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THE HARMFUL HARVEST RAIN

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I wish to express my gratitude to the Farrer Memorial Trust for selecting me as the recipient of the Farrer Memorial Medal for 1981. In accepting this honour, I wish to emphasize that plant breeding is no longer a single persons's task but is largely a team effort. For this reason I regard this distinction as a recognition of the efforts of all my associates who have collaborated with me over the years. It is generally recognized that behind every successful plant breeder there is a team of good technicians and the efforts of my technical staff have contributed in no small measure to my success.

On this occasion each year we remember a great Australian, William James Farrer, who was arguably the most imaginative plant breeder to work in Australia. The pioneering work of Farrer was instrumental in establishing a successful wheat industry in Australia. He bred and named 220 wheat cultivars which have been listed by Macindoe and Walkden Brown (1968). Federation, the most significant cultivar bred by Farrer, was widely grown in Australia between 1901-1938 and during the 1920's it was also popular on the Pacific Coast of the U.S.A. and was cultivated in India. Federation, Comeback, Bunyip, Florence, Bobs and many other Farrer wheats became the basis of numerous Australian wheat cultivars. By coincidence or good management all the Australian wheat cultivars which show some tolerance to pre-harvest sprouting damage include several Farrer wheats in their pedigree. At the present time three Australian cultivars exhibit some tolerance to pre-harvest rain damage: Ford, Kite and SUN 44E. All three have Comeback in their pedigree and, in addition, Kite has Florence, Federation, Sunset, Cleveland, Bunyip and Jonathan in its pedigree whilst SUN 44E has Florence, Federation and

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Bobs, all of which were bred by Farrer.

WHAT IS PRE-HARVEST RAIN DAMAGE?

Rain just prior to or during harvest can induce germination in the ear. Germination or sprouting as it is often called, consists of a complex sequence of events including the production of plant hormones and hydrolytic enzymes and eventually the degradation of the grain starch and protein reserves which renders the grain unsuitable for industrial use. In addition the pre-harvest^{rain} damaged crop may give an inferior yield and grain with a reduced test weight. Wheat, rye, barley, oats, triticale and rice are all liable to pre-harvest sprouting damage. Strictly speaking, none of the cultivated temperate zone cereals possess long lasting resistance against pre-harvest sprouting. Nearly all wild wheat species, however, have some degree of protection against early sprouting in the head and most of these species have tangible grain dormancy. A large number of wild wheats are endemic to the near east (Asia Minor and Trans Caucasian) where they are grown during early spring when cool and rainy climatic conditions prevail and they mature before the onset of the hot, dry, long summer. After maturity either the shattered grain or the fragile parts of the spike fall to the ground where they await environmental conditions which favour germination. Germination may take place when the temperature drops and the autumn rains begin, or the next spring, depending on what sort of dormancy is preventing early germination, e.g. *T. aegilopoides* which is a true winter wheat germinates in the autumn and during the winter it is protected from the harshness of the winter by its vernalization and long day length requirement. *T. thauodor* has two seeds per spikelet - one of the seeds, which is large, is ready to germinate in the autumn and produces a winter wheat, while the other smaller seed may germinate only when the winter is over and produces a spring wheat. However, if the conditions are unfavourable during the spring the grain may wait for the next opportunity. Spelta wheat is protected to a certain extent from early germination by its strongly adhering glumes. It is also interesting to note that in the case of wild wheats and those cultivated cultivars which have some degree of dormancy, the seeds coming from the central part of the spike have longer dormancy than the grains from the top or base (Mac Key 1976). The question may be asked: What happened with the cultivated cereals, particularly

