Genetic constraints to improvements for wheat productivity and quality

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Introduction

The final expression of any crop attribute is determined by the interaction of the plant being grown with its surrounding environment. Various papers in this symposium deal in detail with the effect of the environment upon both wheat productivity and quality. Wheat breeding, the development of new wheat cultivars with better attributes than existing cultivars, depends upon an understanding of the relative importance of this environment effect and the cultivar effect, that is, the heritability of these attributes. Simmonds (1979) defines heritability as the portion of overall variance attributable to differences based solely upon the cultivars themselves. Measurement of heritability therefore depends upon separating the effects of cultivar, environment, cultivar x environment interaction and error variances. Their relative importance will determine how the breeder tackles each particular attribute. Griffin (1983a) outlined some basic requirements for successful small-scale quality tests, including repeatability and low cultivar-environment interaction. These directly reflect the complexity of the character's inheritance.

The following sections will detail the major wheat characteristics that have to be considered when breeding improved wheat cultivars in New Zealand, discuss their inheritance and how this determines the overall breeding strategy. Wheat has many end-uses, each with its own particular quality specification and this diversity will be discussed in relation to the type of wheat required.

Productivity

Adaptability

Wheat has an extremely wide adaptability, and Jamieson and Wilson (1992) describe variation in development and relative maturity as the key factors. The period from plant emergence to grain-fill is the critical variable, influenced mainly by two interacting plant processes, daylength response and vernalisation. Both characters have relatively simple genetic control, with a few major genes and some minor modifying genes (Pugsley 1973). True winter wheats generally have both a vernalisation requirement and daylength sensitivity. True spring wheats have no vernalisation requirement and are generally daylength insensitive. Shuttle breeding, whereby two generations per year are grown in different environments, most commonly northern and southern hemispheres, works best with this type of spring crop (Rajaram *et al.*, 1987). Resistance to cold temperatures (Limin and Fowler, 1991) and the ability to survive prolonged snow cover by prostrate early growth habit is also essential for winter wheat adaptation in many countries. Drought resistance (Morgan, 1983) and the ability to maintain growth in various toxic soil conditions (Rajaram *et al.*, 1987, Richards 1983) are other wheat characteristics allowing wide adaptation.

The range of adaptation of wheat is a major factor in defining the cereal growing districts in New Zealand. Our varied topography, soils and maritime climate ensure a wide range of environments, even within the Canterbury Plains. Since the size of our wheat industry does not allow a large number of locally adapted cultivars, they must show general adaptation throughout the growing districts (McEwan and Griffin, 1985). The winters are relatively warm with little snow cover, and plant growth often continues throughout. Therefore, most autumn sown cultivars in New Zealand have only a weak vernalisation requirement, some daylength sensitivity (to stop excessive winter development) and little cold temperature resistance. Days to ear emergence is the most common character scored to indicate relative maturity. Table 1 shows the stability of relative maturity over different seasons, an indication of relatively simple genetic control.

Plant type

The approach to wheat production in New Zealand is somewhere between the low-input low-yields of Australian-type agriculture and the high-input high-yields of Western Europe. Other papers in this symposium discuss how we are moving closer to the European situation. To achieve these high yields the wheat plant must be resistant to lodging (often, but not necessarily,

Table 1. Autumn wheat maturity, height and grain size over years relative to Batten

	Maturity (days to ear emergence)				Height (cm)				1000 grain weight (gm)			
	88/89	89/90	90/91	91/92	88/89	89/90	90/91	91/92	88/89	89/90	90/91	91/92
Batten	161	169	180	176	75	85	95	95	42	38	38	42
Brock	+2	+4	+2	+3	-15	-10	-15	-15	+3	+4	+2	+3
Domino	-1	-1	-1	+2	+10	+10	+10	+10	+4	+6	+5	+4
Monarch	-	+4	+3	+5	-	+35	+25	+25	-	+8	+7	+5
Craw 50	+1	+1	+1	+3	+10	+5	+5	+5	+3	+6	+3	+3

through reduced plant height), straw break and shattering. New Zealand has a particularly windy climate, so straw break and shattering resistance are more significant than in many other countries. Both are easily selected for given appropriate conditions, and susceptible lines are rejected early from the breeding programmes. However, wheat must also be easily threshed by modern harvesting equipment and over-tight chaff should also be avoided. Tight chaff, leading to an excess of white heads within the harvested grain, was a significant problem with the cultivar Kotare.

Plant height can be controlled by various chemicals, but huge variation exists naturally from dwarf types around 20 cm to tall types over 1.5 m (Austin *et al.*, 1980). The discovery of the gibberellin-sensitive major genes for height in Japanese wheats was one of the key factors in Borlaug's "Green Revolution" (Borlaug, 1968). The tall-dwarf concept is based on the premise that wheats should be tall enough to produce the dry matter necessary to allow high grain yields, but short enough to avoid lodging problems under high fertiliser inputs (Gale and Law, 1976). In New Zealand most recent cultivars possess a dwarfing gene (Davies *et al.*, 1985; McEwan 1973). Table 1 shows that height is a relatively stable character and so easily handled within a breeding programme.

Grain size and shape

Grain size, screenings and test weight also all contribute to grain yield and acceptability for further processing. All are strongly influenced by the environment, see Table 1, but also show a marked cultivar effect. Grain size and test weight are important milling quality characteristics, particularly if there is large variation between grain samples or cultivars that are to be blended.

Disease resistance

Cromey *et al.* (1992) cover in detail the effects of diseases on wheat in New Zealand, their genetic controls, resistance breeding strategies and chemical control programmes. Scoring for disease infection and selection against susceptibility is a primary objective within each generation of the Crop & Food Research wheat breeding programmes. Good natural infections are ensured by the presence of regular susceptible spreader rows and a high natural proportion of susceptible types, particularly in the earlier generations. A relatively new innovation in bread wheat trials at Lincoln has been to fully protect half the replications with fungicide sprays. All scoring is done on the unprotected plots and in the yield analysis the effect of fungicide helps identify those lines on the border-line for disease score, see Table 2. Advanced breeding materials, together with all Cereal Recommended List Trial (CRLT) entries and commercial cultivars, are assessed in replicated nurseries specifically designed for each of the major wheat diseases in New Zealand (Munro, 1992). Spreaders, location and sowing date ensures that each particular nursery is highly infected with the target disease. Where possible, glasshouse seedling evaluation for specific races also occurs.

In spite of this considerable effort to breed for disease resistance, Munro (1992) shows that very few advanced lines or commercial cultivars have the most desirable type of resistance; which is seedling susceptibility and adult plant resistance. Many diseases have a high capacity for change, stripe rust has developed 10 races in New Zealand since 1980, and it is certain that without the effort in breeding for resistance the situation would be even worse than it is at present.

