Effects of genotype and environment on the sprouting propensity and other grain characters of wheat (*Triticum aestivum* L.).

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A thesis
presented in partial fulfilment of the requirements
for the degree
of
MASTER OF AGRICULTURAL SCIENCE
in
PLANT SCIENCE

Faculty of Agriculture
Massey University
New Zealand
1977.

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SUMMARY

Six wheat cultivars exhibiting a range in susceptability to sprouting damage were subjected to three artificially controlled environments. Nine characters thought to be involved with sprouting damage were examined. The characters of interest were: dehydration rate (harvest ripeness), grain weight, the red-grained pigment (phlobaphene) and one of its precursors (flavan-3-ol), germination, embryo maturity, embryo dormancy, basal alpha amylase and alpha amylase response to germinible conditions.

Results indicated that lack of germination following standard International Seed Testing procedures (Anon., 1966, 1976) may not be appropriate as an indication of dormancy in all environmental conditions. Lack of germination may be due to embryo immaturity or to embryo dormancy. At cooler temperatures, embryo maturity was delayed well past harvest ripeness, and at this point true dormancy appeared to have been lost. Examination of the synchrony between embryo in maturity and impedence to germination was considered important when examining dormancy. The difference between these two characters appeared to be the most reliable estimate of actual dormancy. Other traits investigated had poor synchrony with true dormancy. Different environments markedly affected the synchrony of embryo immaturity, dormancy and harvest ripeness. The role of anoxia, hormonal balance and other catabolic enzymes involved in early germination were reviewed, and it was suggested that these factors may prove useful in future research

into the sprouting damage problem.

Chapter one : INTRODUCTION

Sprouting damage may occur when wet weather initiates germination processes in unharvested grain, with subsequent deterioration in breadmaking quality. It is a potential hazard to wheat growing regions throughout the world, e.g. Europe (Olered, 1967; Belderok, 1968), Australia (Moss, et al., 1972) and New Zealand (Sanders, 1974; McEwan, 1976a).

Seed dormancy is usually accepted as being related in some way to resistance to sprouting damage (e.g. Belderok, 1968a); that is, dormancy may be associated with lack of catabolic processes in the endosperm (Ching, 1972; Leshem, 1973; Villiers, 1972). Several enzymes initiated during the germination process are involved in the degradation of the starch and protein of the endosperm. These enzymes include alpha-amylase, which break the branch chain amylopectin starch molecules to dextrins and amylases, and beta-amylase which degrade these smaller compounds to low molecular weight dextrins and maltose (Kent-Jones and Amos, 1967; Pyler, 1969). Beta-amylase is present in the sound grain but its activity is restricted, as there are relatively few exo-groups at which this enzyme is capable of hydrolysing (Kent-Jones and Amos, 1967; Pyler, 1969). Alpha-amylase appears a major factor in starch dextrinisation, and levels of this enzyme relate to the degree of sprout damage (Johansson, 1976; Olered, 1967; Moss et al., 1972). Other enzymes may also be involved in early germination, such as proteolytic enzymes (Gordon, 1975; Kruger, 1976). In sprout damaged wheat, the increased level of starch dextrinisation results in an inferior loaf (Olered, 1967; Pyler, 1967; Moss et al., 1972). The loaf is reduced in volume, has a grey and sticky crumb, and a dark crust colour (Olered, 1967; Kent-Jones and Amos, 1968; Pyler, 1969; McDermott, 1971). Sprout damaged grain may also have a lighter bushel or test weight (Ghaderi and Everson, 1971; Fouler and de la Roche, 1975), and lowered milling yield (Belderok, 1968; McEwan, 1959).

Breeding for sprout resistance involves recognition of usable genetic parameters. The relationship between grain colour and pre-harvest sprouting tendency is well documented (e.g. Gfeller and Svejda, 1960; Kimber, 1971) : white grained wheats being susceptible to sprouting, while the red grained wheats exhibit varying degrees of dormancy. However, not all wheats have a sufficiently long enough dormant period to offer reliable crop protection. Other parameters may include : (1) reducing the sensitivity of the aleurone cells to gibberellic acid, (2) selectively inactivating alpha-amylase response to germinible conditions, and (3) identification of the role of specific proteolytic enzymes involved in early germination (Bhatt, et al., 1976; Gale, 1976; Kruger and Preston, 1976). Recent field studies (Gordon, 1975) suggested that enzymes other than amylases may have marked influences on wheat endosperm degradation during early germination.

The present investigation investigates suggestions of earlier work (Gordon, 1975) but taken over a wider genotypic sample and number of environments with particular reference to the magnitude of the genotype environmental interaction. The characters of interest were the red grain pigment (phlobaphene) and one of its precursors (flavan-3-ol), germination, embryo maturity and dormancy, basal alpha-amylase and alpha-amylase response to environmental conditions conducive towards germination, grain weight, and harvest ripeness. Six cultivars were stratified random samples that offered contrasting susceptibilities to pre-harvest sprouting. The strata were : white-grained and red-grained cultivars. Their response in characters relevant to sprouting damage were followed in three climatically controlled laboratories.

Chapter two : REVIEW OF LITERATURE

This review is subdivided into three broad categories : (1) facets of sprouting damage, (2) methods and interpretations upon the genotype-environmental interaction, and (3) analysis of variance procedures.

2.1 FACETS OF SPROUTING DAMAGE

The biochemistry of germination and dormancy are briefly reviewed. With this information as a foundation, aspects of seed technology, environmental effects, and plant breeding procedures relevant to sprouting are discussed. Emphasis is placed whenever possible on wheat, as a search for a universal control mechanism would limit factors peculiar to that species.

2.1.1 Dormancy and Germination

Dormancy is a particular physiological state which manifests itself as the inability of the imbibed, mature, viable seed to germinate when given environmental conditions conducive to growth. These dormant grains will not germinate when freshly harvested, but will do so after a period of dry storage. These seeds are said to have "after-ripened". This form of dormancy is found in many cereals, wild grasses, and a large number of other species (Barton, 1965; Black, 1972; Roberts, 1972; Villiers, 1972).

The control of dormancy appears likely to be regulated, and to a large extent controlled by, the activities of various endogenous growth substances. These substances may be exerting either promoting or inhibiting effects on several key reactions (Ching, 1972; Khan, 1969, 1975; Leshem, 1973; Stoy and Sundin, 1976; Villiers, 1972). Hormonal interplay, action of other growth inhibiting compounds, and environmental effects are considered in the following sections. For convenience, these are discussed separately, but are likely to be involved in a complex and interacting series of processes.

2.1.2 Hormonal Influences

The initiation of germination and subsequent endosperm breakdown is well documented. However, little is known about the actual mechanism of control. Germination, in an extremely simplified manner, may be envisaged as a series of three events (Ching, 1972; Thomas, 1972; Mayer, 1973; Kruger, 1976) : (1) initiation of germination in which numerous metabolic systems are activated, (2) *de novo* synthesis and/or activation of enzymes required for growth processes, and (3) digestion (catabolism) of storage reserves.

The *de novo* synthesis of alpha-amylase (a major enzyme in starch catabolism) induced by gibberellin is well established (e.g. Chrispeels and Varner, 1967; Jones, 1973; Paleg, 1960). Since breakdown of storage reserves is a preparatory step in the germination sequence, Amen (1968) suggested that gibberellin induces germination via alpha amylase production. However, this does not appear to be the case with wild oats (Chen and Varner, 1973; Simpson, 1965), nor perhaps with wheat (Gordon, 1975; Kruger and Preston, 1976). The timing of events suggests some other "mechanism" of control may be operating as alpha-amylase production is fairly slow : some one to two days after imbibition (Gordon, 1975; Naylor, 1966). Gibberellin induces many other enzymes by cereal aleurone layers during these "awakening" stages, including other carbohydrases, esterases, and proteolytic enzymes (Ashton, 1976; Ching, 1972; Ho and Varner, 1976; Jacobsen and Varner, 1967; Jones, 1973; Kruger and Preston, 1976; Spiegel et al., 1975).

Hormonal interaction appears to be the germination control mechanism, particularly the growth promoting effects of gibberellin, and gibberellin antagonism by abscissic acid (Amen, 1968, 1974; Chrispeels and Varner, 1967; Milborrow, 1974; Naudeau and Rapport, 1974; Wareing and Saunders, 1971). In turn, abscissic acid may also be "antagonised" by cytokinins (Ketring, 1973; Khan, 1969, 1975). All three hormones may be involved to a greater or lesser degree. Current concepts suggest either the presence of gibberellin inhibitors (i.e. abscissic acid-like substances), inhibitor antagonisers (i.e. cytokinin-like substances), or absence of promoters (i.e. gibberellin-like substances) can effect dormancy (Khan, 1975).

Several recent investigations involving germination response to gibberellins have established differences amongst sprout-susceptible and sprout-resistant wheat cultivars. These sprout-susceptible cultivars display a high gibberellin response and subsequent high germination percentages, whereas sprout-resistant types exhibit low gibberellin response and low germination (Allan, et al., 1959; Bhatt, et al., 1976; Fick and Qualset, 1975; Gale, 1976; Gale and Marshall, 1973; Gale et al., 1973; MacMaster, 1976). The attribute of low sensitivity to gibberellin and low alpha-amylase response appears moderately heritable (Bhatt, et al., 1976; Gale, 1976, MacMaster, 1976; Radley, 1970) and possibly offers a new criterion in breeding for sprouting damage resistance. Care should be exercised however, as these authors used GA_3 as their source of gibberellic acid. Other gibberellins are known, and the activities of gibberellins GA_4 and GA_9 has been shown to be thirty times more active than GA_3 in stimulating the germination of seeds of *Diplotaxis* and 2000 times more active than GA_3 in the germination of *Lepidium* (Borris and Schmidt, 1961 : after Villiers, 1972). However, in the case of cereals, gibberellins similar to GA_3 and GA_1 are produced by the embryonic axis (Jones, 1973). As dormancy expression also involves levels of the gibberellin inhibitors (i.e. abscissic acid-like substances) and inhibitor antagonisers (i.e. cytokinin-like substances), (Khan, 1975) then the role and activity of alternative gibberellins to GA_3 need also to be established.

2.1.3 Other Growth Inhibiting Compounds

Compounds other than hormones are known to affect dormancy expression in different species (Evenari, 1949; Ketring, 1973). Some of these compounds may be involved in the dormancy mechanism operating in wheat. These may include ferulic acids, coumarin, and some other phenolics (Van Sumere, *et al*., 1972). Belderok (1961) suggested that during after-ripening, a cleavage of disulphide bridges and simultaneous formation of thiol groups in the testa layer occurred, which may result in greater oxygen permeability.

An association often exists between red grain colour and apparent dormancy. Red-grained wheats are generally the same or more resistant than the white-grained wheats in pre-harvest sprouting. It is usually assumed that effective resistance to pre-harvest sprouting can only be found among red-grained cultivars (Derera, 1973; McEwan, 1976b; Moss *et al*., 1969). Miyamoto and Everson (1958) suggested that dormancy was not due to the red pigment (phlobaphene) *per se* but was a function of the precursor compound(s) catechin-tannins. A high correlation between catechin-tannins and sprout resistance has been established in grain sorghum (Harris and Burns, 1970). However, a high correlation does not imply causation. An inhibitory effect by catechin-tannins on mature wheat embryos has been demonstrated in wheat (Stoy and Sundin, 1976), although these *in vitro* observations may not follow *in vivo* conditions. In another study, using whole wheat grains sampled during grain development, little effect of catechin-tannin on germination, embryo growth or alpha amylase activity could be demonstrated (Gordon, 1975). The inhibitory action on germination may be a gibberellin antagonist, as shown with barley seeds (Jacobsen and Corcoran, 1975) and pea and cucumber seedlings (Corcoran, *et al*., 1972). Clearly, timing of events is an important aspect in elucidating the control mechanism. The effects of time embryo maturity, length of dormancy, pigmentation, and their relationship to sprouting susceptibility need to be investigated further (Gordon, 1975).

2.1.4 Anoxia

Anoxia has been implicated as a modifying influence on the length of dormancy expression. For example, removal of flowering parts (i.e. glumes, lemma, palea: Harrington, 1949; Hutchinson, et al., 1948; Wellington and Durham, 1958), rupturing or removal of the grain coat (Belderok, 1961; Miyamoto, et al., 1961), or increasing the oxygen partial pressure (Major and Roberts, 1968) appears to break any dormancy mechanism. Evidence of anoxia conditions in dormant seeds is also supported by the observation of a high respiratory quotient of freshly imbibed seeds (Mayer and Paljakoff-Mayber, 1963; Villiers, 1972) and accumulation of lipids (Ching, 1972). This may explain the phenomenon of "water sensitivity". That is, when excessive amounts of water were present during imbibition, dormancy is expressed (Belderok, 1961; Essery, et al., 1954.

Roberts (1969, 1972) has suggested a biochemical mechanism of dormancy regulation related to the stimulation of the pentose phosphate pathway of glucose metabolism and subsequent energy supply to mitochondria and ribosomes. He hypothesised that anoxia conditions favoured this pathway, and that a "block" to this pathway prevented respiration under anoxia conditions.

Subsequent oxidative conditions were then better utilised by the glycolysis and Kreb pathways (Ching, 1972; Roberts, 1969, 1972; Villiers, 1972). The shift in these pathways may effect much metabolic re-organisation and subsequent changes in hormonal status of the embryo (Ching, 1972; Roberts, 1969, 1972).

Phlobaphene is an oxidative condensation product of the flavan-3-ol monomer catechin and/or flavan-3, 4-diols (Wong, 1973). Polyphenoloxidase is known to oxidatively polymerise flavanols to phlobaphene (Brown, 1958; Taneja and Sachar 1974 a, b; Wong, 1973). This enzyme may thereby create partial anoxia within the seed (Brown, 1958; Conn, 1958; Pollock and Kirsop, 1958).

2.1.5 Environmental Modification

Modification of dormancy expression by the environment is well established among many species, and include temperature at the time of imbibition and the influence of prevailing weather during grain growth and development (Belderok, 1968; Pollock, 1974; Villiers, 1972).

2.1.5a Temperature Effects

Dormancy expression is affected by temperature during the imbibition phase. George (1967) observed deep dormancy in his sample of twelve cultivars when imbibed at high temperatures (30°C). At a lower temperature (20°C), dormancy expression by the various cultivars were more variable. No dormancy was expressed at 10°C. Chilling is known to affect production of gibberellin-like substances (Andrews and Burrows, 1972; Villiers, 1972), and the chilling treatment can be replaced by exogenous gibberellin, although abnormally high levels are required (Bekendam, 1975). Chilling is known to break dormancy in many species, including wheat (Anon, 1966, 1976; Stokes, 1965).

2.1.5b Environmental Effects During Grain Development

Seasonal differences affecting the length of the apparent dormant period have been documented by many authors. Warm and dry seasons, followed by rain on the harvest ripe crop realise the most sprout damage, and conversely least sprout damage from crops grown during cool and dry seasons (e.g. Belderok, 1961, 1968; Greer and Hutchinson, 1945; La Croix *et al*., 1976; Lallukka, 1976; Olsson and Mattsson, 1976; McEwan, 1976; Sanders, 1974).

Belderok (1961, 1968a) demonstrated a temperature effect on the length of "dormancy". He established a direct relationship between the length of the dormant period and a temperature function based on temperature average above 12.5°C summed over the dough stage of grain development. This function was cultivar dependent. For example, critical values for the cultivars Opal, Orca, and Peko were 40, 70 and 140 degree Celcius days above 12.5°C respectively (Belderok, 1968a). Once their respective values are exceeded, then there is a risk of sprouting within ten days under unfavourable weather conditions. The Netherlands Grain Center now operates a warning system using these critical temperature indices as a basis for predicting sprout susceptibility among commercial wheat crops (Belderok, 1968a). Olsson and Mattsson (1976) investigated the feasibility of applying this warning system to the Swedish wheat crop. They found the repeatability of this technique too variable for reliable use, being greatly affected by location and years. Perhaps other base subtracted quantities need be considered or other forms of thermal units such as quadratic formulae (e.g. Major _et al._, 1975) may be more applicable. Further investigation is necessary. For example, temperature during other growth stages may have contributing effects, or perhaps other features of the climate such as air humidity and incoming radiation (Olsson and Mattsson, 1976; Reiner and Lock, 1976). Gordon (1975) suggested environmentally induced differences may exist in embryo maturity rates, period to attain harvest ripeness and onset of true dormancy. These differences in synchronies may explain seasonal variation in apparent dormancy ratings.

2.1.6 Inheritance of Dormancy

Botanically, the wheat seed is a caryopsis, and the red pigment is located in the testa layer and the pericarp, and is therefore of maternal origin (Bradbury, _et al._, 1956a). Numerous genetic studies show up to three gene pairs with dominant alleles may be involved in the formation of the phlobaphene pigment (e.g. Everson and Hart, 1961; Freed, _et al._, 1976; Gfeller and Svejda, 1960; Jan and Qualset, 1976; Kimber, 1970; McIntosh, 1973). The individual loci for pigment formation are located on separate genomes (Allan and Vogel, 1964; McIntosh, 1973; Metzger and Silbaugh, 1970).

Several hypotheses have been proposed to explain the relationship between red grain colour and dormancy. Additivity for redness has been noted (Ibraham, 1966) and the effects of polygenic inheritance suggested (Harrington and Knowles, 1940). Since the association between red seedcoat colour and dormancy appeared complete, Gfeller and Svejda (1960) suggested pleiotrophy. More recently, Gordon (1975) favoured a pleiotropic effect, based on timing of events between synthesis of the phlobaphene pigment and dormancy induction. Everson and Hart (1961) included a red but susceptible to sprouting, genotype in their genotypic sample. These authors acknowledged the possibility of pleiotropy, but suggested a tight linkage may exist between the dormancy and colour genes. Freed (1972) established that the red genes may be linked or independent, depending on the genotype tested. Further, he noted that the various colour genes were associated with different degrees of dormancy (Freed, _et al_., 1976).

In view of the complex physiology of the dormancy and germination processes, any one of these possibilities or combinations of them are possible. The result will also depend on the genotypic sample, the environmental conditions under test, the nature of the genotype-environmental interaction, and types of experimental mating design used.

2.2 MEASUREMENT AND INTERPRETATIONS OF THE GENOTYPE-ENVIRONMENT INTERACTION.

Proper interpretation of experimental data necessitates appropriate analysis of the observations. The present study involves several wheat cultivars observed in three environments, with particular emphasis of the magnitude of the genotype-environment interaction. Several methods exist to test for the presence and internal structure of nonadditivity in two-way classification data. These are considered under the two usual analytical procedures of analysis of variance and regression.

2.2.1 Analysis of Variance Method

The analysis of variance (ANOVA) method usually encompasses means and variance analysis with subsequent estimates of heritability, expected genetic advance and optimum plot allocation. Variance components can be used to separate out the effects of genotypes, sites and years, and their interactions (e.g. Comstock and Robinson, 1952; Comstock and Moll, 1963; Hanson *et al*. 1956; Kaltsikes, 1970; Povilaitis, 1970; Sprague and Federer, 1951). Average genotype and genotype-environment interactions are so obtained, but give little idea of individual genotype performance from environment to environment. The genotype-environmental interaction can be reduced by subdividing the environment into more homogeneous parts (e.g. Horner and Frey, 1959; Liang, 1966; Mungomery, 1974). This move towards regionalisation, however, gives the plant breeder little opportunity to breed for widely adapted genotypes.

2.2.2 Regression on an Independent Variate

If the genotype response is regressed on known levels of the independent variate (i.e. "effects analysis"), then interaction effects can be described in terms of a magnitude and/or direction of the genotype response (Steel and Torrie, 1960). The regression coefficient is usually termed as a "stability index". The technique has been used with varying degrees of success by several authors (e.g. Bradshaw et al. 1964; Easton and Clements, 1973; Loneragan et al., 1968; Mitchell and Lucanus, 1962; Ottaviano and Sari Gorla, 1972; Pederson, 1974a, b).

Another regression technique, often used in studying growth of biological populations, is to describe the data from a fitted curve . Comparisons can then be made based on slope, upper asymptote, and location of the curve in space (e.g. Allard and Bradshaw, 1964; Bliss, 1970; Williamson, 1974). Significance testing is amongst these curves for these parameters (Steel and Torrie, 1960) and a genotype-environmental interaction is detected by a change in rank order across environments (e.g. Foster, 1975; Lazenby and Rodgers, 1965).

2.2.3 Regression on Biological Potential

Natural environments are characterised by a complex of interacting factors (biotic, climatic, or edaphic), so that sometimes it is difficult to obtain meaningful parameters to account for most of the interaction variance. For this reason, the crop itself is considered the best indicator of the importance of environmental effects (e.g. Finlay and Wilkinson, 1963). The regression technique, based on an estimate of the environment, is an empirical approach which allows interpretation of adaptability as a character in its own right, with no assumptions as to its physiological basis. Several authors (e.g. Yates and Cochran, 1938; Finlay and Wilkinson, 1963; Perkins and Jinks, 1968) have shown that environments can be quantified by grading (from low to high) mean expression of all genotypes grown at each site. The performance of an individual genotype is then regressed (as a linear function) on the mean environmental effect. The slope of the regressed line, and the genotype mean, are indications of the range of adaptive performance of individual genotypes. Thus a genotype with a regression coefficient ($\hat{b}$) much less than "1" is best adapted to poor yielding environments; $\hat{b}$ much greater than "1" is better adapted to high yielding environments. A high mean and $\hat{b}=1$ indicates satisfactory adaptability of performance over the range of environments tested. The ideal "stable genotype with a high mean and $\hat{b}=0$ may be an unattainable concept, as there are "good" and "bad" environments as well as "good" and "bad" genotypes (Finlay and Wilkinson, 1963). Mean environmental performance is a function of the genotypes tested, and as such, the idea of stability of performance can be altered (e.g. Hardwick and Wood, 1972; Fripp and Caten, 1973; Mather and Caligari, 1976). Hardwick and Wood (1972) believe that this is most likely to occur when the interaction is due to several major interacting factors (e.g. England, 1974).

Deviations from linearity have caused some concern as to the validity of this technique (e.g. Easton and Clements, 1973; Knight, 1970). Several modifications to regression of individual performance on mean environmental effect have been suggested (e.g. Eberhart and Russell, 1966; Freeman and Perkins, 1971; Perkins and Jinks, 1968). The problem is of linearity, and may be overcome by appropriate transformation (e.g. Bartlett, 1947; Draper and Smith, 1966; Finlay and Wilkinson, 1963; Tukey, 1949, Yates and Cochran, 1938). The data should not be transformed to a scale where all the interactions have disappeared (Mather, 1971). If, however, most of the interacting parameters can be quantified, more elaborate models may be used (e.g. multiple regression or principle component analysis: Freeman and Dowker, 1973, 1974; Perkins, 1972). Usual regression model assumptions include independence of the mean environmental index (Draper and Smith, 1966; Steel and Torrie, 1960). This assumption may be violated as this index is derived from the mean of individual genotypic response. Practical implications of the violation appears not great. Perkins and Jinks (1973) compared dependent and independent environment measures, and found little loss to the power of the analysis. The technique has provided plant breeders with an extremely useful tool (e.g. Breese, 1969; Breese and Hill, 1973; Hill and Perkins, 1969; Frey, 1972; Pacucci and Frey, 1972; Samuel, et al., 1970; Valentine and Charles, 1975; Willey, 1975; Williams et al., 1975).

2.2.4 Joint Regression Analysis

Joint regression analysis is a form of analysis of variance where the genotype-environmental interaction is partitioned into heterogeneity of regressions and deviations from regression (Finlay and Wilkinson, 1963; Freeman, 1973; Perkins and Jinks, 1968; Yates and Cochran, 1938). The proportion of the genotype-environmental interaction due to regression (i.e. among regression coefficients) is of particular interest. When this proportion is small, characterisation of genotypes by their regression coefficients is not effective (Baker, 1969; Eagles, et al., 1976; Shukla, 1972; Freeman, 1973). In this situation, usual analysis of variance procedures with appropriate transformation yields similar information. If a large fraction of the variation for genotype-environmental interaction is due heterogeneity among regression coefficients the regressions on biological potential will isolate those well adapted genotypes (Eagles, et al., 1976), without transformation to a scale where all the interaction has disappeared (Mather, 1971).

2.2.5 Breeding for Adaptability

Stability of performance in those characters of economic importance (e.g. yield, quality) are major considerations in agricultural production. Plants, however, alter the phenotype in response to various environmental forces, and this phenotypic plasticity can affect the economic returns to the commercial grower. A genotype-environmental interaction can be interpreted as a differential plasticity effect. It is this differential response that maintains variability in populations (Schultz and Usanis, 1969). It follows that success depends on a balance between stability and plasticity, which considered together determine the range of adaptability of a cultivar (Finlay and Wilkinson, 1963). Technology often demands special requirements on crop production, such as even maturity or uniform height. To what extent there is contradiction between maximum productivity in the most favoured environment (specific adaptation) and good average yield over a range of environments (general adaptability) will only be resolved by a fuller understanding of the action and interaction of environmental and genetic factors. This is of basic importance to crop production, since it bears on the intimate relationship between individual buffering and the degree of artificial buffering required for economic production, as well as the best means of exploiting uncontrollably variable factors (Allard and Bradshaw, 1964).

Several breeding strategies to attain stability of performance are possible: to breed for well adapted hybrids, pure-line cultivars, or multilines.

In the past, stability of performance has been attributed to heterozygosity (e.g. Lerner, 1954) with the implication that the greater the number of heterozygous genes pairs then the greater their buffering capacity to the environment. Some examples support this postulate (e.g. Gupton, *et al*., 1974; Jowett, 1972; Patanothai and Atkins, 1974; Pederson, 1968). However, not all heterozygotes are stable, and sometimes homozygous lines have comparable (or better) stability to that of the heterozygotes (e.g. Griffing and Langridge, 1963; Mather, 1973; Smith and Foote, 1970). The current model suggests that stability of performance is a factor of genic balance of individual loci (i.e. $\frac{+}{-}$, $\frac{-}{+}$ types), and genetic architecture of genes along a chromosome (e.g. $\frac{+}{-}\ \frac{-}{+}\ \frac{+}{-}\ \frac{-}{+}$). It is this relational balance between and within loci along the chromosome that effects general adaption (Mather, 1973). Breeding heterotic combinations would tend to break linkage blocks and encourage crossing over to an optimal relational balance and may therefore be the most appropriate strategy to obtain widely adapted cultivars.

Multilines or multilineal cultivars may also confer stability of performance. These have been used with success to overcome major environmental problems, commonly disease susceptibility (Anon, 1976; Browning and Frey, 1969; Frey *et al*., 1970, 1975).

Some degree of heterogeneity, either as multilines or heterogeneous populations may therefore be desirable from both favourable disease reaction and possible stability of yield performance. Quality aspects are not well documented, although milling extraction and protein appears not affected by the heterogeneous material (Bhatt and Derera, 1973).

Economic considerations of the use of multilines or hybrid wheats as a means of attaining stability of performance _per se_ may not warrant their use. Hybrid wheats offer little yield or quality advantage (Johnson and Schmidt, 1968) and the increased cost of seed may negate any stability advantage. Multilines require large breeding input (Anon., 1976) and appear only warranted when the rigors of the environment are too great for traditional (i.e. pure-line) cultivar use. Well adapted pure-line cultivars appear the most practical solution.

Adaptability exhibits quantitative variation (e.g. Bradshaw, 1965; Breese, 1969; Bucio-Alanis _et al_., 1969; Finlay, 1971; Finlay and Wilkinson, 1963; Griffing and Langridge, 1963; Perkins and Jinks, 1968). Breeding progress, using the joint regression analysis technique as outlined previously may be the most appropriate procedure of isolating well adapted genotypes.

2.3 ANALYSIS OF VARIANCE PROCEDURE

2.3.1 Statistical Model

Most commercially important plant characteristics are quantitative in inheritance, and therefore display continuous variation. Conclusions about inheritance can only be inferred from observations on the phenotype (Allard, 1960; Falconer, 1960). Populations are therefore characterised by statistical quantities which measure average expression (means) and the variation of expression (variances). These quantities may be partitioned further, using some form of experimental design, the basis of which is a suitable model.

The pooled analysis of the completely randomised block design involves the pooling of observations within an environment across several environments. An appropriate random effects model is :

$$X_{ijk} = \mu + \gamma_i + \beta_j + \lambda_k + (\gamma\lambda)_{ik} + \epsilon_{ijk}$$

where X_{ijk} = the phenotypic value of the i-th genotype in the k-th replicate in the j-th environment;

μ = mean of all genotypes over all environments;

γ_i = the effect of the i-th genotype, i = 1-g;

β_j = the effect of the j-th replicate within the k-th environment, j = 1-r;

λ_k = the effect of the k-th environment, k = 1-s;

$(\gamma\lambda)_{ik}$ = the ik-th genotype-environmental interaction;

ϵ_{ijk} = random error deviate on the i-th genotype in the j-th replicate in the k-th environment.

An analysis of variance (ANOVA) partitions the parameters into variance components corresponding to the effects of the model. In addition other parameters useful in plant breeding may be deduced. For example, using estimates from the variance components, the following statistics may be obtained: (1) heritability (Allard, 1960; Comstock and Robinson, 1948; 1951; Hanson, 1963;

Kearsey, 1965; Kempthorne and Curnow, 1961; Lush, 1940). (2) Optimum plot allocation (Kaltsikes, 1970; Kaltsikes and Larter, 1969; Povilaitis, 1970; Rasmussen and Glass, 1967; Sprague and Federer, 1951; Tyson, et al., 1968), and (3) expected genetic advance (Brim and Stuber, 1973; Comstock and Moll, 1963; Falconer, 1964; Moll and Stuber, 1974; Moll, et al., 1975).

2.3.2 Anova Mechanics

The ANOVA method consists of setting the mean squares equal to their expectations, and solving the resulting equations for parameters contributing to those expectations (Comstock and Moll, 1963; Crump, 1946). The appropriate ANOVA table and the usually accepted expectations are presented in table 2.1 for a single environment (Steel and Torrie, 1960), and Table 2.2 the pooled environments (Gordon et al., 1972). The estimation of variance components and F-ratios can be simply deduced from the expectations. From Table 1, the variance components are estimated as :

$$\sigma_G^2 = MS_3 - MS_1/b$$

$$\sigma_B^2 = MS_2 - MS_1/g$$

From Table 2, the variance components are estimated as :

$$\sigma_G^2 = MS_3 - MS_2/be$$

$$\sigma_{GE}^2 = MS_3 - MS_1/b$$

$$\sigma_{B}^2(E) = MS_4 - MS_1/g$$

$$\sigma_E^2 = MS_5 - MS_4 - MS_3 + MS_1/b\ g$$

Table 2.1 : ANOVA for a single environment

Source	f	M.S.	E(MS)	F
Genotypes	g-1	3	$^{2} + b\sigma^{2}_{G}$	MS_3/MS_1
Blocks	b-1	2	$^{2} + g\sigma^{2}_{B}$	MS_2/MS_1
Error	(b-1)(g-1)	1	^{2}	

Table 2.2 : ANOVA for pooled environments

Source	f	M.S.	E(MS)	F
Environments	e-1	5	$^{2} + g\sigma^{2}_{B} + b\sigma^{2}_{GE} + bg\sigma^{2}_{E}$	$(MS_5 + MS_1)(MS_4 + MS_3)$
Blocks within environments	e(b-1)	4	$^{2} + g\sigma^{2}_{B}$	MS_4/MS_1
Genotypes	g-1	3	$^{2} + b\sigma^{2}_{GE} + be\sigma^{2}_{G}$	MS_3/MS_2
Genotypes x environments	(g-1)(e-1)	2	$^{2} + b\sigma^{2}_{GE}$	MS_2/MS_1
Error	e(g-1)(b-1)	1	^{2}	

When variances are estimated by a linear combination of mean squares (i.e. O_E^2), the complex estimate of variance does not follow exactly the Chi-square distribution with the degrees of freedom appropriate to the variance statistic. (Davenport and Webster, 1972; Satterthwaite, 1941, 1946). The latter author provided an equation where the degrees of freedom are adjusted such that the complex estimate of variance is accurate enough for practical use :

$$f_i = \frac{\sum_i ai\ (MS)_i^2}{\sum_i \frac{ai\ (MS)i^2}{f_i}}$$

where : MS = the i-th mean square present in the linear function,

f_i' = the adjusted degrees of freedom of the i-th linear function of mean squares,

f_i = unadjusted degrees of freedom for the i-th mean square,

a_i = coefficient of the i-th mean square

Standard errors of the estimated variance components (Comstock and Moll, 1963; Crump, 1946; Gordon <u>et</u> <u>al</u>., 1972; Satterthwaite, 1941, 1946) are given by:

$$\sigma^2_{\sigma^2_x} = \frac{1}{n^2_{x_i}} \sum_i \frac{2(MS_i)^2}{f_i + 2}$$

where: n_x = the divisor appropriate in the estimator of the x-th variance component,

MS_i = the i-th mean square contributing to the x-th variance component,

f_i = degrees of freedom associated with
the i-th mean square.

