain per m^2 than Kukri.

Table 55: Mean screened grain weight (g/m^2) Experiment 3, 2000

Variety	
Janz	Kukri
18.2^{A}	14.5^{B}

LSD *(P=0.05)*		
Variety	1.3	*(P < 0.001)*
Seed Rate	n.s.	*(P = 0.465)*
Variety x Seed Rate	n.s.	*(P = 0.397)*

Overall there was no consistent effect of any of the factors on total screenings weight.

5.3.2.4 Screenings %

The results of the screenings percentage calculations are found in Figure 7.

When screenings were calculated as a percentage of the total harvested grain in 1998 there was a significant effect of seed rate. The lowest seed rate had the highest percentage screenings and was significantly different to all the other results except those of 320 s/m^2. There was no significant difference between the screenings percentages from 190, 260, 320 and 450 s/m^2.

Screened grain, as a percentage of the harvested grain, was not significantly different between treatments in 1999 (P=0.058), although the results showed a possible trend towards lower screenings at higher seeding rates.

There was a varietal effect only on screenings percentage in 2000.

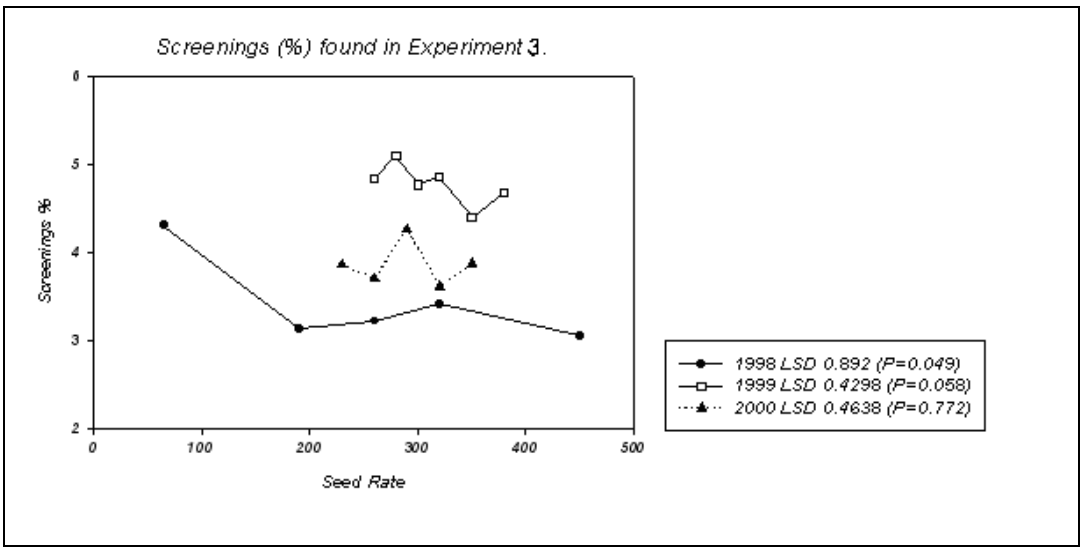

Figure 7: Screenings (%) from Experiment 3 (all years).

Seed rate affected screenings percentages in 2 of the 3 years of the experiment.

5.3.2.5 Protein

Mean grain protein (%) over the three years is summarised in Table 56.

Grain protein was not affected by seed rate in 1998, but was significantly different between the two varieties.

There were no significant differences between treatments in 1999, and only varietal differences apparent in 2000.

Table 56: Mean protein (%) for Experiment 3, all years.

Variety	Protein (%)		
	1998	*1999*	*2000*
Janz	12.83	-	10.55
Kukri	13.41	13.65	11.64
LSD	0.22	-	0.29

5.3.3 Physical quality

During the measurements of quality characteristics in 2000, it was found that one replicate contained a large number of outliers and had consistently different results. Therefore this replicate was eliminated from the results.

5.3.3.1 1000-grain weight

In 1998 there were significant main effects of variety and seed rate (Table 57). The 2 varieties were found to be significantly different in thousand-grain weight (Kukri greater than Janz). Thousand-grain weight was significantly lower at 450 s/m^2 than at

65, 190, and 320 s/m^2. Thousand-grain weight at 260 s/m^2 was not significantly different to any other result.

Table 57: Mean 1000-grain-weights (g) for Experiment 3, 1998.

Variety	
Janz	Kukri
34.06^{A}	37.45^{B}

Seed Rate				
65	190	260	320	450
36.98^{A}	36.60^{A}	35.40^{AB}	35.84^{A}	33.96^{B}

LSD *(P=0.05)*		
Variety	1.15	*(P < 0.001)*
Seed Rate	1.81	*(P = 0.018)*
Variety x Seed Rate	n.s.	*(P = 0.666)*

There were no significant differences between treatments for 1000-grain weight in 1999.

In 2000 the results of the 1000-grain weight measurements showed that there were significant differences between varieties and seed rates but no interaction (Table 58). Kukri had higher 1000-grain weights than Janz, and the lowest seed rate (230 s/m^2) had greater 1000-grain weights than the others, which although constantly decreasing, were not significantly different from each other.

Table 58: Mean 1000-grain weights (g) 2000.

Variety	
Janz	Kukri
34.25[A]	43.56[B]

Seed Rate				
230	260	290	320	350
40.00	39.01[B]	38.86[B]	38.49[B]	38.18[B]

LSD *(P=0.05)*		
Variety	0.60	*(P < 0.001)*
Seed Rate	0.95	*(P = 0.011)*
Variety x Seed Rate	n.s.	*(P = 0.663)*

Seed rate significantly affected 1000-grain weight in 2 of the 3 years of the experiment, while variety had a consistent significant effect.

5.3.3.2 Test weight

No significant differences were found between treatments for test weight in 1998 or 1999. Test weight was not measured in 2000.

5.3.4 Milling and Flour quality

5.3.4.1 Flour yield

There was a significant varietal effect on flour yields in 1998 and 2000 (see Table 59). There was no treatment effect on flour yield in 1999.

Table 59: Varietal effects on flour yield (%), (Buhler mill) in Experiment 3, (all years).

Variety	Flour yield (%)		
	1998	*1999*	*2000*
Janz	74.16	-	73.00
Kukri	75.02	76.31	74.12
LSD	0.38	-	0.23

5.3.4.2 Flour colour

In 1998 flour colour was affected by variety in the "L" and "a" components of the measurement (Table 60). Janz had higher "L" values than Kukri, but lower "a" values.

Table 60: Mean flour colour "L" and "a" values for the varieties in Experiment 3, 1998.

Variety	Minolta "L"	Minolta "a"
Janz	90.93	-0.68
Kukri	90.65	-0.87
LSD	0.09	0.07

Flour colour (b-value) was strongly affected by a variety and seed rate interaction, as was the "L-b" value (see Table 61 and Table 62).

Kukri had a significantly higher "b" value (more yellow) than Janz for all treatments. Kukri "b" values rose between 190 and 320 s/m^2, while Janz "b" values increased from 65 to 260 s/m^2, were not significantly different between 260 and 320 s/m^2, and dropped slightly at 450 s/m^2.

Table 61: Mean Minolta flour colour (b value) in samples from Experiment 3, 1998.

Variety	Seed Rate				
	65	190	260	320	450
Janz	8.69^{F}	8.84^{E}	9.09^{C}	9.03^{CD}	8.94^{DE}
Kukri	9.99^{B}	9.97^{B}	10.04^{AB}	10.15^{A}	10.16^{A}

LSD *(P=0.05)*		
Variety	0.06	*(P < 0.001)*
Seed Rate	0.10	*(P < 0.001)*
Variety x Seed Rate	0.14	*(P = 0.023)*

L-b values for Janz rose from 65 to 260 s/m^2, and then decreased. Values for Kukri were generally declining, however the only significant difference recorded was between the values 190 s/m^2 and 450 s/m^2.

Table 62: Mean Minolta flour colour "L-b" in samples from Experiment 3, 1998.

Variety	Seed Rate				
	65	190	260	320	450
Janz	82.30^{A}	82.12^{AB}	81.705^{C}	81.89^{BC}	82.06^{AB}
Kukri	80.58^{DE}	80.72^{D}	80.63^{DE}	80.57^{DE}	80.43^{E}

LSD *(P=0.05)*		
Variety	0.13	*(P < 0.001)*
Seed Rate	0.20	*(P = 0.029)*
Variety x Seed Rate	0.28	*(P = 0.021)*

In 1999 flour colour was not significantly affected by the treatments in any of the parameters measured (L, a, b or L-b).

In 2000 variety had significant effects on "L", "a" and "L-b" Minolta flour colours (Table 63).

Table 63: Mean flour colour "L", "a" and "L-b" values for the varieties in Experiment 3, 2000.

Variety	Minolta "L"	Minolta "a"	Minolta "L-b"
Janz	93.10	-0.72	84.42
Kukri	92.97	-0.78	83.90
LSD	0.07 (P < 0.001)	0.07 (P = 0.028)	0.38 (P < 0.001)

Minolta "b" values showed a significant interaction of variety and seed rate (Table 64).

Janz had lower "b" values (yellowness) than Kukri except at the highest seed rate. Kukri had lower "b" values at lower seed rates and the highest reading at 320 s/m^2.

Table 64: Mean flour Minolta "b" values, Experiment 3, 2000.

Variety	Seed Rate				
	230	260	290	320	350
Janz	8.74^{D}	8.78^{D}	8.78^{D}	8.75^{D}	8.83^{CD}
Kukri	9.11^{AB}	8.98^{BC}	8.95^{BC}	9.24^{A}	9.08^{AB}

LSD *(P=0.05)*		
Variety	0.07	*(P < 0.001)*
Seed Rate	n.s.	*(P = 0.174)*
Variety x Seed Rate	0.17	*(P = 0.048)*

Overall, the different varieties in the experiment showed consistent significantly different results for all colour parameters. Seed rate significantly affected the "b" value in 2 of the 3 years. A regression analysis to check whether protein content was affecting flour colour showed no significant results (R^2 values in 1998 were 0.3, in 1999 were 0.04, and in 2000 were 0.2).

5.3.5 Dough and Baking quality

5.3.5.1 Farinograph

In 1998 water absorption in the farinograph was significantly different between varieties, and not quite significantly different at the interaction level (P = 0.063). Dough development time and stability in the farinograph showed varietal differences only (see Table 65).

Table 65: Mean varietal results for the farinograph, Experiment 3, 1998.

Variety	Water Absorbance (%)	Dough Development Time (min)	Stability (min)
Janz	63.7	6.9	8.8
Kukri	64.8	9.0	10.5
LSD	0.5 P < 0.001	0.9 P < 0.001	0.8 P < 0.001

There were no significant differences in farinograph results between treatments in 1999.

Farinograph water absorption, dough development time, and stability all showed significant effects of variety but no other parameters in 2000 (see Table 66).

Table 66: Mean varietal results for the farinograph, Experiment 3, 2000.

Variety	Water Absorbance (%)	Dough Development Time (min)	Stability (min)
Janz	62.7	3.7	6.0
Kukri	63.8	6.0	9.9
LSD	0.4 P < 0.001	0.4 P < 0.001	0.3 P < 0.001

Variety was the only treatment that had a consistent significant effect. Farinograph results were not affected by seed rate in any year of the experiment.

5.3.5.2 Extensograph

Extensograph water absorption was not significant in 1998, while extensograph Rmax, length and R5 (area under the graph) showed varietal differences only (Table 67).

Table 67: Extensograph varietal characteristics in Experiment 3, 1998.

Variety	Water Absorbance (%)	Rmax (BU)	Length (cm)	Area (R5) (cm^2)
Janz	61.1	370	22.6	210
Kukri	61.5	491	25.1	227
LSD	n.s.	22 P < 0.001	0.6 P < 0.001	17 P = 0.045

There were no significant differences in extensograph results in 1999.

Extensograph water absorption was not measured in 2000. Extensograph length and height (Rmax, BU) showed significant effects of variety but not seed rate in 2000 (Table 68).

Table 68: Extensograph varietal characteristics in Experiment 3, 2000.

Variety	Length (cm)	Rmax (BU)
Janz	18.1	342
Kukri	21.2	478
LSD	0.8 P < 0.001	16 P < 0.001

Variety had consistent significant effects on the extensograph results. However, seed rate did not affect the extensograph results in any year of the experiment.