Yield

Most genetic investigations of yield and yield components, both in New Zealand (Islam *et al.*, 1985a, b; Lee, 1980) and overseas (Griffin 1982) agree that heritability of yield/plant is lower than the heritabilities of the major components of yield, such as grain weight, grains/ear and ears/plant. Many papers have shown large environmental effects on these characters and Islam *et al.*

(1985b) demonstrated the effect of plant density, critical in a breeding programme where early generations are usually space-planted to ensure easy distinction between individual plants, maximum expression of genetic potential and high seed return. Therefore, yield/plant is rarely a breeding objective and because of practical considerations, components of yield are also not commonly measured in early generations. Harvest index (HI), the proportion of grain yield to total above-ground dry-matter is another character used to describe yield. HI has progressively increased in modern cultivars as grain yields have increased and plant height decreased (Austin *et al.*, 1980). HI, like other components of yield, shows a higher heritability than yield/plant (Griffin 1982) and some breeding programmes do select in early generations for high HI and so indirectly for increased yields (Bhatt, 1977). However, as for the other components of yield, practical considerations preclude this approach in most programmes.

Instead, selection for yield is delayed until numbers are manageable and within-line variability is reduced to a level where bulk-line testing is meaningful, after the 4th or 5th generation. Depending upon numbers, plots sown at commercial seed-rates are replicated or tested against strategically positioned standards and their bulk yields statistically analysed. As soon as is practical, the yield trials are duplicated at different sites representing the diversity of environments and management schemes under which the wheat will be commercially grown. The most promising material is usually held in these trials over several seasons to allow annual variations to be measured and an overall evaluation of yield potential relative to current commercial cultivars. The CRLT is a series of trials jointly organised by plant breeders, producers and processors to measure objectively the relative performance of commercial cultivars and near-release lines. From these trials, Recommended Lists are published for both autumn and spring wheats (see Table 3).

Table 2. Yield response to complete fungicide protection in spring wheat lines with variable disease susceptibilities.

	Disease scores (0-9)*			Yield Response (%)
	Stripe rust	Mildew	*Septoria tritici*	
Acceptable	0	0	0	-2.1
	1	0	1	4.4
	4	0	2	6.2
	4	0	2	0.8
	2	3	4	0.9
	2	0	4	6.2
	0	4	3	4.1
	0	4	0	-4.8
Reject (stripe rust)	7	2	3	44.3
	6	3	3	20.4
	4	0	1	9.1
	4	0	3	10.7
Reject (Septoria)	3	3	6	14.5
	1	0	6	13.1
	2	0	4	12.1
	3	0	4	9.6
Reject (mildew)	2	7	0	31.5
	3	7	2	33.5
	3	4	2	26.2
	0	4	2	23.9

* 0 - no visible disease 9 - fully susceptible

Table 4 illustrates the difficulties for yield assessment in four New Zealand spring wheats. The wheats, grown over widely differing environments, show a large seasonal effect and varying interactions between the cultivars and both site and season. Yield is a highly complex character and the amount of information given in Table 4 is a minimum for successful evaluation. Interpretation of yield trials is not always straightforward and different management inputs and environmental stresses will always affect the results. All factors must be considered before final recommendations are made.

Quality

General requirements

Milling. Most processed wheat products use a white flour, so there is a general requirement for high milling quality in processing wheat. Good milling quality is a reflection of the physical grain size and shape (Baker and Golumbic, 1970), grain hardness (Baruch, 1974; Stenvert, 1974) and the bran-endosperm separation (Griffin, 1978). Most selection tests are based upon grain hardness or micro-milling, as in the Crop & Food Research breeding programme which initially assesses flour yield on a Brabender Quadrumat Junior mill. High heritabilities have usually been found for grain hardness (O'Brien and Ronalds, 1987) and Griffin (1982) postulated control by one major gene with several minor modifying genes. Moderate heritabilities for Quadrumat Junior flour yields have been measured (O'Brien and Ronalds, 1987). Some processed products require soft flours, which present special milling problems. These soft wheats can be milled on specially designed long-run mills, or more commonly, are blended with harder wheats so that a

Table 3. 1992 Recommended List for Autumn Sown Wheats.

	Recommendation								Comments
	Full					Becoming Outclassed	Provisional		
Cultivar	**Pernel**	**Brock**	**Batten**	**Tancred**	**Domino**	**Bounty**[a]	**Sapphire**	**Monarch**	
Owner[1]	H & T	CS	CR	PGG	PGG	CS	CS	CS	
Relative yield [b]	116	108	98	96	94	99	108	81	
Potential end use [c]	F	B, F	M, BF	M, BF	M, BF	B, F	B, F	M	
Wheat grain:									
Protein % [d]	10.1	9.8	11.4	11.7	11.3	10.0	10.4	12.4	Information on
Falling number [e]	324	283	358	349	339	332	352	341	quality is supplied
1000 grain weight	45	44	42	42	44	46	45	45	on behalf of the
Screenings %	2.1	3.3	2.4	2.7	3.1	4.3	2.8	1.5	NZ Flour Millers
Test weight [f]	74	75	76	75	74	72	76	78	Association
Flour:									
MDD score [g]	15	-	21	24	24	-	16	26	
Water absorption [h]	57	-	59	59	58	-	60	61	
Plant height (cm)	81	79	86	82	92	88	104	118	The agronomic
Straw strength	8	8	7	8	8	8	7	8	and disease
Early ripening	4	3	5	6	5	2	4	3	resistance traits are
Resistance to:									scored on a 1-9
Shedding	7	8	8	8	8	7	6	5	scale. A high
Mildew	8	8	7	8	9	9	9	7	scoring cultivar
Stripe rust	6	6*	5	5	7	8	8*	8	possesses a trait to
Leaf rust	8	6	6	5	8	5	5	5	a high degree.
Speckled leaf blotch	8	8	7	4	4	8	6	6	
Eyespot	7	8	5	7	7	8	6	7	* susceptible to
Glume blotch	-	5	6	-	8	7	7	6	stripe rust in head

Full: Recommended for growing in the whole of the autumn wheat area (Canterbury - North Otago) on the basis of performance in comparative trials for at least four seasons.

Bec. Out: Cultivars previously Full or Provisional which are now becoming outclassed.

Provisional: Cultivars with "Provisional" recommendation have shown merit in comparative trials over at least three seasons but further trials will be necessary before they receive "Full" recommendations. As an indication of availability, provisionally listed cultivars must have breeders' grade seed being sown in the season under consideration.

[1] H & T - Hodder & Tolley Ltd.; CR - DSIR Crop Research; CS - Challenge Seeds Ltd.; PGG - Pyne Gould Guinness Ltd.

[a] Seed of Bounty is no longer being maintained. No certified seed will be available in 1991.

[b] Grain yield at 14% mc is expressed as a % of the mean of all cultivars. This percentage is a composite of results over the last 5 years from many trials in the autumn wheat area with differing management programmes.

[c] B = Biscuit; BF = Bulk Fermentation; F = Feed; M = Mechanical Dough Development.