2.3.3 Assumptions underlying the Anova

The assumptions underlying the use of the random model are : (1) random independant effects, (2) additivity of variance effects, (3) equal (i.e. homogeneous) variances across subsets of effects, and (4) the effects are normally distributed.

The consequences of these assumptions are (in order of listing): (1) that the variables are independent, and (2) may be represented by a linear function. Assumption (3) ensures that variances within any component is homogeneous, and that covariance between components is negligible: a situation which may be not normally met in practice. For example, in a regional trial, it is implicitly assumed that the environments are a random sample of all possible environments. Even if this were so, the genotypes tested are sometimes related in some way. The expectations (Comstock and Moll, 1963), variance components (Cochran, 1947) and error term (Bartlett, 1947) may therefore be biased. Fortunately, pooling the error term reduces this effect (Cochran, 1947), since averaging a mean square is a better estimate of the common variance. Assumption (4) ensures the variables follow a normal (Gaussian) distribution. This enables valid tests of significance and confidence intervals. Heterogeneity occurs frequently in field trials and transformations may be used to restore normality (Bartlett, 1947, Steel and Torrie, 1960). Where none of the transformations restore normality, it is usual to accept the transformation giving the least heterogeneity of error variance (Steel and Torrie, 1960).

Chapter three : MATERIALS AND METHODS

3.1 EXPERIMENTAL DESIGN

A randomised complete block was employed, using six wheat cultivars, twelve plants per replicate, and three replications per cultivar. Three environments were employed, and the environmental variables used are given in Table 3.1.

Table 3.1 : Environmental Variables

Environment		I	II	III
Temperature	day	18	18	30
	night (^{o}C)	12	12	20
Vapour pressure deficit (kPa)		-1.0	-0.4	-1.0

Cultivars were a random stratified sample chosen to cover the range from sprout susceptible to strongly dormant. One stratum was white-grained, the other red-grained. Cultivars investigated were three white-grained wheats (Gamut, Timgalen, Sherbati-Sonora) and three red-grained wheats (Sonora-64A, Pembina, Karamu). Sonora-64A has little or no dormancy, and has one gene for redness (Jan and Qualset, 1976). Pembina and Karamu are dormant wheats (Gordon, 1975; McEwan, 1976a). Karamu has a single gene for red seed coat colour (McEwan, pers. comm.). Unfortunately, it appears the number of genes for seed coat colour in Pembina has not been reported (McIntosh, 1973). Sherbati-Sonora is a γ-irradiated mutant from the red-grained cultivar

Sonora-64A (Jan and Qualset, 1976; Kohli, 1968). For convenience, Sonora-64A will be forthwith referred to as Sonora.

3.2 CULTURAL ASPECTS

All seeds were dusted with the fungicide Benlate prior to sowing. Four seeds per pot (14 cm diameter, 1.2 litre capacity) were sown at a depth of 2 cm. Plants were thinned to two per pot at the 3-5 true leaf stage. Potting mixture was 70% gravel, 15% peat, 15% vermiculite. Prior to head emergence, all cultivars were grown in a cooled ($25^oC/15^oC$) glasshouse. Three sowing dates of each cultivar were employed to facilitate even growth stage of plants on entry to the climatically controlled laboratories. In the glasshouse, 100 cm^3 of 1/4 strength Hoagland's nutrient solution (appendix 1) was applied daily. Pest and disease control was effected using Menazon (for aphid control), Kelthane (Red Spider) and Milstem (Powdery Mildew).

Climate room environmental factors, other than the treatment variables, were: (1) light intensity approximately 160 Wm^{-2} with a 14 hour photoperiod, and an abrupt light-dark change-over; (2) changes in humidity and temperature occurred over two hours, equally spaced between the light and dark period, (3) CO_2 concentration was ambient at 320-340 ppm, and the air flow down through the plants was 0.3 - 0.5 m sec^{-2}, measured at the top of the canopy; (4) nutrient regime was 6 x 100 cm^3 applications of one quarter strength Hoagland's solution daily (appendix A2), through an automated micro-tube system.

3.3 SAMPLING PROCEDURES

Five points during grain development were used to locate the positions of the curves under investigation. Some characters were sampled more intensively to estimate physiological age. The five major sampling points were at approximately :

(1) 60% moisture content (caryopsis yellowing)
(2) 40% " " (milk dough stage)
(3) 30% " " (soft dough stage)
(4) 20% moisture content (firm dough stage)
(5) 12½% moisture content (harvest ripeness)

Spikes were tagged and recorded at the appearance of the first anthers from the mid-section of the spike, so that physiological age was known. However, anthers were poorly extruded in the hot environment, so that observation of dehiscence of the anthers was only possible by opening up individual florets with forceps. Grains were sampled only from the outer positions of each floret (i.e. from the A and B positions), and from the mid-section of the spike, as growth and development rates may vary according to grain location (Evans, et al., 1972; Hardesty and Elliot, 1956; Kirby, 1974; Rawson and Evans, 1970).

3.4 ASSAY PROCEDURES

Some assays were performed on fresh material (germination and dormancy tests, grain colour, and moisture content). Grain for basal alpha-amylase levels, alpha amylase response, and flavan-3-ol determinations, were dried under vacuum (40°C, -100 kPa) and stored at 5°C in screw capped vials. These were crushed and ground in a mortar and pestal just prior to laboratory determination.

3.4.1 Germination

Germination was recorded at five days after wetting. Grains were counted as germinated when the embryo ruptured the pericarp. Two tests were performed: (1) a standard germination test, according to International Seed Testing rules (Anon., 1966, 1976) and (2) dormancy breakage involving part of the International Seed Testing Association recommendations (Anon., 1966, 1976) as used by Gordon (1975). Conditions were alternating temperature and light (20°C for 16 hours in diffuse light/15°C for 8 hours in darkness), and a moist substratum of 0.2% aqueous KNO_3.

Since the test is designed to break dormancy (Gordon, 1975), lack of germination is due to either embryonic immaturity, or dead seeds. Gordon (loc. cit.) considered the latter possibility as extremely unlikely. A series of random tetrazolium tests (Anon., 1966) during grain development were conducted, and showed no dead seeds. Number of dormant grains are therefore the difference between number of caryopses germinated under the dormancy breaking regime minus the number of caryopses germinating under the standard germination test. This, expressed as a ratio to the number of mature grains is a dormancy expression, henceforth termed "embryo dormancy". The embryonic immature stage was considered as 100% impedence to germination.

In contrast, "embryo maturity" is the point when the embryo is capable of growth, as estimated by the dormancy breakage regime.

3.4.2 Alpha-amylase

Two levels of alpha-amylase were assayed: (1) a "field" or basal level and (2) a sprouted level henceforth termed basal alpha-amylase and alpha amylase response respectively. The latter was assayed from grains placed under standard germination conditions (Anon., 1966) for 33 hours (Gordon, 1975), then oven dried under vacuum (40°C, -100 kPa). The assay procedure employed used Phadebus ® tablets according to the method of Barnes and Blackeney (1974). Ground wheat (0.5-1.0 g dry weight) was added to 20 cm^3 of extractant. The extractant was distilled water containing 5 g/litre of NaCl, and 0.2 g/litre C.10 mesh $CaCl_2$. The suspension was gently shaken for five minutes, then centrifuged at 2000 G for five minutes. The supernatant was decanted off, and 5 cm^3 pipetted into a test tube and placed for two minutes in a water bath at 50 ± 0.5°C to equilibrate. A timer was started at the addition of a Phadebus tablet, the tablet being completely dispersed with gentle hand-shaking. The digest was incubated for 15 minutes, with a hand-shake every 5 minutes. On completion of incubation, 1 cm^3 of 0.5M NaOH was added, the volume made up to 10 cm^3, filtered through Whatman No. 1 filter paper, and the absorbance read at 620nm with a Guilford 300N spectrophotometer.

3.4.3 Flavan-3-ol Concentration

Ten grains were crushed and ground, and the flavan-3-ols extracted using a 10% aqueous methanolic solution left standing for 24 hours (Gordon, 1975). The suspension was centrifuged at 2000 G for five minutes. The supernatant was decanted off and the flavan-3-ol concentration of two 1 cm^3 aliquots (A and B) from this source determined according to the procedure of Swain and Hillis (1959). Heat of reaction was controlled by cooling the reaction mixture in an iced water bath. These were removed after two minutes and left for exactly 15 minutes at room temperature for colour development. Absorbance was read against a vanillin blank (C) which was prepared at the same time as the flavan-3-ol determination, to allow for vanillin ageing. The Guilford 300N spectrophotometer was set at 500nm and zeroed against a sulphuric acid blank (D). A standard curve for the flavan-3-ol (+) catechin, Flüka, Germany was constructed to cover the range 1.0 to 10.0 ug cm^{-3}. Assay procedure was according to Swain and Hillis (1959) with the modification that the known flavan-3-ol concentration solutions replaced the grain sample. The predictive equation was estimated as :

$$Y = 6.0352 (1 + A - B - C) - 6.0676$$

where Y = concentration of flavan-3-ol (ug cm^{-3})

X = adjusted absorbance (1 + A - B - C)

Multiple coefficient of determination (R^2) = 0.9857 and F for regression was 2627.27 (***). Estimated standard error of estimate was 0.3519, and standard error of the regression coefficient was 0.9928.

3.4.4 Pericarp Colour

A modified technique of Quartley and Wellington's (1962) method of distinguishing between red and white grains was employed. Two or three whole grains were immersed in 3 cm^3 of 5% NaOH and the colour change noted after one hour. A visual comparison to a set of ten graded standards (Gordon, pers. comm.; Appendix A4) prepared at the same time enabled a semi-quantitative measure of the phlobaphene content (Miyamoto and Everson, 1958).

3.4.5 Grain moisture

Grains were weighed immediately after removal from the spike, then dried in a vacuum (-100 kPa) oven at 40°C and left for 24 hours. The dried samples were allowed to equilibrate (for one hour) under standard conditions (22°C, 40% relative humidity) before reweighing. The final percentage moisture was expressed in terms of its fresh weight.

3.5 STATISTICAL METHODS

Most of the types of curves describing the characters under investigation had been established by Gordon (1975). In the present study, the same types of curves were fitted to the data. In the cases of poor or marginal fit, other related or similar types of curves were attempted, and the curve of best fit used. Criteria of best fit was highest R^2 over all cultivars in all environments. Characters, and their respective curves, are shown below in Table 3.2

Table 3.2 : Curves describing the development in time of nine characters over three environments.

Character	Curve description
Moisture content	logistic
Pigmentation	logistic
Grain dry-weight	Gompertz
Germination	quadratic logistic
Embryo maturity	quadratic logistic
Embryo dormancy	quadratic logistic
Basal alpha-amylase activity	Makeham
Alpha amylase response	third degree polynomial
Flavan-3-ol concentration	Makeham

Overall regression analyses were performed using each character in turn as the dependent variable, with days from anthesis as the independent variable. Replications were not treated separately, and were pooled in the regression analyses.

Usual methods of least squares fitting were used (Bliss, 1970; Draper and Smith, 1966; Steel and Torrie, 1960). Regressions and data plots were effected using Burroughs B6700 computer programs BASIS/MULTR and BASIS/PLOT respectively.

Theory and execution of polynomial curve fitting and of asymptotic curve types were according to Steel and Torrie (1960) and Bliss (1970) (see Appendix A3. The asymptotic curves considered relevant were Gompertz, Makeham, quadratic Makeham, logistic, loglogistic, and quadratic logistic. Where the upper asymptote was reached by the raw data, slight downward adjustment of raw data (-0.01) was necessary to effect curve fitting techniques. Similarly, slight upward adjustment (+ 0.01) was necessary for zero data. Theory and execution relating to curve fitting used in the present study are given in appendix 2.

Statistical differences amongst cultivar curves, within and between environments were established by comparing the Y-intercepts ($\hat{a}$) and the regression coefficients ($\hat{b}$). A significant difference in either of these statistics indicated a different pattern of development. Random tests for homogeneity (Steel and Torrie, 1960) indicated the variances from the six genotypes to be heterogeneous. The appropriate t-test was therefore :

$$t = \frac{x_2 - x_1}{\sqrt{\sigma_2^{\,2} + \sigma_1^{\,2}}}$$

where x_1 and x_2 are the statistics of interest (i.e.

$\hat{a}$'s or $\hat{b}$'s), and σ_1^2, σ_2^2 their respective variances (Steel and Torrie, 1960). Where this test was marginal for significance, the weighted test criterion (t') was employed as follows :

$$t' = \frac{\sigma_1^2 t_1 + \sigma_2^2 t_2}{\sigma_1^2 + \sigma_2^2}$$

where t_1 and t_2 are the tabulated values of t at the degrees of freedom applicable to σ_1^2 and σ_2^2 respectively (Steel and Torrie, 1960).

Chapter four : RESULTS

4.1 MOISTURE CONTENT

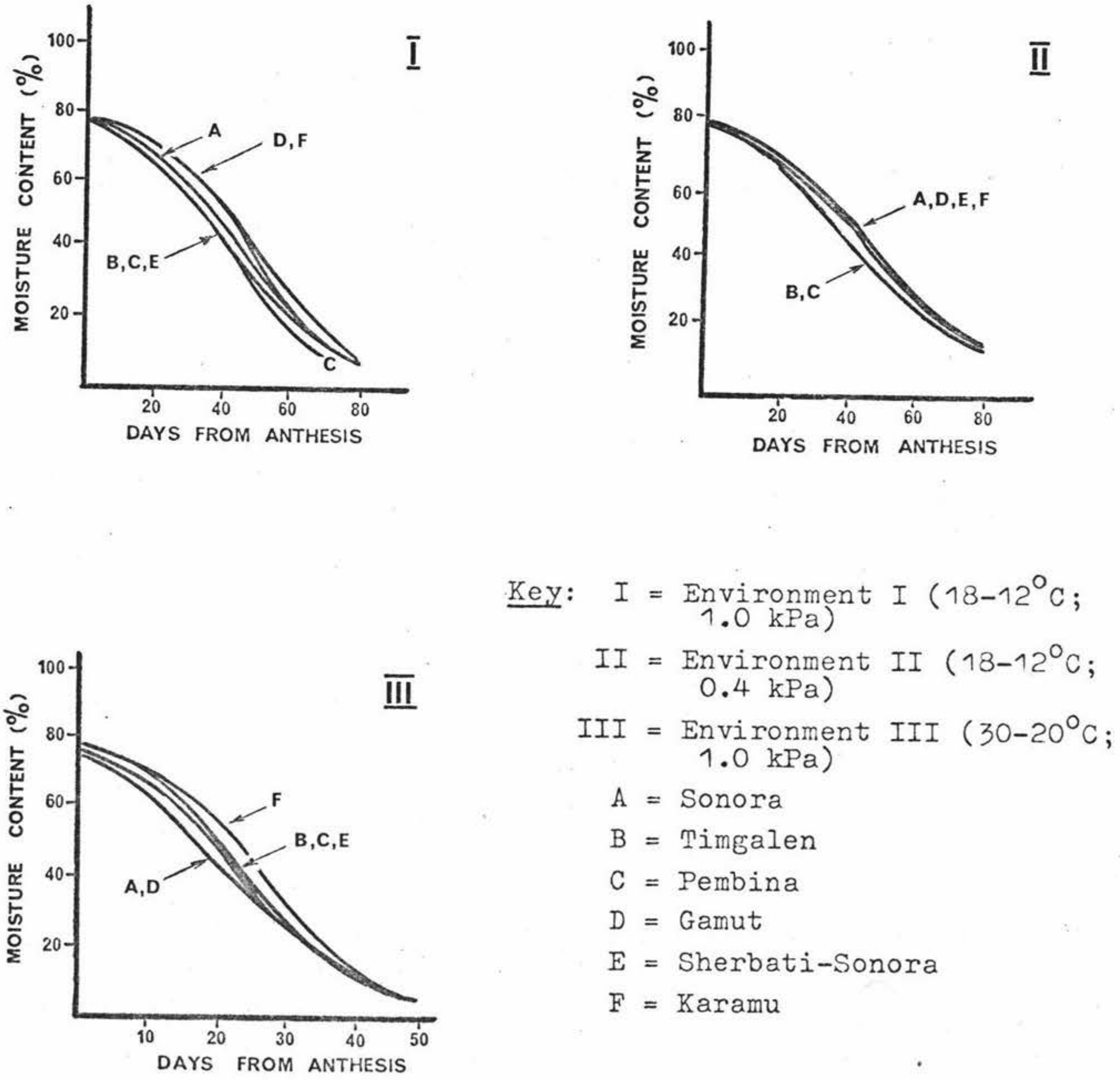
Changes in moisture content were described by logistic curves (table 4.1; figures A1.1.1, A1.1.2, A1.1.3). Cultivars within each environment are superimposed in figure 4.1.

In the cool, dry environment (env. I) significance groupings for the Y-intercept (appendix A5.1) fell into two distinct groups i.e. (Sherbati-Sonora, Sonora, Timgalen) (Gamut, Pembina, Karamu). This pattern changed with environments. In the cool, wet environment (env. II) Gamut had a significantly higher Y-intercept whereas the remaining cultivars formed an overlapping series of significance groupings. A complete merge for $\hat{a}$ occurred in the third hot, dry environment (env. III).

Similar patterns of cultivar groups were observed for slope of regression (appendix A5.1). Two distinct groupings occurred in environment I (Sonora, Timgalen, Sherbati-Sonora, Gamut) (Karamu, Pembina). An overlapping series of significance groupings occurred in environment II, and complete non-significance in environment III.

The number of days from anthesis to harvest ripeness ($12\frac{1}{2}\%$ moisture content) were estimated by reverse regression (Steel and Torrie, 1960). These statistics are presented in table 4.2. In the cool, dry environment (env. I) there was separation of cultivars into three distinct significance

Figure 4.1 Changes in grain moisture content during grain development showing six wheat cultivars superimposed within each of three environments. (Tests of significance amongst cultivars are presented in appendix A5.1).



Key: I = Environment I (18-12°C; 1.0 kPa)
II = Environment II (18-12°C; 0.4 kPa)
III = Environment III (30-20°C; 1.0 kPa)
A = Sonora
B = Timgalen
C = Pembina
D = Gamut
E = Sherbati-Sonora
F = Karamu

Figure 4.2 Changes in grain moisture content during grain development amongst six wheat cultivars across three environments. (Tests of significance amongst cultivars are presented in appendix A6.1).

Key :

I = environment I (18-12°C; 1.0 kPa)
II = environment II (18-12°C; 0.4 kPa)
III = environment III (30-20°C; 1.0 kPa)

A = Sonora
B = Timgalen
C = Pembina
D = Gamut
E = Sherbati-Sonora
F = Karamu

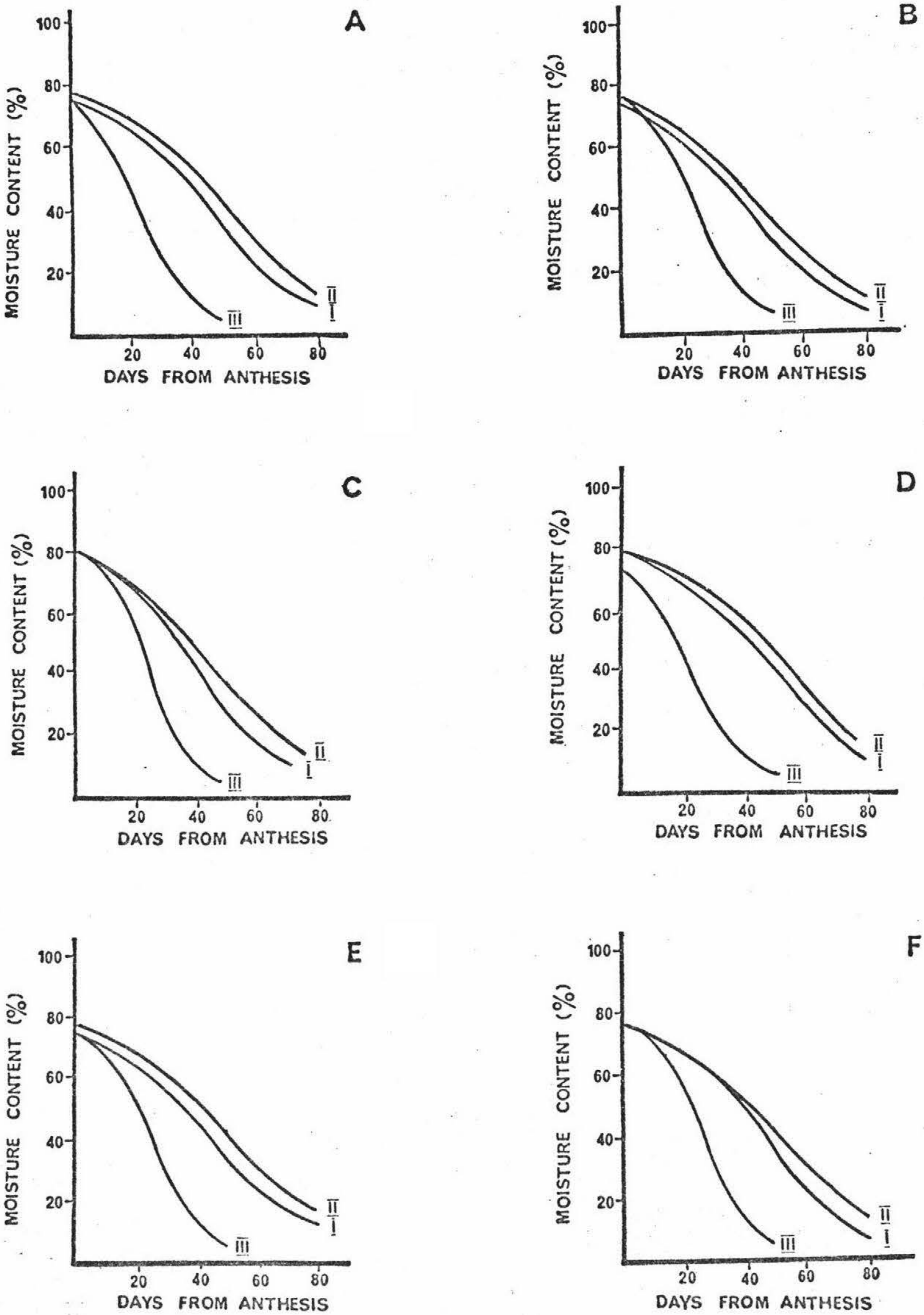

A
B
C
D
E
F
MOISTURE CONTENT (%)
100
80
60
40
20
DAYS FROM ANTHESIS
20
40
60
80
I
II
III

Table **4.1**

Estimated statistics of final curves[1] within three environments describing changes in moisture content during grain development amongst six wheat cultivars.

Table **4.1.1** : Environment I (18-12°C; 1.0 kPa).

Statistic	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Y-intercept ($\hat{a}$)	2.7596	2.7396	3.6119	3.4435	2.7533	4.1020
s.e. of Y-intercept	0.1169	0.1396	0.1696	0.1674	0.0898	0.3175
$\hat{b}$	-0.0576	-0.0613	-0.0823	-0.0650	-0.0585	-0.0803
s.e. of $\hat{b}$	0.0020	0.0024	0.0036	0.0029	0.0015	0.0054
upper asymptote	79.90	76.96	78.99	77.48	76.82	78.55
R^2	0.9638	0.9549	0.9604	0.9430	0.9790	0.8753
F for regression	826.21**	655.86**	534.18**	513.24**	1442.95**	217.61**
s.e. of estimate	0.2949	0.3523	0.3909	0.4224	0.2266	0.8012

Table **4.1.2** : Environment II (18-12°C; 0.4 kPa)

Statistic	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Y-intercept ($\hat{a}$)	2.9971	2.4089	2.3657	3.7635	2.6460	2.9970
s.e. of Y-intercept	0.1650	0.1070	0.0565	0.2343	0.1324	0.2252
$\hat{b}$	-0.0573	-0.0530	-0.0538	-0.0668	-0.0512	-0.0577
s.e. of $\hat{b}$	0.0028	0.0018	0.0011	0.0046	0.0023	0.0039
upper asymptote	77.39	75.50	80.20	78.20	77.14	76.24
R^2	0.9296	0.9641	0.9897	0.8957	0.9425	0.8848
F for regression	409.53**	832.96**	2391.46**	214.63**	508.44**	222.71**
s.e. of estimate	0.4163	0.2700	0.1344	0.5576	0.3341	0.4896

Table **4.1.3** : Environment III (30-20°C; 1.0 kPa).

Statistic	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Y-intercept ($\hat{a}$)	2.4249	3.0759	3.6142	2.5362	2.8889	3.7287
s.e. of Y-intercept	0.3443	0.3868	0.5748	0.2978	0.4372	0.5723
$\hat{b}$	-0.1052	-0.1225	-0.1367	-0.1074	-0.1184	-0.1353
s.e. of $\hat{b}$	0.0112	0.0126	0.0188	0.0097	0.0143	0.0187
upper asymptote	75.82	77.50	80.47	75.92	77.13	78.50
R^2	0.8455	0.8546	0.7682	0.8841	0.8112	0.7769
F for regression	87.58**	94.02**	53.01**	122.03**	68.76**	52.22**
s.e. of estimate	0.7716	0.8668	1.2882	0.6674	0.9799	1.1908

[1] Linear form : logit (percent moisture) = a + b (days from anthesis).

Table 4.2

Regressed estimates of days[1] to harvest ripeness (12½% moisture content) within three environments amongst six wheat cultivars.

Cultivar	Environment I		Environment II		Environment III	
	days	std. error	days	std. error	days	std. error
Sonora	77.2	0.3212	81.1	1.9824	38.5	2.1589
Timgalen	71.5	1.3153	76.0	1.3234	38.6	2.0723
Pembina	64.2	0.1208	75.4	0.8495	38.8	2.5428
Gamut	78.3	1.6814	81.2	2.8830	38.7	1.8992
Sherbati-Sonora	75.1	0.8156	83.8	1.9090	38.3	2.3246
Karamu	71.8	2.1306	80.2	2.2110	39.9	2.4223

[1] where days = days from anthesis

groupings (appendix A7.1). These were: (Gamut, Sonora, Sherbati-Sonora)(Karamu, Timgalen) (Pembina). These cultivars formed an overlapping series in the cool, moist environment, and merged completely in the hot, dry environment. Considerable genotype-environmental interaction was therefore recorded for harvest ripeness.

Average days to reach harvest ripeness (from anthesis) were 73.0 ± 5.1, 79.6 ± 3.3 and 38.8 ± 0.3 days for environments I, II, III respectively. There were non-significant differences between the two cool environments ($P < 0.005$) and highly significant differences between the cool and hot environments ($P < 0.001$).

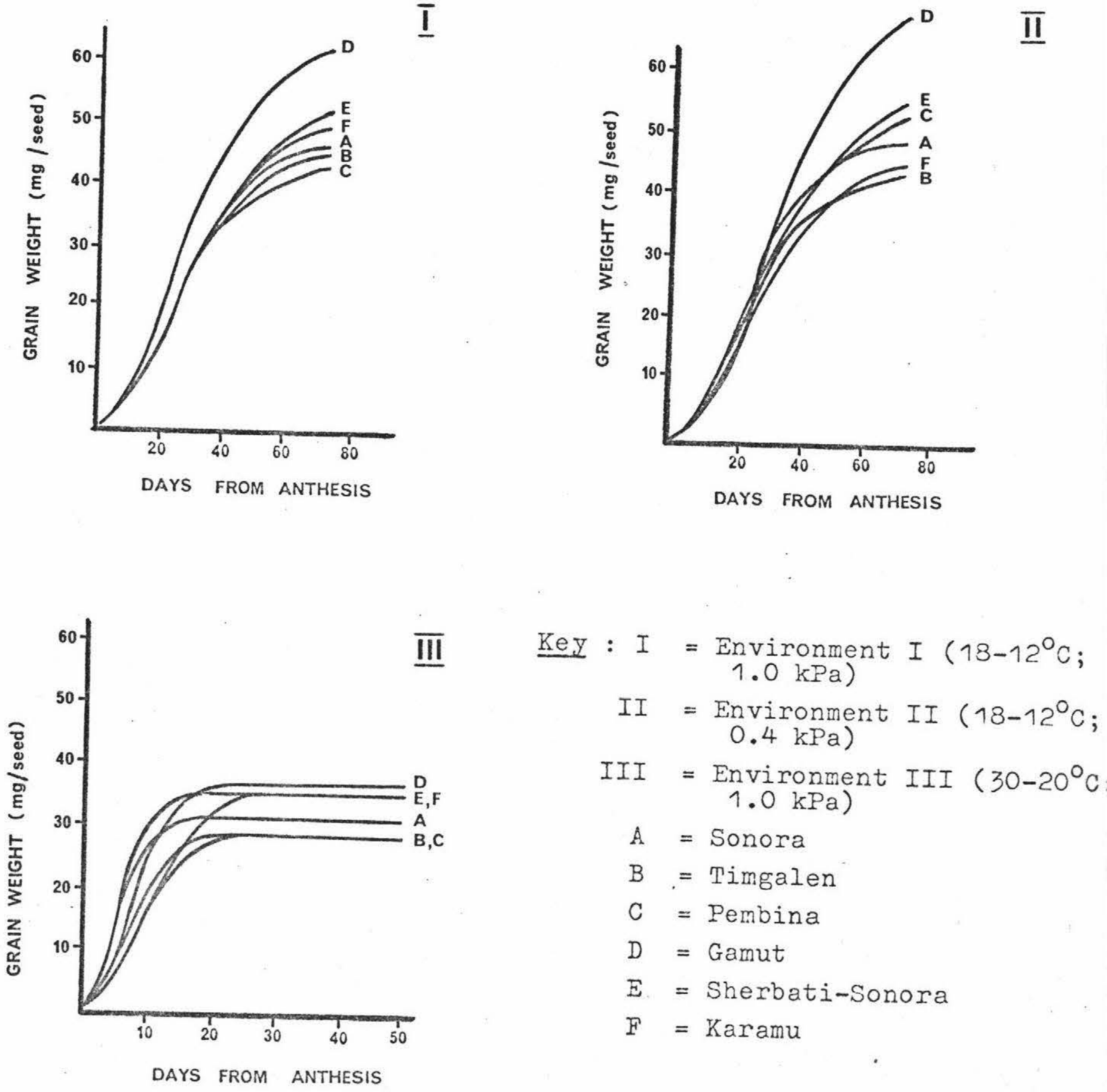
4.2 GRAIN DRY-WEIGHT

Change in grain dry-weight was described by the Gompertz equation (table 4.3; figures A1.2.1, A1.2.2, A1.2.3). Cultivar performance within each environment are superimposed in figure 4.3.