with the wheat, that we are now forced to enter into sophisticated research and breeding programmes to find protection against the harmful harvest rain? I am afraid the drastic reduction in the dormancy factor was caused by the intervention of man. From the time that wheat was taken into cultivation man has unknowingly selected against dormancy, particularly in the winter cereal crops of the northern hemisphere where the harvest of one crop is closely followed by the sowing of the next. Only genotypes with the ability to germinate quickly and vigorously survive in these situations. In any case, wheat no longer has to "store" its own seed as this task has been taken over by man. More recently, human greed or, more precisely, the efficiency of plant breeders have combined to erode the last traces of dormancy in spring wheat. Many modern wheat breeding programmes are growing two or some times three crops per year, either with the aid of alternating between low land and high altitude sites or utilizing opposite hemisphere locations. CIMMYT grows a crop at Cd. Obregon on 39 m altitude between November and May, and within a couple of weeks of the May harvest they sow the next generation crop at Toluca on 2640 m altitude. Here they harvest in November and the following generation is sown at Cd. Obregon and/or Toluca almost immediately. A similar system is practised by many northern hemisphere breeding stations. They grow a generation in Europe or Northern America which is harvested in September/October and taken by air to New Zealand or Mexico and sown again, then harvested at the end of April or May and taken back to the original station to sow the next generation. Under this inadvertent selection pressure only those genotypes can survive which do not possess any dormancy at harvest.

The higher quality standards demanded in recent years also force us to give special attention to the effect of harvest rains. During Farrer's time with their relatively late maturing wheats and different quality requirements sprouting damage was not regarded as a real problem. In later years the proportion of sprouted grains was the only criteria for assessment of sprouting damage at silos. This system was proven unsatisfactory because the industrial processors (bakers, noodle makers, etc.) are only interested in how far the baking or noodle making quality is influenced by sprouting damage and the estimate of the number of sprouted grains do not give a proper indication of the degree of starch degradation which is

the crucial factor (Moss *et al.* 1972). Therefore new and more sensitive testing methods are being introduced by the industry (Kruger 1980) which demands that the chemists, breeders and physiologists should seriously consider the problems associated with the harvest rain.

Pre-harvest rain damage is a menace in the north west, central west and alpine regions of Europe, in most of the cereal growing regions of South America, South Africa, Kenya, Zimbabwe and in the eastern part of New Zealand. In the western provinces of Canada and the very northern states of the U.S.A. a special problem arises as a result of the swathing practice; if rain falls while the crop is still lying in the swathes (wind rows) the loss due to germination can be substantial. In the author's experience losses due to germination in the ear may exceed the 80% mark. In Eastern Canada, the eastern states and the Pacific north west of the U.S.A., and Australia highly sprouting-susceptible white wheats are grown and the chances of sustaining losses from "weather damage" are extremely high. The Australian northern wheat belt, which consists of northern N.S.W. and southern Queensland, is situated in a predominantly summer rainfall area and as such there is a high probability of rain in the usual harvest months of October-December (Fig. 1).

This northern wheat belt which is frequently "hit" by severe drought during the growing season also has a very high probability of receiving harmful rain during the harvest period. As an indication of the behavioural pattern of the northern New South Wales' wheat region the mean probabilities of receiving rainfall during October to December harvest are: 12.7 mm ($\frac{1}{2}$ ") = 89.4%, 25.4 mm (1") = 75.2% and 50.8 mm (2") = 47.3%. During the 3 year period 1977-78 to 1979-80 in the Division I area of the Grain Handling Authority, which is basically the Newcastle freight zone, the farmers lost 32.25 million dollars premium due to the downgrading of 2.29 million tonnes of potentially prime hard wheats. This amounts to an average loss of \$14 per tonne as a consequence of sprouting damage (Prime Wheat Association pers. comm.). An earlier assessment estimated the loss of \$18 million annually to the Australian wheat grower (Derera 1980).