[d] Protein % = wheat protein corrected to 14% moisture basis. Flour protein levels are usually lower than wheat protein levels.

[e] Falling number gives an indication of sprouting damage.

[f] Test weight is measured in kg/hectolitre and indicates grain shape, regularity and density.

[g] MDD Score = Mechanical dough development bake score, determined by the 125g MDD test bake system, Grain Processing Laboratory of DSIR Crop Research. The MDD score is the sum of scores for loaf volume and texture.

[h] Water absorption % - Optimum water absorption, as determined on the 125g MDD test bake system.

Prepared by: Cereal Recommended List Committee, C/- DSIR Crop Research, Lincoln

Table 4. Spring wheat yields over sites and years relative (%) to Otane (t/ha).

Southern North Island:

Cultivar:	Kairanga 89/90	Kairanga 90/91	Kairanga 91/92	Marton 89/90	Marton 90/91	Marton 91/92	Otane 89/90	Otane 90/91	Otane 91/92
Otane	8.5	6.5	8.0	6.1	4.9	-	7.6	8.2	-
Kokako	98	105	95	95	121	-	102	101	-
693.01	100	102	96	96	102	-	92	100	-
694.01	103	98	98	102	120	-	106	93	-

Canterbury:

Cultivar:	Lyndhurst 89/90	Lyndhurst 90/91	Lyndhurst 91/92	Eiffelton 89/90	Eiffelton 90/91	Eiffelton 91/92	Rakaia 89/90	Rakaia 90/91	Rakaia 91/92
Otane	6.5	5.2	6.0	5.9	4.7	6.2	5.0	5.2	5.5
Kokako	103	100	113	107	103	100	100	134	105
693.01	119	107	122	121	132	110	117	125	104
694.01	113	104	125	123	108	108	128	132	112

Southland:

Cultivar:	Drummond 89/90	Drummond 90/91	Drummond 91/92	Chatton 89/90	Chatton 90/91	Chatton 91/92
Otane	5.3	6.9	7.7	10.9	10.6	-
Kokako	115	91	110	107	91	-
693.01	-	118	117	-	109	-
694.01	108	104	109	103	105	-

normal mill can be used.

Alpha-amylase level. Another general requirement for most processed wheat products is low α-amylase activity. Unacceptably high levels cause starch breakdown under processing conditions, resulting in wet and sticky doughs unsuitable for most baking, biscuit or cooking processes. Some wheats have intrinsically high α-amylase levels (Bingham, 1966), but more commonly these result from pre-harvest sprouting. There is extensive variation for sprouting resistance, with most studies showing relatively simple genetic control (Gordon, 1980; Gale, 1976). A number of grain and head characteristics have been associated with sprouting resistance, but grain colour is the most significant with red colour closely linked to resistance (McEwan, 1980; 1976). In countries like New Zealand with maritime climates, this means most commercial wheat are red (McEwan and Griffin 1985). Advanced lines in the Crop & Food Research breeding programme are assessed for sprouting resistance in a nursery grown in Palmerston North and Southland, two districts with a high risk of natural pre-harvest sprouting, by comparing sequentially harvested plots.

Resistance in white wheats was considered to be virtually non-existent (Mares, 1984), until relatively recently, when several white, sprout-resistant wheats were identified (De Pauw *et al.*, 1990). In New Zealand, Crop & Food Research, with funding from the New Zealand Flour Millers Association (NZFMA) has begun a breeding project to incorporate this form of sprout-resistance into locally adapted white wheats. In most cases the original wheats showing these characters are totally unsuited to our environment (very tall, low yielding, poor disease resistance and processing characteristics), so a long-term breeding strategy has had to be developed. The genetical control of the resistance appears to vary depending upon the parental lines studied, see Table 5, although early results suggest that it is relatively simple and white sprout resistant segregants should be easily identified.

Grain colour. Wheat is most commonly white or red, determined by three genes for redness (McEwan, 1980). Colour can be modified by the environment and it is often difficult to distinguish white and one-gene red wheats visually, so various chemical tests are used to enhance differentiation (De Pauw and McCaig, 1988). For wheats which are processed into white flour, there is a general preference for white wheats since at a given flour extraction rate they produce flours of a lower wheats, below) are controlled by a number of different genes. Purple wheat colour is controlled by duplicate genes showing a maternal inheritance (Griffin, 1987).

Specific wheat types

New Zealand wheat is processed into numerous different end-products: 87% milling (60% bread manufacture, 10% biscuit, 30% other uses) and 13% feed (S. Suckling, pers. comm.) Many of these products require wheats with fundamentally different physical and processing properties.

Feed wheat. Feed wheat have typically been those which yield very well with minimal inputs for factors such as disease control. They have had minimal quality standards, usually only concerned with grain size and shape and sometimes protein content. These basic requirements still apply, but increasingly the feed industry is defining specific processing characteristics and imposing new specifications (Foulds, 1989). Evaluation of new feed cultivars involves joint ventures between the breeders and the feed industry and differences between wheats for metabolisable energy, anti-nutrient factors such as alkyl resorcinols and mycotoxins, and characters like pelleting ability are being identified. Little is known about the inheritance of these factors, but there are both environmental and cultivar differences (Foulds, 1989). Breeding for feed wheat will become increasingly sophisticated as these factors are defined and accounted for in the testing and selection programme.

Table 5. A comparison of various sources of sprouting resistance on percentage sprouting in wheat F_2 populations.

Source	Total No. of ears	Percentage sprouted		
		Badly	Moderately	None
White sprout resistance:				
TSA 1166[1]	539	22	56	22
AUS 633	404	60	33	7
Red sprout resistance:				
AUS 1490	566	23	45	32
White sprout susceptible:				
Raven	562	34	47	19
87SN230	947	32	46	22

[1] Transvaal/South Africa 1166

Biscuit wheat. Parkyn (1985) described two basic types of biscuits (cookies and crackers) and the flour properties which are important for each. Some of these are just the opposite of characteristics required for good bread baking (protein quantity, protein quality, water absorption). Crop & Food Research is closely involved with New Zealand flour millers and biscuit manufacturers in assessing biscuit quality in advanced lines from its breeding programme and recently lines have been identified with significant improvements over current commercial cultivars (C. Thomas, pers. comm.). In the past biscuit manufacturers have had to use low protein bread wheats (Mitchell, 1985), which became unsuitable at protein levels above 9%. The new material, with genuine biscuit quality, is much more tolerant of increased protein contents, see Figure 1.