5.3.5.3 RVA

RVA showed significant differences between the two varieties in 1998 for initial, peak and final viscosity (Table 69) as well as a significant effect of seed rate on peak viscosity (Table 70). Kukri had a higher peak viscosity than Janz over all seed rates, and peak viscosity was greatest at 320 s/m^2, and lowest at 190 and 450 s/m^2.

Table 69: RVA varietal characteristics in Experiment 3, 1998.

Variety	Initial Viscosity	Peak Viscosity	Final Viscosity
Janz	65.1	137.7	199.6
Kukri	63.7	153.4	212.8
LSD	0.5 P < 0.001	0.4 P < 0.001	4.4 P < 0.001

Table 70: RVA Peak Viscosity Experiment 3, 1998.

Seed Rate				
65	190	260	320	450
148.4^{AB}	142.1^{B}	145.5^{AB}	151.2^{A}	142.7^{B}

LSD *(P=0.05)*		
Variety	4.4	*(P < 0.001)*
Seed Rate	6.9	*(P = 0.038)*
Variety x Seed Rate	n.s.	*(P = 0.441)*
(1 outlier removed)		

In 1999 RVA showed no significant differences between treatments for the initial, peak or final results, however peak values were close to significantly different between seed rates (P = 0.075).

In 2000 there were independent effects of variety and seed rate on RVA peak height (Table 71). (Initial and final measurements were not taken.) Kukri had a higher peak height than Janz. Peak height was lowest at 260 and 320 s/m^2 (not significantly different from each other) and highest at the higher seed rates of 290, 320 and 350 s/m^2.

Table 71: Mean RVA Peak height Experiment 3, 2000.

Variety	
Janz	Kukri
111.2^{A}	137.8^{B}

Seed Rate				
230	260	290	320	350
122.6^{AB}	119.1^{B}	126.4^{A}	126.2^{A}	128.4^{A}

LSD *(P=0.05)*		
Variety	3.7	*(P < 0.001)*
Seed Rate	5.9	*(P = 0.025))*
Variety x Seed Rate	n.s.	*(P = 0.696))*

The RVA Peak Viscosity results from the 3 years of Experiment 3 are shown in Figure 8.

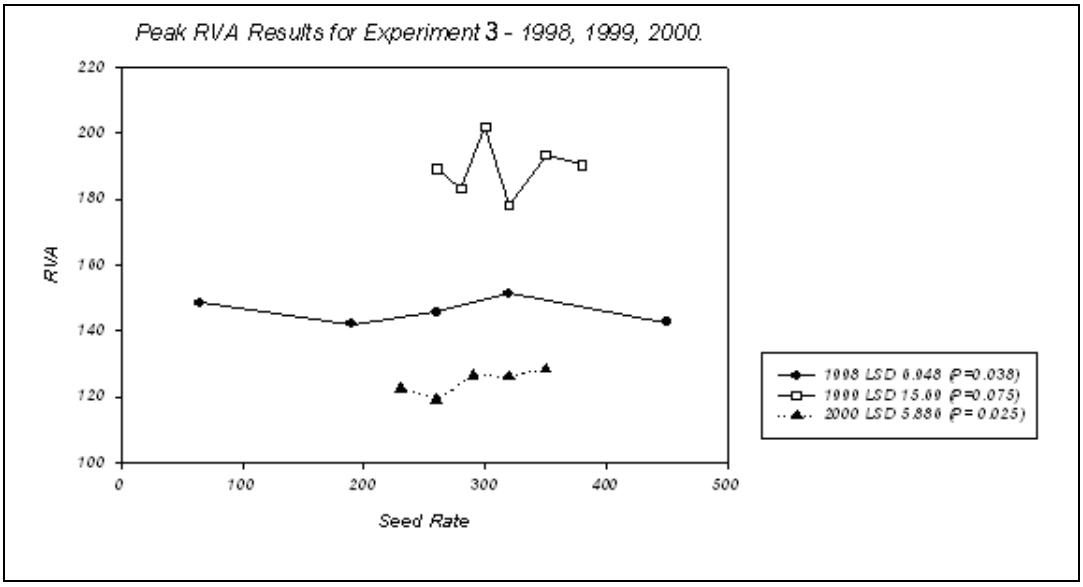

Figure 8: Peak Viscosity (RVA) Experiment 3 (all years).

The peak viscosity measurement of the RVA was significantly or close to significantly affected by seed rate in all 3 years of the experiment.

5.3.5.4 Bake tests

In 1998 the bake tests showed a significant interaction of variety and seed rate affecting the loaf volume, and hence the loaf score (Table 72 and Table 73). Janz loaves decreased in volume from 65 to 260 s/m^2 and then were not significantly different. Kukri loaves showed no significant differences between seeding rates. Loaf volume score was taken directly from the volume measurements and so showed the same results.

Table 72: Mean Loaf volume 1998

Variety	Seed Rate				
	65	190	260	320	450
Janz	683^{BC}	658^{CD}	630^{D}	639^{D}	643^{D}
Kukri	723^{A}	725^{A}	716^{AB}	749^{A}	748^{A}

LSD *(P=0.05)*		
Variety	16	*(P < 0.001)*
Seed Rate	n.s.	*(P = 0.195)*
Variety x Seed Rate	35	*(P = 0.044)*

Table 73: Mean Volume Score 1998

Variety	Seed Rate				
	65	190	260	320	450
Janz	22.8^{BC}	21.9^{CD}	21.0^{D}	21.3^{D}	21.4^{D}
Kukri	24.1^{A}	24.2^{A}	23.9^{AB}	25.0^{A}	24.9^{A}

LSD *(P=0.05)*		
Variety	0.5	*(P < 0.001)*
Seed Rate	n.s.	*(P = 0.195)*
Variety x Seed Rate	1.2	*(P = 0.044)*

The loaf quality scores for external appearance, external colour, internal colour, internal structure, internal texture and total loaf score all showed significant differences between varieties but not seed rates.

In 1999 loaf volume, volume score, external appearance, external colour, internal colour, internal structure, texture and total loaf score showed no significant differences between any of the treatments.

In 2000 loaf volume showed a significant difference between varieties but not seed rates. No other loaf characteristics were measured in 2000.

Overall, loaf characteristics did not show consistent results for any of the factors in the experiment.

5.3.5.5 Loaf colour

In 1998 loaf colour showed a significant interaction of variety and seed rate in the "L" results (Table 74), and significant independent effects of seed rate and variety on the "b" and "L-b" results (Table 75 and Table 76). The "a" results were not significantly different between any of the treatments.

Janz had higher "L" loaf colour values than Kukri, rising between 65 and 260 s/m^2 and then showing no significant differences. Kukri "L" values also rose between 65 and 260 s/m^2, with no significant difference between 260 and 320 s/m^2, but dropped significantly at 450 s/m^2.

Table 74: Loaf colour – L (minolta) Experiment 3, 1998.

Variety	Seed Rate				
	65	190	260	320	450
Janz	69.51^{BC}	70.81^{AB}	72.42^{A}	72.15^{AB}	72.41^{A}
Kukri	68.13^{CD}	68.70^{C}	70.51^{BC}	68.97^{BC}	66.61^{D}

LSD *(P=0.05)*		
Variety	0.85	*(P < 0.001)*
Seed Rate	1.34	*(P = 0.002)*
Variety x Seed Rate	1.89	*(P = 0.013)*

Loaf "b" values were higher for Janz than Kukri in 1998, and tended overall towards higher values at higher seed rates.

Table 75: Loaf colour – "b" Experiment 3, 1998.

	Variety	
	Janz	Kukri
	11.51^{A}	10.57^{B}

Seed Rate				
230	260	290	320	350
10.85^{BC}	10.66^{C}	11.44^{A}	11.01^{ABC}	11.25^{AB}

LSD *(P=0.05)*		
Variety	0.33	*(P < 0.001)*
Seed Rate	0.52	*(P = 0.032)*
Variety x Seed Rate	n.s.	*(P = 0.221)*

Loaf "L-b" values (Table 76) rose from 65 to 260 s/m^2, then dropped but at a reduced rate between 260 and 450 s/m^2 (see Table 76). The interaction was also close to being significant (P = 0.062).

Table 76: Loaf colour, L-b, Experiment 3, 1998

Variety	
Janz	Kukri
59.95^{A}	58.02^{B}

Seed Rate				
230	260	290	320	350
57.98^{C}	59.10^{ABC}	60.03^{A}	59.55^{AB}	58.26^{BC}

LSD *(P=0.05)*		
Variety	0.10	*(P < 0.001)*
Seed Rate	1.25	*(P = 0.007)*
Variety x Seed Rate	n.s.	*(P = 0.062)*

In 1999 loaf colour "L", "a" and "L-b" measurements showed no effect of seed rate, however, loaf colour "b" values showed significant differences between seed rates (Table 77). Loaf "b" values tended to rise as seed rate increased, with the highest "b" value at 320 s/m^2.

Table 77: Mean loaf colour "b" values Experiment 1, 1999.

Seed Rate						
260	280	300	320	350	380	Mean
10.32^{C}	10.28^{BC}	10.24^{C}	11.15^{A}	10.29^{BC}	10.98^{AB}	10.54

LSD *(P=0.05)*		
Seed Rate	0.71	*(P = 0.041)*

Loaf colour measurements were unavailable in 2000.

Figure 9 shows the loaf "b" values for the years 1998 and 1999.

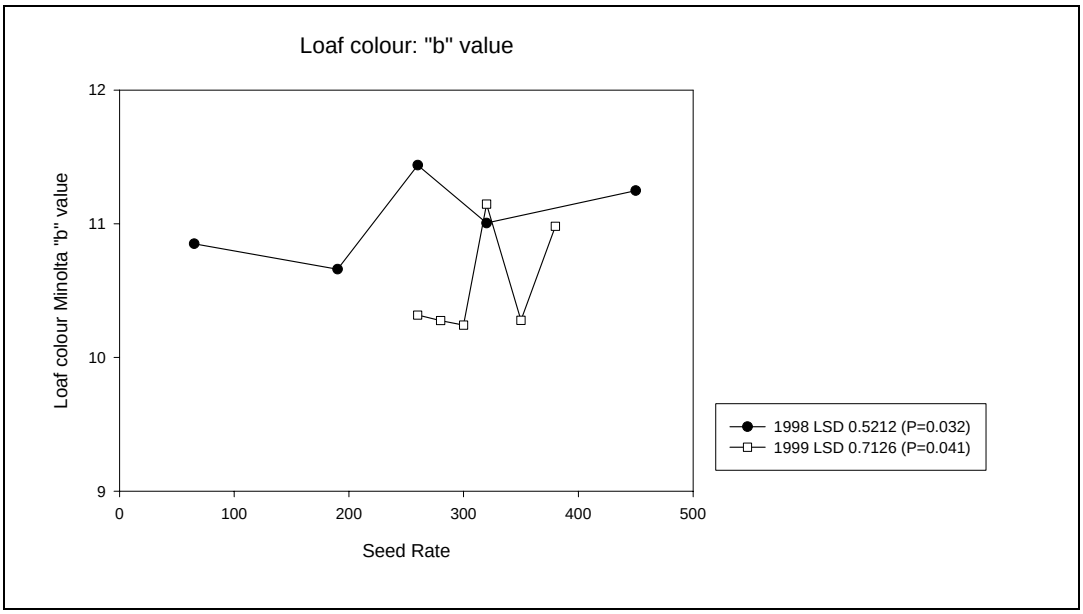

Figure 9: Loaf colour "b" values Experiment 3, 1998 & 1999.

Of the 2 years that loaf colour was measured, seed rate significantly affected "b" values in both, and "L" values in one. Minolta "a" and "L-b" values were not significantly affected in any year.

5.4 DISCUSSION

5.4.1 Physiological data

Dry matter weights at tillering reflected the increases in plant density, increasing as densities increased. There was also a varietal effect, with Kukri having consistently higher DM weights than Janz. Similar results were obtained for total plant dry matter production at anthesis, although the differences between seed rates were not as marked. Apart from the differences in seed rates between the years, this was probably due to the effects of increasing competition for light, water and nutrients at the higher seed rates reducing growth, and the plants at the lowest seed rate being well tillered and having more resources available to them during booting and pre-anthesis.