Sprouting damage resistance:

While a high degree of tolerance to sprouting damage can be found in some of the red wheats it is rather more difficult to find tolerance in white wheat

cultivars (Nilsson-Ehle 1914; Åkerman 1936; Gfeller & Svejda 1960; Freed & Everson 1972; Moss *et al.* 1972; Derera 1973). Close linkage between red pericarp and sprouting resistance (dormancy) was detected although Åkerman (1936), Voss (1939) and Isenbeck (1950) reported some rare recombinants in which this linkage was seemingly broken. However, it must be noted that not all red wheats possess sprouting damage resistance, there are many red cultivars which are extremely susceptible to pre-harvest sprouting (^{Fig. 4} [redacted]). Despite the fact that red wheats possess more readily available dormancy factors, we cannot utilise them, mainly because their type of dormancy is strictly associated with the red pericarp and Australian wheat is known and sought after on the world market as white wheat which has better milling characteristics than most red wheats.

The year 1973 saw a significant change in pre-harvest sprouting damage studies which previously had concentrated almost exclusively on dormancy. A number of scientists initiated a co-operative venture that eventually resulted in the organization of the First International Symposium on Pre-harvest Sprouting Damage in Cereals which was held in Röstänga, Sweden in 1975 (Derera 1976). It was followed by a second symposium in Cambridge, U.K. during 1979 (Stoy 1980). The Third International Symposium on Pre-harvest Sprouting Damage in Cereals will be held in Winnipeg, Canada during June 1982. Intensified research into the problems associated with pre-harvest sprouting during the past eight years has generated a better understanding of the germination process and the factors which may influence germination. As a result the chance of improving the pre-harvest sprouting resistance of the cultivated cereals has significantly improved. Pre-harvest sprouting resistance in cereals, particularly in wheat, is a complex interaction of a great many physiological, biochemical, physical and environmental factors. During the years whilst I have been endeavouring to find some protection against pre-harvest sprouting damage I developed a simple working hypothesis which I have specified below and for which I will present some verification in the following paragraphs/ (Fig. 2). In general terms, the major factors which influence sprouting damage resistance can be divided into two groups: the maturity-dependent components which are highly influenced by environment and

a multi-component character. The seed coat, pericarp, aleurone, endosperm and embryo are all involved in germination and so in dormancy.

The seed coat may influence sprouting by imposing barriers to water absorption and gaseous exchange, particularly oxygen uptake, and may obstruct outward diffusion of hypothetical endogenous germination inhibitors. Belderok (1976a) maintains that restriction of water uptake does not influence dormancy. However, Takahashi (1980) found convincing evidence in rice and barley that the water uptake pattern is influenced by dormancy. Mares (pers. comm.) found significant cultivar differences in water uptake into grain in intact ears whilst Butcher & Stenvert (1973), Stenvert & Kingswood (1976) have also found significant cultivar differences in water penetration into threshed wheat grain. Experimental procedures such as the removal of the pericarp and testa, puncturing the outer layers of the caryopsis or adding hydrogen peroxide to the water when germinating dormant grain frequently enhance germination. Since oxygen permeability of the outer layers of the wheat caryopsis has never been reported there is no direct evidence indicating genotypic differences, however, hypo-oxia has been proposed as a mechanism to explain dormancy (Gordon 1980). With the aid of scanning electron microscopy Belderok (1976b) was able to detect differences in the structure of the seed coat (testa) layers of dormant and non-dormant wheats. In the non-dormant or sprouting susceptible cultivars, one week before maturity, he found that the so called "coloured" layer and the outer cuticle were clearly visible and that they consisted of a dense homogeneous material; one week after maturity the layer had decreased in diameter and changed to a granular consistency. Belderok argued that the layer was now probably permeable to gaseous materials and posed no obstruction to water absorption. The resistant cultivar (red) was characterised by two thick homogeneous testa layers one week before ripeness. One week after maturity the cuticle had fused with the "colour" layer to such an extent that no difference was detectable. The testa was a fairly thick, homogeneous structure and could possibly impede gaseous exchange. Mitchell *et al.* (1980a) state that dehydration of the grain, particularly the pericarp, is part of an after ripening process and may cause loss of dormancy. They also suggested that an improved oxygen permeability may result.