Pasta wheat. Pasta is made from durum wheat which has four sets of chromosome (tetraploid) in contrast to

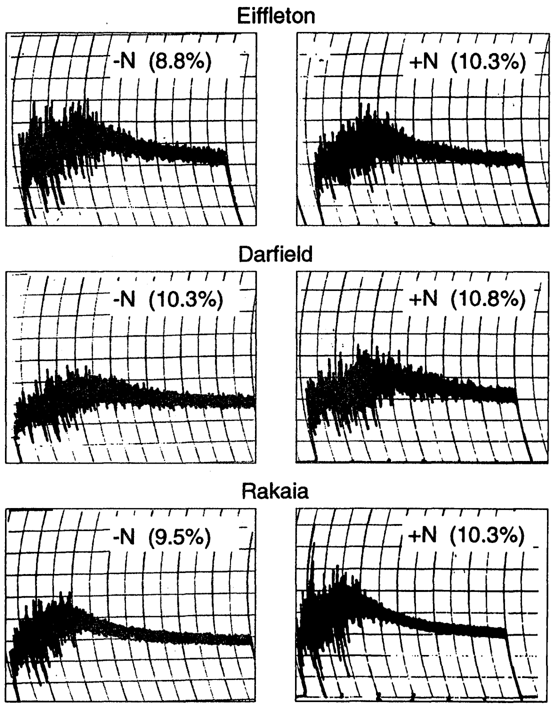

Figure 1. Mixographs and proteins for Awatere biscuit wheat with and without nitrogen over three sites.

the six sets in bread wheat (hexaploid). The lack of this third pair of chromosome sets means durum flour dough is not extensible and gas retentive like bread-dough, but protein quantity and quality are still important for pasta quality. Strong dough strength is required and is selected for in the Crop & Food Research durum breeding programme using similar screening techniques as those used in the bread programme (See Bread wheat - small-scale tests, below). Colour is another major quality characteristic, with a deep yellow/orange colour desirable. Carotene content varies widely within durum wheat and can be significantly effected by the environment, see Table 6. Selection for improved colour has meant recent breeding material is significantly higher in carotene and more stable across environments than the original durum cultivar Tara, see Table 6. This breeding programme is partially funded by a New Zealand commercial pasta manufacturer, who is closely involved in the quality assessment of advanced lines.

Other wheats. These include wheats with unique characteristics, such as the purple wheats or very large-grained *T. polonicum* wheats suitable for breakfast and snack food processes such as rolling, puffing and flaking. These are all relatively small niche markets, ideal for joint private industry-crown research and development, such as is being undertaken presently in the coloured wheat programme. Very little work is being done developing such wheats by overseas breeders concerned with the larger commodity markets and perhaps an opportunity exists for New Zealand to take this sort of specialty product to the world (Strategic Partnerships, 1991). Already there is very keen interest from Australia (A. Stratton, pers. comm.). Other types of specialty wheat have specific quality requirements, such as pastry wheats or specialty starch wheats. There is no specific breeding programme for these in New Zealand, but as their quality parameters are defined, then lines which are suitable but are currently rejected from other programmes could be retained. Pastry and weetbix wheat are two specialty uses which can be selected from the bread and biscuit programmes, respectively, by using the mixograph (See Bread wheat - small-scale tests, below). A weetbix line is currently under larger-scale evaluation after initial selection in this manner.

Table 6. Carotene levels (µg/g) in Durum wheats at two sites over two years.

	Milford		Eiffelton	
	90/91	89/90	90/91	89/90
Tara	16.3	7.3	14.8	7.7
Waitohi	16.5	12.4	19.0	14.2
CB55	19.8	11.8	21.5	13.8
CB79	17.9	11.5	19.7	14.5

***Bread wheat** - Types*. There are several different baking processes, with different optimum values for the quality parameters. In New Zealand, over 80% of dough is produced by a mechanical dough development (MDD) process, whereby the dough is mixed in high-speed mixers capable of expending the necessary work for optimum dough development in a very short time (Skeggs and Kingswood, 1981). The older, more traditional bulk fermentation (BF) process, where the dough is developed over a much longer period, accounts for most of the remaining bread. Flours which perform well in one system do not necessarily perform equally well in the other. Batten has only moderate MDD quality, largely because of poor extensibility. However, for BF mixing, where dough development occurs over a long period and extensibility is therefore not such a critical factor, Batten performs much better and is the preferred cultivar for most BF wheat contracts (D. Gallis, pers.com.). Other baking processes such as sponge and dough making, the new Grain Processing Laboratory's (GPL) continuous dough mixing, and specialist bakery processes like the production of hamburger buns have other particular requirements.

Tables 7-10 illustrate the MDD test baking data (Wooding, 1988), that is used to evaluate bread baking quality in the final stages of the Crop & Food Research bread wheat breeding programme, and shows the large seasonal and site effects. The inheritance of these parameters is only moderate because of this large environmental effect and like yield, evaluation must occur over a number of years and sites for accurate relative assessment. This variability in quality, exacerbated by our variable climate and topography, means consistency is a key problem for the New Zealand wheat industry (Mitchell, 1985). A large part of this variation can be explained by the relationship between protein content and yield (Jamieson and Wilson, 1992) and then between protein content and baking quality, see Table 11. However, in some wheats there remains an intrinsic variability in quality which is yet to be satisfactorily linked to any chemical or grain marker (Griffin, 1989)

Two major quality factors in addition to loaf volume and texture are optimum work input and water absorption (W). High W is desirable because of its effect on loaf texture, staling and the relative use of "cheap" water.

Table 7. Spring wheat MDD bake scores over sites and years.

Southern North Island:

Cultivar:	Kairanga 89/90	Kairanga 90/91	Kairanga 91/92	Marton 89/90	Marton 90/91	Marton 91/92	Otane 89/90	Otane 90/91	Otane 91/92
Otane	25	23	26	25	19(s1)	-	28	23	-
Kokako	23	21	19	25	19	-	26	24	-
693.01	23	22	25	28	19(s1)	-	24	24	-
694.01	27	21	21	27	17	-	25	19	-

Canterbury:

Cultivar:	Lyndhurst 89/90	Lyndhurst 90/91	Lyndhurst 91/92	Eiffelton 89/90	Eiffelton 90/91	Eiffelton 91/92	Rakaia 89/90	Rakaia 90/91	Rakaia 91/92
Otane	22	22	26	23	24	27	26	23	24
Kokako	19	22	27	25	23	26	26	24	24
693.01	20	27	25	25	27	25	27	24	23
694.01	22	22	27	26	26	26	26	24	19

Southland:

Cultivar:	Drummond 89/90	Drummond 90/91	Drummond 91/92	Chatton 89/90	Chatton 90/91	Chatton 91/92
Otane	23	19	17(s1)	27	23(s1)	-
Kokako	25	14	14	23	15	-
693.01	-	15	13(s1)	-	16(s3)	-
694.01	24	17	16(s1)	24	20	-

Table 8. Spring wheat work input (wh/kg) over sites and years.