The numbers and types of stems present at anthesis were affected by the variety, seed rate and type of stem in all years of the experiment. This agrees with work by Anderson (1986) looking at the relationships between plant populations, yield components and grain yield of wheat.

However, in 1998 there was a 3-way interaction, in 1999 (one variety only) a 2 way interaction, and in 2000 an interaction between variety and stem type and an independent effect of seed rate. The reason for this change is not clear. It may be due to the changes in the densities between the years, or due to the different environmental effects in each year. What is clear is that the numbers of both main stems and tillers initially increase as plant densities increase, until they reach a point at which competition between plants forces tiller numbers to decline while main

stems continue to increase. In relative terms, the numbers of tillers per plant is at a maximum at lower densities, and declines as plant densities increase.

Main stem numbers (which also indicate plant density at anthesis) showed the increasing effects of competition at the higher plant densities for both varieties. Tiller numbers were greater at higher densities for the variety Janz than they were for Kukri, due to the different physiological characteristics of the two varieties. Kukri, having larger leaves and stems, probably had less substrate available for tiller production, whereas Janz, having smaller leaves and stems, probably had more resources to produce greater numbers of tillers. However, both varieties showed that as plant numbers increased, the number of tillers per plant decreased, giving an overall stable stem population. Further, while Kukri always had higher tiller numbers than main stem numbers (although not significantly different at the higher seed rates), tiller numbers for Janz at the highest seed rate of 450 s/m^2 were lower than the number of main stems, showing that some plants had no tillers. This could be due to the competition at the highest seed rates causing low or no tiller production, or more likely, death of tillers as the effects of water deficit and declining nutrient availability became apparent.

Ear numbers agreed with the stem number trends, but being significantly affected by the stem type in all years of the experiment. Main stem ear numbers were more stable in all years, as the main stem tended to produce an ear in all but the most competitive situations, while tillers were more variable in the response to seasonal and environmental conditions

This has potential consequences for grain production as if tillers per plant decrease as plant density rises, then the proportions of heads from main stems and heads from

tillers must change as plant density changes. Differences in the quality of the grain produced from different head types could cause differences in the quality of crops grown at different densities, even though other factors such as variety and management were the same.

Total plant dry matter production (ie. main stems and tillers not separated) at anthesis showed a significant result of seed rate only in 1998. This is likely to be due to the larger differences in plant density in 1998, the seeding rates in the later experiments being too close together to show differences. In support of this it can be seen in section 5.3.1.3.1 (Mean Dry Matter) that there are no significant differences between the mid range of densities (190 – 320 s/m^2), in which range the values chosen for 1999 and 2000 mostly fall.

Further, the dry matter weight per stem for each treatment measured at anthesis showed that in each year, stem type, seed rate and variety (if included in the treatment) had significant effects. This gives further support to the theory that varietal differences in quality may be partly accounted for by the physiological differences between them (van Herwaarden *et al.*, 1996(b)). Work by van Herwaarden *et al.* (1996(a); 1998(a); 1998(b); 1998(c)) on haying-off in wheat showed that non-structural carbohydrates, stored in the stems, played an important part in providing assimilate to the plant when under stress. This is of importance not only in conditions which may lead to haying off, but in the (similar) conditions that prevail during grain filling. It is known that non-structural (also known as water-soluble) carbohydrates play an important part in the filling of grain under conditions of water and/or heat stress (Pheloung and Siddique, 1991; Blum *et al.*, 1994; Blum *et*

al., 1997). The differences between the main stems and tillers in dry matter weight per stem may indicate that there are fewer reserves available for use by tiller heads than there are for main stem heads. This in turn may impact on the quality of the grain produced from each type of stem.

5.4.2 Harvest

Work by Anderson and Barclay (1991) has shown that as seed rate increases, yield also increases until a maximum is reached, at which point yield remains stable or declines as competition between plants results in death of plants, smaller heads and/or smaller seeds. The results of these experiments agreed with this.

Screenings percentages decreased with higher seeding rates in 2 of the 3 years of the study. This is probably due to the higher percentage of main stem heads in the higher density crops, since the main stem heads tend to produce larger grains, and more uniform grains than tillers.

The lower screenings percentages at the higher seeding rates agreed with work in Canada by Moes *et al.* (1992), which looked at the effect of increased seeding rate on seed size and found that more regular seed size was obtainable from evenly sown higher seeding rates. However Moes *et al* (1992) did not investigate the effects the seeding rates had on stem type distribution.

Protein appeared unaffected by seed rate throughout the experiment. This may have been due to the large amounts of N supplied, so that nitrogen was not a limiting factor in the experiments. However, there may have been other factors at work. It is not possible to tell from the current experiment whether seed rate affects protein percentage in the grain or not.

5.4.3 Physical Quality

Thousand-grain weights did not show consistent effects in all years. The results suggest that after a certain plant density is reached grain weight is more dependent on genetic factors than environmental ones. This is seen in the differences in grain weight between the two varieties.

Further, because the 1000-grain weight samples were taken after the grain was screened, samples would have been missing smaller grains that could have affected the measurements. This is consistent with the results from the screenings measurements, which showed that lower seeding rates had higher percentage screenings.

Work by Turner *et al.* (1994) showed that later formed tillers had smaller 1000-grain weights than main stems or the first tiller when the plants were subjected to stress during grain filling. The results from this experiment agree with the suggestion that the lower density crops with greater tiller numbers had lower 1000-grain weights and hence also higher screenings in the years when there were greater stresses on the plants during grain filling.

5.4.4 Milling and Flour Quality

There was no effect of seed rate on flour yield throughout the experiment. This suggests that flour yield is not easily affected by changing plant density. It must be remembered that all grain was screened over a 2mm sieve prior to milling, so any smaller grains from the different densities would be lost anyway. Further, an experiment by Schuler *et al* (1995), which examined the effects of physical grain characteristics on milling and flour yield in soft red winter wheats, showed that physical characteristics of grain had no effect on milling quality. It is feasible then

that the effects that the different seeding rates in this experiment had on the physical quality of the grain would not affect the milling quality. This is supported by the evidence of Marshall *et al* (1986), and Hook (1984), who both investigated the relationships between grain quality and milling yield (in Australia and the United Kingdom respectively) and came to similar conclusions.

Flour colour (Minolta "b" value) was affected by seed rate in all the years measured. There was a consistent trend towards higher (more yellow) "b" values at higher seed rates. Yellow colour is caused by the presence of xanthophylls (Simmonds, 1989) in the protein fraction of the endosperm. It is possible that at higher seeding rates, stress during grain filling caused greater amounts of these compounds to be deposited. Alternatively, the stress that occurred during grain filling could have reduced starch deposition to a slight degree, and hence increased protein percentage enough to cause a significant colour difference in the flour although the protein differences between treatments were not significant. If so, this would be of particular importance for further investigation using high protein wheats, as increased protein should theoretically result in yellower flour. However, this does not appear to be the case. Another explanation could be that the stress during grain filling caused the endosperm to be more closely associated with the bran, increasing the proportion of bran which passed into the flour when milled, and thus increased the yellowness of the flour.

An explanation, which at first could be plausible, is that smaller 1000-grain weights at higher seeding rates resulted in a higher proportion of bran to endosperm in the milled grain, and hence higher "b" values. However, the milling data do not support this theory, since there were no significant differences in milling yield between the seed rate treatments. Further, the 1000-grain weights did not significantly differ

between the higher seed rates whereas the differences in “b” values extend across the entire seed rate range.

There were differences in colour (“L”, “a” and “b”) apparent between the 2 varieties, however the interaction between the varieties and seed rates is of greater interest. It is well known that certain varieties differ in flour colour, but that environmental factors cause different flour colour responses in different varieties is of importance to breeders, growers and marketers. With this information, breeders can select for colour-stable varieties, growers may be able to optimise crops better though care in seeding rates and variety selection, and marketers select the wheats from the best areas to suit their needs in accordance with their clients’ demands.

5.4.5 Dough and Baking Quality

Farinograph and extensograph tests showed varietal differences (as would be expected, particularly between Janz and Kukri) but no effects of seed rate. This shows that these quality parameters were unaffected by changes in seed rate, and were affected more by genetic variables than by changes in the environment. This is consistent with other work that has shown that the quality of varieties can be predicted with more accuracy from their genetic data than from environmental measurements (Payne *et al.*, 1987), providing that the crop is not severely stressed, eg. sulphur deficiency or extreme heat stress. The results of farinograph and extensograph tests are heavily dependent on the types of protein (glutenins and gliadins) present in the flour, and it is known that protein production in the grain is less affected by ordinary water or heat stress than is the production of starch. Changes in seed rates therefore did not affect farinograph or extensograph measurements.

Seed rate had significant or close to significant effects on peak viscosity from the RVA measurements in all years. However, the differences were not consistent. More research would have to be conducted in this area to determine whether seed rate significantly affected RVA values or not. It is possible that the starch properties may have been affected in some way due to changes in the ratios of A and B granules. Brocklehurst and Evers (1977) found that mean starch granule sizes differed between large and small grains; it may be that tiller grains have different starch properties than grains from main stems.

In 1998, the year when the seed rates differed by the greatest amounts, the loaf volume of Janz was significantly higher at the lowest seeding rate than at the highest seeding rates. Kukri did not change significantly in loaf volume. This result was not seen in 1999 or 2000, possibly due to the smaller differences between seed rates. Alternatively, the result in 1998 could have been a seasonal difference, which would not show in all circumstances.

Loaf “b” colour showed significant differences similar to the flour “b” results. This shows that the increased yellowness of the flour caused by the increased seeding rates carried through to the baking stage, affecting the final quality of the product.

5.5 CONCLUSION

In summary, differences in plant density affected plant physiology, main stem and tiller numbers, yield, screenings percentages, flour colour, RVA peak height and loaf colour. Protein, flour yield, farinograph, extensograph and loaf volume were

unaffected by changes in seeding rate. The change in flour colour was the most unexpected result, and one that could have implications for end-product quality. To more closely examine whether the differences in quality were caused by the changes in proportions of main stems and tillers, samples of main stems and tillers were harvested in each year from within the trial plots. These samples were used to test for differences in various quality parameters that could be tested using small-scale equipment. Experiment 4 details the method and results from this study.

CHAPTER 6 EXPERIMENT 4 - EFFECTS OF CROP DENSITY ON MAIN STEM AND TILLER GRAIN QUALITY

6.1 INTRODUCTION

Tillers, the shoots that grow from the main stem, usually make up a significant proportion of the wheat crop biomass and grain harvest. Depending on the resources available, a wheat plant may produce many tillers, or no tillers at all (McMaster *et al.*, 1994; Metho *et al.*, 1998). Despite this, most studies on wheat grain physiology or stresses on grains have either concentrated on the main stem alone (by removing tillers as they grow), or have not differentiated between main stems and tillers. Although the physiological aspects of tiller growth have been well investigated (Williams and Langer, 1975; Williams *et al.*, 1975), the end product has been assumed to be similar to that of the main stem. A tiller, therefore, acts in the same way as a main stem, but with less time to complete filling in the field (as the tiller reaches anthesis later than it's main stem). Work by Turner *et al.* (1994) showed that tillers yielded less and produced grains of lower 1000-grain weight than main stems. However, little other work has been done assessing grain quality in this area, particularly from wheat grown in a field environment. No work appears to have been published where the dough or baking quality of tiller grain has been investigated and compared to that of main stem grain.

With the trend in South Australian wheat growing towards denser crops, and payment on quality attributes, the importance of knowing the contribution that tillers make to the quality of a crop is essential.

This experiment used individual heads gathered from the main stems and tillers produced in Experiment 3 to more closely check for differences in quality between main stem grains and tiller grains grown at different plant densities.

6.2 MATERIALS AND METHODS

6.2.1 Location, Soil and Climate

As for Chapter 5 .

6.2.2 Experiment Design

This experiment used the main stem and tiller ears collected from the experiments described in Chapter 5 . The growing conditions and treatments for the samples used for measurement and analysis are detailed in sections 5.2.2 and 5.2.3. After quality testing the grain from 1998, it was noted that the amount of grain derived from 25 ears was barely sufficient to provide enough flour for repeated quality testing, and although it was too late to alter the numbers for 1999, in 2000, 50 ears each of main stems and tillers were collected to ensure sufficient flour.