Many research workers have emphasized the significance of gaseous exchange by the outer layers of the caryopsis. Although these factors are most likely involved, it must be accepted that as hormones play a crucial function in many aspects of growth and development, their influence on dormancy cannot be ignored (Wareing & Saunders 1971). There is a strong possibility that the interaction of plant hormones, abscisic and gibberellic acids, cytokinins and ethylene has an important role in dormancy (Taylorson & Hendricks 1977).

The presence of germination inhibitors in the caryopsis has been indicated by a number of studies. Miyamoto & Everson (1958) extracted catechin and catechin tannin from the seed coat and found a positive correlation between the degree of redness and the quantity of catechin and catechin tannin present. These authors indicated that catechin and catechin tannin which are the water soluble precursors of water insoluble brown phlobaphene inhibit germination. Later Miyamoto *et al.* 1961 alleged that dormancy was not connected to restricted water or oxygen uptake. Rather the inhibitory effects are due to catechin tannin, a chloroform or low pH water (acidified) soluble alkaloid and an unknown compound also soluble in chloroform. Whitmore (1974) found that ferulic acid extracted from wheat coleoptiles also has a germination inhibitory effect. Exogenously applied abscisic acid is known to inhibit germination even in very low concentrations. Abscisic acid was found in dormant seeds of a large number of species (Milborrow 1974), however, its role in dormancy is not yet quite clear.

Stoy and Sundin (1976) and later Stoy & Olsen (1980) presented evidence on the inhibitory effects of catechin tannins on the growth of excised spring wheat embryos. These authors also found genotypic differences and demonstrated that the germination responses of the excised wheat embryos to catechin tannins is controlled by one pair of alleles within a single gene locus. The allele causing strong germinating inhibition in the presence of catechin tannins has an incomplete dominance over sensitivity which may be modified to a certain extent by other factors.

One of the factors which has a strong influence on dormancy is the temperature conditions which are experienced during the late grain filling period.

Low temperatures enhance, while high temperatures reduce dormancy. In the northern hemisphere the temperature during late grain filling is frequently low and definitely below 30°C. In Australia, particularly in the northern wheat belt, the temperature is nearly always between 30-40°C during the late grain filling period and this is one reason why even some of the dormant red wheats show only limited dormancy under our environmental conditions.

While discussing dormancy, it must be pointed out that the seed of a cultivar which has dormancy will not necessarily have a slow germination ability and poor stand establishment after sowing. The type of dormancy that exists in the cultivated wheats invariably "breaks down" within 6-30 days after maturity.

Alpha-amylase synthesis:

In terms of the commercial utilization of wheat flour for bread manufacture pre-harvest sprouting damage resistance is synonymous with an inhibition or reduction in the synthesis of hydrolytic enzymes, particularly α -amylase, under conditions which are favourable for grain germination. The synthesis of hydrolytic enzymes accompanies germination or, more specifically, is stimulated by the group of plant hormones called gibberellins which are released by the embryonic tissues of germinating cereal grains. Excess natural α -amylase activity produces a highly coloured loaf with a sticky crumb resulting from the production of sugars, the degradation products of starch, during the baking process. Flour from sprouted wheat is also unsuitable for the manufacture of Japanese or Chinese noodles. While discussing the effect of α -amylase the role of protein degrading (proteolytic) enzymes should also be pointed out. This enzyme system may influence the rheological properties of the gluten (Kruger 1980).