Southern North Island:

Cultivar:	Kairanga 89/90	Kairanga 90/91	Kairanga 91/92	Marton 89/90	Marton 90/91	Marton 91/92	Otane 89/90	Otane 90/91	Otane 91/92
Otane	11	17	14	20	10	-	21	14	-
Kokako	11	14	12	17	10	-	16	10	-
693.01	10	11	12	15	8	-	16	10	-
694.01	17	19	19	21	13	-	23	17	-

Canterbury:

Cultivar:	Lyndhurst 89/90	Lyndhurst 90/91	Lyndhurst 91/92	Eiffelton 89/90	Eiffelton 90/91	Eiffelton 91/92	Rakaia 89/90	Rakaia 90/91	Rakaia 91/92
Otane	8	15	14	18	14	16	24	13	13
Kokako	10	15	14	15	11	12	13	12	10
693.01	11	12	9	13	13	10	11	9	9
694.01	14	17	14	13	18	20	18	18	16

Southland:

Cultivar:	Drummond 89/90	Drummond 90/91	Drummond 91/92	Chatton 89/90	Chatton 90/91	Chatton 91/92
Otane	12	12	11	15	16	-
Kokako	16	8	11	13	12	-
693.01	-	12	8	-	10	-
694.01	17	16	15	19	20	-

Table 9. Spring wheat water absorptions (%) over sites and years.

Southern North Island:

Cultivar:	Kairanga 89/90	Kairanga 90/91	Kairanga 91/92	Marton 89/90	Marton 90/91	Marton 91/92	Otane 89/90	Otane 90/91	Otane 91/92
Otane	60	60	56.5	60	60	-	59	61	-
Kokako	61	61	58	62	60	-	60	61	-
693.01	60	60	56.5	60	58	-	58	60	-
694.01	61	61	54	60	57	-	60	61	-

Canterbury:

Cultivar:	Lyndhurst 89/90	Lyndhurst 90/91	Lyndhurst 91/92	Eiffelton 89/90	Eiffelton 90/91	Eiffelton 91/92	Rakaia 89/90	Rakaia 90/91	Rakaia 91/92
Otane	67	59	60.5	65	60	60	61	61	57
Kokako	65	59	60.5	64	62	59.5	67	60	58.5
693.01	65	59	59.5	65	60	60.5	64	59	58
694.01	63	60	60	63	62	61	67	61	56.5

Southland:

Cultivar:	Drummond 89/90	Drummond 90/91	Drummond 91/92	Chatton 89/90	Chatton 90/91	Chatton 91/92
Otane	61	59	62	61	62	-
Kokako	60	62	62	64	62	-
693.01	-	62	62	-	62	-
694.01	61	59	61	61	63	-

Table 10. Spring wheat protein percentages (14% moisture) over sites and years.

Southern North Island:

Cultivar:	Kairanga 89/90	Kairanga 90/91	Kairanga 91/92	Marton 89/90	Marton 90/91	Marton 91/92	Otane 89/90	Otane 90/91	Otane 91/92
Otane	11.1	11.6	11.5	12.2	10.2	-	11.9	10.7	-
Kokako	11.2	12.0	11.6	12.1	10.2	-	11.7	11.0	-
693.01	11.9	12.2	11.9	13.1	11.0	-	12.0	11.7	-
694.01	11.3	11.7	11.2	12.2	10.2	-	11.6	10.4	-

Canterbury:

Cultivar:	Lyndhurst 89/90	Lyndhurst 90/91	Lyndhurst 91/92	Eiffelton 89/90	Eiffelton 90/91	Eiffelton 91/92	Rakaia 89/90	Rakaia 90/91	Rakaia 91/92
Otane	11.5	11.7	12.0	12.6	11.8	12.1	13.1	12.2	10.6
Kokako	11.3	11.7	12.1	11.8	12.1	11.7	12.5	12.0	10.6
693.01	11.6	12.3	12.2	11.8	12.5	12.4	13.5	12.5	11.4
694.01	10.8	12.1	11.5	11.5	12.7	12.5	12.9	12.6	10.0

Southland:

Cultivar:	Drummond 89/90	Drummond 90/91	Drummond 91/92	Chatton 89/90	Chatton 90/91	Chatton 91/92
Otane	11.8	10.3	11.9	12.7	12.9	-
Kokako	12.1	10.3	11.6	12.2	12.5	-
693.01	-	10.2	11.5	-	12.9	-
694.01	12.1	10.2	11.3	12.1	12.9	-

The optimum work input is a measure of the energy necessary to achieve optimum dough development; too little may cause ingredient mixing problems, too high and consequent dough heating means cooling may be required. Loaf volume and work input tend to be positively related and unless selected for in tandem, over-strong wheats can result which are unsuitable as non-blended variety flours. However, such wheats are vital as the high quality component in the blends which millers normally grind. It is also possible that they have a high tolerance for reduced work input without significantly influencing loaf volume. This possibility is now being measured routinely in the Crop & Food Research breeding programme by a double bake test: firstly at optimum work input, then secondly at 11 wh/kg (the industry optimum) if the optimum is significantly greater (Griffin and Wooding, 1992). The new GPL continuous dough mixer is also less affected by work input and may be able to use flours unacceptable for MDD mixing (A. Wilson, pers com.).

Dough strength properties as measured by the farinograph and extensograph are also evaluated for advanced breeding lines and used to build up an overall quality profile for lines nearing commercial release. The NZFMA has recently begun funding an extensive quality testing programme for CRLT entries, which will include test baking and dough strength evaluation.

***Bread wheat** - Protein quality and quantity.* There is good evidence of a general positive relationship between grain protein content and baking quality, see Table 11, although in New Zealand this is generally accepted as not being good enough for predictive purposes (Stevenson, 1987). Table 11 also shows that there is a cultivar effect on this relationship, as discussed by Stevenson (1987) and Martin *et al.*, (1992). Quality indices based upon protein content may have to vary between cultivars to take this effect into account. Cultivars may also have different mean protein levels but similar loaf volumes, again requiring a cultivar adjustment to a protein content index. The New Zealand wheat quality surveys (Simmonds, 1992; 1991; Lindley and Moore, 1989; 1988), show that Otane has the highest mean bake score, but amongst the lowest mean protein content. It is clear however, that below around 10.5% flour protein content, bake-score rapidly decreases (Stevenson, 1987) and processors are correct in having a purchase option at this point.

Table 11. The protein-bake score relationship for some spring wheat lines tested in the DSIR Crop Research regional trials from 1989-1991.

	Correlation statistics	
	r	b
Otane	0.58**	1.59
Kokako	0.48*	2.07
693.01	0.85**	3.06
694.01	0.69**	2.40
Overall	0.64**	2.27

* significant at 5% confidence level
** significant at 1% confidence level

Protein content is highly dependent upon the environment, see Table 10. There are many conflicting reports on the complexity of genetic control and the value of selecting for improved levels within a breeding programme. Lee *et al.*, (1982) found relatively simple genetic control in some New Zealand wheats, although this was carried out with few lines and environments. Griffin (1982) suggested that many inheritance studies of protein content failed to take into account the effect of yield, and if adjusted, much of the variation measured may be lost.