6.2.3 Measurements and Procedures

Each year after harvest the ears were stored for some weeks until threshing. The thresher used was a Walter-Wintersteiger drum thresher, and aspiration was used to remove chaff, leaving a clean sample. The grain from each sample was weighed, counted, and in 1999 and 2000, screened over a 2mm screen. The screenings were also weighed and counted. Thousand-grain weights were derived from the measurements.

In 1998, the grain was then taken to the CSIRO Grain Quality Research Laboratory (GQRL) at North Ryde, NSW. It was NIR analysed for protein and moisture, and then conditioned to 16% moisture prior to Quadrumat milling.

The milling products (flour and bran) were weighed and the bran discarded. The flour was re-tested using the NIR for moisture and protein.

The flour was then tested on a 2-gram mixograph, a scaled down version of the 35-gram mixograph used for ordinary quality testing. It measures dough development time, peak resistance (dough strength), maximum bandwidth, resistance breakdown and bandwidth breakdown. (See General Methods and Information.) The mixograph test is outlined in the AACC Method 54-40 (American Association of Cereal Chemists, 2000)**.**

The flour was also tested for extensibility on a small version of an extensograph. (See General Methodology.)

The flour was further tested for loaf characteristics by mixing the flour to a scaled down version of the baking test. (See General Methods and Information)

The grain collected in 1999 was held in cold storage (4 °C) until the next year and both the 1999 and 2000 grain samples were milled at the Waite Grain Quality Laboratory on a Quadrumat mill, using the same procedure as above. The flour was NIR analysed for moisture and protein, and also tested for colour characteristics using a Minolta colorimeter.

The samples were then taken to the CSIRO Grain Quality Research Laboratory and tested using the same procedures as previously on the 2-gram mixograph. However it was not possible to also perform thimble loaf baking tests or dough extensibility tests.

Table 78: Tests performed in Experiment 4.

Year	Samples Collected	Tests
1998	Main Stems	No. of Grains, Total Weight (yield), 1000-grain weight, Moisture, Protein, Flour yield, 2-gram mixograph, thimble loaf height (baking test), dough extensibility.
	Tillers	as above
1999	Main Stems	No. of Grains, Total Weight (yield), 1000-grain weight, % screenings, screenings 1000-grain weight, Moisture, Protein, Flour yield, Flour colour, 2-gram mixograph.
	Tillers	as above
2000	Main Stems	No. of Grains, Total Weight (yield), 1000-grain weight, % screenings, screenings 1000-grain weight, Moisture, Protein, Flour yield, Flour colour, 2-gram mixograph.
	Tillers	as above

6.2.4 Statistical Analysis

All data were analysed using the statistical package Genstat 5.

6.3 RESULTS

6.3.1 Harvest

6.3.1.1 Ear Yield

In 1998 the results showed 3 independent significant effects of variety, seed rate and stem type on the yield (g) per ear (Table 79).

Kukri had heavier yields than Janz, and yields per ear declined as seed rate increased.

Main stems produced heavier ears than tillers.

Table 79: Mean yield (g) per ear - Experiment 4, 1998.

Variety	
Janz	Kukri
1.40^{B}	1.48^{A}

Seed Rate				
65	190	260	320	450
1.94^{A}	1.53^{B}	1.31^{C}	1.25^{CD}	1.16^{D}

Stem Type	
Main Stems	Tillers
1.66^{A}	1.22^{B}

LSD *(P=0.05)*		
Variety	0.06	*(P = 0.011)*
Seed Rate	0.10	*(P < 0.001)*
Stem Type	0.06	*(P < 0.001)*
Variety.Seed Rate	n.s.	*(P = 0.151)*
Variety.Stem Type	n.s.	*(P = 0.429)*
Seed Rate.Stem Type	n.s.	*(P = 0.452)*
Variety.Seed Rate.Stem Type	n.s.	*(P = 0.831)*

In 1999, stem type only had a significant effect on ear yield, main stems again yielding higher than tillers (Table 80).

Table 80: Yield (g) per ear Experiment 4, 1999.

Stem Type	
Main Stems	Tillers
1.37^{A}	0.46^{B}

LSD *(P=0.05)*		
Stem Type	0.07	*(P < 0.001)*
Seed Rate	n.s.	*(P = 0.372)*
Stem Type x Seed Rate	n.s.	*(P = 0.838)*

In 2000, there was a variety-stem type interaction affecting the results and an independent effect of seed rate (Table 81).

Main stems were significantly different in ear yield from tillers for both varieties, and main stems of Janz yielded higher than main stems of Kukri. However tillers of the two varieties were not significantly different.

Table 81: Yield (g) per ear Experiment 4, 2000.

Variety	Stem Type	
	Main Stems	Tillers
Janz	1.71[A]	0.73[C]
Kukri	1.58[B]	0.73[C]

Seed Rate				
230	260	290	320	350
1.25[A]	1.21[AB]	1.19[B]	1.17[B]	1.11[C]

LSD *(P=0.05)*		
Variety	0.04	*(P < 0.001)*
Seed Rate	0.06	*(P < 0.001)*
Stem Type	0.04	*(P < 0.001)*
Variety.Seed Rate	n.s.	*(P = 0.183)*
Variety.Stem Type	0.05	*(P < 0.001)*
Seed Rate.Stem Type	n.s.	*(P = 0.117)*
Variety.Seed Rate.Stem Type	n.s.	*(P = 0.080)*

Overall, stem type had a significant effect in all years, with main effects in 1998 and 1999, and interaction with variety in 2000. Variety also had significant effects in 1999 and 2000, the two years that there were two varieties in the trial. There was a main effect of variety in 1998 and variety interacted with stem type in 2000. Seed rate showed significant main effects in 1998 and 2000, but not 1999.

6.3.1.2 Number of grains per ear

In 1998, number of grains per ear showed 3 significant independent effects (Table 82). Janz had more grains per ear than Kukri, more grains were produced at lower seed rates, and main stems produced more grains than tillers.

Table 82: Mean number of grains per ear (main stems and tillers) from Experiment 4, 1998.

Variety	
Janz	Kukri
40.1[A]	37.6[B]

Seed Rate				
65	190	260	320	450
50.0[A]	40.7[B]	36.1[C]	35.0[C]	32.4[D]

Stem Type	
Main Stems	Tillers
44.49[A]	33.18[B]

LSD *(P=0.05)*		
Variety	1.4	*(P = 0.001)*
Seed Rate	2.3	*(P < 0.001)*
Stem Type	1.4	*(P < 0.001)*
Variety.Seed Rate	n.s.	*(P = 0.427)*
Variety.Stem Type	n.s.	*(P = 0.369)*
Seed Rate.Stem Type	n.s.	*(P = 0.533)*
Variety.Seed Rate.Stem Type	n.s.	*(P = 0.700)*

In 1999 there was a significant difference apparent between the stem types, with main stems producing more grains than tillers (Table 83).

Table 83: Mean no. of grains per ear Experiment 4, 1999.

Stem Type	
Main Stems	Tillers
35.46[A]	14.03[B]

LSD *(P=0.05)*		
Stem Type	1.74	*(P < 0.001)*
Seed Rate	n.s.	*(P = 0.552)*
Stem Type x Seed Rate	n.s.	*(P = 0.728)*

In 2000, a significant interaction was again present between variety and stem type, and there was an independent significant effect of seed rate (Table 84).

Janz had greater numbers of grains per ear than Kukri for both main stems and tillers, and main stems produced more grains than tillers for both varieties.

Table 84: Mean no. of grains per ear, Experiment 4, 2000.

Variety	Stem Type	
	Main Stems	Tillers
Janz	50.74^{A}	23.52^{C}
Kukri	36.29^{B}	19.81^{D}

Seed Rate				
230	260	290	320	350
33.38^{A}	33.21^{A}	33.04^{A}	32.62^{A}	30.66^{B}

LSD *(P=0.05)*		
Variety	0.559	*(P < 0.001)*
Seed Rate	0.884	*(P = 0.019)*
Stem Type	0.559	*(P < 0.001)*
Variety.Seed Rate	n.s.	*(P = 0.493)*
Variety.Stem Type	0.79	*(P < 0.001)*
Seed Rate.Stem Type	n.s.	*(P = 0.079)*
Variety.Seed Rate.Stem Type	n.s.	*(P = 0.192)*

Overall, grains per ear showed similar results to yield over the 3 years – stem type was a significant effect in all 3 years, while variety and seed rate were significant in 1998 and 2000.

6.3.1.3 Screenings (%) per Ear

No screenings measurements were taken in 1998.

In 1999 tillers produced significantly more screenings than main stems (Table 85).

Seed rate was not significant (P= 0.08).

Table 85: Mean screenings (%) Experiment 4, 1999.

Stem Type	
Main Stems	Tillers
4.3[A]	6.0[B]

LSD *(P=0.05)*		
Stem Type	0.9	*(P < 0.001)*
Seed Rate	n.s.	*(P = 0.080)*
Stem Type x Seed Rate	n.s.	*(P = 0.135)*

In 2000, there was again a variety-stem type interaction (Table 86). Janz produced more screenings than Kukri for both stem types, but Janz main stems produced more screenings than Janz tillers while Kukri main stems produced less screenings than Kukri tillers.

Table 86: Mean screenings % Experiment 4, 2000.

Variety	Stem Type	
	Main Stems	Tillers
Janz	7.7[A]	6.7[B]
Kukri	3.4[D]	4.8[C]

LSD *(P=0.05)*		
Variety	0.5	*(P < 0.001)*
Seed Rate	n.s.	*(P = 0.141)*
Stem Type	n.s.	*(P = 0.715)*
Variety.Seed Rate	n.s.	*(P = 0.176)*
Variety.Stem Type	0.7	*(P = 0.016)*
Seed Rate.Stem Type	n.s.	*(P = 0.360)*
Variety.Seed Rate.Stem Type	n.s.	*(P = 0.990)*

Stem type significantly affected screenings percentage in both the years screenings measures were performed.

6.3.2 Physical Quality

6.3.2.1 Thousand-grain weights of grains from main stems and tillers.

In 1998 there was a significant interaction between variety and seed rate accompanied by an independent effect of stem type (Table 87).

Janz had significantly lower 1000-grain weights than Kukri for all seed rates, and higher 1000-grain weights at seed rates of 65 and 190 s/m^2 than at 260, 320 and 450 s/m^2.

Kukri had the highest 1000-grain weight at 65 s/m^2, and significantly lower 1000-grain weights between 190 and 450 s/m^2.

Main stems had higher 1000-grain weights than tillers.

Table 87: Mean 1000 grain weights (g) of main stems and tillers from Experiment 4, 1998.

Variety	Seed Rate				
	65	190	260	320	450
Janz	36.95^{C}	36.38^{C}	33.64^{D}	32.52^{D}	33.30^{D}
Kukri	40.43^{A}	39.04^{B}	38.75^{B}	38.78^{B}	38.59^{B}

Stem Type	
Main Stems	Tillers
37.23^{A}	36.44^{B}

LSD *(P=0.05)*		
Variety	0.63	*(P < 0.001)*
Seed Rate	0.10	*(P < 0.001)*
Stem Type	0.63	*(P = 0.014)*
Variety.Seed Rate	1.37	*(P = 0.004)*
Variety.Stem Type	n.s.	*(P = 0.429)*
Seed Rate.Stem Type	n.s.	*(P = 0.452)*
Variety.Seed Rate.Stem Type	n.s.	*(P = 0.831)*

In 1999 there were significant differences in 1000-grain weight between stem types, with main stems having higher 1000-grain weights than tillers (Table 88).

Table 88: Mean 1000-grain weights Experiment 4, 1999

	Stem Type	
	Main Stems	Tillers
	38.71[A]	32.56[B]

LSD *(P=0.05)*		
Stem Type	0.72	*(P < 0.001)*
Seed Rate	n.s.	*(P = 0.191)*
Stem Type x Seed Rate	n.s.	*(P = 0.547)*

In 2000, there was a significant variety-stem type interaction present, but no significant effect of seed rate (Table 89).