In barley where gibberellic acid effects on α -amylase synthesis have been studied more extensively, the increase in gibberellin was found to antecede the protrusion of radicle and it was believed that the build-up in α -amylase was post-germinative (Taylorson & Hendricks 1977). Claims by many authors that α -amylase is synthesised only in the aleurone layer and that the production of significant amounts of α -amylase commences from the fourth day after germination have been refuted by Gibbons (1979), who used immunohistochemical techniques to prove that the scutellum

of Nordal barley plays an important role in the release of α -amylase during the first 3 days after imbibition. He also demonstrated that after 30 hours of imbibition α -amylase was present in the endosperm tissue immediately adjacent to the scutellum. This elegant piece of work verified an old hypothesis first proposed by Tangl in 1886. Since Marchylo *et al.* (1980) have indicated that the scutellum of wheat is able to synthesise α -amylase during germination, it seems reasonable to assume that Gibbons' findings and Tangl's theory may also apply to wheat. Potentially, genotypic differences in either the amount of gibberellins produced or in the sensitivity of the α -amylase synthesizing tissues to gibberellins could be utilized to achieve a reduced rate of α -amylase synthesis. Gale & Marshall (1975) did not find any differences amongst tall wheats in the rates at which gibberellin was released from the embryo. However, we have found indirect evidence of significant varietal differences that may exist in both the rate and amount of gibberellin released from the embryo (Derera *et al.* 1977). Gale & Marshall (1975) discovered that the caryopsis of certain dwarf varieties did not respond to the exogenously applied GA₃ and that the rate of α -amylase production was relatively low. They also found that these particular dwarfs had a fairly high level of endogenous gibberellins. These dwarf cultivars were winter wheats, Tom Thumb and Minster Dwarf, which were found to carry a gene for GA insensitivity (Gai₃) which is either closely linked or pleiotropic with Rht₃ dwarfing gene (Gale 1976). The same gene was found in the Mexican spring wheat cultivar, Tordo (Fig. 3). (Derera *et al.* 1976; Bhatt *et al.* 1977). This gene appeared extremely attractive, particularly in white wheats, since it induced both a lower germination rate and a reduced rate of α -amylase synthesis, however, the Rht₃ gene for extreme dwarfness, 50-60 cm, would create major difficulties at harvest. Whilst preliminary work suggested that Gai₃ and semi-dwarf growth habit could be combined, further work has failed to produce an acceptable recombinant. It is interesting to note that using a single grain gel-diffusion method (Derera 1978; Hejgaard & Gibbons 1979) I found variation in gibberellin insensitivity among grains of the cultivar Songlen (rht₂) and Shortim (rht₁ plus rht₂). The variation was particularly obvious in Shortim where a portion of the individual grains showed a reduced α -amylase synthesis

in the presence of exogenous GA₃. This phenomenon is being further investigated by D.J. Mares at our centre. Bhatt *et al.* (1976) reported that the reduced α -amylase synthesis can be separated from the Gai3/Rht3 gene. These authors suggested that low α -amylase synthesis may be governed by two major complementary genes and that the low α -amylase synthesis was dominant over the high α -amylase synthesis.

Recently, two semi-dwarf cultivars showing a reduced rate of α -amylase generation in response to pre-harvest rain have been identified. These cultivars, Kite and SUN 44E, are presently being studied to find out the mechanism involved in their tolerance to harvest rain. Moss & Kirby (1976) reported that the fibre content of the endosperm definitely influenced the flour paste viscosity. They suggested that the thick cell walls may obstruct the movement of α -amylase or in some way inhibit its effects. They also postulated that the fibrous material might contribute directly to the flour paste viscosity. The use of high fibre content to limit the activity of α -amylase is not a practical consideration since thick cell walls and high fibre content have an adverse effect on milling.

Breeding for pre-harvest sprouting resistance:

Breeding for pre-harvest sprouting resistance is a complex task. In regions where red wheat is produced breeding is simplified by the close association between the red pericarp and dormancy. However, in many regions (e.g. Northern and Western Europe) a long dormancy cannot be tolerated since the harvest in late August and early September is closely followed by the sowing of the next year's crop. My own experience indicates that even in the case of cultivars possessing the strongest dormancy, resistance may break down relatively rapidly if exposed to intermittent rains and drying-out periods. For this reason more and more breeders agree that no single component of sprouting resistance will provide sufficient protection in all years. A combination of the previously mentioned resistance factors such as dormancy, slow water absorption, inhibitors in the husk, low α -amylase synthesis and/or gibberellin insensitivity may provide an effective protection (Derera *et al.* 1976). On the basis of the recent research an exploratory breeding procedure has been initiated at the Plant Breeding Institute, Narrabri.