Most of the variation in baking quality is explained by the gluten protein fraction (Wall, 1979), although free-lipid content also has an effect (Panozzo *et al.*, 1991). The presence or absence of particular glutenin subunits have been clearly linked to baking quality (Payne, 1987; Payne *et al.*, 1987; Gupta and Shepherd, 1988), as well as the relative amounts of glutenin proteins (Sutton *et al.*, 1989). Gliadin protein subunits may also influence quality (Payne, 1987; Sozinov and Poperella, 1980). These individual protein subunits are controlled by relatively few complex genes, each with many allelic alternatives (Payne *et al.*, 1982) and their presence is independent of environment. However, protein content is greatly influenced by environment, so the relative amounts of these functionally important protein fractions may also vary (Sutton *et al.*, 1990). The timing of nitrogen application is critical to its subsequent effect on grain protein content and baking quality (Stevenson, 1987; Martin *et al.*, 1992). Stevenson (1987) found that this timing effect varied between cultivars and he suggested that this could be due to differences in the glutenin/gliadin ratio. Differences between cultivars in the production of various protein fractions relative to varying overall protein content was demonstrated by Martin *et al.* (1992), who showed that the better baking quality lines had a relatively greater response by the critical glutenin fractions than the poorer quality lines.

Many of the wheats responsible for increased productivity around the world, and particularly those developed by the international wheat programme at CIMMYT, have a piece of chromosome derived from ryecorn (Rajaram *et al.*, 1983). However, associated with this rye translocation is a sticky dough quality defect, which is particularly significant under some mixing systems and at high protein contents (Dhaliwal *et al.*, 1987). The translocation is readily identified using electrophoresis and most baking quality breeding programmes, including Crop & Food Research's, select against it. However, there is some doubt that these wheats grown in New Zealand and baked by the MDD process would show a significant sticky dough problem (Atkins, 1989).

Bread wheat *- Small-scale tests.* Sample size and number preclude the use of full-scale baking tests in the early stages of a breeding programme, and instead rapid small-scale tests which predict final processing qualities are necessary. Dough rheological tests by a mixograph or small-scale extensograph, or chemical tests for protein quality such as the Zeleny sedimentation test, Pelshenke test or residue-protein test (Pinckney *et al.*, 1957; Pushman and Bingham, 1975; O'Brien and Orth, 1977), have been extensively used by wheat breeding programmes. Moderate to high heritabilities have been measured (O'Brien and Ronalds, 1987). However, most have practical problems (slow preparation time and through-put, requirement for white flour, poor correlation to final quality) and during the 1980s the sodium dodecyl sulphate (SDS) sedimentation test became widely used (Blackman and Gill, 1980; Moonen *et al.*, 1982; Preston *et al.*, 1982; Griffin, 1983a). The SDS test is also successfully used in selecting for pasta quality in durum programmes (Dexter *et al.*, 1980), including those at Crop & Food Research. Griffin (1982) found moderate to high heritabilities for SDS-volume, particularly when adjusted for protein content. Correlation of SDS-volume in F_2 with bake-score in F_5 was also highly significant (Griffin, 1983b), indicating good heritability. The SDS test is still an integral part of the quality testing at Crop & Food Research (Griffin *et al.*, 1990), and starts the quality evaluation procedure in the 4th generation. In Australia, a small-scale test for free-lipid content has also been proposed for early generation selection of baking quality (Panozzo *et al.*, 1991).

Baking quality is a highly complex character and another reason for using tests other than bake-score is to break this complexity into simpler components (Griffin, 1985). Measurement of dough rheological properties provide additional data which helps interpret bake-score weaknesses. Large-scale measurements can be made by the farinograph and extensograph. In the Crop & Food Research programmes this information comes from cooperating with commercial milling company laboratories who evaluate a few advanced breeding lines and the CRLT entries. The mixograph, see Figure 1, is a smaller-scale version of the farinograph, which has recently been modified to allow single plant progeny testing (Rath *et al.*, 1990). The 35 g mixograph has provided the second stage quality test in the 5th generation of the CFR programmes since 1988 (Griffin *et al.*, 1990). This sort of evaluation system should identify at an early stage lines with rheological problems, such as extensibility in Batten.

Electrophoretic analysis of glutenin subunit composition has not been routinely applied as an early generation screening test in most programmes because of its limited throughput and complicated procedure. However, it has been successfully used in a backcross breeding project in Cambridge where 2000 lines per week were processed (J. Bingham, pers. comm.). More commonly, electrophoresis is used to characterise parental lines so that only crosses with the greatest chances of producing high quality progenies are made (Griffin, 1983; Griffin *et al.*, 1990). The high performance liquid chromatography (HPLC) technique of Sutton *et al.* (1989) shows more promise as a screening test, although throughout may still be limiting. A study comparing this HPLC test with the other quality tests used in the Crop & Food Research programme (protein content, SDS-volume sedimentation, mixograph and test baking) has begun, and preliminary data indicates SDS-volume is more closely associated with low molecular weight (LMW) glutenins than high molecular weight (HMW) glutenins (Sutton and Griffin, 1992). This is in contrast to Moonen *et al.* (1982) who linked the effect of the SDS test to HMW glutenins, but may support the work of Gupta *et al.* (1990), who argue that LMW glutenins are just as important for baking quality as the HMW glutenins. Depending upon the outcomes of this investigation, the HPLC test may become a routine part of Crop & Food Research baking quality evaluation.

Acknowledgements

The authors acknowledge the contributions made by the New Zealand wheat industry to the Crop & Food Research wheat breeding programmes: United Wheat Growers; New Zealand Flour Millers Association; Goodman, Fielder Wattie Ltd; Defiance Milling; and Auckland Flour Mills.

Literature

Atkins, T.D. 1989. Prediction of dough stickiness using an instron universal testing machine. WRI Report No. 89/126.

Austin, R.B., Bingham, J., Blackwell, R.D., Evans, L.T, Ford, M.A., Morgan, C.L. and Taylor, M. 1980. Genetic improvements in winter wheat yields since 1900 and associated physiological changes. *Journal of Agricultural Science* ***94***, 675-689.

Baker, D. and Golumbic, C. 1970. Estimation of flour yielding capacity of wheat. *The Northwestern Miller* ***277***, 8-11.

Baruch, D.W. 1974. Wheat flour particle size distribution related to compressibility and bridging tests. *New Zealand Journal of Science* ***17***, 21-32.

Bates, R. 1992. New Zealand wheat growing: an international perspective. *In* Wheat symposium: Limits to production and quality. pp. 11-16. Agronomy Society of New Zealand, Special Publication No. 8. Lincoln University.

Bhatt, G.M. 1977. Response to two-way selection for harvest index in wheat (*Triticum aestivum* L.) crosses. *Australian Journal of Agricultural Research* ***28***, 29-36.