In all environments there was clear separation of Gamut for the Y-intercept ($\hat{a}$) being the heaviest seed, the remaining cultivars forming an overlapping series of significance groupings (appendix A5.2).

Rate of grain weight increment changed markedly with environments. In the cool, dry environment (env. I) cultivar significance groupings were (Sherbati-Sonora, Karamu, Sonora) (Timgalen, Pembina, Gamut). In the cool, moist environment (env. II) Timgalen was significantly smaller, whereas

Figure 4.3 Changes in grain dry weight during grain development amongst six wheat cultivars superimposed within each of three environments (Tests of significance amongst cultivars are presented in appendix A5.2).



Key : I = Environment I (18-12°C; 1.0 kPa)

II = Environment II (18-12°C; 0.4 kPa)

III = Environment III (30-20°C 1.0 kPa)

A = Sonora

B = Timgalen

C = Pembina

D = Gamut

E = Sherbati-Sonora

F = Karamu

Figure 4.4 Changes in grain dry weight during grain development amongst six wheat cultivars across three environments. (Tests of significance amongst cultivars are presented in appendix A6.2).

Key :

I = Environment I (18-12°C; 1.0 kPa)
II = Environment II (18-12°C; 0.4 kPa)
III = Environment III (30-20°C; 1.0 kPa)

A = Sonora
B = Timgalen
C = Pembina
D = Gamut
E = Sherbati-Sonora
F = Karamu

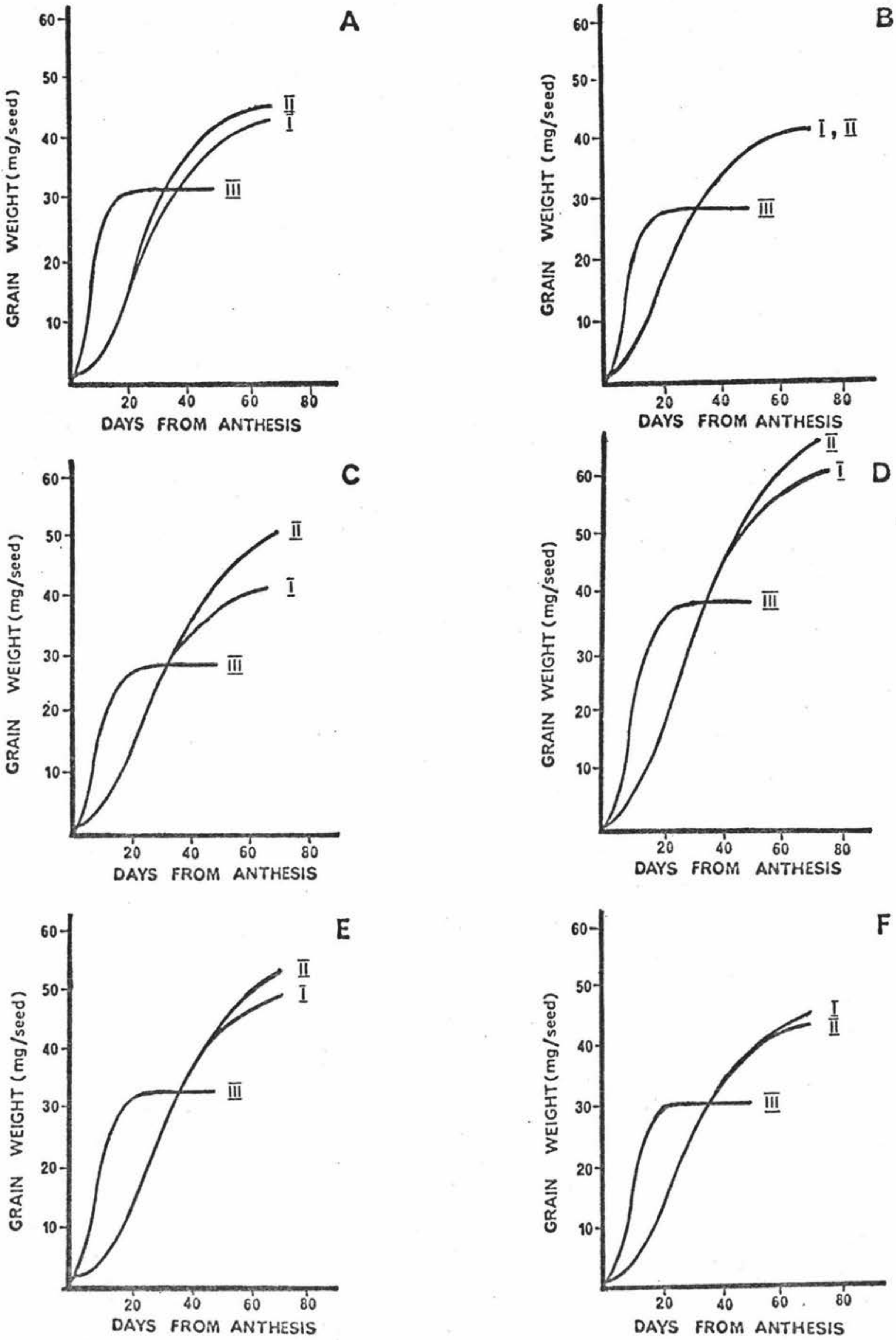

A
GRAIN WEIGHT (mg/seed)
60
50
40
30
20
10
20
40
60
80
DAYS FROM ANTHESIS
II
I
III
B
GRAIN WEIGHT (mg/seed)
I, II
III
C
GRAIN WEIGHT (mg/seed)
II
I
III
D
GRAIN WEIGHT (mg/seed)
II
I
III
E
GRAIN WEIGHT (mg/seed)
II
I
III
F
GRAIN WEIGHT (mg/seed)
I
II
III

Table **4.3**

Estimated statistics of final curves[1] within three environments describing changes in grain dry-weight during grain development amongst six wheat cultivars.

Table **4.3.1** : Environment I (18-12°C; 1.0 kPa).

Statistic	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Y-intercept ($\hat{a}$)	3.8581	3.8211	3.7879	4.1629	3.9804	3.9182
s.e. of Y-intercept	0.0373	0.0488	0.0513	0.0294	0.0477	0.0339
$\hat{b}$	-4.5654	-4.0879	-3.9533	-4.1742	-4.5708	-4.5057
s.e. of $\hat{b}$	0.1005	0.1304	0.1386	0.0783	0.1285	0.0913
$\hat{B}$	0.6318	0.6477	0.6300	0.6538	0.6377	0.6365
R^2	0.9894	0.9781	0.9737	0.9923	0.9830	0.9911
F for regression	2058.18**	981.94**	815.13**	2845.65**	1269.26**	2437.31**
s.e. of estimate	0.1553	0.2004	0.2138	0.1200	0.1977	0.1407

Table **4.3.2** : Environment II (18-12°C; 0.4 kPa).

Statistic	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Y-intercept ($\hat{a}$)	3.8864	3.7504	3.9738	4.2922	4.0440	3.8112
s.e. of Y-intercept	0.0418	0.0263	0.0260	0.0290	0.0376	0.0470
$\hat{b}$	-4.5732	-3.7984	-4.2747	-4.3402	-4.3113	-4.5162
s.e. of $\hat{b}$	0.1221	0.0717	0.0691	0.0763	0.0993	0.1356
$\hat{B}$	0.6023	0.6054	0.6559	0.6762	0.6690	0.6208
R^2	0.9846	0.9922	0.9943	0.9933	0.9885	0.9806
F for regression	1403.31**	2808.48**	3827.43**	3238.66**	1886.48**	1110.09**
s.e. of estimate	0.1764	0.1114	0.1059	0.1160	0.1514	0.1959

Table **4.3.3** : Environment III (30-20°C; 1.0 kPa)

Statistic	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Y-intercept ($\hat{a}$)	3.4403	3.3574	3.3561	3.6561	3.4629	3.5010
s.e. of Y-intercept	0.0395	0.0564	0.0502	0.0248	0.0245	0.0254
$\hat{b}$	-3.0132	-3.2818	-3.8076	-3.3916	-3.7816	-3.3622
s.e. of $\hat{b}$	0.0968	0.1378	0.1229	0.0607	0.0600	0.0619
$\hat{B}$	0.0972	0.1535	0.2532	0.2165	0.0751	0.2832
R^2	0.9838	0.9724	0.9836	0.9949	0.9960	0.9946
F for regression	968.93**	564.18**	961.92**	3121.55**	3971.57**	2948.42**
s.e. of estimate	0.1528	0.2175	0.1914	0.0950	0.0948	0.0962

[1] Linear form : Ln (grain weight, mg per seed) = a+ B^t, where t = (days from anthesis/7).

the remaining cultivars formed an overlapping series of significance groupings. Cultivars were regrouped in the hot, dry environment (env. III) with Sherbati-Sonora and Pembina being identified as being distinctly different from the remaining cultivars (appendix A5.2).

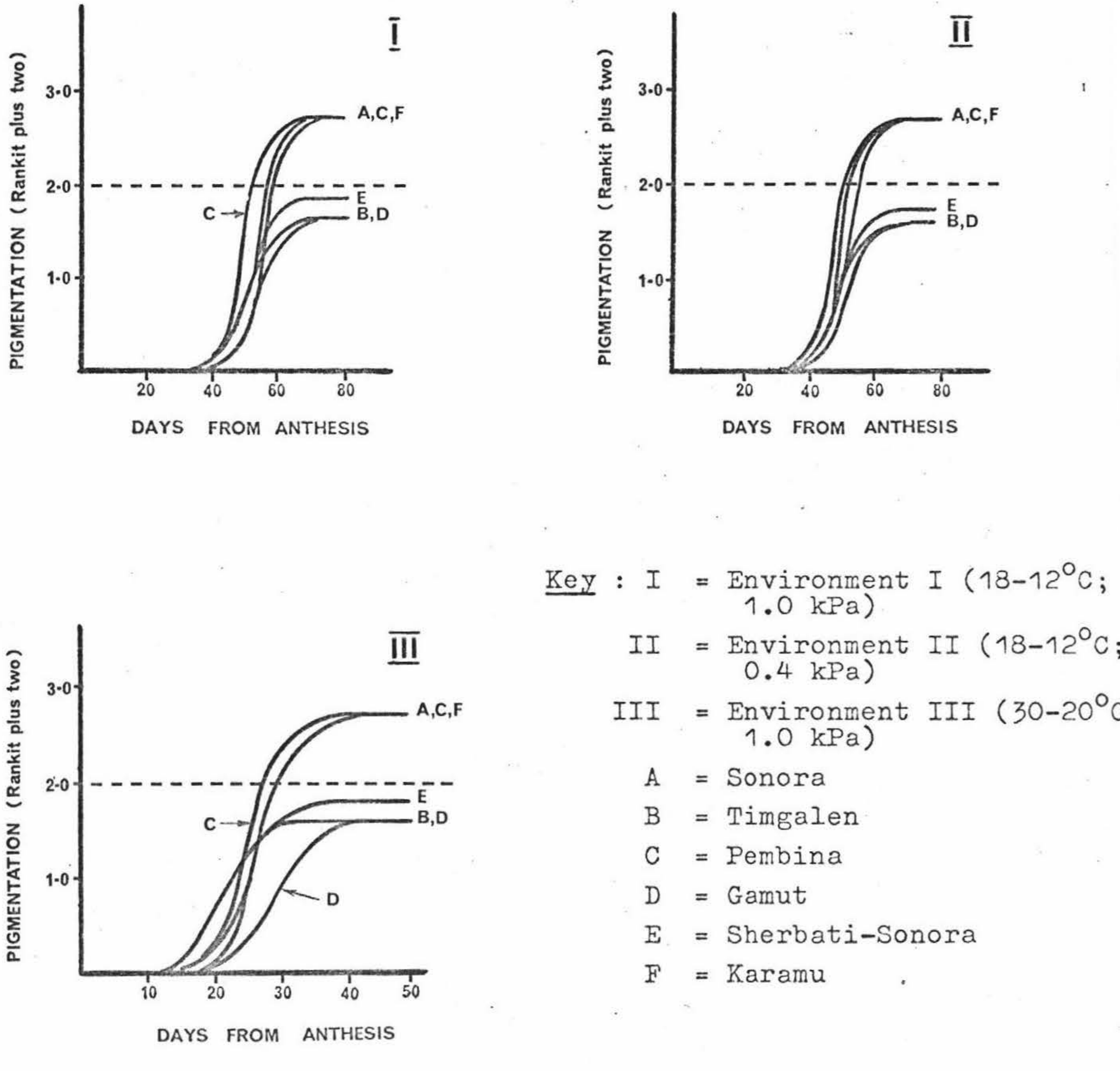
4.3 PIGMENTATION

Developmental patterns of the phlobaphene pigment were described by logistic curves (table 4.4; figures A1.3.1, A1.3.2, A1.3.3). Cultivar performances within each of the three environments are superimposed in figure 4.5.

In all three environments, the upper asymptotes ($\hat{a}$) were clearly distinguished into red and white groups (appendix A5.3). A red-white group also existed for slope ($\hat{b}$) in the cool, moist environment (env. II) but distinctiveness of any sort of grouping of slopes was lost in the cool, dry environment (env. I). All cultivars had similar slopes in the third (hot, dry) environment.

Regressed estimates of days to 50% pigment formation for all environments are presented in table 4.5. All cultivars were similar to each other within each environment (appendix A7.2). Average number of days to reach 50% pigment formation were 52.4 ± 3.3, 50.2 ± 1.8 and 25.8 ± 3.4 days for environments I, II, III respectively. Environments I and II were not significantly ($P < 0.005$) different to each other; whereas

Figure 4.5 Development of pigmentation during grain development amongst six wheat cultivars superimposed within each of three environments. (Tests of significance amongst cultivars are presented in appendix A5.3)[1].



Key : I = Environment I (18-12°C; 1.0 kPa)

II = Environment II (18-12°C; 0.4 kPa)

III = Environment III (30-20°C 1.0 kPa)

A = Sonora

B = Timgalen

C = Pembina

D = Gamut

E = Sherbati-Sonora

F = Karamu

---

[1] white-red interface between 1.877 and 2.123

Figure 4.6 Development of pigmentation during grain development amongst six wheat cultivars across three environments (Tests of significance amongst cultivars are presented in appendix A6.3)[1].

Key :

I = Environment I (18-12°C; 1.0 kPa)
II = Environment II (18-12°C; 0.4 kPa)
III = Environment III (30-20°C; 1.0 kPa)

A = Sonora
B = Timgalen
C = Pembina
D = Gamut
E = Sherbati-Sonora
F = Karamu

[1] white-red interface between 1.877 and 2.123

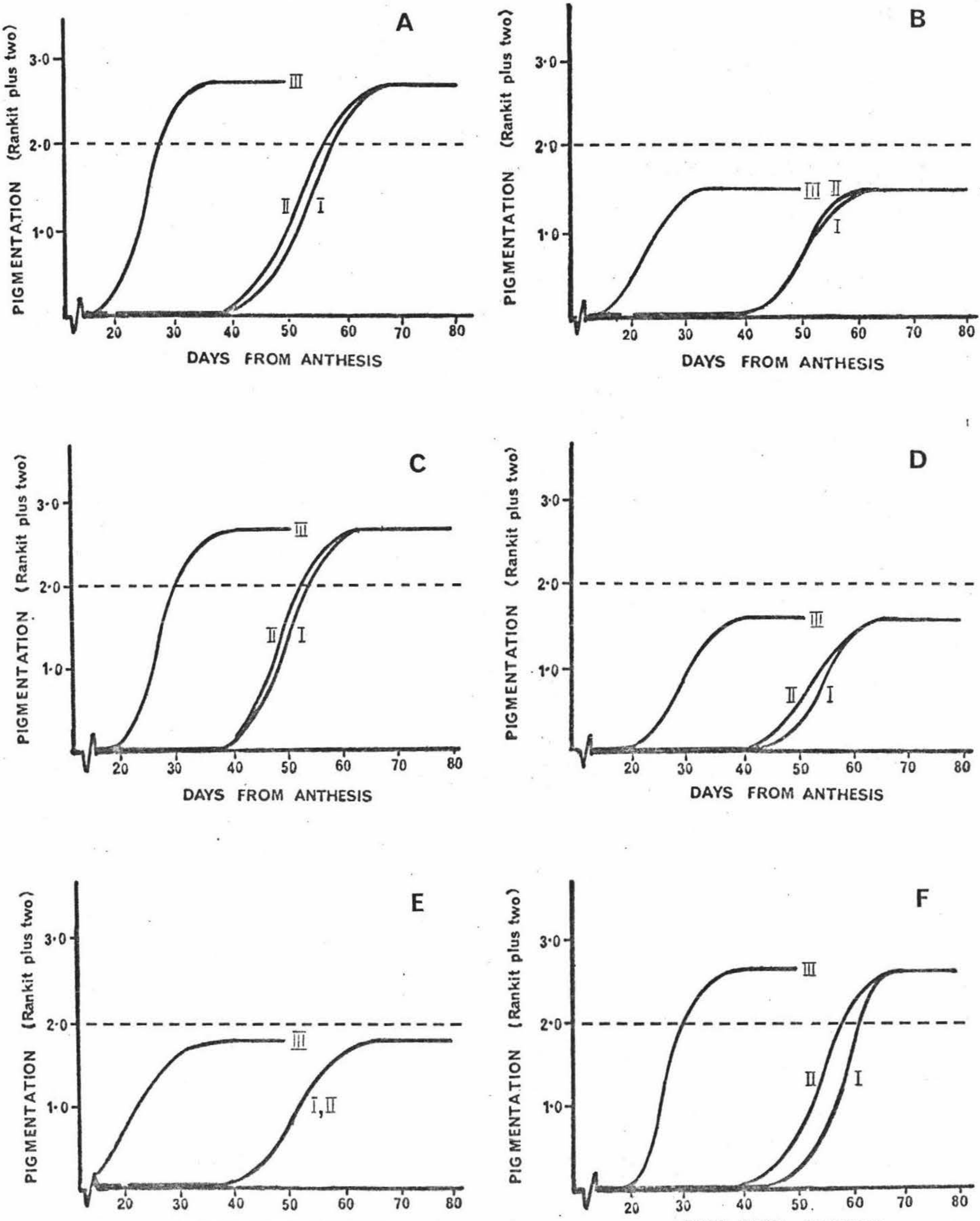

A
PIGMENTATION (Rankit plus two)
3·0
2·0
1·0
III
II
I
20
30
40
50
60
70
80
DAYS FROM ANTHESIS
B
PIGMENTATION (Rankit plus two)
3·0
2·0
1·0
III
II
I
20
30
40
50
60
70
80
DAYS FROM ANTHESIS
C
PIGMENTATION (Rankit plus two)
3·0
2·0
1·0
III
II
I
20
30
40
50
60
70
80
DAYS FROM ANTHESIS
D
PIGMENTATION (Rankit plus two)
3·0
2·0
1·0
III
II
I
20
30
40
50
60
70
80
DAYS FROM ANTHESIS
E
PIGMENTATION (Rankit plus two)
3·0
2·0
1·0
III
I, II
20
30
40
50
60
70
80
DAYS FROM ANTHESIS
F
PIGMENTATION (Rankit plus two)
3·0
2·0
1·0
III
II
I
20
30
40
50
60
70
80
DAYS FROM ANTHESIS

Table 4.4

Estimated statistics of final curves[1] within three environments describing development of pigmentation during grain development amongst six wheat cultivars.

Table 4.4.1 : Environment I (18-12°C; 1.0 kPa).

Statistic	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Y-intercept ($\hat{a}$)	-16.3454	-11.8908	-17.7822	-11.3494	-12.1399	-17.3964
s.e. of Y-intercept	1.0961	1.2553	1.7284	2.0455	1.1799	1.3757
$\hat{b}$	0.3055	0.2410	0.3563	0.2168	0.2367	0.2982
s.e. of $\hat{b}$	0.0187	0.0215	0.0332	0.0342	0.0202	0.0225
upper asymptote	2.656	1.624	2.656	1.624	1.877	2.656
R^2	0.9038	0.8016	0.8527	0.5840	0.8153	0.8625
F for regression	263.17**	125.23**	110.02**	40.19**	136.81**	175.63**
s.e. of estimate	2.1418	3.1683	2.6914	4.2172	2.9777	2.5596

Table 4.4.2 : Environment II (18-12°C; 0.4 kPa).

Statistic	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Y-intercept ($\hat{a}$)	-15.9049	-11.6138	-17.8357	-11.0854	-11.5340	-16.6113
s.e. of Y-intercept	1.3896	1.3271	1.5300	1.4369	1.5590	1.4236
$\hat{b}$	0.3111	0.2376	0.3644	0.2256	0.2325	0.3114
s.e. of $\hat{b}$	0.0227	0.0228	0.0281	0.0345	0.0267	0.0233
upper asymptote	2.656	1.624	2.656	1.624	1.877	2.656
R^2	0.8700	0.7784	0.8844	0.7986	0.7419	0.8646
F for regression	187.38**	108.92**	168.36**	187.65**	89.09**	178.82**
s.e. of estimate	2.5854	3.3495	2.5448	3.3340	3.9348	2.6487

Table 4.4.3 : Environment III (30-20°C; 1.0 kPa).

Statistic	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Y-intercept ($\hat{a}$)	-13.4214	-7.9008	-14.5192	-7.1528	-7.6479	-14.5192
s.e. of Y-intercept	1.5605	1.4637	1.5543	1.4797	1.7094	2.8568
$\hat{b}$	0.4432	0.3613	0.5192	0.4507	0.3625	0.5192
s.e. of $\hat{b}$	0.0763	0.0477	0.0852	0.0740	0.0558	0.0852
upper asymptote	2.656	1.624	2.656	1.624	1.877	2.656
R^2	0.7216	0.7312	0.7409	0.7409	0.7249	0.7409
F for regression	33.70**	57.03**	37.16**	37.17**	42.17**	37.16**
s.e. of estimate	3.7863	3.2304	4.2244	3.6668	3.8312	4.2244

---

[1] Linear form : logit (pigmentation, rankit plus two) = a + b (days from anthesis).

Table 4.5

Regressed estimates of days from anthesis at 50% pigment formation within three environments amongst six wheat cultivars.

Cultivar	Environment I		Environment II		Environment III	
	days	std. error	days	std. error	days	std. error
Sonora	53.5	3.8233	51.1	3.9394	26.4	2.3700
Timgalen	49.3	3.5029	48.9	3.4271	21.9	2.5820
Pembina	49.9	3.4342	48.9	1.4780	28.0	2.2524
Gamut	52.3	1.5084	49.1	2.4294	29.2	2.835
Sherbati-Sonora	51.3	3.5068	49.6	3.5970	21.1	3.3789
Karamu	58.3	2.8729	53.3	3.9356	28.0	2.0770

where days = days from anthesis

Table 4.6

Stage of grain development at which 50% of pigment was formed with respect to harvest ripeness (P50/HR)[1]

	Environment I	Environment II	Environment III
Sonora	0.7	0.6	0.7
Timgalen	0.7	0.6	0.6
Pembina	0.8	0.6	0.7
Gamut	0.7	0.6	0.8
Sherbati-Sonora	0.7	0.6	0.6
Karamu	0.8	0.7	0.7

---

[1] P50 = days to 50% pigment formation
HR = days to harvest ripeness

environments I and III, and environments II and III were significantly different to each other ($P < 0.001$).

Estimates of days to 50% pigment formation as a function of days to harvest ripeness are given in table 4.6.

4.4 FLAVAN-3-OL CONCENTRATION

Changes in flavan-3-ol concentration were described by Makeham curves (table 4.7; figures A1.4.1, A1.4.2, A1.4.3). Cultivar performances within each of three environments are superimposed in figure 4.7.

In most cases, there was clear separation amongst individual cultivars for the upper asymptote, and marked changes in rank order were observed across environments. The only exception was an overlap of significance for Karamu and Sonora in environment II (appendix A5.4).

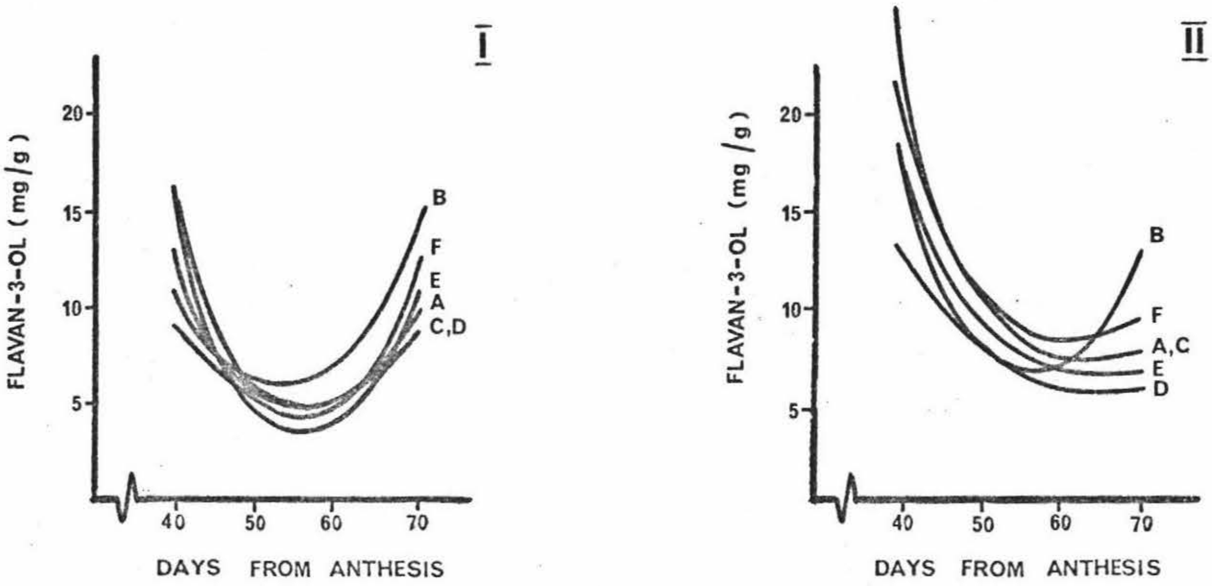
Slopes of regression (for both $\hat{b}_1$ and $\hat{b}_2$) formed varying degrees of significance overlapping amongst all cultivars in all three environments (appendix A5.5).

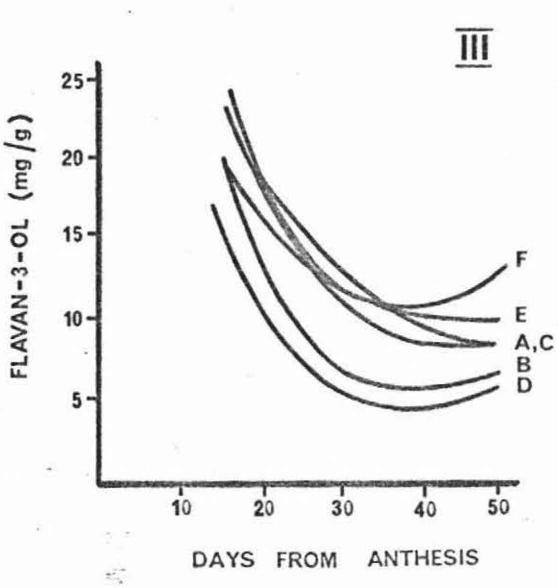
4.5 GERMINATION

Changes in germination were described by quadratic logistic curves (table 4.8; figures A1.5.1, A1.5.2, A1.5.3). Cultivar performances within each of the three environments are superimposed in figure 4.9.

In the cool, moist environment (env. II) Gamut

Figure 4.7 Changes in flavan-3-ol concentration during grain development amongst six wheat cultivars superimposed within each of three environments (Tests of significance amongst cultivars are presented in appendices A5.4 and A5.5).





Key : I = Environment I (18-12°C; 1.0 kPa)
II = Environment II (18-12°C; 0.4 kPa)
III = Environment III (30-20° 1.0 kPa)
A = Sonora
B = Timgalen
C = Pembina
D = Gamut
E = Sherbati-Sonora
F = Karamu

Figure 4.8 Changes in flavan-3-ol concentration during grain development amongst six wheat cultivars across three environments. (Tests of significance amongst cultivars are presented in appendices A6.4 and A6.5).

Key :

I = Environment I (18-12°C; 1.0 kPa)
II = Environment II (18-12°C; 0.4 kPa)
III = Environment III (30-20°C; 1.0 kPa)

A = Sonora
B = Timgalen
C = Pembina
D = Gamut
E = Sherbati-Sonora
F = Karamu

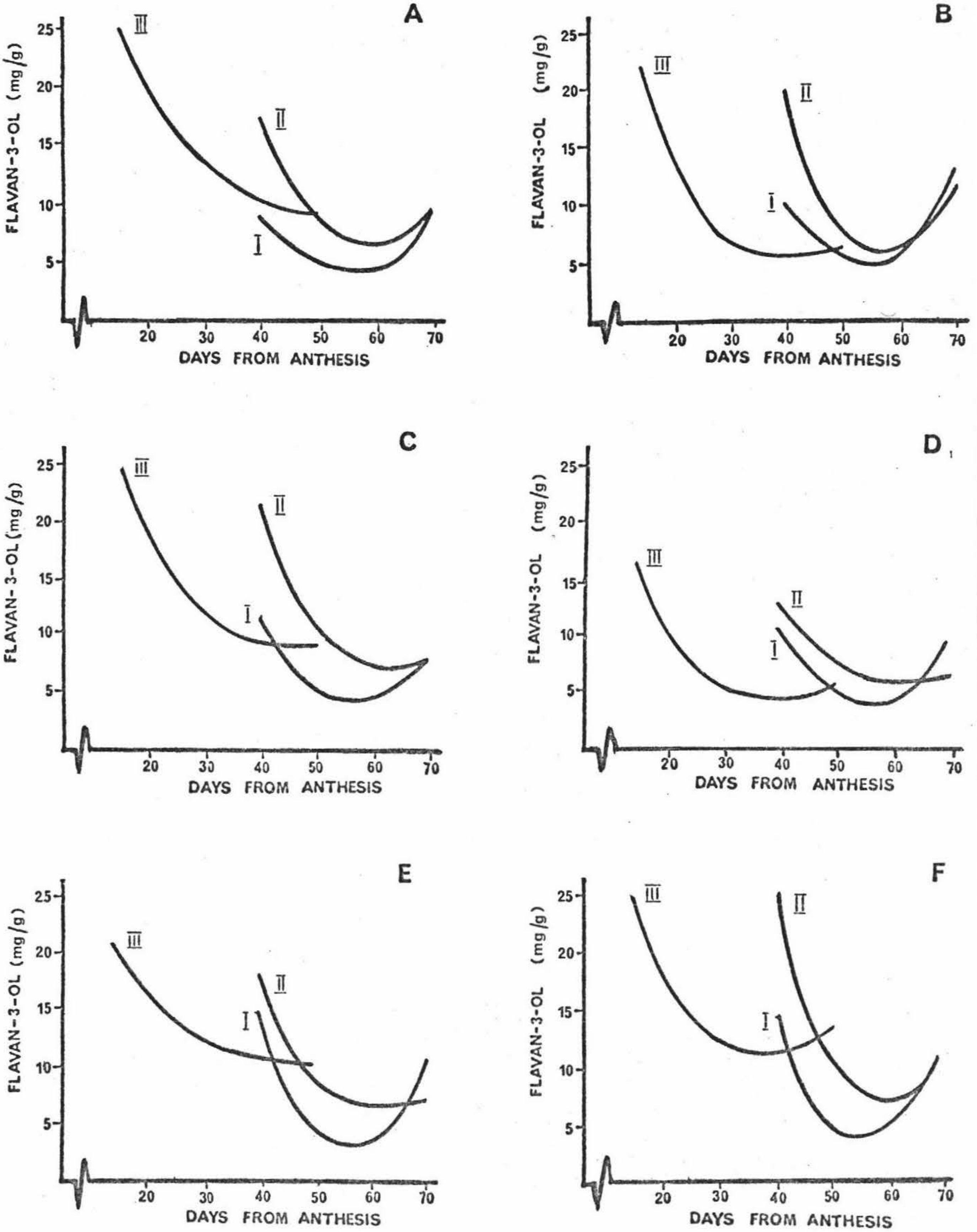

A
III
II
I
FLAVAN-3-OL (mg/g)
25
20
15
10
5
20
30
40
50
60
70
DAYS FROM ANTHESIS
B
III
II
I
FLAVAN-3-OL (mg/g)
25
20
15
10
5
20
30
40
50
60
70
DAYS FROM ANTHESIS
C
III
II
I
FLAVAN-3-OL (mg/g)
25
20
15
10
5
20
30
40
50
60
70
DAYS FROM ANTHESIS
D
III
II
I
FLAVAN-3-OL (mg/g)
25
20
15
10
5
20
30
40
50
60
70
DAYS FROM ANTHESIS
E
III
II
I
FLAVAN-3-OL (mg/g)
25
20
15
10
5
20
30
40
50
60
70
DAYS FROM ANTHESIS
F
III
II
I
FLAVAN-3-OL (mg/g)
25
20
15
10
5
20
30
40
50
60
70
DAYS FROM ANTHESIS

Table **4.7**

Estimated statistics of final curves[1] within three environments describing changes in flavan-3-ol concentration during grain development amongst six wheat cultivars.