Selection of parents:

It is relatively easy to find an appropriate dormant parent among red wheats. For example, RL 4137, a Canadian red spring wheat, displayed the highest degree and longest lasting dormancy among the cultivars tested (Figs. 4 & 5) (Derera *et al.* 1977). This may be an ideal parent in a red spring wheat programme, but very few white wheats with dormancy have been identified. Kenya 321 BT.1.B.1 (a Canadian selection) appears to be the best source of dormancy among white wheats, whilst the Australian cultivar, Ford, has a limited dormancy (Figs. 6 & 7) (Derera *et al.* 1977). It is believed that the white winter wheats, Rieder and Peck from the U.S.A. also have a degree of dormancy (W. Pope pers. comm.). In addition there may be more white wheats possessing some dormancy factors and certain diploid and tetraploid wheats may have dormancy genes that could be transferred to white bread wheats. For example, *T. aegilopoides* and *T. thaoudar*, both have strong and long lasting dormancy, perhaps attributable to rare embryo dormancy (Mac Key 1976).

Unfortunately, very little has been done to find further sources of dormancy genes in white wheats. I initiated the task of screening the Australian Wheat Collection to find further sources of sprouting resistant genes that can be used in white wheat breeding programmes. This task is very demanding and should be continued for at least three years.

The German cultivar Kleiber is reputed to possess germination inhibitors in the husk (Derera *et al.* 1976; Derera & Bhatt 1980). However, it appears that this character is highly influenced by environment and its usefulness seems questionable. It must be noted, however, that nearly all the identified components of pre-harvest sprouting resistance are influenced by environment to some degree.

It was found that Tom Thumb, Minster Dwarf, Topo and Tordo are good sources of gibberellin insensitivity and/or low apparent α -amylase synthetic potential. The first two cultivars are red winter wheats while the last two are white grained spring wheats. To date, from crosses involving an Rht3 parent and conventional tall or semi-dwarf wheats, no useful gibberellin insensitive tall or

semi-dwarf recombinants have been found. However, from crosses with Tordo we found recombinants with reduced apparent α -amylase synthetic potential. Despite the disappointment with the Gai3/Rht3 further investigations are needed before any firm conclusions can be drawn. To utilise the slow water absorption factor, among others, Kite and SUN 44E may be used as parents. The inheritance of this factor needs to be investigated.

Back-crossing programme:

A breeder using a back-crossing programme for pre-harvest sprouting resistance faces two choices: either to handle it as a complex quantitative character in which case a very large number of crosses must be made, or alternatively to find a way to determine which individual plants are carrying the required genes for resistance. For the purpose of achieving the latter, the non-destructive single grain test may be useful (Derera & Noll 1978; Hejgaard & Gibbons 1979). To select for gibberellin insensitivity and/or low α -amylase generation it would seem that with the help of this test the insensitive and/or low α -amylase producing genotypes can be identified. It must, however, be noted that the variation within the spike and the plant may exceed the genetic variation between plants. Nevertheless, the method can still be used with care to detect consistent trends. Certainly, when the single grain method is used and the plants are grown their height must be monitored since the extreme dwarf genotypes are undesirable.

A similar approach may be used with more confidence to select for dormancy. Ten days after harvest maturity, the seed of appropriate populations is placed in conditions conducive to germination. After four days the germinated grains are rejected and the ungerminated ones are assumed to be dormant and following drying are retained for sowing in the crossing nursery at a later date when the dormancy has "broken down".