Bingham, J. 1966. Grain quality from the genetic and plant breeding point of view. *In* Proceedings 4th International Cereal and Bread Congress. Vienna.

Borlaug, N.E. 1968. Wheat breeding and its impact on world food supply. *In* Proceedings 3rd International Wheat Genetics Symposium. pp. 1-36. Canberra.

Cromey, M.G., Harvey, I.C., Brathwaite, M., Farrell, J.A.K. and Ganev, S. 1992. Effects of disease and pests on yield and quality of wheat. *In* Wheat symposium: Limits to production and quality. pp. 63-72. Agronomy Society of New Zealand, Special Publication No. 8. Lincoln University.

Davies, L., McEwan, J.M. and Cross, R.J. 1975. Effects of height reducing genes on yield in bread wheat: overseas and New Zealand results. *Proceedings Agronomy Society of New Zealand* ***15***, 71-74.

Dexter, J.E., Matsuo, R.R., Kosmolak, F.G., Leisle, D. and Marchylo, B.A. 1980. The suitability of the SDS-sedimentation test for assessing gluten strength in durum wheat. *Canadian Journal of Plant Science* ***60***, 25-29.

De Pauw, R.M., McCaig, T.N., Mares, D.J., Brennan, P., Henry, R.J., King, R., McEwan, J.M. and Gordon, I. 1990. Genetic variation for length of dormancy period, sprouting resistance and α-amylase content in wheat. *In* Proceedings 5th International Symposium on Pre-Harvest Sprouting in Cereals. Westview Press, Boulder, Colorado, USA

De Pauw, R.M. and McCaig, T.N. 1988. Utilization of NaOH to assess kernel colour and its inheritance in 11 spring wheat varieties. *Canadian Journal of Plant Science* ***68***, 323-329.

Dhaliwal, A.S., Mares, D.J. and Marshall, D.R. 1987. Effect of IB/IR chromosome translocation on milling and quality characteristics of breed wheats. *Cereal Chem.* ***64***, 72-76.

Foulds, J.G. 1989. Cereals in animal nutrition. *In* Proceedings 1989 Cereal Science Conf. pp. 70-72. DSIR, Christchurch.

Gale, M.D. 1976. High α-amylase: breeding and genetical aspects of the problem. *Cereal Research Comm.* ***4***, 231-243.

Gale, M.D. and Law, C.N. 1976. Norin-10 based semi-dwarfism. *In* Genetic Diversity in Plants. pp. 133-151. (ed. A. Muhammed, and R.C. von Borstel). Plenum Press, New York.

Gordon, I.L. 1980. Heritability of grain development traits associated with sprouting damage in wheat inbreds. *Cereal Research Comm.* ***8***, 185-192.

Griffin, W.B. 1978. Early generation selection for wheat milling quality. *Proceedings Agronomy Society of New Zealand* ***8***, 83-85.

Griffin, W.B. 1982. Inheritance of grain quality and agronomic characters in wheat. Ph.D thesis. University of Cambridge.

Griffin, W.B. 1983a. Small-scale quality tests in wheat breeding. *In* Proceedings 1983 Cereal Science Conf. pp. 44-54. DSIR, Christchurch.

Griffin, W.B. 1983b. Screening for bread baking quality by the SDS-sedimentation test and SDS-polyacrylamide gel electrophoresis. *Proceedings Agronomy Society of New Zealand* ***13***, 111-115.

Griffin, W.B. 1985. Breeding for quality specifications. *In* Proceedings 1985 Cereal Science Conf. pp. 102-105. DSIR, Christchurch.

Griffin, W.B. 1987. Outcrossing in New Zealand wheats measured by occurrence of purple grain. *New Zealand Journal of Agriculture Research* ***30***, 287-290.

Griffin, W.B. 1989. Influence of high molecular weight glutenin subunits on environmentally affected variations of wheat quality. *In* Proceedings 1989 Cereal Science Conf. pp. 46-50. DSIR, Christchurch.

Griffin, W.B., Harvey, W. and Bezar, H.J. 1990. Wheat breeding quality in New Zealand: meeting the challenge. *In* Proceedings 6th Assembly Wheat Breeding Society of Australia. pp. 243-248. Tamworth.

Griffin, W.B. and Wooding, A.R. 1992. The importance of work input in breeding for improved wheat bread baking quality. *In* Proceedings 42 RACI Cereal Chem. Conf. pp. 235-244. Christchurch.

Gupta, R.B., Bekes, F., Wrigley, C.W. and Moss, H.J. 1990. Prediction of wheat dough quality in breeding on the basis of LMW and HMW glutenin composition. *In* Proceedings 6th Assembly Wheat Breeding Society of Australia. pp. 217-226.

Gupta, R.B. and Shepherd, K.W. 1988. Low molecular-weight glutenin subunits in wheat: their variation, inheritance and association with bread-making quality. *In* Proceedings 7th International Wheat Genetics Symposium. pp. 943-950. Cambridge.

Islam, M.A., Fautrier, A.G. and Langer, R.H.M. 1985a. Early generation selection in two wheat crosses. 1. F_2 single plant selection. *New Zealand Journal of Agriculture Research* ***28***, 313-317.

Islam, M.A., Fautrier, A.G. and Langer, R.H.M. 1985b. Early generation selection in 2 wheat crosses. 2. F_3 line selection. *New Zealand Journal of Agriculture Research* ***28***, 319-323.

Jamieson, P.D. and Wilson, D.R. 1992. Physiological and agronomic limits to wheat yield and quality. *In* Wheat symposium: Limits to production and quality. pp. 25-32. Agronomy Society of New Zealand, Special Publication No. 8. Lincoln University.

Lee, C.K. 1980. Quantitative inheritance in wheat. Ph.D. thesis. Lincoln College, University of Canterbury.

Lee, C.K. Fautrier, A.G. and Langer, R.H.M. 1982. Diallel analysis of flour protein content in some NZ wheats. *New Zealand Journal of Agriculture Research* ***25***, 167-173.

Limin, A.E. and Fowler, D.B. 1991. Breeding for cold hardiness in winter wheat: problems, progress and alien gene expression. *Field Crops Research* ***27***, 201-218.

Lindley, T.N. and Moore, R.D. 1988. The 1988 New Zealand Wheat quality survey. WRI Report No. 88/123. DSIR.

Lindley, T.N. and Moore, R.D. 1989. The 1989 New Zealand wheat quality survey. WRI Report No. 89.127. DSIR.

McEwan, J.M. 1973. The performance of semi-dwarf wheats in New Zealand: implications for New Zealand wheat breeding. *In* Proceedings 4th International Wheat Genetics Symposium. pp. 557-449. Columbia.

McEwan, J.M. 1976. Breeding for resistance to pre-harvest sprouting in New Zealand wheats. *Cereal Research Comm.* ***4***, 97-100.