Kukri had higher 1000-grain weights than Janz for both stem types, while main stems had higher 1000-grain weights than tillers for both varieties.

Table 89: Mean 1000-grain weights of Experiment 4, 2000.

Variety	Stem Type	
	Main Stems	Tillers
Janz	33.75[C]	30.87[D]
Kukri	43.56[A]	36.81[B]

LSD *(P=0.05)*		
Variety	0.47	*(P < 0.001)*
Seed Rate	n.s.	*(P = 0.156)*
Stem Type	0.47	*(P < 0.001)*
Variety.Seed Rate	n.s.	*(P = 0.153)*
Variety.Stem Type	0.67	*(P < 0.001)*
Seed Rate.Stem Type	n.s.	*(P = 0.436)*
Variety.Seed Rate.Stem Type	n.s.	*(P = 0.881)*

Overall, stem type showed significant main effects in 1998 and 1999, and interacted with variety in 2000. Variety also had an effect in 1998, interacting with seed rate.

6.3.2.2 Screenings 1000-grain weights of main stems and tillers

Screenings 1000-grain weight was not measured in 1998.

The results from 1999 showed a significant difference between stem types for screenings 1000-grain weight (Table 90). Main stems had higher screenings 1000-grain weights than tillers.

Table 90: Mean screenings 1000-grain weights, Experiment 4, 1999

	Stem Type	
	Main Stems	Tillers
	19.34^{A}	18.02^{B}

LSD *(P=0.05)*		
Stem Type	0.65	*(P < 0.001)*
Seed Rate	n.s.	*(P = 0.597)*
Stem Type x Seed Rate	n.s.	*(P = 0.210)*

In 2000 there were significant independent effects of variety and stem type on screenings 1000-grain weight (Table 91).

Kukri had higher screenings 1000-grain weights than Janz, and main stems had higher screenings 1000-grain weights than tillers.

Table 91: Mean screenings 1000-grain weights, Experiment 4, 2000.

Variety	
Janz	Kukri
18.94[A]	21.12[B]

Stem Type	
Main Stems	Tillers
20.69[A]	19.38[B]

LSD *(P=0.05)*		
Variety	0.53	*(P < 0.001)*
Seed Rate	n.s.	*(P = 0.904)*
Stem Type	0.53	*(P < 0.001)*
Variety.Seed Rate	n.s.	*(P = 0.537)*
Variety.Stem Type	n.s.	*(P = 0.870)*
Seed Rate.Stem Type	n.s.	*(P = 0.551)*
Variety.Seed Rate.Stem Type	n.s.	*(P = 0.700)*

Stem type showed significant main effects on screenings 1000-grain weight in 1999 and 2000. Seed rate was not significant in either year.

6.3.3 Milling and Flour Quality

6.3.3.1 Flour yield from main stems and tillers

As samples from 1998 were milled on a different mill from the samples of 1999 and 2000, there is a considerable difference apparent in the amounts of flour yielded from each year.

In 1998 there were significant differences apparent between varieties and stem types (Table 92). Janz yielded higher than Kukri, and main stem grains yielded more flour than tiller grains.

Table 92: Mean flour yield (%), Experiment 4, 1998.

Variety	
Janz	Kukri
47.10[A]	45.12[B]

Stem Type	
Main Stems	Tillers
46.59[A]	45.63[B]

LSD *(P=0.05)*		
Variety	0.66	*(P < 0.001)*
Seed Rate	n.s.	*(P = 0.321)*
Stem Type	0.66	*(P = 0.005)*
Variety.Seed Rate	n.s.	*(P = 0.910)*
Variety.Stem Type	n.s.	*(P = 0.741)*
Seed Rate.Stem Type	n.s.	*(P = 0.359)*
Variety.Seed Rate.Stem Type	n.s.	*(P = 0.088)*

Flour yield in 1999 was not significantly different between treatments.

Flour yield in 2000 showed significant independent effects of variety and stem type (Table 93). Kukri had higher flour yield than Janz and tillers had higher flour yield than main stems.

Table 93: Mean flour yield (%), Experiment 4, 2000.

Variety	
Janz	Kukri
69.00[A]	69.47[B]

Stem Type	
Main Stems	Tillers
68.18[A]	70.30[B]

LSD *(P=0.05)*		
Variety	0.39	*(P = 0.020)*
Seed Rate	n.s.	*(P = 0.299)*
Stem Type	0.39	*(P < 0.001)*
Variety.Seed Rate	n.s.	*(P = 0.345)*
Variety.Stem Type	n.s.	*(P = 0.285)*
Seed Rate.Stem Type	n.s.	*(P = 0.737)*
Variety.Seed Rate.Stem Type	n.s.	*(P = 0.382)*

Flour yield results varied from year to year, however there was no consistent significant result of any treatment apart from variety in any of the years measured.

6.3.3.2 Flour Protein

Flour protein content is generally approximately 1% less than grain protein content. Variety and seed rate had significant independent effects on flour protein levels from main stems and tillers in 1998 (Table 94). Stem type had no significant effect (P = 0.083).

Kukri had higher flour protein than Janz. Flour protein was highest at 260 s/m^2 but not significantly different from 320 or 450 s/m^2, and lowest at 190 s/m^2.

Table 94: Mean flour protein, Experiment 4, 1998

Variety	
Janz	Kukri
12.04[A]	12.63[B]

Seed Rate				
65	190	260	320	450
12.23[BC]	11.93[C]	12.58[A]	12.48[AB]	12.44[AB]

LSD *(P=0.05)*		
Variety	0.20	*(P < 0.001)*
Seed Rate	0.33	*(P = 0.001)*
Stem Type	n.s.	*(P = 0.083)*
Variety.Seed Rate	n.s.	*(P = 0.343)*
Variety.Stem Type	n.s.	*(P = 0.142)*
Seed Rate.Stem Type	n.s.	*(P = 0.751)*
Variety.Seed Rate.Stem Type	n.s.	*(P = 0.791)*

Flour protein content in 1999 was not significantly different between treatments.

In 2000 flour protein differed significantly between variety and seed rate but not stem type (Table 95).

Kukri had higher flour protein than Janz over all treatments.

Flour protein was highest at 290 s/m^2, and lowest at 230 s/m^2.

Table 95: Mean flour protein content, Experiment 4, 2000.

Variety	
Janz	Kukri
9.94^{A}	11.24^{B}

Seed Rate				
230	260	290	320	350
10.24^{C}	10.54^{BC}	10.95^{A}	10.48^{BC}	10.75^{AB}

LSD *(P=0.05)*		
Variety	0.24	*(P < 0.001)*
Seed Rate	0.39	*(P = 0.006)*
Stem Type	n.s.	*(P = 0.770)*
Variety.Seed Rate	n.s.	*(P = 0.695)*
Variety.Stem Type	n.s.	*(P = 0.122)*
Seed Rate.Stem Type	n.s.	*(P = 0.991)*
Variety.Seed Rate.Stem Type	n.s.	*(P = 0.724)*

Overall, flour protein content was significantly affected by variety and seed rate in 2 of the 3 years tested (1998 and 2000). However, very few samples attained high levels of protein, as are required for Prime Hard quality classes.

6.3.3.3 Flour colour of main stems and tillers.

Flour colour of main stems and tillers was not measured in 1998.

Flour colour measures “L”, and “a” showed no significant differences between treatments in 1999.

Flour colour “b” showed a significant difference between stem types in 1999 (Table 96).

Table 96: Mean flour colour "b", Experiment 4, 1999.

Stem Type	
Main Stems	Tillers
10.42[A]	10.71[B]

LSD *(P=0.05)*		
Stem Type	0.22	*(P < 0.001)*
Seed Rate	n.s.	*(P = 0.895)*
Stem Type x Seed Rate	n.s.	*(P = 0.681)*

The flour colour parameter "L-b" also showed significant differences between stem types in 1999 (Table 97).

Table 97: Mean flour colour "L-b", Experiment 4, 1999.

Stem Type	
Main Stems	Tillers
79.52[A]	79.16[B]

LSD *(P=0.05)*		
Stem Type	0.38	*(P = 0.002)*
Seed Rate	n.s.	*(P = 0.714)*
Stem Type x Seed Rate	n.s.	*(P = 0.423)*

In 2000, flour colours "L", "b" and "L-b" showed significant differences between treatments (Table 98, Table 99 and Table 100). Flour colour "a" showed no significant differences between treatments.

"L" values showed an interaction of variety and seed rate (0). Janz "L" values were higher than Kukri "L" values, but did not vary with seed rate. Kukri "L" values were lowest at 290 s/m^2 and highest at 320 s/m^2. These values were significantly different from each other, but not significantly different from the other Kukri seed rate values.

Table 98: Mean flour colour "L", Experiment 4, 2000.

Variety	Seed Rate				
	230	260	290	320	350
Janz	90.17^{A}	90.06^{A}	90.24^{A}	90.08^{A}	90.23^{A}
Kukri	89.70^{BC}	89.76^{BC}	89.59^{C}	89.79^{B}	89.76^{BC}

LSD *(P=0.05)*		
Variety	0.08	*(P < 0.001)*
Seed Rate	n.s.	*(P = 0.650)*
Stem Type	n.s.	*(P = 0.972)*
Variety.Seed Rate	0.18	*(P = 0.037)*
Variety.Stem Type	n.s.	*(P = 0.769)*
Seed Rate.Stem Type	n.s.	*(P = 0.704)*
Variety.Seed Rate.Stem Type	n.s.	*(P = 0.452)*

The "b" values of the flour in 2000 showed independent significant effects of variety and stem type (Table 99). Kukri had higher "b" values than Janz, and tillers had higher "b" values than main stems.

Table 99: Mean "b" values, Experiment 4, 2000.

Variety	
Janz	Kukri
10.75^{A}	11.34^{B}

Stem Type	
Main Stems	Tillers
10.93^{A}	11.16^{B}

LSD *(P=0.05)*		
Variety	0.10	*(P < 0.001)*
Seed Rate	n.s.	*(P = 0.330)*
Stem Type	0.10	*(P < 0.001)*
Variety.Seed Rate	n.s.	*(P = 0.527)*
Variety.Stem Type	n.s.	*(P = 0.110)*
Seed Rate.Stem Type	n.s.	*(P = 0.649)*
Variety.Seed Rate.Stem Type	n.s.	*(P = 0.190)*

The “L-b” colour measures from 2000 also showed independent significant effects of variety and seed rate. Janz had higher “L-b” values than Kukri, and main stems had higher “L-b” values than tillers.

Table 100: Flour colour “L-b” Experiment 4, 2000.

Variety	
Janz	Kukri
79.41[A]	78.38[B]

Stem Type	
Main Stems	Tillers
79.01[A]	78.77[B]

LSD *(P=0.05)*		
Variety	0.15	*(P < 0.001)*
Seed Rate	n.s.	*(P = 0.481)*
Stem Type	0.15	*(P = 0.002)*
Variety.Seed Rate	n.s.	*(P = 0.149)*
Variety.Stem Type	n.s.	*(P = 0.207)*
Seed Rate.Stem Type	n.s.	*(P = 0.550)*
Variety.Seed Rate.Stem Type	n.s.	*(P = 0.167)*

Flour “b” and “L-b” colour values showed significant main effects of stem type in all years measured. “L” values were significant in only one year, but “a” values were not significant in all years.

6.3.4 Dough and Baking Quality of Main Stems and Tillers

6.3.4.1 2-gram Mixograph

6.3.4.1.1 Mix time

There was a significant interaction of variety and stem type for mix time in 1998 (Table 101). Kukri had a longer mix time than Janz for both main stems and tillers.

Main stems were not significantly different from tillers for the variety Janz, but tillers had significantly shorter mixing times than main stems for the variety Kukri.

Table 101: Mean mix time (s) Experiment 4, 1998.

Variety	Stem Type	
	Main Stems	Tillers
Janz	246.5^{C}	239.6^{C}
Kukri	359.3^{A}	322.3^{B}

LSD *(P=0.05)*		
Variety	14.6	*(P < 0.001)*
Seed Rate	n.s.	*(P = 0.424)*
Stem Type	14.6	*(P = 0.004)*
Variety.Seed Rate	n.s.	*(P = 0.642)*
Variety.Stem Type	20.6	*(P = 0.043)*
Seed Rate.Stem Type	n.s.	*(P = 0.252)*
Variety.Seed Rate.Stem Type	n.s.	*(P = 0.877)*

Mean mix time showed no significant differences between treatments in 1999. There were significant independent effects of variety and of stem type on mix times in 2000 (Table 102). Kukri had longer mix times than Janz, and all main stems had shorter mix times than tillers.