Selection of progenies:

The simplest way to handle segregating populations is to apply the mass selection method described by Svensson (1976) and Strand (1980). The aim of this method is to increase the frequency of sprouting-resistant genotypes in the population before the actual single plant selection takes place in F₄ and F₅. The

mass selection itself is conducted under simulated rainfall conditions (McMaster & Derera 1976). The single plant or spike progenies can be subjected to a full pre-harvest sprouting resistance test in the simulated rainfall chamber using 10-30 spikes per progeny. The treated samples may either be assayed for α -amylase production or subjected to the Hagberg falling number test (McMaster & Derera 1976). The falling number test has the advantage that besides evaluating α -amylase activity it also evaluates other factors which affect flour viscosity. It should be emphasized that the results of a single year's progeny test can be misleading, particularly if the progenies possess only one pre-harvest sprouting resistance component. As mentioned previously, adverse environmental conditions may counteract genotypes with a single factor more readily than those possessing complex resistance.

Testing advanced lines:

Advanced generation lines are usually tested over 3-4 years in order that their genotype environment interaction can be assessed. Depending on the aims of the breeding programme advanced or so called "fixed lines" may be subjected to a full gibberellin sensitivity test, apparent α -amylase production assay and a replicated ear sprouting test in simulated rainfall chamber. It is strongly recommended that the ear sprouting test be conducted at 3 stages; 10, 20 and 30 days after morphological maturity. In this way the duration of resistance can be ascertained. In most cases the degree of resistance is also of interest so that it is advisable to keep the samples in the moisture chamber up to 96 hours and sample both after 60 and 96 hours' duration (Figs. 4, 5, 6 & 7). Following the treatment the samples are subjected to the falling number test.

The degree of maturity or, more precisely, the days after morphological maturity when the tests are carried out is very important. Therefore, an appropriate evaluation or an index is needed which includes the falling number results and the degree of maturity. Weilenmann (1976a,b) developed a useful empirical formula which provides a sprouting index corrected with respect to the degree of ripeness (Fig. 8). It was found that with the use of this index a reasonable relative value for genotypes could be obtained as an aid to a more objective selection. It cannot be over emphasized that most of the components of

sprouting resistance are strongly influenced by the changing environment, and in order to evaluate the breeding lines accurately an eco-analysis is suggested. Weilenmann (1980) recommended the use of the method developed by Wricke (1962). With the eco-values the phenotypic stability of the new lines can be measured in the changing environment (Wricke 1965).

The chances of finding recombinants which have sprouting resistance together with all the other essential characters such as high yield, acceptable quality, disease resistance, etc. are low, particularly since some of the factors controlling sprouting resistance are associated, in varying degrees, with adverse quality traits.

Research on germination, particularly on sprouting damage problems, was significantly intensified over the past 8 years. Numerous articles (over 1500) and a few books have been published and two successful symposiums have been held. Nevertheless, I am using a large number of "ifs", "maybes" and "could bes" throughout this oration as we are still far from a clear understanding of the fundamentals of dormancy or even the control mechanism which regulates the very early stages of germination. More organized research is needed in this field and there is a great need to establish a team of scientists consisting of physiologists, cytogeneticists, biochemists, agronomists and plant breeders to conduct an integrated study of the fundamentals of cereal germination with special reference to the sprouting damage problems. If I may quote from my opening address to the Second International Symposium on Pre-harvest Sprouting Damage in Cereals: "There are plenty of excellent research workers who are ready and capable to combat the problems jointly, and it is up to the various Governments and other granting bodies to establish the required task force at the appropriate locations such as Western Europe for red wheats and Australia for the white wheat problems".

My presentation would not be complete without expressing my appreciation to a great number of people who have helped and co-operated with me over the years. Here I am referring to my associates at The I.A. Watson Wheat Research Centre, my colleagues at The University of Sydney - particularly from the Faculty of ^{Bread Research Institute of Australia} Agriculture, the N.S.W. Department of Agriculture, the members of the Wheat Industry Research Committee of N.S.W., The Prime Wheat Association and the co-operating farmers.

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