McEwan, J.M. 1980. The sprouting reaction of stocks with single genes for red grain colour derived from Hilgendorf 61 wheat. *Cereal. Research Comm.* ***8***, 261-264.

McEwan, J.M. and Griffin, W.B. 1985. Plant breeding. *In* Wheat Research Progress and Opportunities. *New Zealand Wheat Review, Special Edition* ***15A***, 45-57.

Mares, D.J. 1984. Pre-harvest sprouting in wheat. *In* Proceedings 4th Assembly Wheat Breeding Society of Australia. pp. 129-132. Toowoomba.

Martin, R.J., Sutton, K.H., Moyle, T., Hay, R.L. and Gillespie, R.N. 1992. The effect of nitrogen fertilizer on the yield and quality of six cultivars of autumn sown wheat. *New Zealand Journal of Crop and Horticultural Science* ***20,*** 273-282.

Mitchell, T.A. 1985. Processing and end uses. *In* Wheat Research Progress and Opportunities. *New Zealand Wheat Review, Special Edition* ***15A***, 59-65.

Moonen, J.H.E., Scheepstra, A. and Graveland, A. 1982. Use of the SDS-sedimentation test and SDS-polyacylamide electrophoresis for screening breeders' samples of wheat for bread-making quality. *Euphytica* ***31***, 677-690.

Morgan, J.M. 1983. Osmoregulation as a selection criterion for drought tolerance in wheat. *New Zealand Journal of Agriculture Research* ***34***, 607-614.

Munro, C. 1992. Results of the 1991/92 Cereal Disease Nurseries. Internal Report No.55. DSIR Crop Research.

O'Brien, L. and Orth, R.A. 1977. Effect of geographic location of growth on wheat milling yield, farinograph properties, flour protein and residue protein. *New Zealand Journal of Agriculture Research* ***28***, 5-9.

O'Brien, L. and Ronalds, J.A. 1987. Heritabilities of small-scale and standard measures of wheat quality for early generation selection. *New Zealand Journal of Agriculture Research* ***38***, 801-808.

Panozzo, J.F., Bekes, F., O'Brien, L. and Khan, A. 1991. Selection of wheat breeders' lines for improved baking quality based on their free lipid content. *New Zealand Journal of Agriculture Research* ***42***, 715-721.

Parkyn, C. 1985. Flour requirements for quality biscuits. *In* Proceedings 1985 Cereal Science Conference. pp. 56-59. DSIR, Christchurch.

Payne, P.I. 1987. The genetical basis of bread making quality in wheat. *Aspects of Applied Biology* ***15***, 79-90.

Payne, P.I., Holt, L.M., Worland, A.J. and Law, C.N. 1982. Structural and genetical studies on the higher molecular weight subunits of wheat glutenin. III. Telocentric mapping of the subunit genes on the long arms of the homoecologous Group 1 chromosomes. *Theoretical and Applied Genetics* ***63***, 129-138

Payne, P.I., Nightingale, M.A., Krattiger, A.F. and Holt, L.M. 1987. The relationship between HMW glutenin subunit composition and the bread making quality of British grown wheat varieties. *Journal of Science and Food* ***40***, 51-65.

Pinckney, A.J., Grainy, W.T. and Zeleny, L. 1957. Further developments in the sedimentation test for wheat quality. *Cereal Chem.* ***34***, 16-25.

Preston, K.R., March, P.R. and Tipples, K.H. 1982. As assessment of the SDS-sedimentation test for the prediction of Canadian bread wheat quality. *Canadian Journal of Plant Science* ***62***, 545-554.

Pugsley, A.T. 1973. Control of developmental patterns in wheat through breeding. *In* Proceedings 4th International Wheat Genetics Symposium. pp. 857-859.

Pushman, F.M. and Bingham, J. 1975. A reappraisal of the Pelshenke test as a screening technique in the breeding of bread making wheats for the United Kingdom. *Journal Agric. Science (Cambridge)* ***85***, 221-231.

Rajaram, S., Mann, C.E., Ortiz-Ferrara, G. and Mujeeb-Kazi, A. 1983. Adaptation, stability and high yield potential of certain IB/IR CIMMYT wheats. *In* Proceedings 6th International Wheat Genetics Symposium. pp. 613-621. Kyoto.

Rajaram, S., Matzenbacher, R., Rosa, O. de S., 1987. Developing bread wheats for acid soils through shuttle breeding. *In* CIMMYT Research Highlights 1986. CIMMYT. Mexico.

Rath, C.R., Gras, P.W., Wrigley, C.W. and Walker, C.E. 1990. Evaluation of dough properties from 2 g of flour using the mixograph principle. *Cereal Foods World* ***35***, 572-574.

Richards, R.A. 1983. Should selection for yield in saline regions be made on saline or non-saline soils. *Euphytica* ***32***, 431-438.

Simmonds, L.D. 1991. The 1990 New Zealand wheat quality survey. DSIR Crop Research Food Report No. 3.

Simmonds, L.D. 1992. The 1991 New Zealand wheat quality survey. DSIR Crop Research Internal Report No. 54.

Simmonds, N.W. 1979. Principles of Crop Improvement. Longman. London and New York. 408 pp.

Skeggs, P.K. and Kingswood, K. 1981. Mechanical dough development - pilot scale studies. *Cereal Chem.* ***58***, 256-250.

Sozinov, A.A. and Poperelya, F.A. 1980. Genetic classification of prolamines and its use for plant breeding. *Ann. Tech. Agric.* ***29***, 229-245.

Stenvert, N.L. 1974. Grinding resistance - a simple measure of gain hardness. *Journal of Flour and Animal Feed Milling* ***156***, 24-27.

Stevenson, K.R. 1987. Yield-quality relationships in some New Zealand wheat cultivars. M.Agric.Sci. Thesis. Lincoln College, University of Canterbury.

Strategic Partnerships. 1991. Achievement of a sustainable New Zealand wheat and flour milling industry in the 90's..

Sutton, K.H., Hay, R.L. and Griffin, W.B. 1989. Assessment of potential breadbaking quality of NZ wheats by RP-HPLC glutenins. *Journal Cereal Science* ***10***, 113-121.

Sutton, K.H., Hay, R.L., Mouat, C.L. and Griffin, W.B. 1990. The influence of environment, milling and blending on assessment of the potential bread making quality of wheat by RP-HPLC of glutenin subunits. *Journal of Cereal Science* ***12***, 145-153.

Sutton, K.H. and Griffin, W.B. 1992. Selection for bread baking quality: early generation screening. *In* Proceedings 42 RACI Cereal Chem. Conf. pp. 254-259. Christchurch.

Wall, J.S. 1979. The role of wheat proteins in determining baking quality. *In* Recent advances in the Biochemistry of Cereals. pp. 275-311. Phytochemical Society of Europe Symposia, Series No. 16. Academic Press.

Wooding, A.R. 1988. The WRI bake tests. WRI Report ISBN No. 0-477-02546-3 DSIR.