Table **4.7.1** : Environment I (18-12°C; 1.0 kPa).

Statistic	Sonora	Timgalen	Pembina	Gamut	Sherbati Sonora	Karamu
Y-intercept ($\hat{a}$)	-172.6669	-50.9203	-57.9796	-64.5284	-93.0432	-305.3412
s.e. of Y-intercept	0.5614	0.2851	0.3490	0.4406	0.4511	0.3883
$\hat{b}_1$	-2.2538	-1.3475	-1.6634	-1.6473	-2.5037	-3.9241
$\hat{b}_2$	173.6203	51.9094	59.3163	65.7223	94.3529	307.4023
s.e. of $\hat{b}_1$	0.9534	0.4660	0.5699	0.6186	0.7382	0.6466
s.e. of $\hat{b}_2$	73.8350	17.3609	20.4433	24.7403	23.0046	50.7403
$\hat{B}$	1.0119	1.0222	1.0235	1.0214	1.0224	1.0117
R^2	0.3155	0.4448	0.4554	0.3797	0.5049	0.7652
F for regression	2.77	4.31*	5.02*	3.67	6.12*	19.56**
s.e. of estimate	0.4032	0.3639	0.4708	0.4659	0.5816	0.2673

Table **4.7.2** : Environment II (18-12°C; 0.4 kPa).

Statistic	Sonora	Timgalen	Pembina	Gamut	Sherbati Sonora	Karamu
Y-intercept ($\hat{a}$)	-33.6613	-62.4786	-25.0166	-22.6219	-40.6000	-33.0389
s.e. of Y-intercept	0.1915	0.1412	0.1715	0.1275	0.18667	0.2526
$\hat{b}_1$	-0.9745	-1.7320	-0.7666	-0.6672	-0.9201	-1.0058
$\hat{b}_2$	34.6491	63.8907	25.9402	23.3857	41.4544	34.1115
s.e. of $\hat{b}_1$	0.3129	0.2310	0.2798	0.2082	0.3067	0.4114
s.e. of $\hat{b}_2$	11.3380	8.5330	9.7930	7.5061	14.0580	14.2581
$\hat{B}$	1.0233	1.0228	1.0240	1.0234	1.0190	1.0242
R^2	0.6958	0.8581	0.8021	0.8114	0.7750	0.6181
F for regression	13.72**	36.29**	24.32**	25.81**	20.66**	9.71**
s.e. of estimate	0.2564	0.1852	0.2360	0.1713	0.2053	0.3499

Table **4.7.3** : Environment III (30-20°C; 1.0 kPa).

Statistic	Sonora	Timgalen	Pembina	Gamut	Sherbati Sonora	Karamu
Y-intercept ($\hat{a}$)	-30.4163	-46.6418	-54.8764	-79.9536	-20.4868	-100.5935
s.e. of Y-intercept	0.1230	0.0969	0.1615	0.3279	0.1153	0.1669
$\hat{b}_1$	-0.5093	-0.9478	-0.8275	-1.3323	-0.3913	-1.3324
$\hat{b}_2$	30.8391	47.1245	55.3241	80.4297	20.8579	101.0668
s.e. of $\hat{b}_1$	0.1777	0.1397	0.2337	0.4723	0.1666	0.4064
s.e. of $\hat{b}_2$	11.2216	7.1219	16.0013	29.0247	9.1970	31.1440
$\hat{B}$	1.0149	1.0182	1.0138	1.0153	1.0169	1.0124
R^2	0.9208	0.9505	0.8822	0.6959	0.8187	0.6875
F for regression	69.73**	115.10**	44.96**	13.73**	27.10**	13.20**
s.e. of estimate	0.1289	0.1236	0.1571	0.3521	0.1369	0.2457

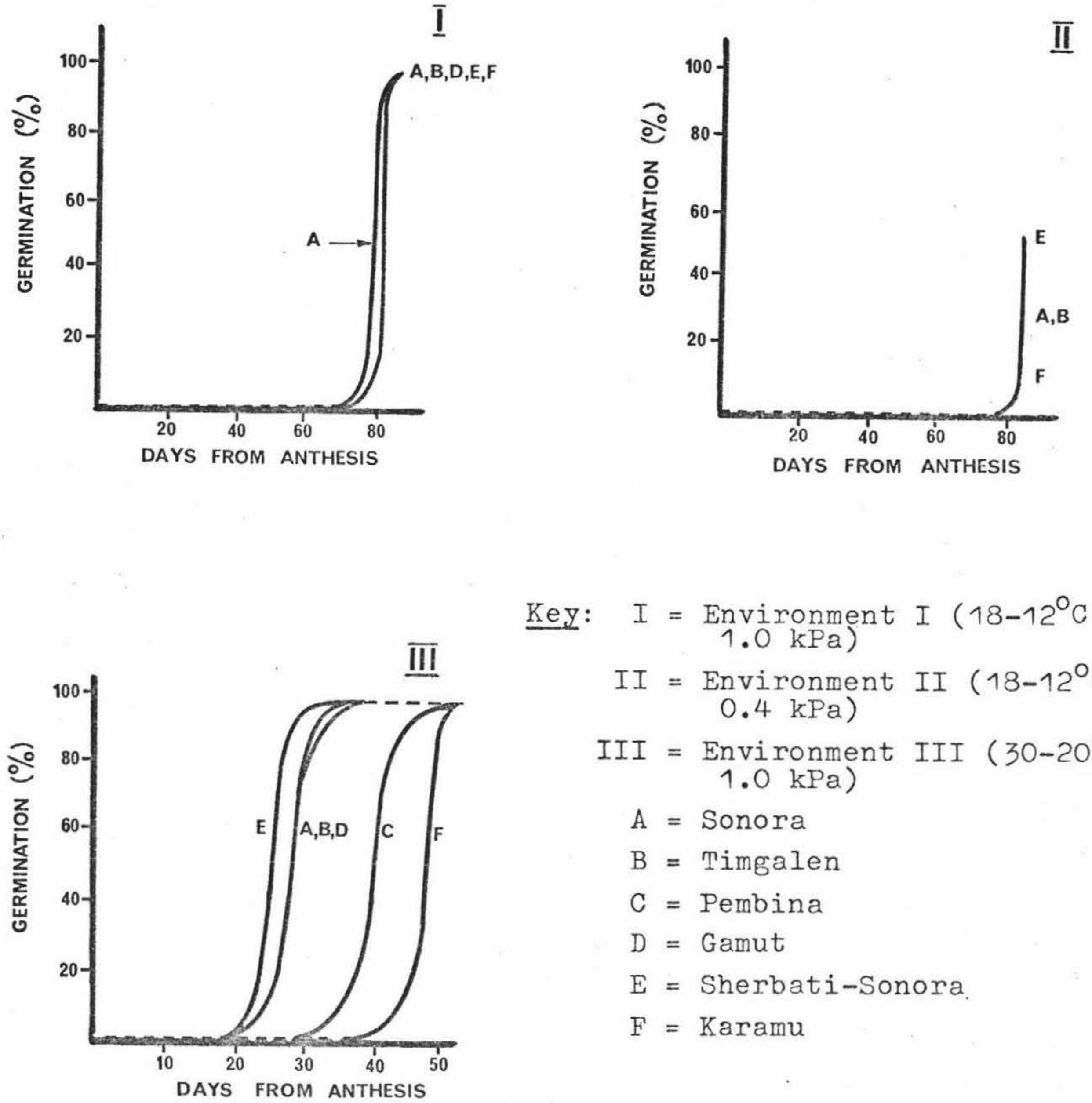
[1] Linear form : ln (flavan-3-ol concentration, %) = $a + b_1x + b_2B^t$, where t = (days from anthesis/7).

failed to germinate; Pembina failed to germinate in both of the cool environments. These two cultivars flowered later than the remaining cultivars. Y-intercepts ($\hat{a}$) for the remaining cultivars were different from one another in both of the cool environments. Marked changes in rank order were observed across these two environments (appendix A5.6). Four cultivars merged in significance in the hot, dry environment (env. III), with Karamu and Sherbati-Sonora being distinct to each other and to the remaining cultivars (appendix A5.6).

Slopes of regression ($\hat{b}_1$ and $\hat{b}_2$) of the various cultivars in the cool environments were similar (figure 4.9, appendix A5.7). Only a few cultivars were distinct in the third (hot, dry) environment (i.e. Karamu and Sherbati-Sonora for $\hat{b}_1$; Karamu, Pembina, Sherbati-Sonora for $\hat{b}_2$).

Regressed estimates of germination at harvest ripeness within each of the three environments are presented in table 4.9. In the cool, dry environment (env. I) Sonora was significantly higher, the remaining cultivars formed an overlapping series of significance groupings (appendix A7.3). Sonora was replaced by Sherbati-Sonora in the cool, moist environment as the only significantly high cultivar (appendix A7.3). In addition to Sherbati-Sonora, Pembina and Karamu were significantly different to each other and to the remaining cultivars in the third (hot, dry) environment (appendix A7.3).

Figure 4.9 Changes in germination during grain development amongst six wheat cultivars superimposed within each of three environments. (Tests of significance amongst cultivars are presented in appendices A5.6 and A5.7).



Key:
I = Environment I (18-12°C ; 1.0 kPa)
II = Environment II (18-12°C; 0.4 kPa)
III = Environment III (30-20°C; 1.0 kPa)
A = Sonora
B = Timgalen
C = Pembina
D = Gamut
E = Sherbati-Sonora
F = Karamu

Figure 4.10 Changes in germination during grain development amongst six wheat cultivars across three environments. (Tests of significance amongst cultivars are presented in appendices A6.6 and A6.7).

Key

I = Environment I (18-12°C; 1.0 kPa)
II = Environment II (18-12°C; 0.4 kPa)
III = Environment III (30-20°C; 1.0 kPa)

A = Sonora
B = Timgalen
C = Pembina
D = Gamut
E = Sherbati-Sonora
F = Karamu

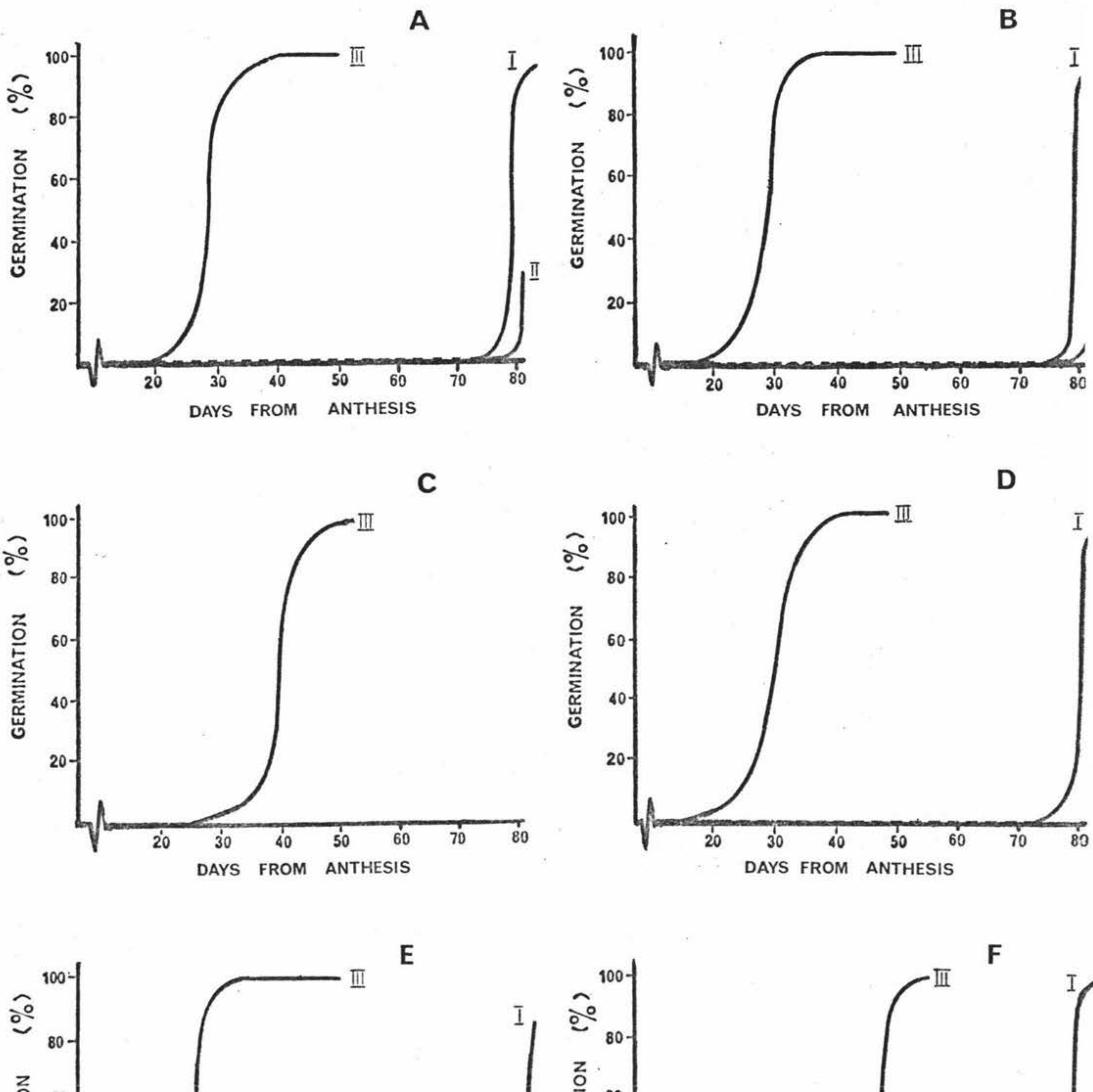

A
B
C
D
E
F
GERMINATION (%)
100
80
60
40
20
DAYS FROM ANTHESIS
20
30
40
50
60
70
80
III
I
II

Table **4.8**

Estimated statistics of final curves[1] in three environments describing changes in germination during grain development amongst six wheat cultivars.

Table **4.8.1** : Environment I (18-12°C; 1.0 kPa).

Statistic	Sonora	Timgalen	Pembina	Gamut	Sherbati Sonora	Karamu
Y-intercept ($\hat{a}$)	-167.0103	169.2811	-	220.6378	-82.3067	-487.4223
s.e. of Y-intercept	6.8247	8.2463	-	7.2479	5.9113	16.7396
$\hat{b}_1$	3.6274	-5.2281	-	-6.5613	1.4645	11.9780
$\hat{b}_2$	-0.0192	0.0336	-	0.0472	-0.0056	-0.0733
s.e. of $\hat{b}_1$	2.7172	3.2832	-	2.8855	2.3534	6.6645
s.e. of $\hat{b}_2$	0.0175	0.0212	-	0.0186	0.0152	0.0430
upper asymptote	100	100	-	100	100	100
R^2	0.8859	0.8828	-	0.9086	0.8980	0.5949
F for regression	34.94••	33.90••	-	44.71••	39.60••	6.61••
s.e. of estimate	1.5175	1.8336	-	1.6116	1.3144	3.7221

Table **4.8.2** : Environment II (18-12°C; 0.4 kPa)

Statistic	Sonora	Timgalen	Pembina	Gamut	Sherbati Sonora	Karamu
Y-intercept ($\hat{a}$)	732.5614	332.2507	-	-	444.2579	603.4395
s.e. of Y-intercept	2.9543	11.8678	-	-	12.3335	0.6289
$\hat{b}_1$	-19.1029	-9.0559	-	-	-11.9494	-15.7673
$\hat{b}_2$	0.1232	0.0605	-	-	0.0791	0.1017
s.e. of $\hat{b}_1$	1.8262	7.3364	-	-	7.6243	0.3889
s.e. of $\hat{b}_2$	0.0114	0.0458	-	-	0.0476	0.0024
upper asymptote	100	100	-	-	100	100
R^2	0.9873	0.7961	-	-	0.8304	0.9991
F for regression	233.27••	11.71••	-	-	14.69••	3504.04••
s.e. of estimate	0.4035	1.6209	-	-	1.6845	0.0859

Table **4.8.3** : Environment III (30-20°C; 1.0 kPa)

Statistic	Sonora	Timgalen	Pembina	Gamut	Sherbati Sonora	Karamu
Y-intercept ($\hat{a}$)	-19.9811	-18.4519	-13.3129	-15.6804	-26.5161	1.5861
s.e. of Y-intercept	0.7386	1.0516	0.6083	1.2525	1.0339	1.6763
$\hat{b}_1$	1.0435	0.9746	0.4130	0.7564	1.6305	-0.7448
$\hat{b}_2$	-0.0100	-0.0095	-0.0019	-0.0062	-0.0194	0.0158
s.e. of $\hat{b}_1$	0.1341	0.1783	0.1031	0.2123	0.1753	0.2841
s.e. of $\hat{b}_2$	0.0020	0.0027	0.0016	0.0032	0.0027	0.0043
upper asymptote	100	100	100	100	100	100
R^2	0.9747	0.9431	0.9680	0.9165	0.9566	0.8245
F for regression	212.30••	99.37••	181.54••	65.86••	132.27••	28.19••
s.e. of estimate	0.9523	1.3100	0.7578	1.5602	1.2879	2.0831

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[1] Linear form : logit (percent germinated caryopses) $= a + b_1t + b_2t^2$ where t = days from anthesis

Table 4.9

Regressed estimates of germination at harvest ripeness within three environments amongst six wheat cultivars.

Cultivar	Environment I Logit	%[1]	Environment II Logit	%	Environment III Logit	%
Sonora	-1.4039	19.8	-6.3715	0.0	5.3712	100
(Std. error)	0.4387		0.1393		0.2519	
Timgalen	-7.1952	0.0	-6.5497	0.0	5.0130	100
(Std. error)	0.7759		0.7564		0.3933	
Pembina	-	-	-	-	-0.1488	46.3
(Std. error)	-		-		0.2291	
Gamut	-3.7340	2.3	-	-	4.3066	98.7
(Std. error)	0.4700		-		0.4701	
Sherbati-Sonora	-3.9068	2.0	-1.6268	16.4	7.4744	100
(Std. error)	0.4128		0.7671		0.3399	
Karamu	-5.2810	0.0	-6.9595	0.0	-2.9777	4.8
(Std. error)	1.5334		0.0287		0.6566	

[1] where % = percent germinated caryopses

4.6 EMBRYO MATURITY

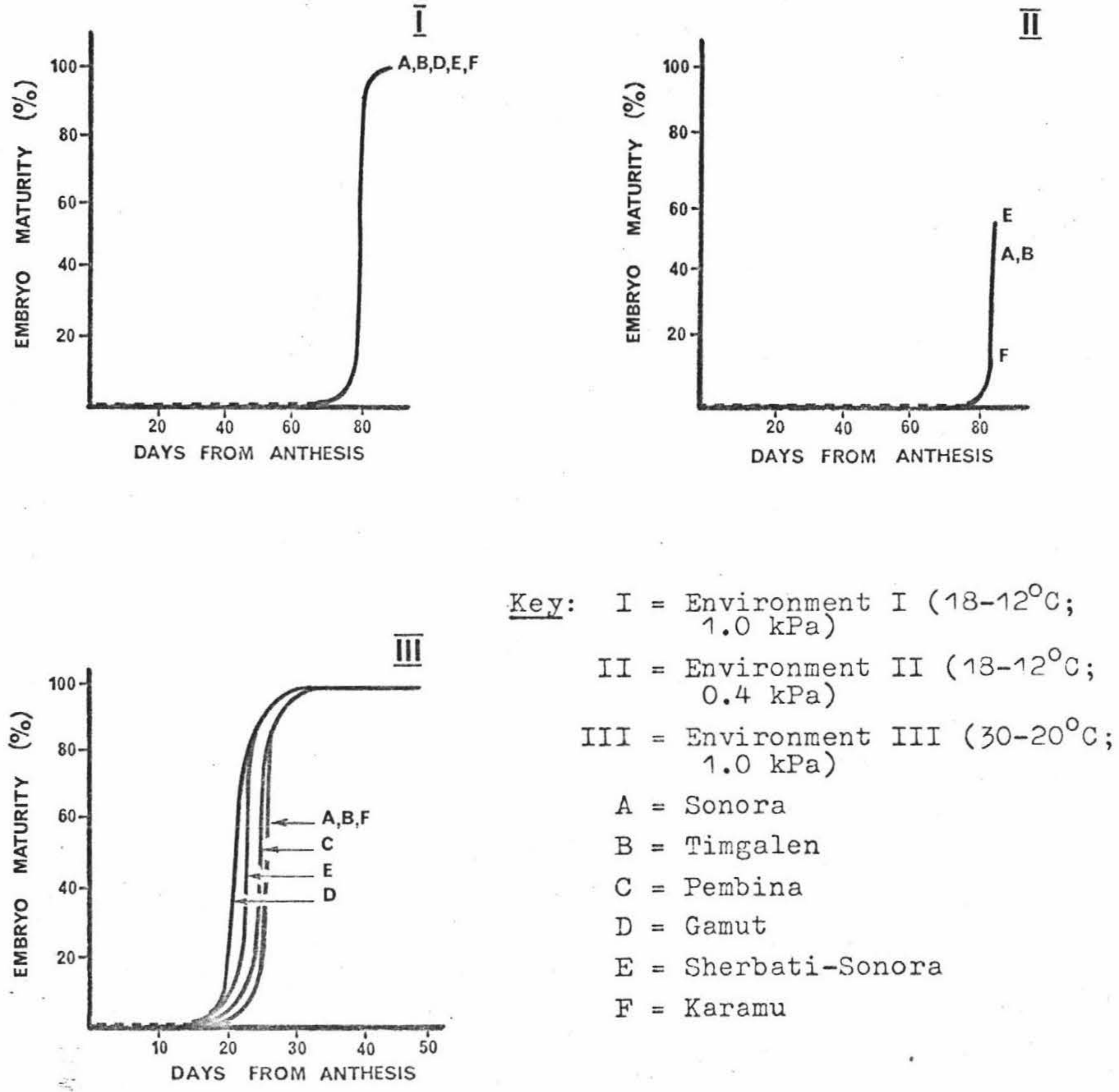
Changes in embryo maturity were described by quadratic logistic curves (table 4.10; figures A1.6.1, A1.6.2, A1.6.3). Cultivar performances within each of the three environments are superimposed in figure 4.11.

In the cool, moist environment (env. III) Gamut embryos failed to reach maturity. Pembina embryos failed to reach maturity in both of the cool environments. All cultivars were significantly distinct (appendix A5.8) in the cool, moist environment (env. II). Sonora and Sherbati-Sonora formed a non-significance grouping in the cool, dry environment (env. I); and all cultivars formed an overlapping series of significance groupings in the third (hot, dry) environment (appendix A5.8). The differences in individual responses for Y-intercept ($\hat{a}$) across environments are presented in figure 4.1 and appendix A6.8.

Little change in rank order was observed for slope (for either $\hat{b}_1$ or $\hat{b}_2$) : Cultivars were either not significantly (appendix A5.9) different amongst one another over the whole cultivar range (env. I), or formed an overlapping series of significance groupings (env's II, III).

Regressed estimates of embryo maturity at harvest ripeness (12½% moisture content) within each of the three environments are presented in table 4.11. In the cool, dry environment significance groupings were (Sonora) (Gamut, Sherbati-Sonora) (Karamu,

Figure 4.11 Changes in embryo maturity during grain development amongst six wheat cultivars within each of three environments. (Tests of significance amongst cultivars are presented in appendices A5.8 and A5.9).



Key: I = Environment I (18-12°C; 1.0 kPa)

II = Environment II (18-12°C; 0.4 kPa)

III = Environment III (30-20°C; 1.0 kPa)

A = Sonora

B = Timgalen

C = Pembina

D = Gamut

E = Sherbati-Sonora

F = Karamu

<u>Figure 4.12</u> Changes in embryo maturity during grain development amongst six wheat cultivars across three environments. (Tests of significance amongst cultivars are presented in appendices A6.8 and A6.9).

<u>Key</u> :

I = Environment I (18-12°C; 1.0 kPa)
II = Environment II (18-12°C; 0.4 kPa)
III = Environment III (30-20°C; 1.0 kPa)

A = Sonora
B = Timgalen
C = Pembina
D = Gamut
E = Sherbati-Sonora
F = Karamu

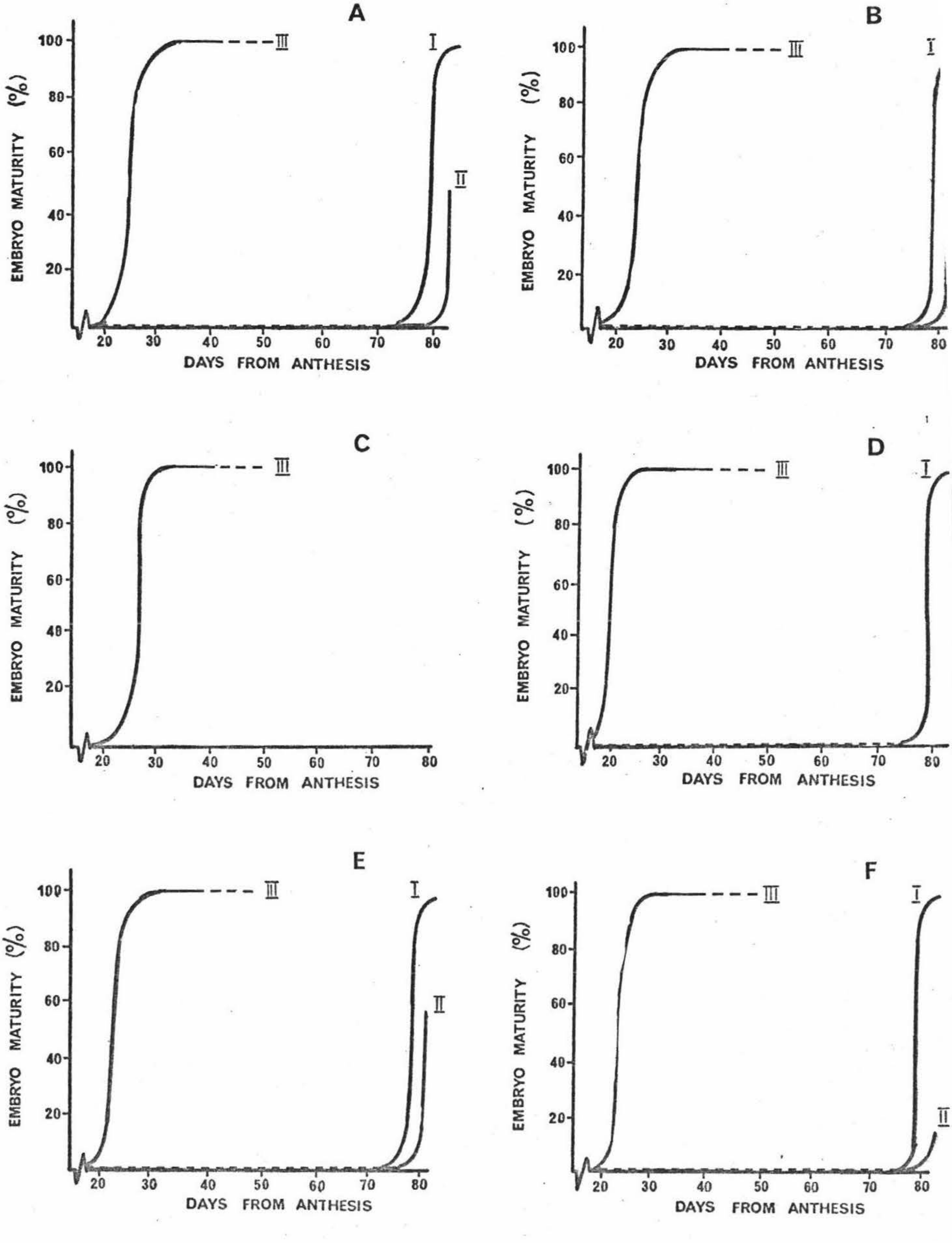

A
B
C
D
E
F
EMBRYO MATURITY (%)
100
80
60
40
20
DAYS FROM ANTHESIS
20
30
40
50
60
70
80
I
II
III

Table **4.10**

Estimated statistics of final curves[1] in three environments describing changes in embryo maturity during grain development amongst six wheat cultivars.

Table **4.10.1** : Environment I (18-12°C; 1.0 kPa).