Table 102: Mean mix time (s), Experiment 4, 2000.

Variety	
Janz	Kukri
174.3[A]	210.6[B]

Stem Type	
Main Stems	Tillers
185.8[A]	199.1[B]

LSD *(P=0.05)*		
Variety	4.2	*(P < 0.001)*
Seed Rate	n.s.	*(P = 0.363)*
Stem Type	4.2	*(P < 0.001)*
Variety.Seed Rate	n.s.	*(P = 0.640)*
Variety.Stem Type	n.s.	*(P = 0.799)*
Seed Rate.Stem Type	n.s.	*(P = 0.299)*
Variety.Seed Rate.Stem Type	n.s.	*(P = 0.689)*

Variety and stem type were both significant in 2 of the 3 years measured; there was an interaction in 1998 and main effects in 2000. Seed rate had no effect on mix time in any year.

6.3.4.1.2 Peak Resistance

Peak resistance in 1998 showed a significant effect of variety but no other factors. Kukri had a higher peak resistance than Janz.

In 1999 peak resistance showed a significant effect of seed rate (Table 103), with the highest values at 260, 300, 320 and 350 s/m^2, and lowest at 280 and 380 s/m^2.

Table 103: Mean Peak Resistance (MU), Experiment 4, 1999

Seed Rate					
260	280	300	320	350	380
379.6^{A}	368.5^{BC}	373.0^{ABC}	378.3^{AB}	381.3^{A}	367.5^{C}

LSD *(P=0.05)*		
Stem Type	n.s.	*(P = 0.645)*
Seed Rate	10.3	*(P = 0.030)*
Stem Type x Seed Rate	n.s.	*(P = 0.412)*

In 2000 peak resistance showed a significant interaction of variety and seed rate (Table 104). For the variety Janz, peak resistance increased between 230 and 290 s/m^2, then decreased. For the variety Kukri, although values varied, there was a general trend towards increased resistance at higher seed rates.

The interaction between stem type and variety was also close to significant (P = 0.066).

Table 104: Mean Peak Resistance (MU) Experiment 4, 2000.

Variety	Seed Rate				
	230	260	290	320	350
Janz	327.9^{G}	337.1^{FG}	345.4^{EF}	337.4^{FG}	332.0^{G}
Kukri	361.0^{CD}	350.7^{DE}	377.5^{AB}	365.8^{BC}	379.2^{A}

LSD *(P=0.05)*		
Variety	5.5	*(P < 0.001)*
Seed Rate	8.7	*(P < 0.001)*
Stem Type	n.s.	*(P = 0.073)*
Variety.Seed Rate	12.3	*(P = 0.006)*
Variety.Stem Type	n.s.	*(P = 0.066)*
Seed Rate.Stem Type	n.s.	*(P = 0.964)*
Variety.Seed Rate.Stem Type	n.s.	*(P = 0.265)*

Overall, stem type showed no effects on peak resistance in any year. Seed rate affected peak resistance with a main effect in 1998 and interacting with variety in 2000.

6.3.4.1.3 Bandwidth

In 1998 there was a significant interaction of seed rate and stem type, and an independent significant effect of variety (Table 105).

Mean bandwidth for main stems did not differ significantly between seed rates, but mean bandwidth for tillers was significantly greater for the lowest seed rate (65 s/m^2) and lower at the higher seed rates of 260, 320 and 450 s/m^2. Main stems and tillers differed significantly between some but not all seed rates.

Kukri had a greater bandwidth than Janz.

Table 105: Mean Maximum Bandwidth (MU), Experiment 4, 1998

Stem Type	Seed Rate				
	65	190	260	320	450
Main Stems	28.2^{BC}	29.1^{AB}	27.3^{BC}	28.7^{BC}	29.2^{AB}
Tillers	31.0^{A}	29.1^{AB}	28.1^{BC}	29.0^{ABC}	27.1^{C}

Variety	
Janz	Kukri
27.17^{A}	29.17^{B}

LSD *(P=0.05)*		
Variety	0.9	*(P = 0.030)*
Seed Rate	n.s.	*(P = 0.072)*
Stem Type	n.s.	*(P = 0.411)*
Variety.Seed Rate	n.s.	*(P = 0.141)*
Variety.Stem Type	n.s.	*(P = 0.287)*
Seed Rate.Stem Type	2.0	*(P = 0.023)*
Variety.Seed Rate.Stem	n.s.	*(P = 0.666)*

Maximum bandwidth in 1999 showed a significant effect of seed rate (Table 106). Stem type was close to significant (P=0.051).

Bandwidth was greatest at 320 s/m^2, and lowest at 280 and 380 s/m^2. Main stems had greater bandwidth than tillers, but the difference was not quite significant.

Table 106: Mean Maximum Bandwidth (MU), Experiment 4, 1999.

Stem Type	
Main Stems	Tillers
241.9	238.2

Seed Rate					
260	280	300	320	350	380
240.1^{ABC}	235.6^{D}	239.6^{B}	245.2^{A}	242.9^{AB}	237.1^{CD}

LSD *(P=0.05)*		
Stem Type	n.s *(6.4)*	*(P = 0.051)*
Seed Rate	3.7	*(P = 0.039)*
Stem Type x Seed Rate	n.s.	*(P = 0.411)*

In 2000 there were significant independent effects of variety and seed rate, but not stem type (Table 107).

Kukri had higher bandwidth than Janz. Bandwidth was significantly lower at 260 s/m^2 than 290 and 350 s/m^2, while 230 and 320 s/m^2 showed no significant differences from any other treatments.

Table 107: Mean Maximum Bandwidth (MU), Experiment 4, 2000.

Variety	
Janz	Kukri
218.9[A]	239.0[B]

Seed Rate				
230	260	290	320	350
226.9[AB]	224.9[B]	232.9[A]	227.7[AB]	232.4[A]

LSD *(P=0.05)*		
Variety	3.9	*(P < 0.001)*
Seed Rate	6.2	*(P = 0.042)*
Stem Type	n.s.	*(P = 0.486)*
Variety.Seed Rate	n.s.	*(P = 0.143)*
Variety.Stem Type	n.s.	*(P = 0.231)*
Seed Rate.Stem Type	n.s.	*(P = 0.756)*
Variety.Seed Rate.Stem Type	n.s.	*(P = 0.196)*

Seed rate affected maximum bandwidth in all years – in interaction with stem type in 1998 and as a main effect in 1999 and 2000. Stem type and variety were significant in some but not all years.

6.3.4.1.4 Resistance Breakdown

There was a varietal effect only on resistance breakdown in 1998.

There were no significant effects present in 1999.

In 2000 there was a significant interaction of variety and seed rate, and an independent significant effect of stem type on dough resistance to breakdown (Table 108). Main stems showed greater resistance to breakdown than tillers for all treatments. There were no significant differences between seed rates for Janz, however for Kukri the value at 290 s/m^2 was significantly higher than all other Kukri seed rates. Kukri tended to have lower resistance to breakdown then Janz, but the differences were not always significant.

Table 108: Resistance breakdown (%), Experiment 4, 2000.

	Stem Type	
	Main Stems	Tillers
	16.3^{A}	11.4^{B}

Variety	Seed Rate				
	230	260	290	320	350
Janz	14.5^{ABC}	14.5^{ABC}	13.7^{ABC}	15.1^{A}	14.4^{ABC}
Kukri	12.1^{D}	13.3^{CD}	14.9^{AB}	13.1^{CD}	13.2^{CD}

LSD *(P=0.05)*		
Variety	0.7	*(P < 0.001)*
Seed Rate	n.s.	*(P = 0.447)*
Stem Type	0.7	*(P < 0.001)*
Variety.Seed Rate	1.5	*(P = 0.011)*
Variety.Stem Type	n.s.	*(P = 0.614)*
Seed Rate.Stem Type	n.s.	*(P = 0.479)*
Variety.Seed Rate.Stem Type	n.s.	*(P = 0.092)*

Overall, resistance breakdown showed no consistent effects of any of the factors over the 3 years of the experiment.

6.3.4.1.5 Bandwidth Breakdown

There was a significant varietal effect present in 1998, but no other significant effects.

There was a significant effect of stem type on bandwidth breakdown in 1999 (Table 109). Main stems had a greater bandwidth breakdown percentage than tillers.

Table 109: Bandwidth breakdown (%), Experiment 4, 1999.

Stem Type	
Main Stems	Tillers
43.6[A]	39.8[B]

LSD *(P=0.05)*		
Stem Type	1.8	*(P < 0.001)*
Seed Rate	n.s.	*(P = 0.191)*
Stem Type x Seed Rate	n.s.	*(P = 0.896)*

There was a significant interaction of variety and seed rate and a significant independent effect of stem type in 2000 (Table 110), where main stems had greater bandwidth breakdown than tillers.

Janz showed no significant difference in bandwidth breakdown between all seed rates, while Kukri had significantly higher bandwidth breakdown at 290, 320 and 350 s/m^2 than at 230 or 260 s/m^2. Kukri also had significantly higher bandwidth breakdown values at 290, 320 and 350 s/m^2 than all Janz values except 230 s/m^2.

Table 110: Bandwidth breakdown (%) Experiment 4, 2000.

	Stem Type	
	Main Stems	Tillers
	37.3^{A}	32.3^{B}

Variety	Seed Rate				
	230	260	290	320	350
Janz	36.1^{AB}	34.0^{B}	34.0^{B}	33.1^{B}	33.5^{B}
Kukri	33.4^{B}	33.7^{B}	37.6^{A}	35.4^{A}	37.4^{A}

LSD *(P=0.05)*		
Variety	n.s.	*(P = 0.051)*
Seed Rate	n.s.	*(P = 0.318)*
Stem Type	1.4	*(P < 0.001)*
Variety.Seed Rate	3.0	*(P = 0.010)*
Variety.Stem Type	n.s.	*(P = 0.953)*
Seed Rate.Stem Type	n.s.	*(P = 0.939)*
Variety.Seed Rate.Stem Type	n.s.	*(P = 0.422)*

Bandwidth breakdown did not show any consistent significant effects of any of the variables over the 3 years of the experiment.

6.3.4.2 2-gram Extensograph

6.3.4.2.1 Extensibility

Dough extensibility tests were only performed in 1998. The machinery was unavailable for the 1999 and 2000 tests.

There was a highly significant 3-way interaction present for dough extensibility in 1998 (Table 111).

Janz main stems had significantly lower extensibility than tillers at 65 s/m^2, but were not significantly different from tillers at all other seed rates.

Kukri main stems had significantly lower extensibility than tillers at 190 and 260 s/m^2, and were not significantly different at the other seed rates.

The two varieties differed in extensibility on the main stems at 190 and 260 s/m^2, where Janz main stems showed significantly greater extensibility than Kukri main stems.

The two varieties also showed significantly different extensibility for tiller measurements at 65, 260 and 320 s/m^2, where Janz had higher tiller extensibility than Kukri.

The higher seed rates of 260, 320 and 450 s/m^2 showed significantly greater extensibility than the lower ones (65 and 190 s/m^2) for Janz main stems. Kukri main stems were significantly greater in extensibility at 320 and 450 s/m^2 than at 190 s/m^2, while 65 and 260 s/m^2, were not significantly different from either.

Janz tillers showed a significant difference between 65, 260 and 320 s/m^2 and 190 and 450 s/m^2. Kukri tillers had significantly greater extensibility at 190 and 260 s/m^2 than at 65 and 320 s/m^2, while 450 s/m^2 was not significantly different from either group.

Table 111: Dough extensibility (cm), Experiment 4, 1998.