Statistic	Sonora	Timgalen	Pembina	Gamut	Sherbati Sonora	Karamu
Y-intercept ($\hat{a}$)	-91.2406	192.9750	-	160.5395	-119.6307	122.6840
s.e. of Y-intercept	8.5063	8.8395	-	9.1728	10.0418	7.9963
$\hat{b}_1$	1.4720	-5.9555	-	-5.1380	2.2574	-4.1755
$\hat{b}_2$	-0.0038	0.0442	-	0.0391	-0.0093	0.0331
s.e. of $\hat{b}_1$	3.3866	3.5179	-	3.6520	3.9996	3.1836
s.e. of $\hat{b}_2$	0.0218	0.0227	-	0.0236	0.0258	0.0205
upper asymptote	100	100	-	100	100	100
R^2	0.8999	0.8999	-	0.8980	0.8501	0.9258
F for regression	40.44**	40.47**	-	39.63**	25.52**	56.12**
s.e. of estimate	1.8914	1.9647	-	2.0396	2.2338	1.7780

Table **4.10.2** : Environment II (18-12°C; 0.4 kPa)

Statistic	Sonora	Timgalen	Pembina	Gamut	Sherbati Sonora	Karamu
Y-intercept ($\hat{a}$)	796.0401	328.2123	-	-	452.8009	627.6850
s.e. of Y-intercept	2.3510	14.4151	-	-	12.2136	0.8501
$\hat{b}_1$	-20.7423	-9.0203	-	-	-12.1701	-16.3936
$\hat{b}_2$	0.1338	0.0607	-	-	0.0805	0.1058
s.e. of $\hat{b}_1$	1.4535	8.9110	-	-	7.5535	0.5254
s.e. of $\hat{b}_2$	0.0091	0.0557	-	-	0.0472	0.0033
upper asymptote	100	100	-	-	100	100
R^2	0.9931	0.7661	-	-	0.8360	0.9986
F for regression	434.14**	9.82**	-	-	15.29**	2075.23**
s.e. of estimate	0.3211	1.9688	-	-	1.6688	0.1161

Table **4.10.3** : Environment III (30-20°C; 1.0 kPa)

Statistic	Sonora	Timgalen	Pembina	Gamut	Sherbati Sonora	Karamu
Y-intercept ($\hat{a}$)	-24.4922	-23.3877	-20.4834	-26.0371	-28.8884	-31.8062
s.e. of Y-intercept	0.9767	1.1585	1.3884	1.2708	0.8044	1.5534
$\hat{b}_1$	1.4645	1.3859	0.9467	1.6392	1.8397	1.9697
$\hat{b}_2$	-0.0168	-0.0158	-0.0080	-0.0198	-0.0227	-0.0245
s.e. of $\hat{b}_1$	0.1774	0.1964	0.2353	0.2154	0.1364	0.2633
s.e. of $\hat{b}_2$	0.0027	0.0030	0.0036	0.0033	0.0021	0.0040
upper asymptote	100	100	100	100	100	100
R^2	0.9572	0.9396	0.9295	0.9316	0.9745	0.9186
F for regression	123.00**	93.35**	79.07**	81.76**	229.27**	67.72**
s.e. of estimate	1.2592	1.4432	1.7295	1.5830	1.0020	1.9351

---

[1] Linear form : logit (percent embryo mature caryopses) = $a + b_1 t + b_2 t^2$ where t = days from anthesis

Table 4.11

Regressed estimates of embryo maturity at harvest ripeness (12½% moisture content) within three environments amongst six wheat cultivars.

Cultivar	Environment I		Environment II		Environment III	
	logit	%	logit	%	logit	%
Sonora	-0.2496	43.8	-6.1703	0.0	6.9893	100
(std. error)	0.5468		0.1109		0.3331	
Timgalen	-6.8818	0.0	-6.7273	0.0	6.5667	100
(std. error)	0.8314		0.9188		0.4333	
Pembina	-	-	-	-	4.2050	98.5
(std. error)	-		-		0.5229	
Gamut	-2.0481	11.4	-	-	7.7457	100
(std. error)	0.5948		-		0.4769	
Sherbati-Sonora	-2.5521	7.2	-1.7471	14.9	8.2737	100
(std. error)	0.7016		0.7600		0.2644	
Karamu	-6.4784	0.0	-6.5719	0.0	7.7806	100
(std. error)	0.7325		0.0387		0.6085	

where % = percent embryo mature caryopses.

Table 4.12

Regressed estimates at time (days from anthesis) of 50% embryo maturity (M50) amongst six wheat cultivars within three environments.

Cultivar	Environment I		Environment II		Environment III	
	M50	Std. Error	M50	Std. Error	M50	Std. Error
Sonora	77.5	0.5	85.2	0.3	22.6	0.4
Timgalen	80.5	0.6	85.0	0.7	22.8	0.4
Pembina	n.d.[1]	n.d.	n.d.	n.d.	28.5	0.5
Gamut	80.2	0.6	n.d.	n.d.	21.4	0.5
Sherbati-Sonora	78.2	0.7	85.0	0.4	21.3	0.3
Karamu	79.6	0.5	85.8	0.3	22.4	0.6

[1] n.d. = no data, due to persisting full immaturity

Timgalen). In the cool, moist environment only Sherbati-Sonora was distinctly different from the remaining cultivars (appendix A7.4). All cultivars, with the exception of Pembina, formed an overlapping series of significance in the third environment (appendix A7.4).

Regressed estimates of time (days from anthesis) to reach 50% embryo maturity (M50) amongst six wheat cultivars within three environments are presented in table 4.12. Average number of days to reach 50% embryo maturity (M50) were 79.2 ± 1.3, 85.3 ± 0.4 and 23.2 ± 2.7 days respectively, and were significantly different to each other ($P < 0.01$).

4.7 EMBRYO "DORMANCY"

Changes in embryo "dormancy" were described by quadratic logistic curves (table 4.13; figures A1.7.1, A1.7.2, A1.7.3). Cultivar performances within each of the three environments are superimposed in figure 4.1 The "dormancy" statistic actually measures germination impedence relative to embryo maturity. It indicates dormancy as the embryos become mature; otherwise it represents embryo immaturity (Gordon, 1975). In the cool, moist environment, Gamut failed to reach embryo maturity within the time limits of the experiment so that no "dormancy" curves were available. Similarly, Pembina embryos failed to mature in both of the cool environments.

All cultivars were distinct in the cool, dry environment (env. I). Rank order significantly changed in environment II : Sherbati-Sonora and

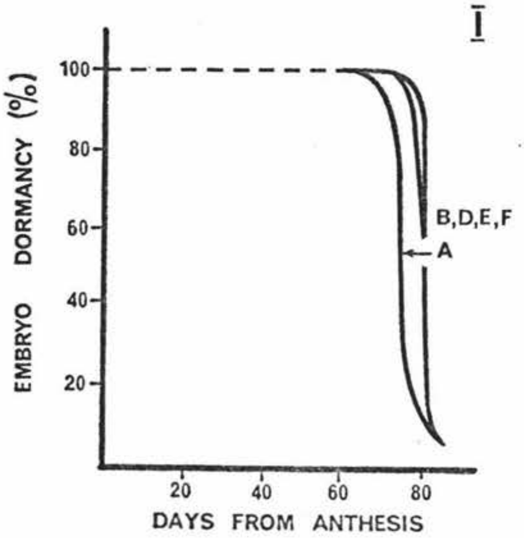
Timgalen remaining significantly different from each other and the remaining cultivars which formed their own non-significance grouping (appendix A5.10). Karamu was the only significantly different cultivar for $\hat{a}$ in the third environment (appendix A5.10).

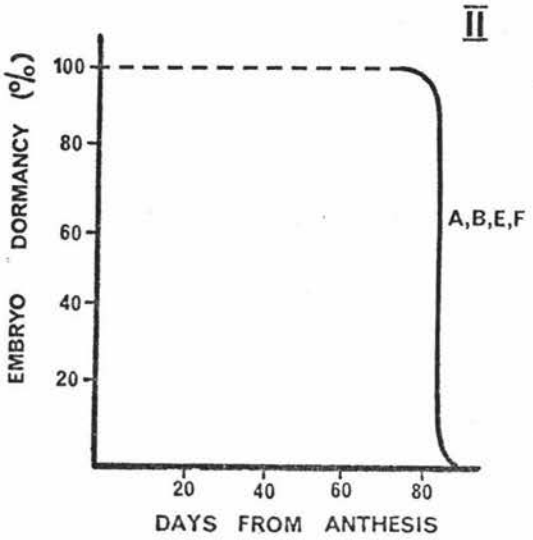
Cultivar estimates for slope of regression in the cool environments were similar for both the $\hat{b}_1$ and $\hat{b}_2$ statistics (appendix A6.11). In the third (hot, dry) environment Karamu was the only significantly different cultivar, and was so for both $\hat{b}_1$ and $\hat{b}_2$.

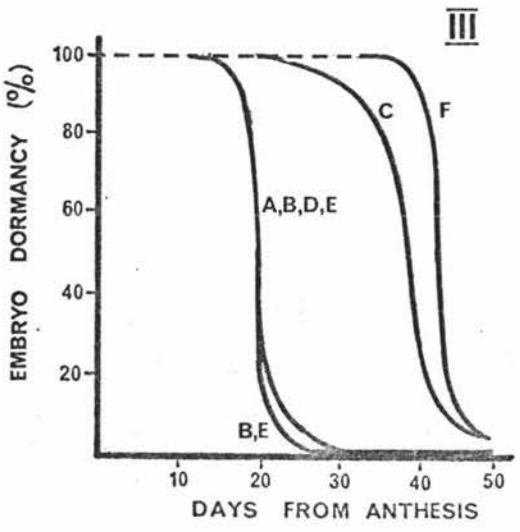
Regressed estimates of embryo "dormancy at harvest ripeness within each of the three environments are presented in table 4.14 and significance testing for differences presented in appendix A7.5. In the cool, dry environment Sonora was significantly higher from the remaining cultivars which formed an overlapping series of significance groupings. In the cool moist environment, all cultivars formed a complete merge of significance groupings.

Regressed estimates of time (days from anthesis) at which 50% "dormancy" (D50) occurred are presented in table 4.15 . Average days to reach 50% impedence to germination ("dormancy") were 80.1 ± 1.3 and 83.1 ± 0.9 days for the two cool environments (I and II) respectively, and were non significantly different ($P < 0.05$). Average days to reach 50% impedence to germination for the non-dormant cultivars in the third

Figure 4.13 Changes in embryo "dormancy" during grain development amongst six wheat cultivars within each of three environments. (Tests of significance amongst cultivars are presented in appendices A.10 and A.11).







Key: I = Environment I (18-12°C; 1.0 kPa)
II = Environment II (18-12°C; 0.4 kPa)
III = Environment III (30-20°C; 1.0 kPa)
A = Sonora
B = Timgalen
C = Pembina
D = Gamut
E = Sherbati-Sonora
F = Karamu

Figure 4.14 Changes in embryo "dormancy" during grain development amongst six wheat cultivars across three environments. (Tests of significance amongst cultivars are presented in appendices A6.10 and A6.11).

Key :

I = Environment I (18-12°C; 1.0 kPa)
II = Environment II (18-12°C; 0.4 kPa)
III = Environment III (30-20°C; 1.0 kPa)

A = Sonora
B = Timgalen
C = Pembina
D = Gamut
E = Sherbati-Sonora
F = Karamu

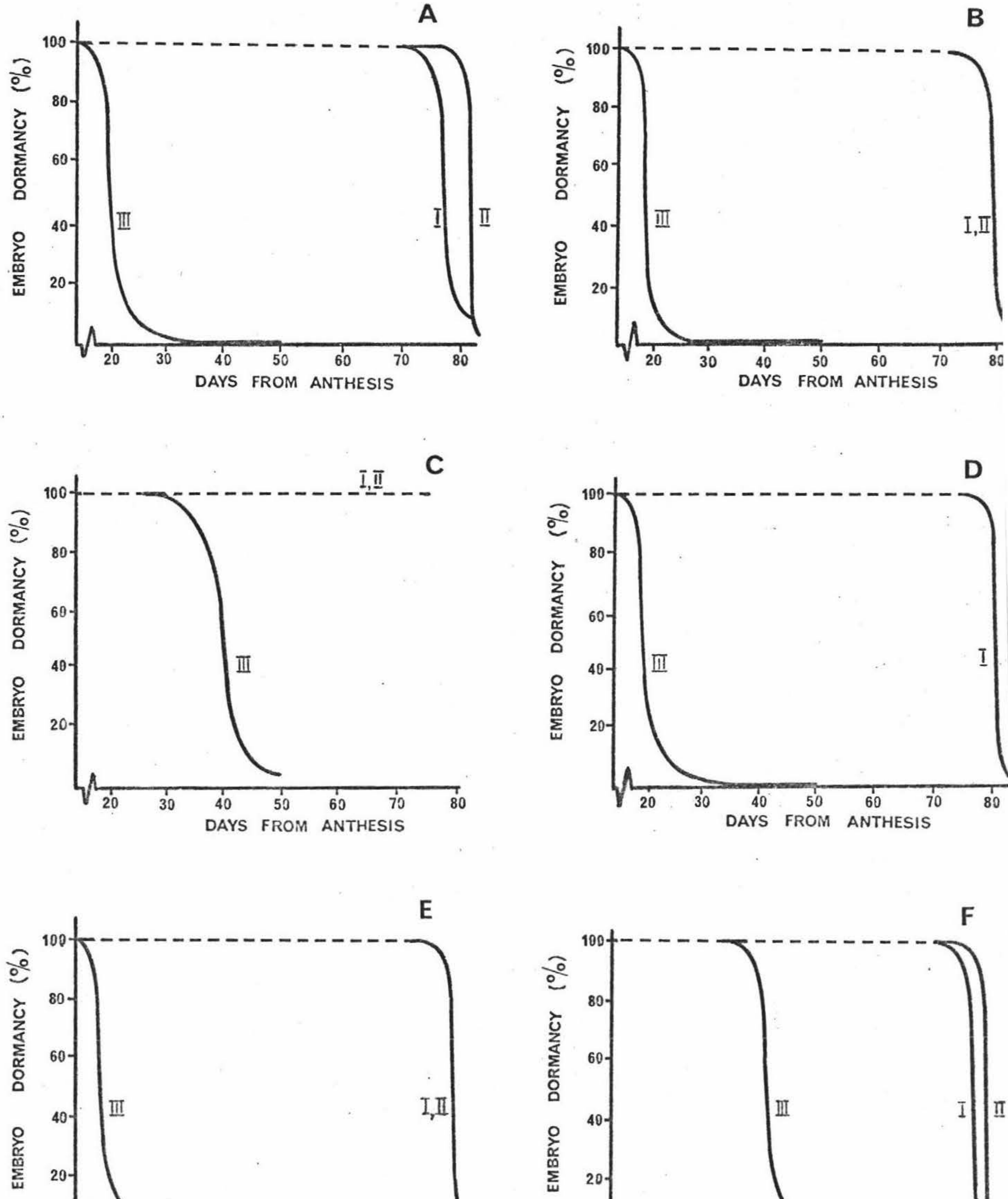

A
B
C
D
E
F
EMBRYO DORMANCY (%)
100
80
60
40
20
DAYS FROM ANTHESIS
20
30
40
50
60
70
80
III
I
II
I,II

Table **4.13**

Estimated statistics of final curves[1] in three environments describing changes in embryo dormancy during grain development amongst six wheat cultivars.

Table **4.13.1** : Environment I (18-12°C; 1.0 kPa)

Statistic	Sonora	Timgalen	Pembina	Gamut	Sherbati Sonora	Karamu
Y-intercept ($\hat{a}$)	233.1356	-140.5017	-	-221.8935	105.5366	42.2090
s.e. of Y-intercept	7.6347	8.6574	-	7.1180	7.0707	18.0955
$\hat{b}_1$	-5.3429	4.5076	-	6.6150	-2.0532	-0.2755
$\hat{b}_2$	0.0302	-0.0342	-	-0.0477	0.0092	-0.0033
s.e. of $\hat{b}_1$	3.0396	3.4468	-	2.8339	2.8151	7.2044
s.e. of $\hat{b}_2$	0.0196	0.0222	-	0.0183	0.0182	0.0465
upper asymptote	100	100	-	100	100	100
R^2	0.8630	0.8800	-	0.9163	0.8690	0.6156
F for regression	29.58**	32.98**	-	49.28**	29.86**	7.21**
s.e. of estimate	1.6976	1.9250	-	1.5827	1.5722	4.0236

Table **4.13.2** : Environment II (18-12°C; 0.4 kPa)

Statistic	Sonora	Timgalen	Pembina	Gamut	Sherbati Sonora	Karamu
Y-intercept ($\hat{a}$)	-1365.4487	-585.5577	-	-	-278.1329	-1390.6651
s.e. of Y-intercept	17.4053	22.9354	-	-	35.8210	15.8670
$\hat{b}_1$	35.4525	15.7117	-	-	8.2269	36.1039
$\hat{b}_2$	-0.2287	-0.1042	-	-	-0.0590	-0.2329
s.e. of $\hat{b}_1$	10.7599	14.1783	-	-	22.1442	9.3087
s.e. of $\hat{b}_2$	0.0672	0.0886	-	-	0.1384	0.0613
upper asymptote	100	100	-	-	100	100
R^2	0.8352	0.7183	-	-	0.6116	0.9059
F for regression	23.14**	7.65**	-	-	4.72*	28.88**
s.e. of estimate	2.3772	3.1325	-	-	4.8924	2.1671

Table **4.13.3** : Environment III (30-20°C; 1.0 kPa)

Statistic	Sonora	Timgalen	Pembina	Gamut	Sherbati Sonora	Karamu
Y-intercept ($\hat{a}$)	19.6912	20.1129	12.9026	16.5775	24.6476	-2.3232
s.e. of Y-intercept	1.1152	2.5474	0.7422	2.4715	1.3950	2.5590
$\hat{b}_1$	-1.0786	-1.2579	-0.3759	-0.9269	-1.6238	0.7038
$\hat{b}_2$	0.0109	0.0146	0.0011	0.0093	0.0201	-0.0150
s.e. of $\hat{b}_1$	0.2025	0.4318	0.1258	0.4189	0.3725	0.4338
s.e. of $\hat{b}_2$	0.0031	0.0066	0.0019	0.0064	0.0057	0.0066
upper asymptote	100	100	100	100	100	100
R^2	0.9339	0.7054	0.9572	0.7151	0.7959	0.6476
F for regression	84.56**	14.37**	134.34**	15.06**	23.39**	11.03**
s.e. of estimate	1.4378	3.1733	0.9246	3.0787	2.7377	3.1877

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[1] Linear form : logit (percent embryo dormant caryopses) = $a + b_1t + b_2t^2$ where t = days from anthesis

Table 4.14

Regressed estimates of embryo "dormancy" at harvest ripeness ($12\frac{1}{2}$% moisture content) within three environments amongst six wheat cultivars.

	logit	%[1]	logit	%	logit	%
Sonora	immature		immature		-5.6784	0.0
std. error					0.3803	
Timgalen	immature		immature		-6.6886	0.0
std. error					0.9528	
Pembina	-[2]		-		-0.0263	49.3
std. error	-		-		0.2795	
Gamut	immature		-		-5.3650	0.0
std. error			-		0.9275	
Sherbati-Sonora	immature		immature		-8.0595	0.0
std. error					0.7224	
Karamu	immature		immature		1.8783	86.8
std. error					1.0023	

[1] where % = percent embryo "dormant" caryopses

[2] "-" means no regressed estimate was possible because of lack of change

Table 4.15

Regressed estimates at time (days from anthesis) of 50% embryo "dormancy" (D50) amongst six wheat cultivars within three environments.

Cultivar	Environment I		Environment II		Environment III	
	D50	Std. Error	D50	Std. Error	D50	Std. Error
Sonora	78.3	0.5	83.6	1.1	24.2	0.4
Timgalen	81.2	0.7	83.4	1.4	21.2	1.0
Pembina	n.d.[1]	n.d.	n.d.	n.d.	38.7	0.3
Gamut	81.8	0.6	n.d.	n.d.	23.4	0.9
Sherbati-Sonora	80.3	0.5	81.8	1.5	20.3	0.9
Karamu	78.8	1.2	83.6	1.0	43.3	1.1

[1] n.d. = no data

environment (Sonora, Timgalen, Gamut, Sherbati-Sonora : section 5.4.4) were 23.3 ±2.2 days, and 38.7 ± 0.3 and 43.3 ± 1.1 days for Pembina and Karamu respectively.

4.8 BASAL ALPHA-AMYLASE CONCENTRATION

Changes in basal alpha amylase levels were described by Makeham curves (table 4.15; figures A1.8.1, A1.8.2, A1.8.3). Cultivar performances within each of the three environments are superimposed in figure 4.16.

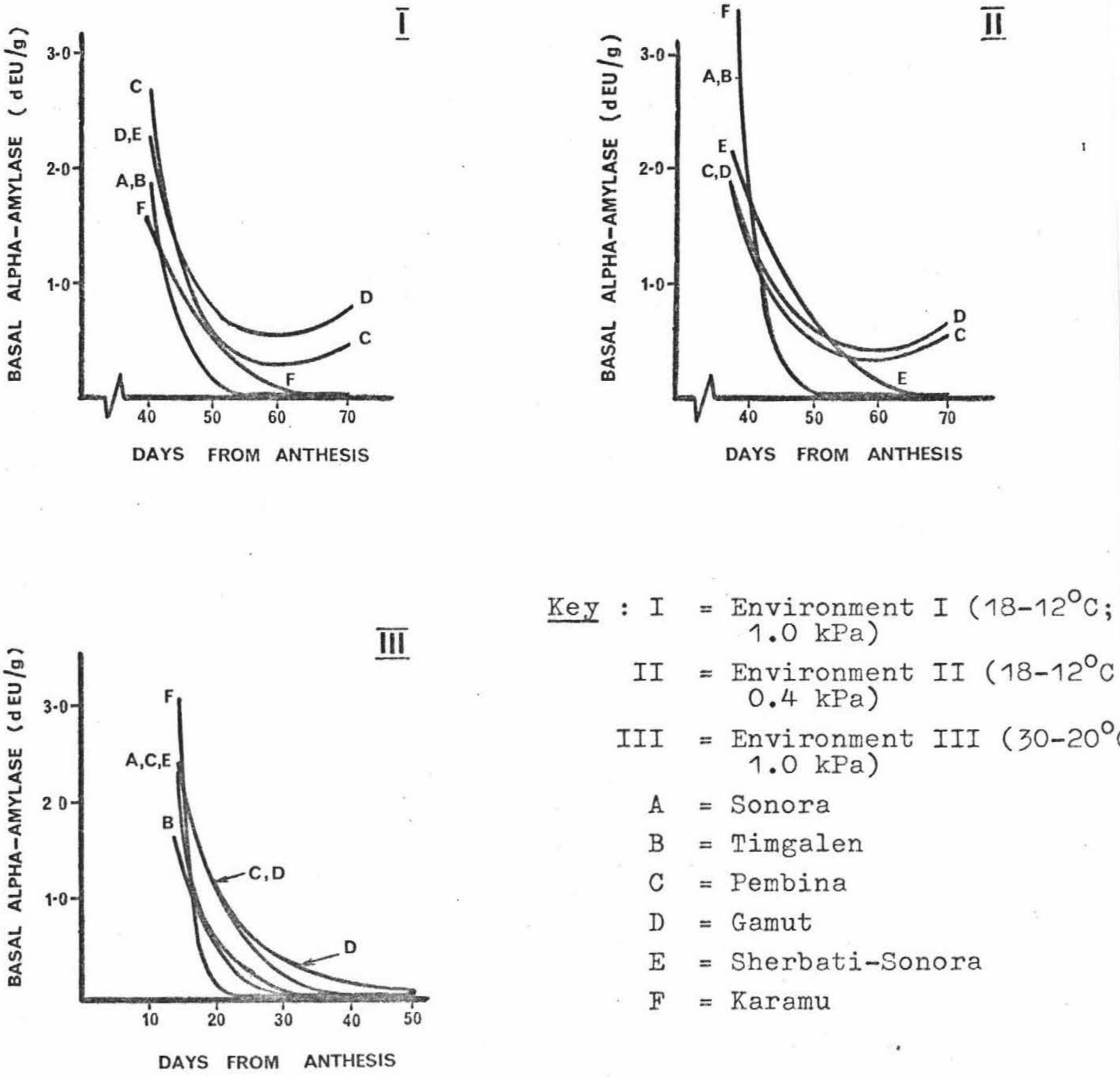
In nearly all environments, there were clear separations for upper asymptotes amongst all cultivars, and marked changes in rank order across environments (appendix A5.12). The only exception was in the hot, dry environment (env. III) where Timgalen and Gamut overlapped each other in significant groupings (appendix A5.12).

In the cool, moist environment (env. II) both $\hat{b}_1$ and $\hat{b}_2$ amongst all cultivars were similar, with the exception of Sherbati-Sonora, which remained distinct for both $\hat{b}_1$ and $\hat{b}_2$ (appendix A5.13). However, in the cool dry environment (env. I) and in the hot, dry environment (env. II) the only significantly different cultivar was Karamu, and it was so for both $\hat{b}_1$ and $\hat{b}_2$.

Minima basal alpha-amylase levels usually reached and stabilised at an extremely low level, with only two apparent exceptions : Gamut and Pembina in the cool environments (figure A1.8.1, A1.8.2, A1.8.3).

Regressed estimates of alpha-amylase levels at

Figure 4.15 Changes in basal alpha-amylase activity during grain development amongst six wheat cultivars superimposed within each of three environments. (Tests of significance amongst cultivars are presented in appendices A5.12 and A5.13).



Key : I = Environment I (18-12°C;
1.0 kPa)
II = Environment II (18-12°C
0.4 kPa)
III = Environment III (30-20°
1.0 kPa)
A = Sonora
B = Timgalen
C = Pembina
D = Gamut
E = Sherbati-Sonora
F = Karamu

Figure 4.16 Changes in basal alpha-amylase activity during grain development amongst six wheat cultivars across three environments. (Tests of significance amongst cultivars are presented in appendices A6.12 and A6.13).

Key :

I = Environment I (18-12°C; 1.0 kPa)
II = Environment II (18-12°C; 0.4 kPa)
III = Environment III (30-20°C; 1.0 kPa)

A = Sonora
B = Timgalen
C = Pembina
D = Gamut
E = Sherbati-Sonora
F = Karamu

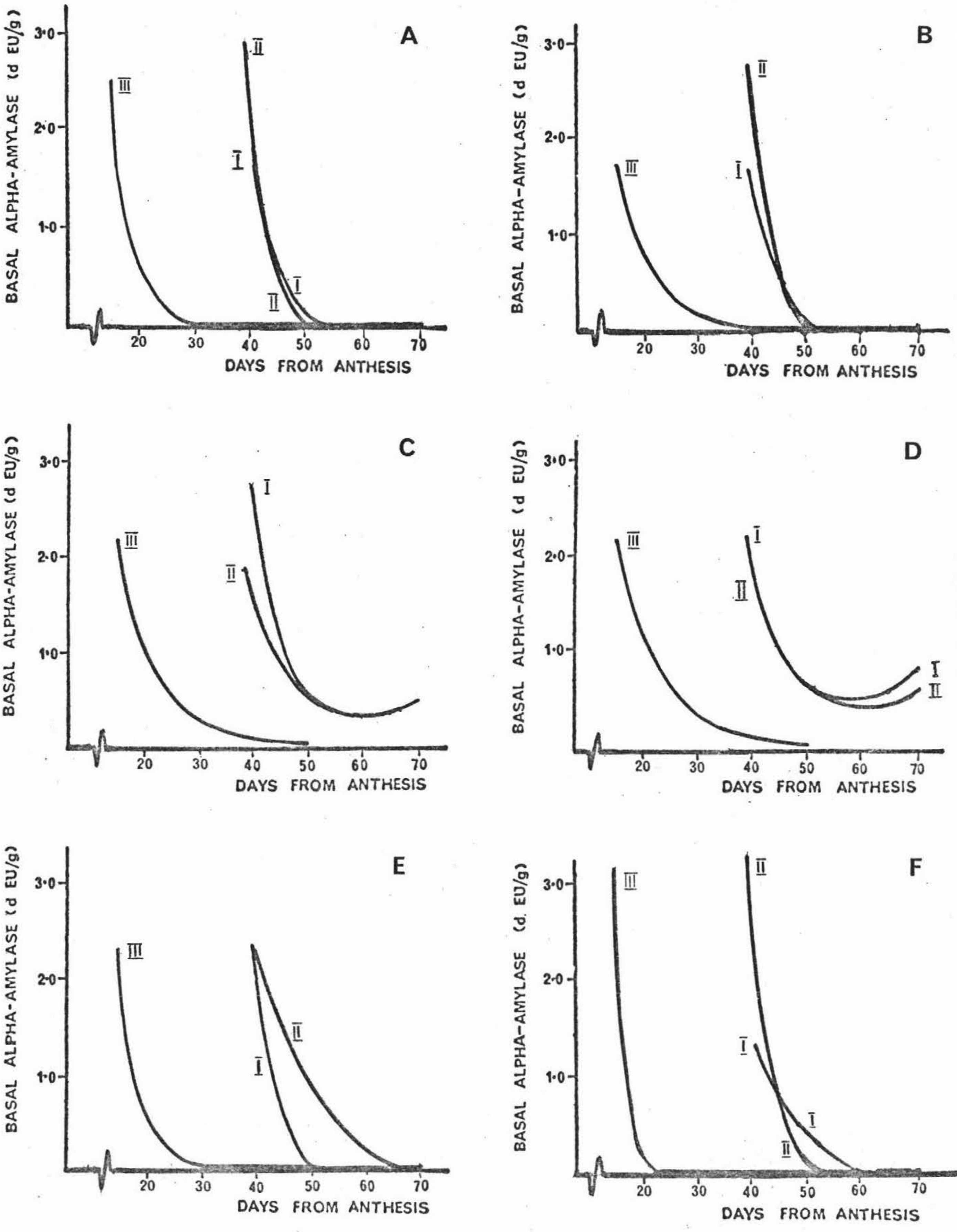

A
B
C
D
E
F
BASAL ALPHA-AMYLASE (d EU/g)
3·0
2·0
1·0
20
30
40
50
60
70
DAYS FROM ANTHESIS
I
II
III

Table 4.16

Estimated statistics of final curves[1] within three environments describing changes in basal alpha-amylase activity during grain development amongst six wheat genotypes.

Table 4.16.1 : Environment I (18-12°C; 1.0 kPa).

Statistic	Sonora	Timgalen	Pembina	Gamut	Sherbati Sonora	Karamu
Y-intercept ($\hat{a}$)	-115.5641	-62.7932	-45.9054	-43.2413	-94.7637	310.6512
s.e. of Y-intercept	3.5064	1.8179	1.3556	1.2276	1.6539	2.0590
$\hat{b}_1$	-10.0000	-10.6280	-7.3739	-6.3034	-14.8591	18.7616
$\hat{b}_2$	133.1474	34.4327	60.6400	60.9224	123.5563	-321.9383
s.e. of $\hat{b}_1$	5.3994	2.6016	1.9401	1.7746	2.3756	3.1735
s.e. of $\hat{b}_2$	91.2063	22.6931	16.9231	16.4306	21.2157	49.9021
$\hat{B}$	1.0473	1.0697	1.0697	1.0663	1.0636	1.0465
R^2	0.8394	0.8902	0.7939	0.6994	0.9281	0.9323
F for regression	31.13**	43.64**	21.77**	13.96**	77.39**	333.82**
s.e. of estimate	0.9931	0.6240	0.4653	0.4035	0.5611	0.5141

Table 4.16.2 : Environment II (18-12°C; 0.4 kPa)

Statistic	Sonora	Timgalen	Pembina	Gamut	Sherbati Sonora	Karamu
Y-intercept ($\hat{a}$)	-118.9388	-86.8835	-46.2588	-39.5102	318.5932	-136.0388
s.e. of Y-intercept	3.3046	2.4553	1.1919	0.7558	3.9730	2.8856
$\hat{b}_1$	-17.7399	-13.6525	-6.7074	-5.5953	30.0338	-22.2434
$\hat{b}_2$	152.0392	113.2247	58.5730	49.6968	-353.1869	180.3736
s.e. of $\hat{b}_1$	4.7599	3.5257	1.7185	1.0917	5.8965	4.1361
s.e. of $\hat{b}_2$	43.1581	31.4196	15.7175	10.0945	65.3179	36.4661
$\hat{B}$	1.0679	1.0687	1.0675	1.0670	1.0591	1.0692
R^2	0.7687	0.8328	0.7447	0.8138	0.9026	0.9227
F for regression	19.94**	29.89**	17.50**	26.23**	55.60**	71.58**
s.e. of estimate	1.1131	0.8339	0.3996	0.2520	1.2051	0.9851

Table 4.16.3 : Environment III (30-20°C; 1.0 kPa)

Statistic	Sonora	Timgalen	Pembina	Gamut	Sherbati Sonora	Karamu
Y-intercept ($\hat{a}$)	-103.1116	-21.1737	-61.9191	-21.5855	-81.9723	-456.7527
s.e. of Y-intercept	1.6743	1.0389	1.4122	0.4040	0.7144	5.8760
$\hat{b}_1$	-8.7253	-2.9362	-5.3347	-2.6372	-8.2723	-35.1082
$\hat{b}_2$	109.0007	24.4313	65.8339	24.5301	88.0521	472.9835
s.e. of $\hat{b}_1$	2.3435	1.4384	1.9750	0.5607	0.9915	8.2161
s.e. of $\hat{b}_2$	32.6870	16.8393	27.3702	6.7975	12.0214	113.1281
$\hat{B}$	1.0569	1.0229	1.0572	1.0637	1.0637	1.0575
R^2	0.9056	0.9386	0.8449	0.9825	0.9312	0.6623
F for regression	57.53**	91.65**	32.69**	335.98**	313.87**	11.77**
s.e. of estimate	0.6368	0.4481	0.5394	0.1700	0.3006	2.2553

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[1] Linear form : ln (basal alpha-amylase activity, dEU/g) = $a + b_1x + b_2B^x$, where x = (days from anthesis/7).

Table 4.17

Regressed estimates of basal alpha-amylase levels at harvest ripeness (12½% moisture content) within three environments amongst six wheat cultivars.

	Environment I		Environment II		Environment III	
Cultivar	Y[1]	std. error	Y	std. error	Y	std. error
Sonora	0.0152	0.4874	1.7800	0.4502	0.0361	0.1905
Timgalen	0.0361	0.2702	0.1879	0.4366	0.000	0.1345
Pembina	0.3378	0.1445	0.8762	0.2042	0.1525	0.1630
Gamut	2.7927	0.2337	2.8057	0.1600	0.1914	0.0512
Sherbati-Sonora	0.0956	0.2833	0.0000	0.8344	0.0000	0.0893
Karamu	0.0062	0.2256	0.0342	0.6040	0.0002	0.7091

[1] Y = alpha-amylase activity (d EU/g).

harvest ripeness (12½% moisture content) within each environment are presented in table 4.17 Significance testing for differences amongst these estimates (appendix A7.6) showed either non-significant differences amongst cultivars or overlapping series of significance groupings in all three environments. The only exception was Gamut, which had a significantly high level, but in environment I only.

Average levels of basal alpha-amylase at harvest ripeness were estimated as 0.5473 ± 1.1, 0.9473 ± 1.1 and 0.0634 ± 0.1 d EU/g for environments I, II and III respectively, which were non-significantly different ($P < 0.05$).

4.9 ALPHA-AMYLASE RESPONSE

Changes in alpha-amylase response were described by third degree polynomials (table 4.18, figures A1.9.1, A1.9.2, A1.9.3). Cultivar performances within each of the three environments are superimposed in figure 4.17.

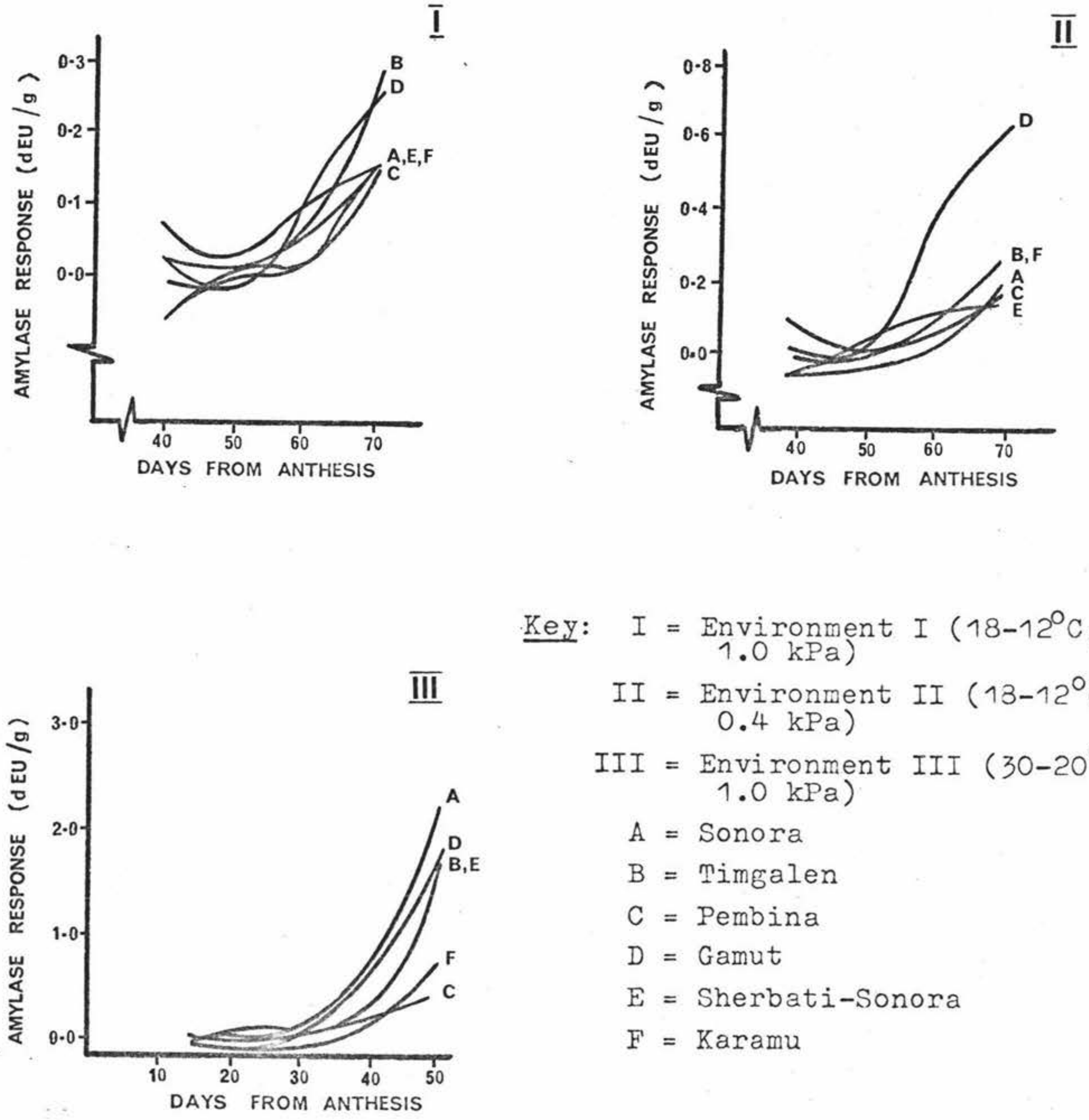
In nearly all comparisons, there were clear separations and marked changes in rank order for the upper asymptote amongst all cultivars in all three environments (appendix A5.14). The only exception was the grouping together of Pembina, Sonora and Karamu in environment III (appendix A5.14).

There was no clear significance separation amongst the regression coefficients in any of the three environments tested. The only possible exception was Sonora.

Regressed estimates of alpha-amylase response at harvest ripeness ($12\frac{1}{2}\%$ moisture content) are presented in table 4.19. Significance testing (appendix A7.7) yielded the following groupings, in order of high to low alpha-amylase response within each environment : (1) environment I (cool, dry) : (Gamut) (Timgalen, Pembina) (Karamu) (Sherbati-Sonora) (Sonora); (2) environment II (cool, moist) : (Karamu) (Gamut, Sonora, Sherbati-Sonora, Timgalen, Pembina); and (3) environment III (hot, dry) : (Timgalen, Sonora, Gamut, Sherbati-Sonora) (Pembina, Karamu).

Average levels of alpha-amylase response at harvest ripeness were 0.3827 ± 0.1833, 0.5210 ± 0.2718 and 0.4164 ± 0.2664 dEU/g for environments I, II and III respectively, and were non-significantly different ($P < 0.05$).

Figure 4.17 Changes in alpha-amylase response during grain development amongst six wheat cultivars superimposed within each of three environments. (Tests of significance amongst cultivars are presented in appendices A5.14 and A5.15).



Key: I = Environment I (18-12°C; 1.0 kPa)

II = Environment II (18-12°C; 0.4 kPa)

III = Environment III (30-20°C; 1.0 kPa)

A = Sonora

B = Timgalen

C = Pembina

D = Gamut

E = Sherbati-Sonora

F = Karamu

Figure 4.18 Changes in alpha-amylase response during grain development amongst six wheat cultivars across three environments. (Tests of significance amongst cultivars are presented in appendices A6.14 and A6.15).

Key :

I = Environment I (18-12^{o}C; 1.0 kPa)
II = Environment II (18-12^{o}C; 0.4 kPa)
III = Environment III (30-20^{o}C; 1.0 kPa)

A = Sonora
B = Timgalen
C = Pembina
D = Gamut
E = Sherbati-Sonora
F = Karamu

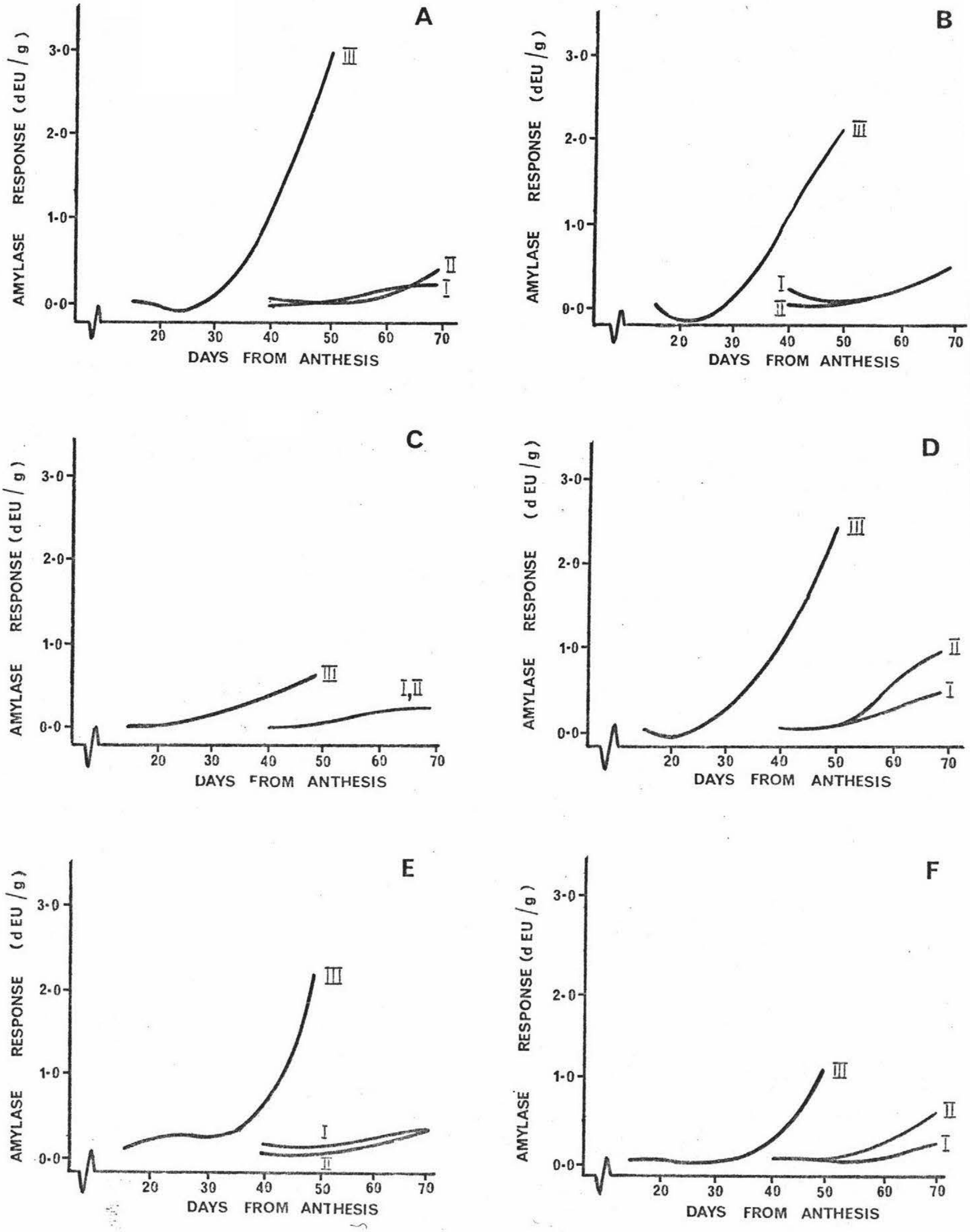

A
AMYLASE RESPONSE (dEU/g)
3·0
2·0
1·0
0·0
III
II
I
20
30
40
50
60
70
DAYS FROM ANTHESIS
B
AMYLASE RESPONSE (dEU/g)
3·0
2·0
1·0
0·0
III
I
II
20
30
40
50
60
70
DAYS FROM ANTHESIS
C
AMYLASE RESPONSE (dEU/g)
3·0
2·0
1·0
0·0
III
I,II
20
30
40
50
60
70
DAYS FROM ANTHESIS
D
AMYLASE RESPONSE (dEU/g)
3·0
2·0
1·0
0·0
III
II
I
20
30
40
50
60
70
DAYS FROM ANTHESIS
E
AMYLASE RESPONSE (dEU/g)
3·0
2·0
1·0
0·0
III
I
II
20
30
40
50
60
70
DAYS FROM ANTHESIS
F
AMYLASE RESPONSE (dEU/g)
3·0
2·0
1·0
0·0
III
II
I
20
30
40
50
60
70
DAYS FROM ANTHESIS

Table 4.18

Estimated statistics of final curves[1] within three environments describing changes in alpha amylase response during grain development amongst six wheat cultivars.

Table 4.18.1 : Environment I (18-12°C; 1.0 kPa)

Statistic	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Y intercept ($\hat{a}$)	-3.5497	5.8369	2.7722	14.7391	1.5234	3.8285
s.e. of Y intercept	0.0745	0.1396	0.2976	0.1801	0.1034	0.1037
$\hat{b}_1$	0.2297	-0.2955	-0.1652	-0.8267	-0.0650	-0.1960
$\hat{b}_2$	-0.0047	0.0050	0.0034	0.0151	0.0010	0.0033
$\hat{b}_3$	3.1 E-05	-2.6 E-05	-2.1 E-05	-8.7 E-05	-4.5 E-06	-1.7 E-05
s.e. of $\hat{b}_1$	0.1425	0.2666	0.5687	0.3442	0.1975	0.2075
s.e. of $\hat{b}_2$	0.0026	0.0049	0.0105	0.0064	0.0036	0.0038
s.e. of $\hat{b}_3$	1.6 E-05	3.0 E-05	6.3 E-05	3.8 E-05	2.2 E-05	2.3 E-05
R^2	0.8343	0.5747	0.1918	0.8931	0.4886	0.8227
F for regression	18.46**	4.95*	0.37	30.63**	3.50	17.02**
s.e. of estimate	0.0439	0.0822	0.1753	0.1061	0.0609	0.0640

Table 4.18.2 : Environment II (18-12°C; 0.4 kPa)

Statistic	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Y intercept ($\hat{a}$)	5.0303	-1.4088	1.9632	7.1004	-3.9552	37.4541
s.e. of Y intercept	0.1141	0.1109	0.0980	0.1986	0.1379	1.6184
$\hat{b}_1$	-0.2675	0.1019	-0.0914	-0.3798	0.2409	-1.8531
$\hat{b}_2$	0.0048	-0.0022	0.0015	0.0067	-0.0047	0.0303
$\hat{b}_3$	-2.7 E-05	1.6 E-05	-7.3 E-06	-3.7 E-05	3.0 E-05	1.6 E-04
s.e. of $\hat{b}_1$	0.2181	0.2117	0.1373	0.3796	0.2634	3.0921
s.e. of $\hat{b}_2$	0.0040	0.0039	0.0035	0.0070	0.0049	0.0571
s.e. of $\hat{b}_3$	2.4 E-05	2.4 E-05	2.1 E-05	4.2 E-05	2.9 E-05	0.0003
R^2	0.3597	0.7514	0.5673	0.5544	0.5413	0.2401
F for regression	2.06	11.09**	4.81*	4.56*	4.33*	1.16
s.e. of estimate	0.0672	0.0653	0.0577	0.1170	0.0812	0.9532

Table 4.18.3 : Environment III (30-20°C; 1.0 kPa)

Statistic	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Y intercept ($\hat{a}$)	0.1372	2.9836	0.5671	1.6223	-2.4047	-0.3906
s.e. of Y intercept	0.2694	0.1097	0.1492	0.2509	0.1698	0.0717
$\hat{b}_1$	0.0277	-0.3170	-0.0418	-0.1470	0.3186	0.0759
$\hat{b}_2$	-0.0023	0.0101	0.0014	0.0038	-0.0120	-0.0033
$\hat{b}_3$	5.3 E-05	-8.5 E-05	-1.2 E-05	-1.5 E-05	1.5 E-04	4.5 E-05
s.e. of $\hat{b}_1$	0.2228	0.0907	0.1234	0.2075	0.1404	0.0593
s.e. of $\hat{b}_2$	0.0073	0.0030	0.0040	0.0068	0.0046	0.0019
s.e. of $\hat{b}_3$	7.4 E-05	3.0 E-05	4.1 E-05	6.9 E-05	4.7 E-05	2.0 E-05
R^2	0.9090	0.9720	0.4813	0.8987	0.9320	0.9421
F for regression	36.63**	127.07**	3.40	32.52**	50.24**	59.62**
s.e. of estimate	0.3053	0.1243	0.1691	0.2843	0.1924	0.0312

[1] Linear form : $Y = a + b_1t + b_2t^2 + b_3t^3$
where Y = amylase response (dEU + 0.2/g)
t = days from anthesis

Table 4.19

Regressed estimates of alpha-amylase response at harvest ripeness (12½% moisture content) within three environments amongst six wheat cultivars.

	Environment I		Environment II		Environment III	
	Y	Std. error	Y	Std. error	Y	Std. error
Sonora	0.2350	0.0241	0.3045	0.0425	0.6190	0.0914
Timgalen	0.5662	0.0356	0.4520	0.0342	0.7074	0.0373
Pembina	0.4231	0.0544	0.2702	0.0295	0.1519	0.0511
Gamut	0.6207	0.0607	0.4274	0.0743	0.5552	0.0857
Sherbati-Sonora	0.1759	0.0307	0.6812	0.0562	0.4223	0.0572
Karamu	0.2755	0.0281	0.9904	0.0845	0.0426	0.0255

where Y = alpha amylase response (dEU/g)

Chapter five : DISCUSSION

5.1 GENOTYPE, ENVIRONMENT AND GENOTYPE-ENVIRONMENTAL EFFECTS.

In the present study, genotype, environment and genotype-environmental effects are investigated for : (a) two curve statistics (Y-intercept and slope) and (b) estimated levels of the various parameters at harvest ripeness (where applicable). A genotype-environmental interaction is where there are marked changes in rank order amongst significantly different cultivars across environments. Conversely, small changes or non-significance groupings of genotypes across environments exhibits little genotype-environmental interaction.

5.1.1 Curve Statistics

Generally, the effect of the environment on the characters of interest was to cause a change in the Y-intercept ($\hat{a}$) with little effect on slope ($\hat{b}$). Parameters that reacted in this manner were the flavan-3-ol curves, germination, embryo maturity, embryo "dormancy", basal alpha amylase and alpha amylase response. (Tables 4.7, 4.8, 4.10, 4.13, 4.16, 4.18 respectively). Grain dehydration reacted conversely, the slope being affected to a larger extent than the upper asymptote (Table 4.1). Grain dry-weight, however, was susceptible to changes in both slope and upper asymptote (Table 4.3). Pigmentation statistics ($\hat{a}$, $\hat{b}$) were little affected by the environment (Table 4.4), and there were no consistent ranking into red and white, or dormant and non-dormant groups (see section 5.3).

Generally, most of the genotype-environmental effects amongst the characters studied manifested themselves in changes in rank order for the Y-intercept ($\hat{a}$). The traits affected in this way were flavan-3-ol, germination, embryo maturity, embryo "dormancy", basal alpha-amylase and alpha-amylase response (Tables 4.7, 4.8, 4.10, 4.13, 4.16, 4.18 respectively). Only in the case of grain dry-weight did a genotype-environmental interaction manifest itself in slope ($\hat{b}$) differences (Table 4.3). These same characters also exhibited large environmental effects. Genotypically, therefore, these characters would appear to be relatively unstable, and correspondingly would be expected to exhibit low heritability estimates. Pigmentation showed little genotype-environmental interaction (Table 4.4) and also was affected little by the environment (Table 4.4). It would appear, therefore, that the pigmentation character is relatively stable genotypically, and would be expected to have a high heritability estimate. Grain dehydration also exhibited a relatively low level of genotype-environmental effect for both $\hat{a}$ and $\hat{b}$ (Table 4.1). Grain dry-weight was genotypically unstable for slope, exhibiting a large genotype-environmental interaction for the $\hat{b}$ statistic whereas a smaller interaction was observed for the Y-intercept (Table 4.3).

5.1.2 Derived Statistics

(a) Grain Moisture

Average days to reach harvest ripeness (from anthesis) were 73.0 ± 5.1, 79.6 ± 3.3 and 38.8 ± 0.3 days for environments I, II and III respectively.

Differences between the cool environments were non significant ($P < 0.05$) but differences were significantly different between the two cool and the hot environments ($P < 0.001$). These results suggested that desiccation was accelerated by increased temperature, and that lack of difference between the two cool environments may have little effect at those cool temperatures.

Some differences were observed in regressed days to harvest ripeness amongst individual cultivars in environment I, and little or no significant differences amongst cultivars within the remaining two environments (Table 4.2). These moderate changes in rank order across environments indicated some genotype-environmental interaction for this trait. However, the relative differences amongst cultivars within each environment in relation to the environmental averages suggest the effect of the environment is the more important factor. Both factors suggest low heritability for this trait.

(b) Pigmentation.

The environmental effect on pigmentation was estimated from the average of regressed days to 50% pigment formation within each environment. These estimates were 52.4 ± 3.3, 50.2 ± 1.8 and 25.8 ± 3.4 days for environments I, II and III respectively. There were no significant differences ($P < 0.05$) between the cool environments, and highly significant differences ($P < 0.01$) between the two cool and the hot environments. It appears, therefore, that temperature has a more important effect than vapour pressure deficit on the period to reach median pigment formation. This was similar to the environmental effects noted on grain dehydration.

Little change in rank order was observed in regressed days to 50% pigment formation amongst cultivars across environments (Table 4.5). These small changes in rank order indicate little genotype-environmental interaction for this trait. The ratio of timing of 50% pigment formation to harvest ripeness provided a physiological "age" for pigment formation based on progress of grain dehydration (Table 4.6). There were no groupings into either red and white, or dormant and non dormant cultivars (Section 5.3), and the statistic appeared relatively constant over all cultivars and environments.

(c) Flavan-3-ol concentration.

There were no regressed estimates of flavan-3-ol concentration at the time of harvest ripeness, as the period of rapid depletion of this compound and hence the sampled period occurred before harvest ripeness. All cultivars reacted in a similar manner, regardless whether the cultivars were red- or white-grained or dormant and non-dormant (section 5.3). These results suggest little association between flavan-3-ol concentration and other traits investigated.

(d) Germination.

There were relatively few differences amongst cultivars for germination at harvest ripeness (Table 4.9). All cultivars in both cool environments showed little germinative activity, reflecting their immature state. In the hot environment all "non dormant" white grained cultivars, and Sonora (a red grained cultivar) exhibited high germination percentages at harvest ripeness. The cultivars Pembina and Karamu had low germination percentages. In section 5.3 it will be noted that this reflected their dormant state.

(e) Embryo Maturity.

Regressed estimates of embryo maturity at harvest ripeness in the cool environments showed that the embryos were still immature (Table 4.11). This is at variance with observations in the warmer environment where the embryos were fully mature at harvest ripeness. These observations agreed with usual expectations in warmer environments (e.g. Belderok, 1968; Gordon, 1975; McEwan, 1976b; Olsson and Mattsson, 1976). Several authors have suggested that grain moisture and "grain maturity" are inter-related (e.g. Gfeller and Svejda, 1960). However, "grain maturity" was ill-defined. Gordon (1975) clarified maturity, and demonstrated that desiccation (harvest ripeness) and embryo maturity were separate attributes. The present study showed further that, in cool environments, there was a very slow attainment of embryo maturity (Table 4.12). However, grain dehydration was delayed to a lesser extent. These results suggest therefore that grain moisture and harvest ripeness are not reliable guides to embryo maturity, especially in cooler environments.

Since embryos in the cool environments at harvest ripeness were immature, but embryos were mature in the hotter environment, temperature appears to have a major effect on embryo maturity. Vapour pressure deficit had little influence on these characters in the cool environments. These findings agree with those of Belderok (1968), and are discussed further in section 5.3.

(f) "Embryo Dormancy".

The "embryo dormancy" curves fitted were really curves of impedence to germination. During embryo immaturity, these curves represent immaturity. However, when embryos gain maturity, the impedence curves reflect dormancy. The method adopted to differentiate true dormancy was the difference between days to reach 50% impedence to germination, and days to 50% embryo maturity (i.e. true dormancy = D50 - M50 : see section 5.3). True dormancy was thus considered as some impedence of germination of mature embryos under favourable environmental conditions when germination would normally be expected to occur (Amen, 1968; Barton, 1965; Black, 1972; Gordon, 1975; Khan, 1971, 1975; Roberts, 1972; Villiers, 1972).

Regressed estimates of germination impedence at harvest ripeness (Table 4.14) enabled an examination of Belderok's (1968) suggestion that accumulated temperature during grain development may affect variation in dormancy. However, it should be noted that "dormancy" has been used previously to mean "lack of germination" whether it be due to embryo immaturity or true dormancy. Belderok (1968) considered that the influence of temperature and of vapour pressure deficit particularly during the dough stage of development

(Belderok, 1961) and the length of the dough stage were directly related to the length of the dormant period. Considering the two cultivars with real dormancy in the present study (i.e. Pembina and Karamu : see section 5.4.4) the length of the dough stage (section 3.3) was shorter in the hot environment as compared to the cooler environments. This was indicated by the highly significant differences in slope of regression for dehydration. The present study used cool temperatures, as did Belderok (1961). He (Belderok, 1961) observed that full germination of his "reputably dormant" cultivar 'Peko' had occurred by eighty days from anthesis. Unfortunately, he made no comparison to other wheats. The present study suggested that full germination would probably have occurred by 80 to 85 days from anthesis. There were little differences between reputably "dormant" and "non-dormant" wheats. The present results showed, however, that this lack of germination was due to embryo immaturity rather than true dormancy.

The temperature effect in the present study was isolated by comparing environments I and II with III. Impedence to germination was greatly affected by temperature, as suggested by Belderok (1968). The white-grained wheats changed from 100% impedence to germination in the cool environments to no impedence (at harvest ripeness) in the hot environment. Red-grained Sonora reacted in a similar manner to the white-grained wheats. Impedence to germination of Pembina and Karamu (both red-grained) at harvest ripeness were less affected by temperature, being 100%

for both cultivars in the cool environments, and 49.3% and 86.8% impedence in the hot environment respectively (Table 4.14). However, as noted previously, the cause of this germination impedence changed with the temperatures. In the hot environment, true dormancy was apparent (section 5.4.4), while in the cool environment the impedence to germination was due to embryo immaturity.

A vapour pressure deficit effect can also be examined, by comparing the two cool environments. It appears vapour pressure deficit had little effect on impedence to germination, as suggested also by Belderok (1961).

(g) Basal Alpha-Amylase and Alpha-Amylase Response.

Average levels of basal alpha amylase at harvest ripeness were not significantly different to each other, being 0.5473 ± 1.1, 0.9473 ± 1.1 and 0.0634 ± 0.1 dEU/g for environments I, II and III respectively. These results indicated the effects of temperature and of vapour pressure deficit had little effect on the levels of this enzyme at harvest ripeness.

There were no consistent groupings of cultivars within the cool environments at harvest ripeness, irrespective of whether they were red- or white-grained, as based on alpha amylase response activity (Table 4.19). These results appear to reflect the immature state of the embryos at (and after) harvest ripeness. (Tables 4.11, 4.12). However, cultivars within the hot, dry environment were able to be grouped into dormant and non-dormant groups based on their alpha-amylase response activity (Table 4.19). These differing patterns of response constitute a genotype-environmental interaction. These results contrast somewhat with the findings of Gordon (1975), who did not observe any clear association between alpha-amylase response and embryo dormancy, although an incipient association was possibly present. The apparent anomaly may be due to sampling differences and/or different environmental effects. Average levels of alpha amylase response of cultivars within each environment (at harvest ripeness) indicated that there were no significant differences between environments. However, the embryos in the cool environments were immature, while the embryos had reached maturity in the hot environment (Table 4.10). These results indicated that alpha-amylase response in the cool environments developed before embryo maturity; whereas embryo maturity occurred at a similar time to initiation of alpha-amylase response in the hot environment. This point is elaborated upon further in section 5.3.

5.2 COMPARISON OF CURVE TYPES

The present investigation extended concepts of earlier work (Gordon, 1975). It used a wider genotype sample, and sampled several environments. Most characters were common to both investigations; additional characters being pigmentation and germination. Curve descriptions of all characters investigated are given in Table 3.2. In the present cases of marginal or poor fit, related curves other than those of Gordon (1975) were attempted, and the curve of best fit was used. In only two cases did the final curves used in this study differ to those of Gordon (1975). These were for embryo maturity (quadratic logistic in place of logistic) and alpha-amylase response (third degree polynomial in place of fourth degree polynomial). These differences may indicate some differences in biological response, but probably represent sampling differences, or perhaps differences in experimental technique. Generally, the patterns of change for all characters in the hot environment were very similar to those of Gordon (1975), and confirmed those findings. The present warm environment was the most similar to the conditions of Gordon (1975). However, as noted previously, the response patterns in the cooler environments showed several new features, particularly in the timing of development of embryo maturity.

5.3 BIOLOGICAL INTERPRETATIONS

5.3.1 Grain Desiccation and Growth.

A harvest ripe crop is usually determined by its moisture content, although other criteria are involved also, such as colour, hardness (firmness), and as determined by the requirements of the harvesting method (Andersen, 1965). Combine harvesters usually operate well at 15% seed moisture content or less. In some countries, the crop may be as low as 10% moisture content at the time of harvest ripeness. Harvest ripeness has therefore been defined at an intermediate value of 12½% moisture concentration (field weight basis; Gordon, 1975).

Grain dehydration was characterised by a rapidly declining phase. This probably resulted in part from progressive disorganisation of vascular tissues, such as the transfer cells in the rachis and general disorganisation of the pigment strand (Zee and O'Brien, 1970 a, b). The result is isolation of the grain and consequent restriction of translocation of water and solutes (Gordon, 1975; Jennings and Morton, 1963). The timing of events, however, suggest starch synthesis began to slow down earlier than the complete breakdown of translocation pathways in the pigment strand (Jenner, 1974; Jenner and Rathjen, 1975). These authors suggested the accumulation of starch is impeded by a fall in the activity of starch synthesis in the endosperm, and not by a reduction in the supply of sucrose to the sites of carbohydrate synthesis. Grain growth (dry weight) therefore may be largely independent of grain desiccation. Gordon (1975) suggested hormonal levels within the grain may be affected also by the breakdown of translocation pathways in the pigment strand. Whether hormonal levels within the grain are affected at an earlier time to breakdown in function of the pigment strand (as suggested for starch synthesis) remains unresolved.