Variety	Stem Type	Seed Rate				
		65	190	260	320	450
Janz	Main Stems	11.5^{GHI}	11.7^{EFGH}	13.4^{AB}	12.5^{BCDEF}	12.9^{ABCD}
	Tillers	13.3^{AB}	12.0^{DEFGH}	13.6^{A}	13.3^{ABC}	12.2^{DEFG}
Kukri	Main Stems	11.6^{FGHI}	10.7^{I}	11.4^{GHI}	11.9^{DEFGH}	12.3^{CDEFG}
	Tillers	11.2^{GHI}	12.6^{BCDE}	12.5^{BCDEF}	11.0^{HI}	11.9^{DEFGH}

LSD *(P=0.05)*		
Variety	0.3	*(P < 0.001)*
Seed Rate	0.5	*(P = 0.002)*
Stem Type	0.3	*(P = 0.021)*
Variety.Seed Rate	0.7	*(P = 0.021)*
Variety.Stem Type	n.s.	*(P = 0.476)*
Seed Rate.Stem Type	0.7	*(P = 0.010)*
Variety.Seed Rate.Stem Type	1.0	*(P < 0.001)*

6.3.4.2.2 Dough Strength (N)

The values in 1998 for the force exerted by the dough on the apparatus showed a significant interaction of variety and stem type and a significant interaction of stem type and seed rate (Table 112).

Janz strength was significantly less than that of Kukri for both stem types, with no significant difference between Janz main stems and Janz tillers.

Kukri main stems showed a significantly larger strength than Kukri tillers.

There were no significant differences between main stems and tillers at the different seed rates except at 450 s/m^2, where main stems had significantly higher strength than tillers.

Main stem strength at 320 s/m^2 was significantly lower than the strength at 65 and 450 s/m^2, but not significantly different to the strength at 190 and 260 s/m^2, showing that the dough strength decreased as seed rate increased until 320 s/m^2, at which point strength increased.

Tiller dough strength decreased as seed rate increased, with the value at 450 s/m^2 significantly lower than the values at 65, 190 and 260 s/m^2.

Table 112: Dough strength (N), Experiment 4, 1998.

Variety	Stem Type	
	Main Stems	Tillers
Janz	0.398^{C}	0.393^{C}
Kukri	0.567^{A}	0.527^{B}

Stem Type	Seed Rate				
	65	190	260	320	450
Main Stems	0.497^{AB}	0.468^{BC}	0.472^{BC}	0.453^{CD}	0.523^{A}
Tillers	0.496^{AB}	0.470^{BC}	0.479^{BC}	0.441^{CD}	0.415^{D}

LSD *(P=0.05)*		
Variety	0.017	*(P < 0.001)*
Seed Rate	0.028	*(P = 0.016)*
Stem Type	0.017	*(P = 0.013)*
Variety.Seed Rate	n.s.	*(P = 0.862)*
Variety.Stem Type	0.025	*(P = 0.048)*
Seed Rate.Stem Type	0.039	*(P < 0.001)*
Variety.Seed Rate.Stem Type	n.s.	*(P = 0.224)*

6.3.4.3 Loaf Height

There was a varietal effect on loaf height present in 1998, but no other significant effects.

Thimble loaf tests were not performed in 1999 and 2000.

6.4 DISCUSSION

6.4.1 Harvest

The results showed that main stem ears were consistently higher in grain numbers and had larger grains than tiller ears, as was expected from the literature (Fraser and Dougherty, 1978; Sims and Aitken, 1979; Anderson, 1986). In 1998 tiller ears had an average yield of 73 % of the yield of main stem ears, in 1999 this was 33 % and in 2000 tillers yielded 44 % that of main stems. However, these averages were affected by the changing seed rate treatments in these years. For example, in 1998, the mean ear yield was 1.94 grams at the lowest density of 65 p/m^2, but 1.16 g per ear at 450 p/m^2.

The change in yield (g per ear) between main stems and tillers was due to a combination of the numbers of seeds (main stems consistently had higher numbers of seeds/ear than tillers) and the seed weights (again, main stems had higher 1000-grain weights than tillers). This agrees with the results of a study by Sims and Aitken (1979) which concluded that main stems had more grains and grains of higher 1000-grain weight than tillers.

The yield per ear differences apparent between seed rates were also affected by this, since the number of grains per ear decreased as seeding rate increased, as did 1000-grain weights. Indirect confirmation of this is seen in the experiment by Kemp & Whingwiri (1980) where, as tillers were removed from wheat plants, yield on the main stem increased, principally due to more kernels per ear. This can also vary between varieties – for example, in a series of experiments by Anderson and Barclay (1991) the variety Gutha required only half the population density of Aroona or Gamenya to achieve it's optimum yield. This shows that the yield "plateau" for some

varieties may be reached at much lower densities than for other varieties. It is not known if this effect also exists regarding the quality of the grain from such crops, or if there are changes in the grain quality. No marked differences in the yield response to seed rate were seen in the 2 varieties used in this study.

In summary, yield per ear decreased as seed rate increased, presumably due to the effects of competition. The implications of this for yield are well documented, as the increased yield at higher seeding rates is due to the greater number of ears/m^2 outweighing the effects of smaller yields per ear. However, associated changes in quality may also take place, as seen in the quality measurements taken in this experiment, and in the previous chapter.

6.4.2 Physical Quality

Thousand-grain weight was significantly higher for main stems than tillers in all years of the study. This agrees with the results of Turner *et al.* (1994) and Sims and Aitken (1979). Seed rate affected 1000-grain weights only at the lowest seeding rate, suggesting that extremely low rates are needed to reduce the stem density to the point where each ear is relatively free of competition for resources. Varietal differences occurred in each year, showing that 1000-grain weight is strongly dependent on genetic factors. This agrees with results obtained by Fischer and HilleRisLambers (1978), comparing older and modern wheat cultivars with respect to yield components.

An interesting observable fact was the differences in screenings obtained from the two stem types. In 1999 and 2000, the single variety Kukri showed higher screenings from tiller heads than main heads, as should be expected. However in 2000, Janz showed higher screenings from main stem heads than tillers. Whether this is a real result or an unusual observation is unknown. If this was due to better grain filling

conditions experienced by the tillers than the main stems, as may happen with late rains, for example, it would be expected that Kukri would also show this phenomenon. It is possible that Janz has a longer grain filling pattern than Kukri, allowing the main stem heads to opportunistically fill more grain in good seasons, but resulting in small grains and high screenings in shorter seasons. The tiller heads, having a later anthesis date than the main stems would probably not set as many seeds per spikelet and thus the grains would be competing less within the ear, resulting in better filling and less screenings. An alternative hypothesis is that Janz may have had less non-structural carbohydrate (NSC) stored in the stems than Kukri, and so was unable to fill the large numbers of grains in the main stem ear, resulting in higher screenings. Meanwhile the smaller numbers of grains in the tillers were able to be filled with the amount available. Alternatively, the result may be a seasonal aberration and not reflect the usual pattern. A longer experiment with more seed rates and measurements would be needed to properly investigate this.

6.4.3 Milling and Flour Quality

The flour yield results – from 2 different Quadrumat mills - showed no consistent effects. However, due to the differences in the mills, no conclusions should be drawn about flour yield from the current data.

Flour protein showed no differences between stem types. This may be due to the large amounts of nitrogen supplied to the crop, showing that nitrogen was not a limiting factor. Alternatively, if nitrogen were limiting, the tillers would be expected to receive less due to competition in the plant favouring the main stem. However, if the tillers also received less starch substrate, the net result could be an equal

percentage of protein to the main stems grain. Further research with N nutrition and main stems and tillers would be needed to investigate this.
Flour protein showed significant differences between treatments, but these differences appeared random and had no similarities from year to year.

Flour colour "b" differed significantly between stem types in 1999 and 2000 (1998 not measured). Tillers had higher "b" values than main stems in all years and over all treatments. Seed rate did not affect Minolta "b" in either year. It could be hypothesised that in Experiment 3, the changing proportions of main stems and tillers produced the differences in "b" values apparent in the flour colour as seed rate changed. However, the changes in flour colour show that as seed rate increased, flour yellowness also increased. If tiller seeds were causing the increased yellowness, as the proportions of tiller seeds in the total yield *decreased* as seed rate increased, it would be expected that yellowness would also decrease. Since this is not the case, it must be concluded that increased yellowness in flour is caused by an increase in stress during grain filling at the higher seeding rates. This may have caused relatively higher proportions of carotenoids, xanthophylls and other compounds in the seed (Simmonds, 1989). Since tiller ears are more likely to experience this stress, as they attempt to fill grains later in the season, they are more likely to have more yellow flour than main stem ears.

6.4.4 Dough and Baking Quality

Results from the 2-gram mixograph showed no consistent results over the 3 years. Until more data are available, it would appear that seasonal differences may change

main stem and tiller mixing time properties slightly, but not enough to seriously affect performance.

Dough extensibility was affected by both seed rate and stem type (as well as variety) in 1998, the only year that 2-gram extensograph measurements were available. Main stems had lower extensibility than tillers for both varieties at the lower seed rates. Main stems increased in extensibility at the higher seed rates, while tillers, although showing significant differences between seed rates, did not establish any particular trend. The increased extensibility at the higher rates is of interest, as breeders and processors seek to find a good balance between strength and extensibility in dough. A dough with not enough extensibility is “over-strong”, and will not rise well in breadmaking, whereas a dough that is too extensible may not hold its shape in the oven.

Dough strength showed that main stems and tillers did not differ except at the highest seed rate, where main stems had higher dough strength than tillers. Kukri main stems were stronger than Kukri tillers, but Janz stems did not differ.

Main stem dough strength decreased, then increased as seed rate increased, while tiller resistance decreased with increasing seed rates.

Since main stems showed increases in both dough strength and extensibility at higher rates, this could be an indication that dough strength is improved by higher seeding rates, while maintaining a good amount of extensibility. The tillers did not appear to be affected at all. However, since this is only data from a single experiment, more work would have to be done to verify this hypothesis.

Key findings in this experiment were that tillers produced grain with yellower flour (higher Minolta “b” values) than main stems, probably due to the greater likelihood

of moisture stress during grain filling. However, flour colour overall became slightly more yellow as seeding rate increased, showing that flour colour tends to become more yellow, probably as a result of increasing competition for resources during grain filling. This increased yellowness did not appear to be a result of increased protein percentage. Further experimentation should be carried out to verify this result, but the work so far seems to suggest that protein levels can probably be increased without increasing flour yellowness.

CHAPTER 7 GENERAL DISCUSSION

7.1 INTRODUCTION

Wheat quality is extremely important to producers, marketers and product manufacturers as the quality of the wheat determines its suitability for a particular end use. The final suitability of any wheat crop for a particular end use is determined by both genetic and environmental factors. For example, glutenin and gliadin protein types are genetically controlled. However, protein content is strongly affected by the environment (although there is a genetic component as well). Together, the types and quantities of protein present strongly influence dough quality.

Environmental factors can to some degree be controlled by the grower. Although water supply and temperature are difficult to influence, stresses caused by crop nutrition, weeds, soil factors and crop density can all be controlled by the grower. Recently, there has been a trend in wheat growing in South Australia towards the use of higher density crops to produce a more even crop and to smother weeds (Lemerle *et al.*, 1996). In lower rainfall areas, though, growers may reduce crop density in years of lower rainfall in an effort to conserve moisture (Turner *et al.*, 1994). Changing the density of the crop affects the numbers of tillers that survive to set seed (Anderson and Barclay, 1991), as increased density causes greater competition for light, water and nutrients (Donald and Puckridge, 1987).

Very little work has been conducted to examine the effects of stress within the crop on both the main stems and the tillers. Most research has focused on stress effects on the main stem (Virgona and Barlow, 1991; Ciaffi *et al.*, 1996) or on the total yield without differentiating between stem types. Those projects which have examined

main stems and tillers separately (eg. Turner *et al.* (1994)) have not fully examined the quality of the grain produced.

The aims of this study were to:

1. Examine the quality responses of main stems and tillers when exposed to moisture and temperature stress in controlled conditions.
2. Grow wheat in conditions of extreme moisture stress and examine the quality of main stem and tiller grains produced in normal conditions and under drought.
3. Examine the physiological and quality responses of wheat crops to different crop densities, to examine the effects these densities had on the growth of main stems and tillers, and to test the quality of the grain produced from the different crops.
4. Closely examine the quality of grain from the main stems and tillers of crops grown at different densities to establish whether there were significant differences.

Results of the previous chapters related to the above aims have been discussed separately. In the following section, the most important points will be discussed in general terms.