5.3.2 Flavan-3-ol Concentration.

Flavan-3-ol (catechin) depletion showed marked similarities of change across all cultivars, irrespective of whether they produced grain pigment or not. Further, there appeared to be no differences in the rate (slope) of flavan-3-ol depletion between red-and white-grained cultivars. Perhaps the assay method was not sensitive enough to adequately discern between the red- and white-grained cultivars. Phlobaphene has alternative precursors such as flavan-3, 4-diols (Brown, 1964; Wong, 1973) which the present method does not assay for (Swain and Hillis, 1959). However, there appears to be no reports of the existence of flavan-3, 4-diols in wheat grains. The presence of flavan-3-ols was clearly established and are probably contributing precursors of phlobaphene. Stoy and Sundin (1976) reported a catechin inhibitory effect on germination of excised wheat embryos. Conversely, the present results, and those of Gordon (1975), on grain development revealed no association between *in vivo* catechin levels and dormancy. Gordon (1975) also could not demonstrate any inhibition of germination, embryo growth or alpha amylase response in whole grains due to imbibed catechin.

5.3.3 Polyphenoloxidase, Pigmentation, and Colour

In the review of literature, some attention was paid to the possible role of anoxia in inducing dormancy. The enzyme complex polyphenoloxidase is involved in the oxidative polymerisation of flavan-3-ol (and possibly flavan-3, 4 diols) to the red pigment phlobaphene (Brown, 1963; Conn, 1964; Pridham, 1963; Wong, 1973). The enzyme complex is located in the pericarp and integuments as are the catechins and phlobaphene (Kruger, 1976; Taneja and Sachar, 1974 a, b). Gordon (1975) suggested this enzyme may be responsible for dormancy induction by increasing partial anoxia conditions in the region of the embryo. The present study cannot resolve this suggestion, but does not contradict expectations arising from this proposal. Gordon (1975) also suggests that the timing as well as the degree of effective anoxia may be important. More detailed physiological research on the role of anoxia in wheat dormancy is warranted.

Gfeller and Svejda (1960) and Ibrahim (1966) suggested that genes for redness were apparently additive for colour, and possibly were additive for dormancy. The present study used ten graded colour standards as a semi-quantitative measure of pigment, enabling closer inspection of this suggestion. The present results do not agree with the previous suggestions concerning corresponding additivity of genes for grain redness and dormancy. All the red-grained wheats (Sonora, Pembina, Karamu) were observed to have the same colour intensity. Nevertheless, in the hot environment, Sonora displayed no dormancy and was grouped with the non-dormant white wheats. In contrast, Pembina and Karamu were dormant, with a dormancy period estimated as 10.2 ± 0.6 and 20.6 ± 1.3 days from flowering, respectively (Table 5.1). Sonora and Karamu have a single red gene for redness (Jan and Qualset, 1976; McEwan, pers. comm.). Unfortunately, information on the number of genes for redness in Pembina does not appear to be readily available; up to three gene pairs could be involved (Kimber, 1970; McIntosh, 1973). It appears, therefore, that the suggestion of additivity between genes for redness and dormancy (Gfeller and Svejda, 1960; Ibrahim, 1966) is not supported, as concluded also by Gordon (1975). The present results suggest that the processes associated with the red pigment and dormancy have an effect at higher temperatures only. Considering these "truly dormant" wheats (in the hot environment) and based on timing of events between synthesis of the phlobaphene pigment and dormancy induction, pleiotropic effects between red colour genes and dormancy may be postulated, and agrees with the hypotheses of Gfeller and Svejda (1960) and of Gordon (1975). However, the present study showed no true dormancy for Sonora, whereas Gordon (1975) found some weak dormancy in this cultivar. These differences probably result from differences in climate and resultant development. Other authors suggest linkage effects between genes for redness and dormancy and that the different red genes have varying capacities to effect dormancy (Freed, 1972; Freed *et al.*, 1976). The present study did not enable further differentiation between these two hypotheses; but, if the anoxia hypothesis should be confirmed, pleiotropism would be favoured.

5.3.4 Dormancy and the Effects of the Environment.

The effect of seasonal differences on the length of the "dormant" (non-germinative) period has been well documented. Warm and dry seasons, followed by rain on the harvest ripe crop usually result in most sprout damage, and conversely least sprout damage from crops grown during cool and dry seasons (e.g. Belderok, 1961, 1968; Greer and Hutchinson, 1945; La Croix et al., 1976; Lallukka, 1976; Olered, 1967; Olsson and Mattsson, 1976; McEwan, 1976; Sanders, 1974).

Belderok (1961, 1968) showed that the length of the period of lack of germination (termed by him "dormancy") was dependent on the prevailing temperature during the dough stage of grain development, and the length of this dough stage (section 3.3). He suggested (Belderok, 1968) that "dormancy" was dependent on certain biochemical changes which had begun to occur in the grain during the dough stage and remained incomplete when harvest ripeness was attained. The environmental difference in "dormancy" for a given cultivar could then be explained, as these processes would have progressed further because of higher temperatures and/or because of a longer-lasting dough stage (Belderok, 1968). Gordon (1975) suggested that lack of germination at harvest ripeness may be a function of both embryo immaturity and embryo "dormancy", which he was able to differentiate, and is the basis of the present study. Gordon (1975) also suggested that different environments may affect the synchrony of immaturity, dormancy, and harvest ripeness.

The present results also suggested (sections 4.5, 4.6, 4.7) that lack of germination may not always be due to true dormancy, but also to immaturity. With respect to the present curves, a delay between ascent of embryo maturity curve and descent of the germination impedence curve may be considered as an indication of true dormancy. (Gordon, 1975; Gordon pers. comm., 1976). Comparisons of times of median maturity (M50 : Table 4.12) and median impedence (D50: Table 4.15) facilitate differentiating between immaturity and dormancy. The suggested true dormancy statistics (D50 - M50) for the various cultivars are presented in Table 5.1.

The present results (Table 5.1) clarify and reconcile the views of both Belderok (1968) and of Gordon (1975). In both cool environments, time of M50 and of D50 closely coincided. Some minor variations were observed but the magnitude of the differences appeared not too far from the bounds of experimental error. If a true dormancy mechanism was operating, it was very transitory. Impedence to germination in the cool environments was indicated, therefore, to be due to immaturity. The "biochemical" changes of Belderok (1968) would appear to be changes in embryo maturity in such situations which would be expected to improve with longer and/or warmer development periods. In the present warm environment, embryo maturity did develop sooner for all cultivars irrespective of their true dormancy. In the hot environment, two "dormant" red wheats, Pembina and Karamu, had (D50 - M50) estimates of 10.2 ± 0.6 and 20.6 ± 1.3 days respectively, and may therefore be considered to have a true dormancy mechanism operating.

Table 5.1 :

Estimated dormant periods (D50-M50) amongst six wheat cultivars within three environments.

Cultivar	Environment I		Environment II		Environment III	
	(D50-M50)	Std. Error	(D50-M50)	Std. Error	(D50-M50)	Std. Error
Sonora	0.8	0.7	-1.6	1.1	1.6	0.6
Timgalen	0.7	0.9	-0.6	1.6	-1.6	1.1
Pembina	n.d.[1]	n.d.	n.d.	n.d.	10.2	0.6
Gamut	1.6	0.8	n.d.	n.d.	2.0	1.0
Sherbati-Sonora	2.1	0.9	-3.2	1.6	-1.0	0.9
Karamu	-0.8	1.3	-2.2	1.0	20.6	1.3

[1] n.d. = no data, due to persisting full immaturity.

5.3.5 Basal Alpha-Amylase, and Alpha-Amylase Response

Alpha-amylase, during initial grain development, is associated primarily with the pericarp-testa region. Several isozymes exist, and these isozymes reach a peak shortly after anthesis. They are subsequently degraded rapidly to reach a low level sometime before harvest ripeness (Banks, et al., 1972; Bingham and Whitmore, 1966; Olered, 1967). These early isozymes may comprise only a very small fraction of the alpha-amylase response to germination conditions (Kruger, 1972, 1976; Meredith and Jenkins, 1973; Olered and Jonsson, 1970; Olered, 1976).

There was no consistent grouping of cultivars into red and white or dormant and non-dormant groups based on upper asymptote, slope, or minimum basal alpha amylase levels. The lower basal level (i.e. minimum level) is of technological importance (Olered, 1967), and some authors have suggested cultivar differences for this minimum level (e.g. Bingham and Whitmore, 1966; Meredith and Jenkins, 1973). In the present study, nearly all cultivars reached an extremely low basal level in all three environments. Two exceptions did occur (Gamut and Pembina) but only in the cool environments, indicating a major genotype-environmental effect on the deactivation of this enzyme, peculiar to these two cultivars. It appears some cultivars are more stable in this attribute than others, suggesting only a moderate to low heritability estimate.

Alpha amylase responses to germinable conditions at the time immediately prior to harvest ripeness were very low in value. Gordon (1975) found negative responses early in grain development, and also lack of response for a much longer period of time than in the present study, being past harvest ripeness in all cases. Gordon (1975) suggested the period of no response indicated active inhibition, and that the response that eventually occurred may have resulted from a change in inhibitor/promoter balance. Further, this author noted considerable endosperm degradation prior to alpha-amylase activity, and suggested that the activity of other enzymes (e.g. proteolytic enzymes, transphosphorylases, hemicellulases) may have been causative factors. The present results also showed a period of low response (although shorter), but there was little indication of active inhibition. Recent work suggests that there can be partial or relative lack-of-response of the cereal aleurone layers in the production of alpha-amylase after imbibition in gibberellic acid (e.g. Bhatt _et_ _al_., 1976; Fick and Qualset, 1976; Gale, 1976; MacMaster, 1976). These authors have suggested that these results indicate insensitivity of the aleurone to gibberellin. However, these results may also be due to insufficient gibberellin to counter-balance an excess of abscissic acid, lack of cytokinin (Gordon, 1975; Khan, 1971, 1975), or perhaps inappropriateness of the applied GA_3 (compared with _in vivo_ gibberellins such as GA_4, GA_9 : Villiers, 1972). The suggestion of "insensitivity" clearly needs further investigation.

5.4 BREEDING METHODS

Breeding for sprouting damage resistance involves recognition of usable genetic parameters. In the past, the variable association between lack of germination and red grain colour has been used as a criterion in breeding for sprouting damage resistance (e.g. Belderok, 1968a, Derera, 1973; Freed, 1972; 1976; Gfeller and Svejda, 1960; Kimber, 1971; McEwan, 1976a, b). The ability to sprout is determined by maturity as well as dormancy, and the present results suggest these properties change with time, even after harvest ripeness. The lack of synchrony between grain moisture content (harvest ripeness) and embryo maturity render moisture content less desirable as a physiological datum point for comparing sprout susceptibility amongst genotypes. However, detailed physiological selection criteria may be impractical (Gordon, 1975), but observation of embryo maturity at harvest ripeness may suffice instead (Gordon, 1975).

Several authors have indicated that the aleurone may have low sensitivity to exogenous gibberellic acid, as indicated by lack of alpha amylase response. Such lack of response may be heritable (Allen, et al. 1959; Bhatt, et al., 1976; Fick and Qualset, 1975; Gale, 1976; Gale and Marshall, 1973; MacMaster, 1976; Radley, 1970). However, these workers did not clarify whether the lack of enzyme response was due to target insensitivity, lack of translocation of gibberellin to targets, excess of gibberellin inhibitors, lack of cytokinins, or inappropriateness of the GA_3 used

(Gordon, 1975; Jones, 1973; Khan, 1969, 1975; Villiers, 1972). Whatever the cause of lack of alpha-amylase response, it may prove a useful selection criterion in breeding against sprouting damage. However, endosperm degradation may arise from other enzymes also, such as proteolytic enzymes involved in early germination (Bhatt et al., 1976; Ching, 1972; Gale, 1976; Gordon, 1975; Kruger and Preston, 1976). Therefore selection based on endosperm degradation (e.g. falling number), or on assays for other enzymes, should also be considered (Gordon, 1975; Kruger and Preston, 1976; Johansson, 1976; Weilenmann, 1976).

Heritability estimates for the various traits have been deduced from the extent of the genotype-environmental interaction (section 5.1). More precise estimates may be estimated by the Analysis of Variance (ANOVA) procedure (section 2.3). Correlations between traits may also be estimated, and in conjunction with estimates of heritability, an indication of rate of selection response in other traits pertinent to sprouting damage resistance may be deduced.

5.5 EXPERIMENTAL METHODS

The present study used grains removed from the spike. This procedure enabled characteristics of the grain per se to be studied, without the possible confounding effects from the remaining spike parts. This procedure also enabled very small samples of grain to be tested, an important consideration when conducting trials with limited plant material. Had the experiment been conducted on a field scale, then the effects of the intact wheat spike may also have been considered. Some experimenters have observed longer post-harvest "dormancy" from unthreshed wheat grains than from comparable threshed seed (Everson and Hart, 1961; Hutchinson, et al., 1948; Wellington and Durham, 1958), while others have observed little or no effect (Harrington and Knowles, 1940; Lancaster and Wright, 1970). Hutchinson et al. (1948) felt that the glume appeared to facilitate or stimulate the action of some inhibitory factor within the grain itself. However, Wellington and Durham (1958) failed to extract any inhibitory factor and considered the inhibitory effect of the glumes was competition for oxygen as a result of entrapped water. Smith (1948) found aqueous extracts of wheat chaff were sometimes, but not consistently, effective in inhibiting seed germination. Gordon (1975) could not demonstrate any imbibition impedence due to inflorescence tissues, nor any indication of delayed germination in a non-dormant wheat genotype. Appropriate techniques for evaluating the tendency of intact wheat spikes to sprout may include moistened sand trays (Wellington, 1953), or misting chambers (Gordon, 1975; McMaster and Derera, 1976).

Other recommendations for the breaking of wheat dormancy, in addition to the particular treatments used herein (i.e. alternating light and temperature, and 0.2% KNO_3 solution), include chilling, or exogenous gibberellin (Anon., 1966, 1976; Bekendam, 1975; Stokes, 1965). The methods used here to estimate development of embryo maturity (Gordon, 1975) assume that dormancy was successfully broken, and appear to have been successful in that the embryo maturity curves did reach full maturity in the warm environment. However, the estimated timing of embryo maturity may be a function of the dormancy breaking treatments used. For example, the embryo maturity curves may be displaced towards earlier maturity if a prechilling treatment was employed, as chilling is known to stimulate some gibberellin response (Andrews and Burrows, 1972; Villiers, 1972). This may also be the outcome from the methods actually used, but there appears to be little information on this. However, it should be emphasised that it is not known that these alternatives do produce consistent displacements of maturity towards earlier attainment of maturity. The present methods do distinguish between immaturity and maturity, as noted by Gordon (1975). Whether embryo "maturity" (and initiation of embryo "dormancy") actually occur at the times estimated in the present study, or at some earlier time, does not detract from the validity of present results and discussion, as the relativity of statistics of cultivars and environments would probably be preserved. Any real "early" displacement of the maturity curves, resulting from other methods of bypassing dormancy, would not alter the original concept of differentiating between immaturity and dormancy upon which the present methods are based.

CONCLUSION

The present investigation was conducted under artificial environmental conditions, which enabled investigation into several characters without the confounding effects of unknown environmental variation. The results are pertinent to these sets of conditions, and extrapolation into natural environments assumes the present study may be representative of field responses. Further, the cultivars studied represent only a limited sample of wheat genotypes. However, such sampling limitations are typical of biological experiments.

Several main features of the present study are :

(1) Belderok's suggestion (1968) of variable rates of biochemical (i.e. physiological) development as influenced by temperature was supported. Likewise, Gordon's (1975) suggestion of changing synchronies amongst maturation traits in different environments was strongly supported.

(2) Vapour pressure deficit had little affect on embryo maturity.

(3) At cooler temperatures, embryo maturity was delayed until well past harvest ripeness. At this point, dormancy appeared to have been lost.

(4) The extremely long period of immaturity observed in the cooler environments emphasised that lack of germination does not automatically imply dormancy (Gordon, 1975; Villiers, 1972).

(5) It is necessary to consider the two maturation traits of embryo maturity and of embryo dormancy when considering impedence to germination (Gordon, 1975;

Gordon, pers. comm., 1976).

(6) The difference between these two estimates appears a reliable estimate of actual dormancy.

(7) The maturation traits of moisture content, grain weight, and attainment of final grain colour had poor synchrony with the timing of initiation, maintenance, or loss of dormancy.

(8) The lack of synchrony between harvest ripeness and embryo maturity render moisture content less desirable as a physiological datum point for comparing the length of the dormant period.
Detailed investigation of time of embryo maturity may be impractical. However, observation of embryo maturity at harvest ripeness may be the most expedient technique when screening for dormant genotypes.

(9) Alpha-amylase response in the hot environment closely followed the length of the dormant period of the various cultivars. However, alpha-amylase response in the cool environments was not consistent with other developmental patterns.

(10) The roles of the environment on the activity of alpha-amylase, on factors affecting amylase activity (such as growth promoting and inhibiting compounds) (e.g. Khan, 1971; 1975; Stoy and Sundin, 1976) and on other enzymes possibly involved in endosperm degradation (such as proteolytic enzymes, hemicellulases, transphosphorylases) (e.g. Gordon, 1975; Kruger 1976; Kruger and Preston, 1976) need further investigation.

ACKNOWLEDGEMENTS

I wish to acknowledge my supervisor, Dr I.L. Gordon, for his guidance and assistance in this project.

I am particularly grateful for valuable use of the climatically controlled laboratories at the Plant Physiology Division, DSIR, and facilities at the Seed Testing Station, M.A.F., Palmerston North.

The author's activities were supported by funds from a genotype-environment grant from DSIR.

Finally, I am indebted to my friends and colleagues whose interest and assistance was gratefully received.

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APPENDIX

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Appendix

Figure A1.1.1 Changes in grain moisture content during grain development amongst six wheat cultivars in environment I (18-12°C; 1.0 kPa).

(A) Sonora

$R^2 = 0.9638$

(B) Timgalen

$R^2 = 0.9549$

(C) Pembina

$R^2 = 0.9604$

(D) Gamut

$R^2 = 0.9430$

(E) Sherbati-Sonora

$R^2 = 0.9790$

(F) Karamu

$R^2 = 0.8753$

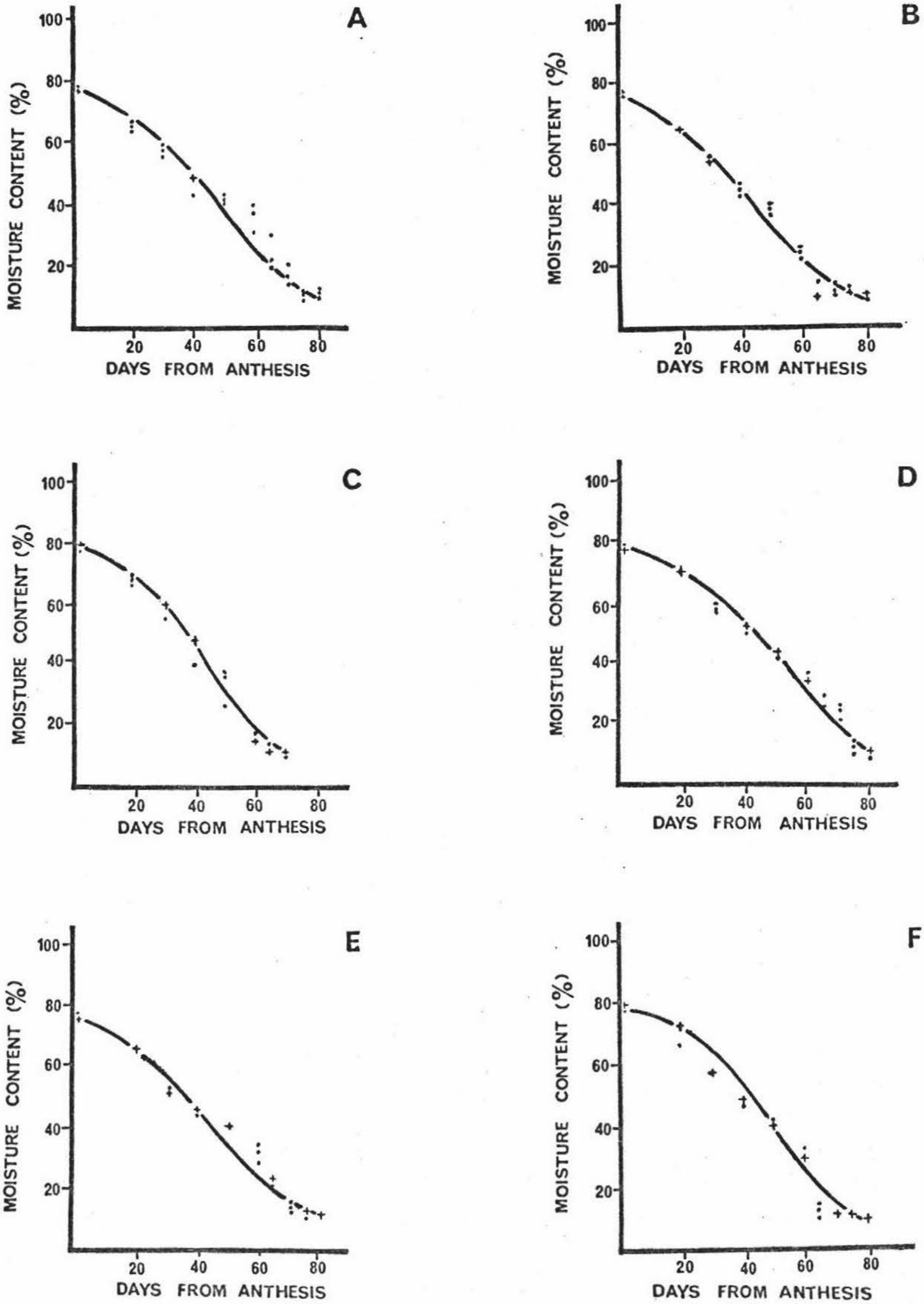

A
MOISTURE CONTENT (%)
100
80
60
40
20
20
40
60
80
DAYS FROM ANTHESIS
B
MOISTURE CONTENT (%)
100
80
60
40
20
20
40
60
80
DAYS FROM ANTHESIS
C
MOISTURE CONTENT (%)
100
80
60
40
20
20
40
60
80
DAYS FROM ANTHESIS
D
MOISTURE CONTENT (%)
100
80
60
40
20
20
40
60
80
DAYS FROM ANTHESIS
E
MOISTURE CONTENT (%)
100
80
60
40
20
20
40
60
80
DAYS FROM ANTHESIS
F
MOISTURE CONTENT (%)
100
80
60
40
20
20
40
60
80
DAYS FROM ANTHESIS

Figure A1.1.2

. Changes in grain moisture content during grain development amongst six wheat cultivars in environment II (18-12°C; 0.4 kPa)

(A) Sonora
$R^2 = 0.9296$

(B) Timgalen
$R^2 = 0.9641$

(C) Pembina
$R^2 = 0.9897$

(D) Gamut
$R^2 = 0.8957$

(E) Sherbati-Sonora
$R^2 = 0.9425$

(F) Karamu
$R^2 = 0.8848$

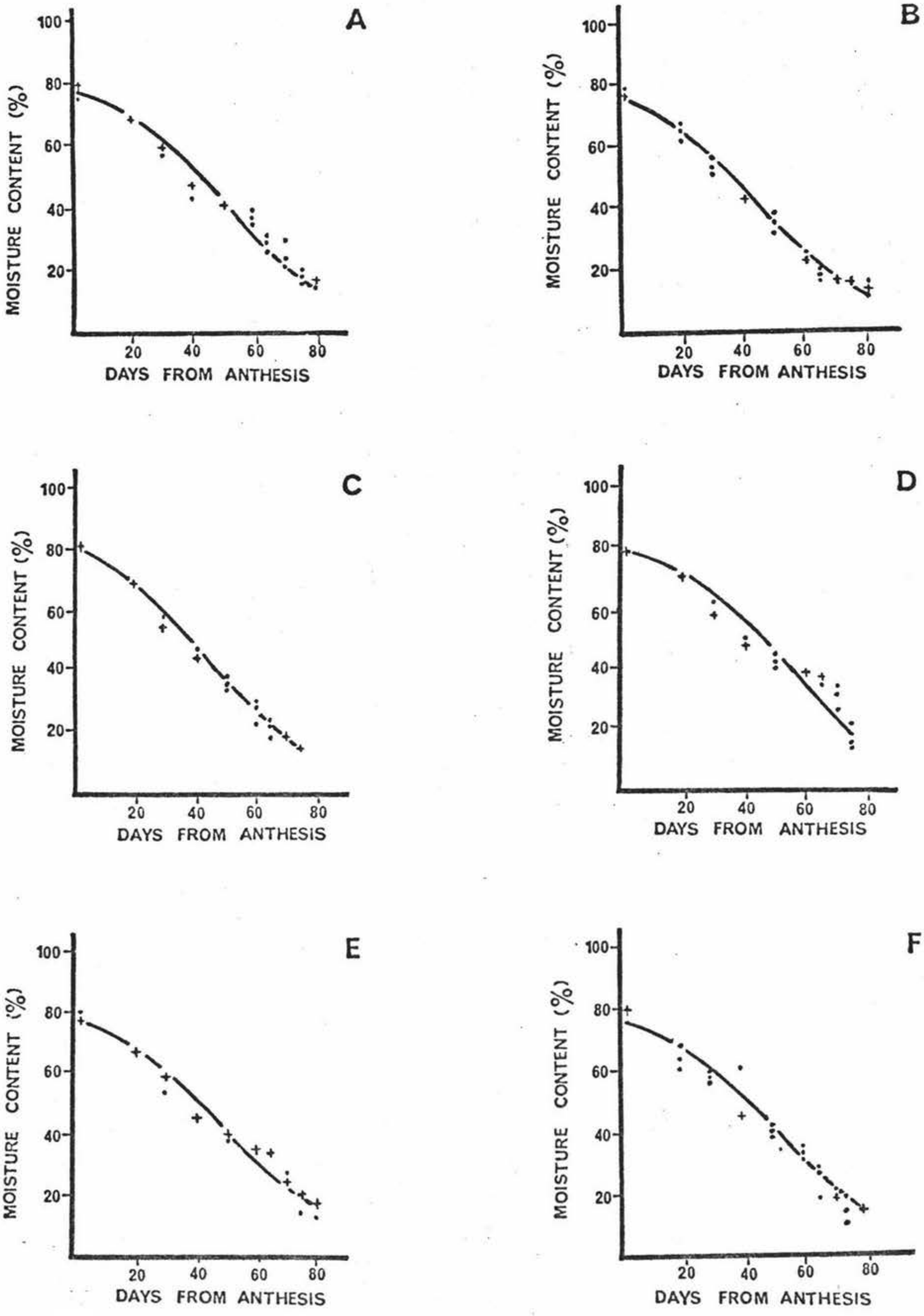

A
100
80
60
40
20
MOISTURE CONTENT (%)
20
40
60
80
DAYS FROM ANTHESIS
B
100
80
60
40
20
MOISTURE CONTENT (%)
20
40
60
80
DAYS FROM ANTHESIS
C
100
80
60
40
20
MOISTURE CONTENT (%)
20
40
60
80
DAYS FROM ANTHESIS
D
100
80
60
40
20
MOISTURE CONTENT (%)
20
40
60
80
DAYS FROM ANTHESIS
E
100
80
60
40
20
MOISTURE CONTENT (%)
20
40
60
80
DAYS FROM ANTHESIS
F
100
80
60
40
20
MOISTURE CONTENT (%)
20
40
60
80
DAYS FROM ANTHESIS

Figure A1.1.3

Changes in grain moisture content during grain development amongst six wheat cultivars in environment III (30-20°C; 1.0 kPa)

(A) Sonora

$R^2 = 0.8455$

(B) Timgalen

$R^2 = 0.8546$

(C) Pembina

$R^2 = 0.7682$

(D) Gamut

$R^2 = 0.8841$

(E) Sherbati-Sonora

$R^2 = 0.8112$

(F) Karamu

$R^2 = 0.7769$

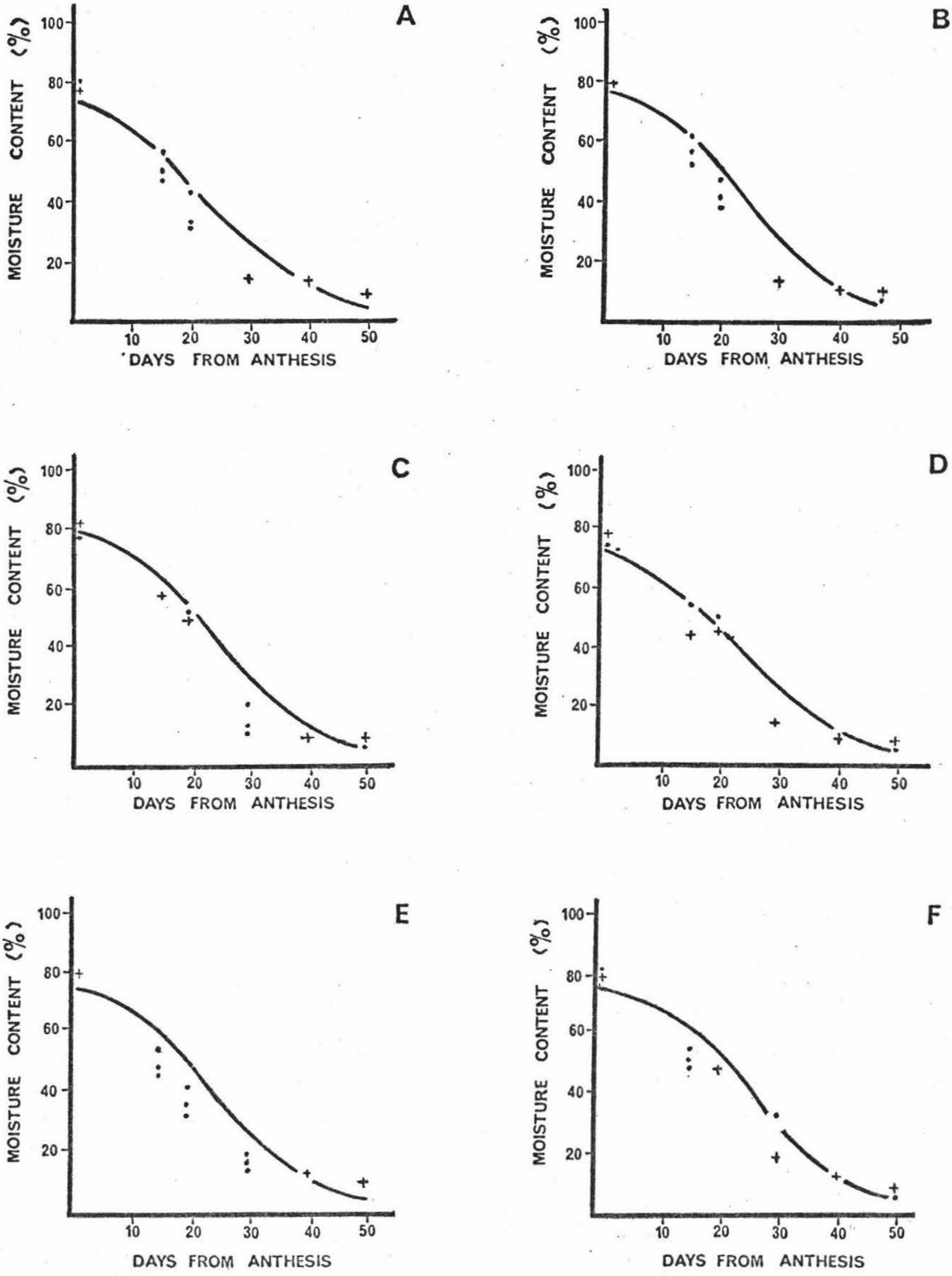

A
B
C
D
E
F
MOISTURE CONTENT (%)
100
80
60
40
20
10
20
30
40
50
DAYS FROM ANTHESIS

Figure A1.2.1 Changes in grain dry weight during grain development amongst six wheat cultivars in environment I (18-12°C; 1.0 kPa)