7.2 RESPONSES OF MAIN STEMS AND TILLERS TO DROUGHT AND TEMPERATURE IN THE GREENHOUSE

Although this experiment was disappointing due to the poor growth and yield of the plants, those results which could be measured, showed that as expected (and consistent with all cited experiments) the tillers produced smaller and less grains than

did the main stems. Drought, increased temperature and the combination of these also reduced grain numbers and weight, and affected the tillers more than the main stems in each case. In practical terms, this means that tillers are less likely to produce large, well-filled grain than main stems when the growing season ends quickly. Later tillers encounter more stress, and are likely to produce small shrivelled grains, leading to lower 1000-grain weights and higher screenings.

7.3 RESPONSES OF MAIN STEMS AND TILLERS TO DROUGHT IN THE FIELD

Main stems and tillers overall reacted to drought as expected in harvest and physical quality characteristics. Yield and grain weights were low, as a result of the low rainfall site in addition to the drought treatments imposed.

Minolta colour was the major quality parameter affected by the water stress imposed. The “b” values were the most severely affected, although due to the high amount of water stress at the site in addition to that imposed by the treatment, “a” values also showed a slight but significant response. The increased yellowness of the droughted grain showed that moisture stress, however imposed, can result in increased yellowness of flour. Further experimentation in this area would be of benefit. Less work has been done on bread wheats in this area than on durum or noodle wheats, where pasta and noodle colour are of importance. Bread flours frequently have bleaching agents added, so that slight increases in yellowness are compensated for. Recent trends towards healthier foods with fewer additives may cause flour colour to become more of an issue. As drought is a common occurrence in many Australian wheat growing areas, knowledge of the potential changes in flour colour as well as

the better known changes in protein, or dough strength, would be useful. Under conditions of water stress, carbohydrate production is usually less, protein is diluted less and the protein percentage is thus increased. It is possible that similar processes to those affecting protein may also be those causing the changes in colour, however the exact mechanisms are unknown.

The only other significant quality attribute affected by the droughting was mixing time, which was increased by drought. This may have been due to the higher protein percentages in the droughted grain. Other parameters measured by the 2-gram mixograph were not consistently unaffected by the treatments. This agrees with the results of the previous experiments.

7.4 QUALITY RESPONSES OF WHEAT CROPS AT DIFFERENT DENSITIES

Thousand-grain weights were lower for the lowest density crop, with screenings highest in the lowest density crops. This agreed with work by Turner *et al.* (1994), showing that later formed tillers have lower 1000-grain weights than earlier ones when subjected to stress during grain filling. The causes of this are likely to be two-fold. Firstly, the later formed tillers do not have as large or as well established nutrient supply systems through the stems as the main stems or first tillers. This results in the main stems receiving larger quantities of moisture and nutrients, and hence producing larger seeds.

Secondly, the tillers have later anthesis dates than the main stems, which means that the tillers usually produce seeds (in South Australia) under greater conditions of water and nutrient stress than the main stems. Usually when wheat is grown for

Prime Hard or Hard quality, water is more of a limiting factor than nitrogen or other nutrients, and so the grains produced under stress may be lacking in starch more than protein. Often these grains are screened out, as they are so small. This agrees with the results of Experiment 1, where plants grown under water stress had higher screenings and lower 1000-grain weights. The tillers, especially the later ones on a well-tillered plant, are most likely to be filling grain with low levels of available water, so grains from the later tillers on a well-tillered plant are likely to be smaller than grains from, for example, single stemmed plants at an equivalent density of heads/m^2. Lower density crops are more likely to have high numbers of tillers per plant than higher density crops, resulting in more, smaller grains from tillers relative to the rest of the crop. This is seen with the lower 1000-grain weights and higher screenings of the lowest seeding density treatments compared to all others.

Milling yield was unaffected by the different density treatments, as predicted from the work of Marshall *et al.* (1986) and Hook (1984). Milling yield appears to be genetically determined and is difficult to influence except by the most extreme environmental conditions.

The most important finding was that higher seeding rates resulted in higher Minolta "b" values in all years of the experiment. Higher "b" values indicate yellower flour. As an important quality trait of Australian wheat is the whiteness of the flour, it is possible that a decrease in whiteness due to increased crop density could be of economic significance. With increased trends towards higher density crops, breeders and marketers should be aware of the possibility of increased flour yellowing. This yellowing carried through to the loaf colour as well, showing that it could impact on end product quality. In some circumstances, however, such as in production of Yellow Alkaline Noodles, this may be a benefit.

7.5 RESPONSES OF MAIN STEMS AND TILLERS TO DIFFERING DENSITIES

When examining main stem and tiller grains separately, the most significant findings in regard to quality were again concerning Minolta colour. Thousand-grain weights of grains from main stems and ears also had consistent significant results. However, the findings and implications of this have been discussed in the previous section. Minolta colour "b" was higher in flours from tillers than in main stems in all years. Seed rate did not affect Minolta colour in Experiment 4. This contrasts with the changes apparent in Experiment 3, where Minolta "b" increased as seed rates increased. Although the tiller flours showed higher "b" values than the main stem flours in Experiment 4, the increase in "b" values of the Experiment 3 flours is probably not due to the tillers, since the tiller numbers decreased at the higher seeding rates. Further complication is caused by the fact that the Experiment 3 flours were milled on a Buhler mill, and the Experiment 4 flours on a Quadrumat mill. This may be causing problems in comparing the results.

However, the implications for wheat quality are still of value. Clearly, excessive water and/or nutrient stress caused by extremely high density crops can result in yellower flour. It is also possible that crops with very large numbers of tillers could also produce yellower flour. Therefore, from my experiments, it can be seen that it is necessary to achieve a crop density which is high enough to reduce tillering, but not so high that competition for water and nutrients results in excessive plant stress. A crop density high enough to reduce tillering would also be dense enough to compete effectively with most weeds, and the reduced tillering should give a more uniform

seed size and reduce screenings. In areas at risk of stress during grain filling, varieties such as Janz, which have whiter flour, should be selected to maintain good flour colour. Protein content did not appear to affect flour colour. More work in this area could be beneficial.

Other quality attributes that were measured showed that main stems and tillers did differ in some characteristics, but that the differences were not consistent from year to year. For example, mixing times were longer for main stems than tillers in 1998, not significantly different in 1999, and shorter in 2000. Seasonal variation appears to play a more important part than stem type for these quality measurements. This shows that from the processing perspective, crop densities can safely be increased without negatively affecting dough quality.

7.6 CONCLUSIONS

The most important conclusions from all of the above and previous discussion in this study were as follows:

1. Altering seeding densities produced changes in the proportions of main stems and tillers in the crop, with increased seeding rates having less tillers per plant.

2. Increasing seeding densities also resulted in changes in the harvest and end-use quality of the crop, particularly by reducing screenings and 1000-grain weight, and increasing flour Minolta “b” values (yellowness). Rheological properties, however, were not consistently affected.

3. Main stem grains and tiller grains differed in some aspects of end-use quality, notably 1000-grain weight and Minolta flour colour.

4. The rheological properties of flour from main stem grains and tiller grains do not appear to be consistently significantly different when tested by the 2-gram mixograph.

5. Stresses imposed on crops by environmental conditions, such as moisture stress caused by drought, not only affect the yield and protein of a crop, but also affect other quality parameters (1000-grain weight and Minolta flour colour).

6. Tillers are produced later than main stems and thus are more likely to be affected by moisture stress than main stems, resulting in the quality of grains from tillers being affected more than that of main stems.

7. As a result of the findings above, it can be said that the trend towards increased seeding rates in South Australia may well increase productivity and crop uniformity, with no loss of dough or baking quality. However, farmers should take care to select varieties with good seed size and white flour, to compensate for lower 1000-grain weights and yellower flour colour. Also of importance is the need for even sowing spacing and depth, to prevent localised high and low densities in the crop.

In relation to the hypotheses stated at the end of the literature review, these conclusions show that:

1. Tillers can make a measurable contribution to the overall quality of the wheat crop, but the way in which they affect it varies from year to year. Environmental conditions may affect the main stems more or less than the tillers in some cases, and the tiller response may be insignificant. This may mean that increased seeding rates result in no measurable changes in the end-use quality (dough and baking quality) of the crop.

2. Tillers do produce smaller grains and less grains than main stems, and these grains do differ in quality to grains from main stems. Thousand-grain weights and Minolta “b” colour produced consistent significant results throughout the experiments. However rheological testing using a 2-gram mixograph did not show consistent significant results.

3. Tillers are probably more severely affected by water stress or temperature rises than main stems, and this does affect the quality of the grain. It is likely though, that this greater sensitivity is due to the later emergence and anthesis dates of the tillers, rather than any intrinsic difference in the stem physiology. Further experiments with main stems and tillers should confirm this.

7.7 RECOMMENDATIONS

Future research topics in this area that could be suggested include:

1. Examining further the effects of a range of moisture stresses on the end-use quality of main stems and tillers in the field, using a larger range of equipment. As well as the 2-gram mixograph, small scale Z-arm mixers, dough extension testers, and thimble loaf baking could be utilised.

2. Further study into the differences between main stems and tillers when subjected to various stresses. With better resources and equipment, it should be possible to conduct small scale testing of grain that is not only separated into main stems and tillers, but further separated into main stems, 1st tillers, 2nd tillers, etc. This could be useful in determining the true value of many laboratory experiments which only evaluated the effect of various nutrients or stresses on the main stem.

3. Recent experiments by Panozzo and Eagles (2000) have looked at the effects of moisture stress and temperature in the field. Further research in this area, separating out the reactions of the main stems and tillers and also conducting full quality testing on the resulting grain could be of benefit. This type of work could help to explain such phenomena as haying off, or heat shock.

4. Work by van Herwaarden (1998(a); 1998(b); 1998(c)) carefully examined haying off in relation to non-structural carbohydrate (NSC) storage and water stress on the crop. Further work in this area, examining the relationships between NSC, main stems and tillers, crop resistance to heat and moisture stresses and crop end-use quality could be useful.

5. The unexpected quality results in Experiment 2 which were attributed to the effects of frost during anthesis could be further investigated. Prime Hard quality wheat-growing areas are traditionally in areas which may be severely affected by frost near anthesis. Little work has been done to investigate frost effects on quality.

Recommendations for growers desiring to use high density crops include the use of wheat varieties that do not have problems with yellowness in the flour, and ensuring even spacing of the crop at sowing to ensure that there are no localised low or very high density patches, which could lead to more variability in seed size and increased screenings.

Breeders need to take care that varieties are produced that do not have yellow flour if white flour is what the market desires.

In the marketing area, processors should note that flour with higher yellow colour may be good for certain end products such as yellow alkaline noodles, but less desirable for breadmaking. Segregation of wheat from areas that have experienced moisture stress, and are more likely to be yellow could be an option.

CHAPTER 8 BIBLIOGRAPHY

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CHAPTER 9 APPENDICES

APPENDIX A: FERTILISER ANALYSIS

NITROPHOSKA ANALYSIS		
N	Nitrogen (Total) *5% NH_4 ammonia form* *4% NO_3 nitrate form* *1% NH_2 amide form* *5% IBDU*	15%
P	Phosphorus (Total) *3.9% citrate soluble, of which* *1.2% water soluble*	3.90%
K	Potassium sulphate	12.40%
Mg	Magnesium carbonate	1.25%
Ca	Dicalcium phosphate	3.40%
S	Sulphates	5.30%
Fe	Iron oxides	0.30%
Cu	Copper oxides	0.0002%
Zn	Zinc oxide	0.007%
B	Calcium borate	0.01%
Mo	Molybdenum oxide	0.0003 %

THRIVE ™ SOLUBLE FERTILISER		
N	Nitrogen (Total) *3% as Nitrate* *2.6% as Ammonium* *21.4% as Urea*	27%
P	Phosphorus *5.5% water soluble*	5.50%
K	Potassium Nitrate	9.00%
Mg	Magnesium Sulphate	0.15%
Ca	Calcium	-
S	Sulphates	0.22%
Fe	Chelated Iron	0.18%
Cu	Copper Sulphate	0.005%
Zn	Zinc Sulphate	0.02%
B	Sodium Borate	0.005%
Mo	Sodium Molybdate	0.002%
Mn	Manganese Sulphate	0.04%