(A) Sonora

$R^2 = 0.9894$

(B) Timgalen

$R^2 = 0.9781$

(C) Pembina

$R^2 = 0.9737$

(D) Gamut

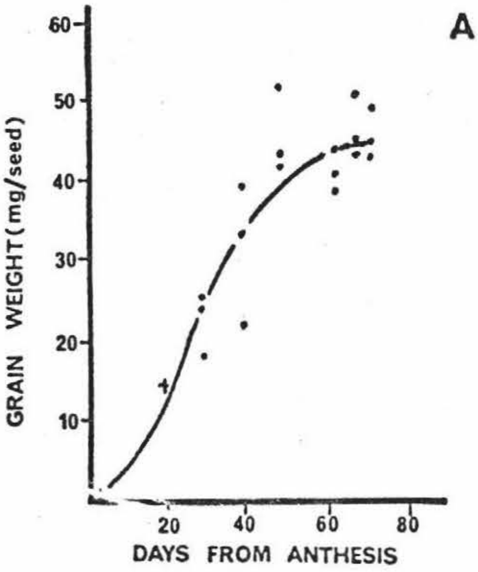
$R^2 = 0.9923$

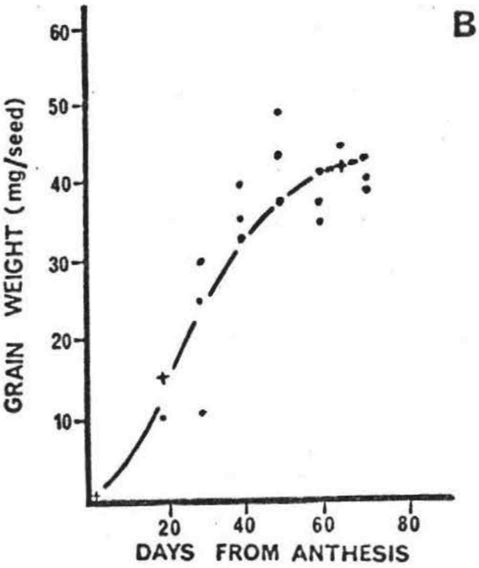
(E) Sherbati-Sonora

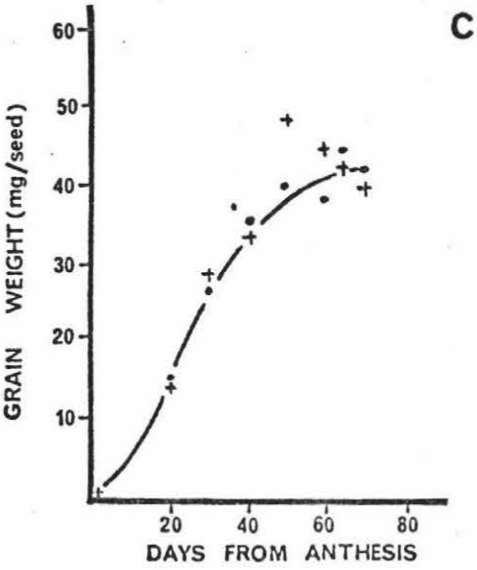
$R^2 = 0.9830$

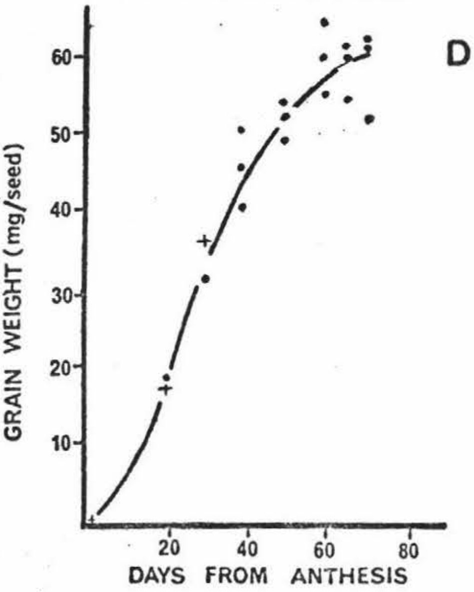
(F) Karamu

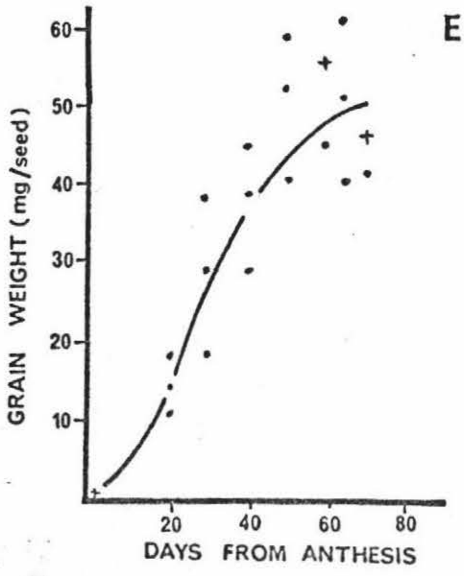
$R^2 = 0.9911$


A
GRAIN WEIGHT (mg/seed)
60
50
40
30
20
10
20
40
60
80
DAYS FROM ANTHESIS


B
GRAIN WEIGHT (mg/seed)
60
50
40
30
20
10
20
40
60
80
DAYS FROM ANTHESIS


C
GRAIN WEIGHT (mg/seed)
60
50
40
30
20
10
20
40
60
80
DAYS FROM ANTHESIS


D
GRAIN WEIGHT (mg/seed)
60
50
40
30
20
10
20
40
60
80
DAYS FROM ANTHESIS


E
GRAIN WEIGHT (mg/seed)
60
50
40
30
20
10
20
40
60
80
DAYS FROM ANTHESIS

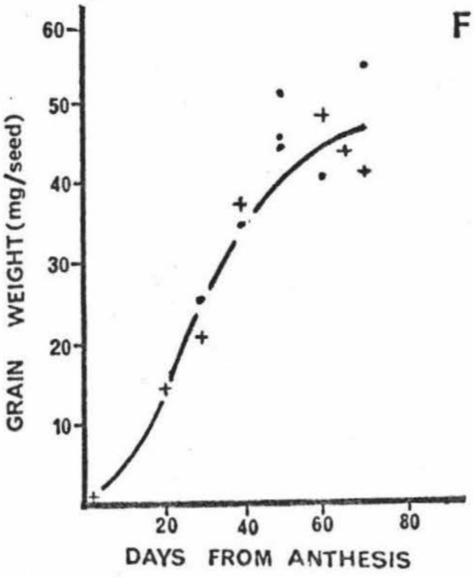

F
GRAIN WEIGHT (mg/seed)
60
50
40
30
20
10
20
40
60
80
DAYS FROM ANTHESIS

Figure A1.2.2 Changes in grain dry weight during grain development amongst six wheat cultivars in environment II (18-12°C; 0.4 kPa)

(A) Sonora

$R^2 = 0.9846$

(B) Timgalen

$R^2 = 0.9922$

(C) Pembina

$R^2 = 0.9943$

(D) Gamut

$R^2 = 0.9933$

(E) Sherbati-Sonora

$R^2 = 0.9885$

(F) Karamu

$R^2 = 0.9806$

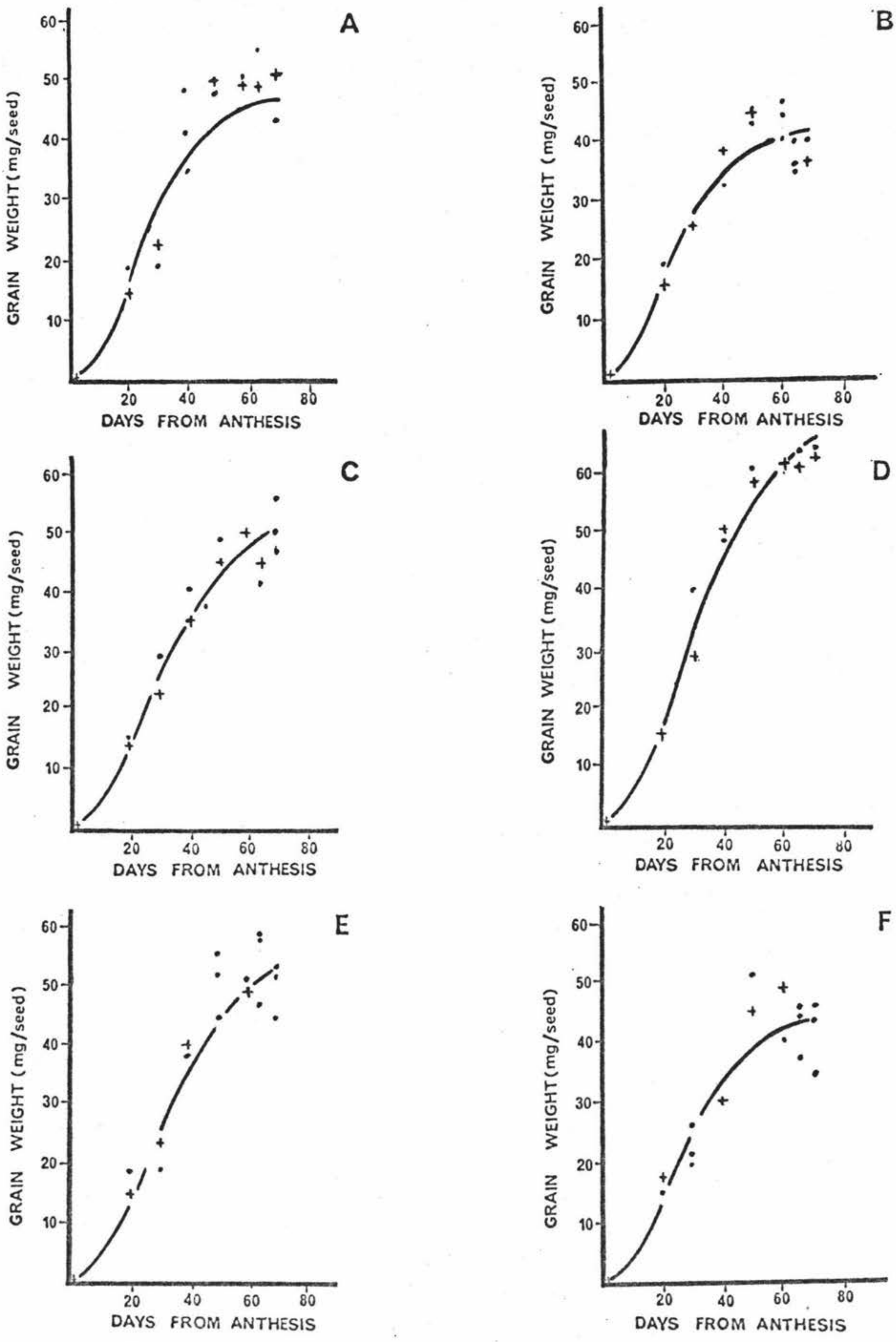

A
B
C
D
E
F
GRAIN WEIGHT (mg/seed)
DAYS FROM ANTHESIS
10
20
30
40
50
60
20
40
60
80

Figure A1.2.3 Changes in grain dry weight during grain development amongst six wheat cultivars in environment III (30-20°C; 1.0 kPa)

(A) Sonora

$R^2 = 0.9838$

(B) Timgalen

$R^2 = 0.9724$

(C) Pembina

$R^2 = 0.9836$

(D) Gamut

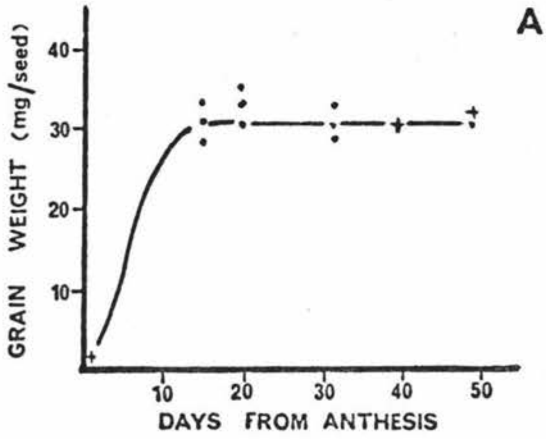
$R^2 = 0.9949$

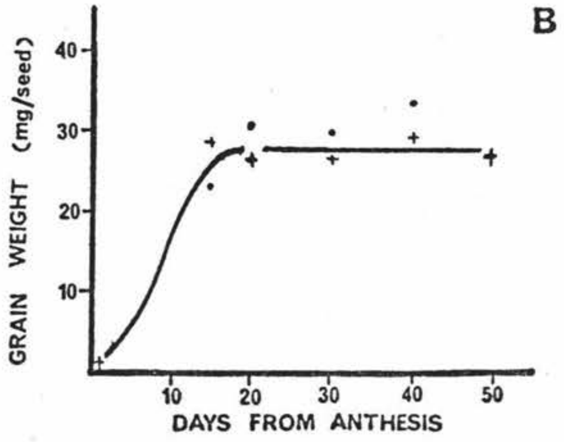
(E) Sherbati-Sonora

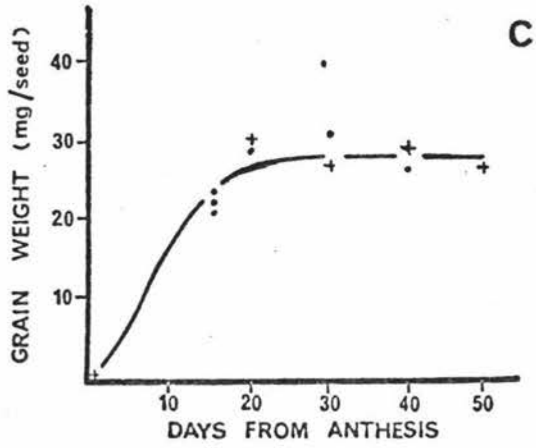
$R^2 = 0.9960$

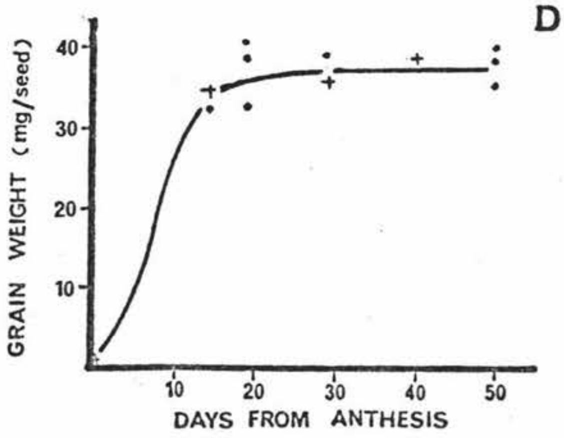
(F) Karamu

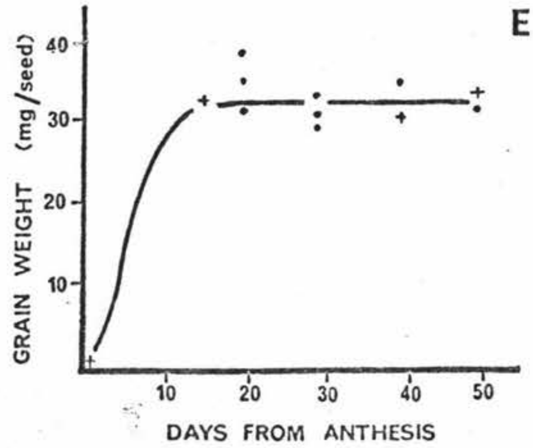
$R^2 = 0.9946$


A
GRAIN WEIGHT (mg/seed)
40
30
20
10
10
20
30
40
50
DAYS FROM ANTHESIS


B
GRAIN WEIGHT (mg/seed)
40
30
20
10
10
20
30
40
50
DAYS FROM ANTHESIS


C
GRAIN WEIGHT (mg/seed)
40
30
20
10
10
20
30
40
50
DAYS FROM ANTHESIS


D
GRAIN WEIGHT (mg/seed)
40
30
20
10
10
20
30
40
50
DAYS FROM ANTHESIS


E
GRAIN WEIGHT (mg/seed)
40
30
20
10
10
20
30
40
50
DAYS FROM ANTHESIS

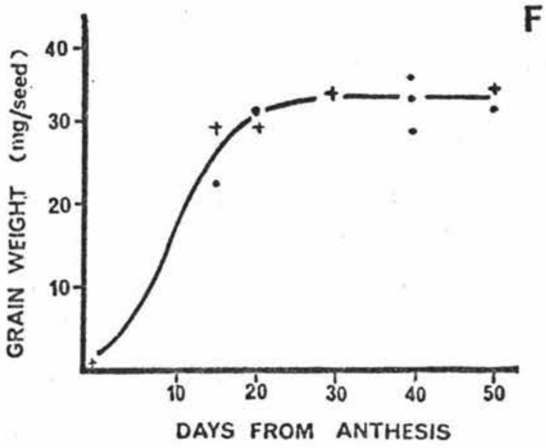

F
GRAIN WEIGHT (mg/seed)
40
30
20
10
10
20
30
40
50
DAYS FROM ANTHESIS

Figure A1.3.1 Development of pigmentation[1] during grain development amongst six wheat cultivars in environment I (18-12°C; 1.0 kPa)

(A) Sonora

$R^2 = 0.9038$

(B) Timgalen

$R^2 = 0.8016$

(C) Pembina

$R^2 = 0.8527$

(D) Gamut

$R^2 = 0.5840$

(E) Sherbati-Sonora

$R^2 = 0.8153$

(F) Karamu

$R^2 = 0.8625$

---

[1] white - red interface between 1.877 and 2.123

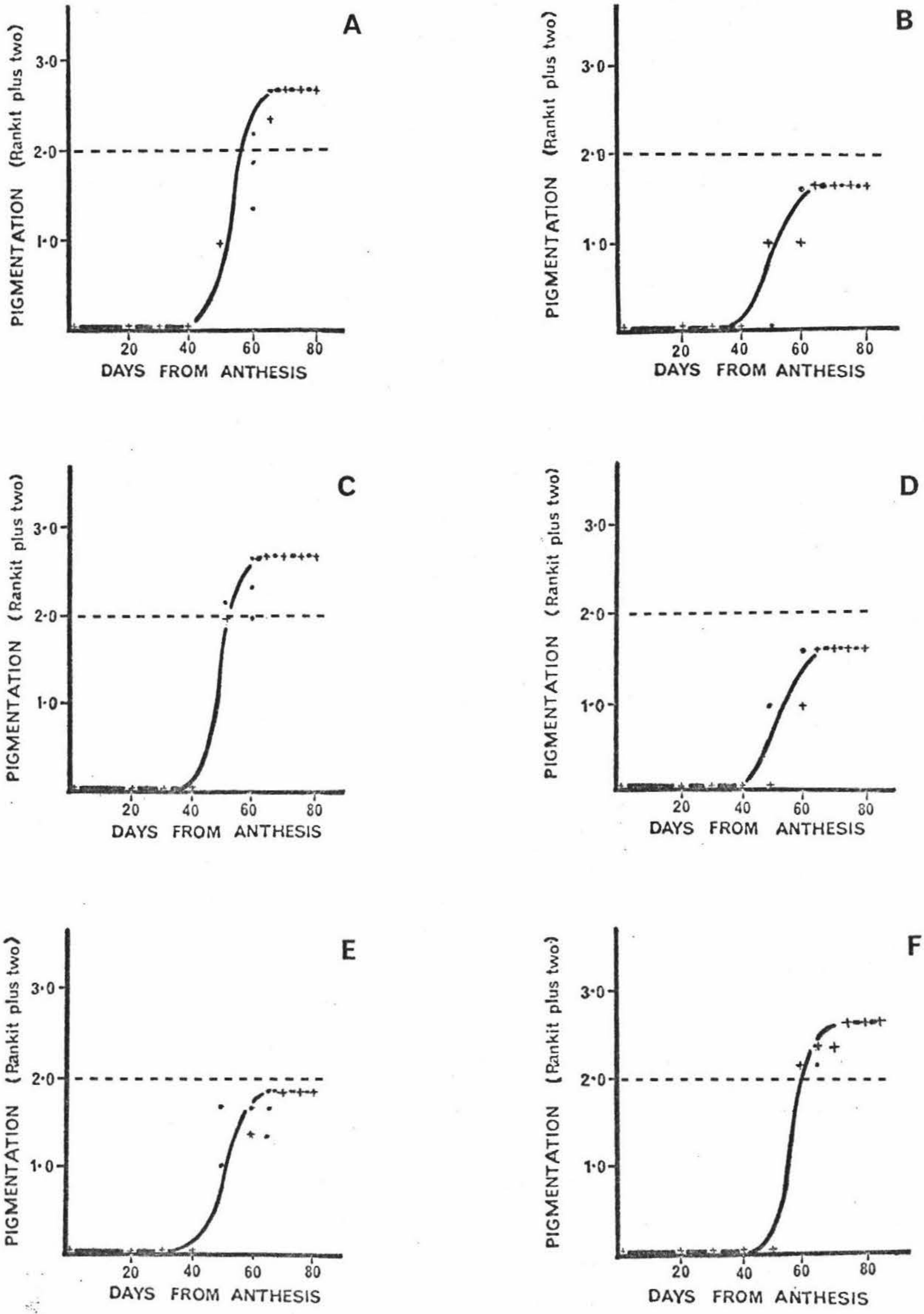

A
B
C
D
E
F
PIGMENTATION (Rankit plus two)
3·0
2·0
1·0
20
40
60
80
DAYS FROM ANTHESIS

Figure A1.3.2 Development of pigmentation[1] during grain development amongst six wheat cultivars in environment II (18-12°C; 0.4 kPa)

(A) Sonora

$R^2 = 0.8700$

(B) Timgalen

$R^2 = 0.7784$

(C) Pembina

$R^2 = 0.8844$

(D) Gamut

$R^2 = 0.7986$

(E) Sherbati-Sonora

$R^2 = 0.7419$

(F) Karamu

$R^2 = 0.8646$

[1] white - red interface between 1.877 and 2.123

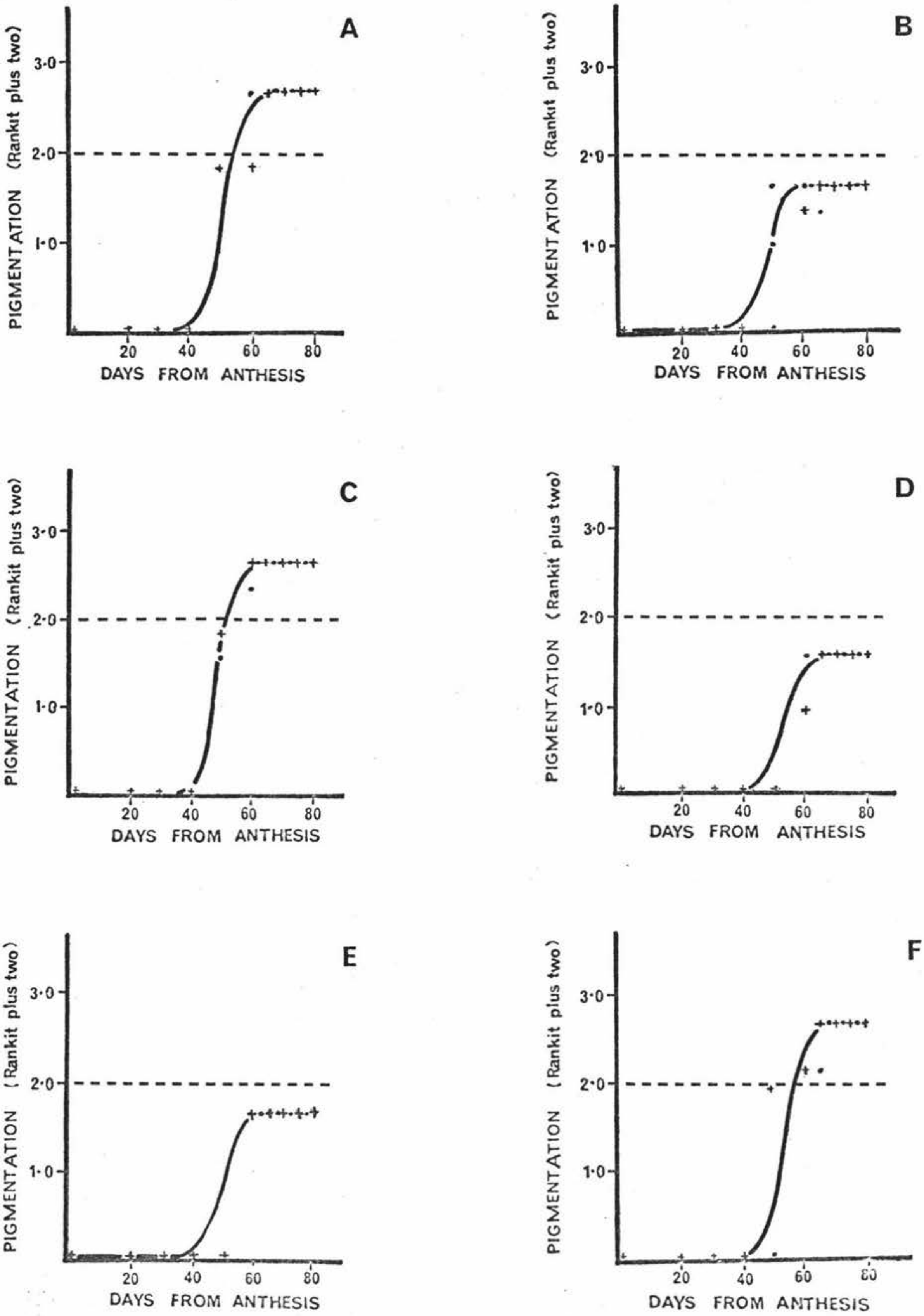

A
B
C
D
E
F
PIGMENTATION (Rankit plus two)
3·0
2·0
1·0
20
40
60
80
DAYS FROM ANTHESIS

Figure A1.3.3 Development of pigmentation[1] during grain development amongst six wheat cultivars in environment III (30-20°C; 1.0 kPa)

(A) Sonora

$R^2 = 0.7216$

(B) Timgalen

$R^2 = 0.7812$

(C) Pembina

$R^2 = 0.7409$

(D) Gamut

$R^2 = 0.7409$

(E) Sherbati-Sonora

$R^2 = 0.7249$

(F) Karamu

$R^2 = 0.7409$

---

[1] white - red interface between 1.877 and 2.123

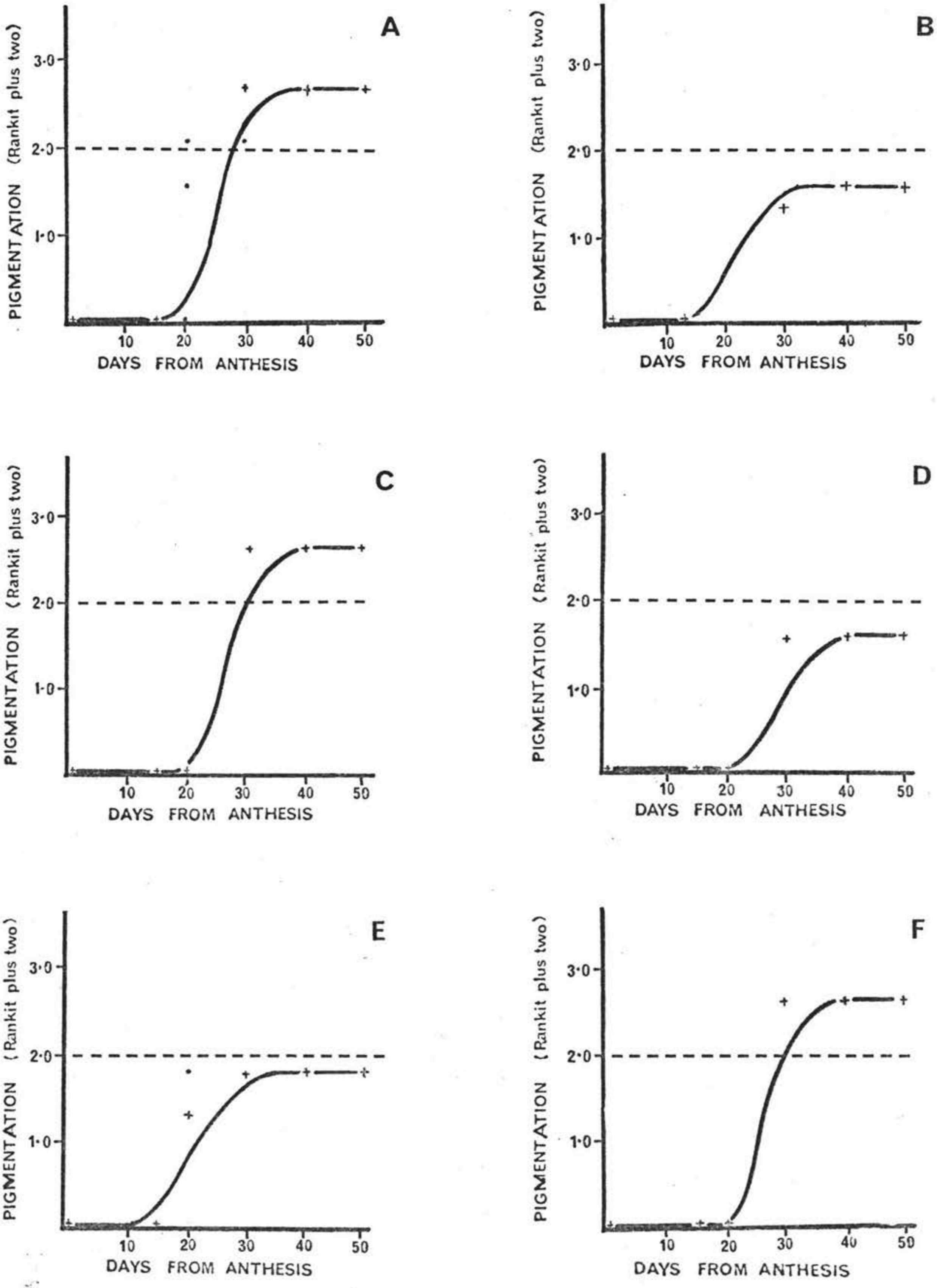

A
PIGMENTATION (Rankit plus two)
3·0
2·0
1·0
10
20
30
40
50
DAYS FROM ANTHESIS
B
PIGMENTATION (Rankit plus two)
3·0
2·0
1·0
10
20
30
40
50
DAYS FROM ANTHESIS
C
PIGMENTATION (Rankit plus two)
3·0
2·0
1·0
10
20
30
40
50
DAYS FROM ANTHESIS
D
PIGMENTATION (Rankit plus two)
3·0
2·0
1·0
10
20
30
40
50
DAYS FROM ANTHESIS
E
PIGMENTATION (Rankit plus two)
3·0
2·0
1·0
10
20
30
40
50
DAYS FROM ANTHESIS
F
PIGMENTATION (Rankit plus two)
3·0
2·0
1·0
10
20
30
40
50
DAYS FROM ANTHESIS

Figure A1.4.1 Changes in flavan-3-ol concentration during grain development amongst six wheat cultivars in environment I (18-12°C; 1.0 kPa)

(A) Sonora

$R^2 = 0.3155$

(B) Timgalen

$R^2 = 0.4448$

(C) Pembina

$R^2 = 0.4554$

(D) Gamut

$R^2 = 0.3797$

(E) Sherbati-Sonora

$R^2 = 0.5049$

(F) Karamu

$R^2 = 0.7652$

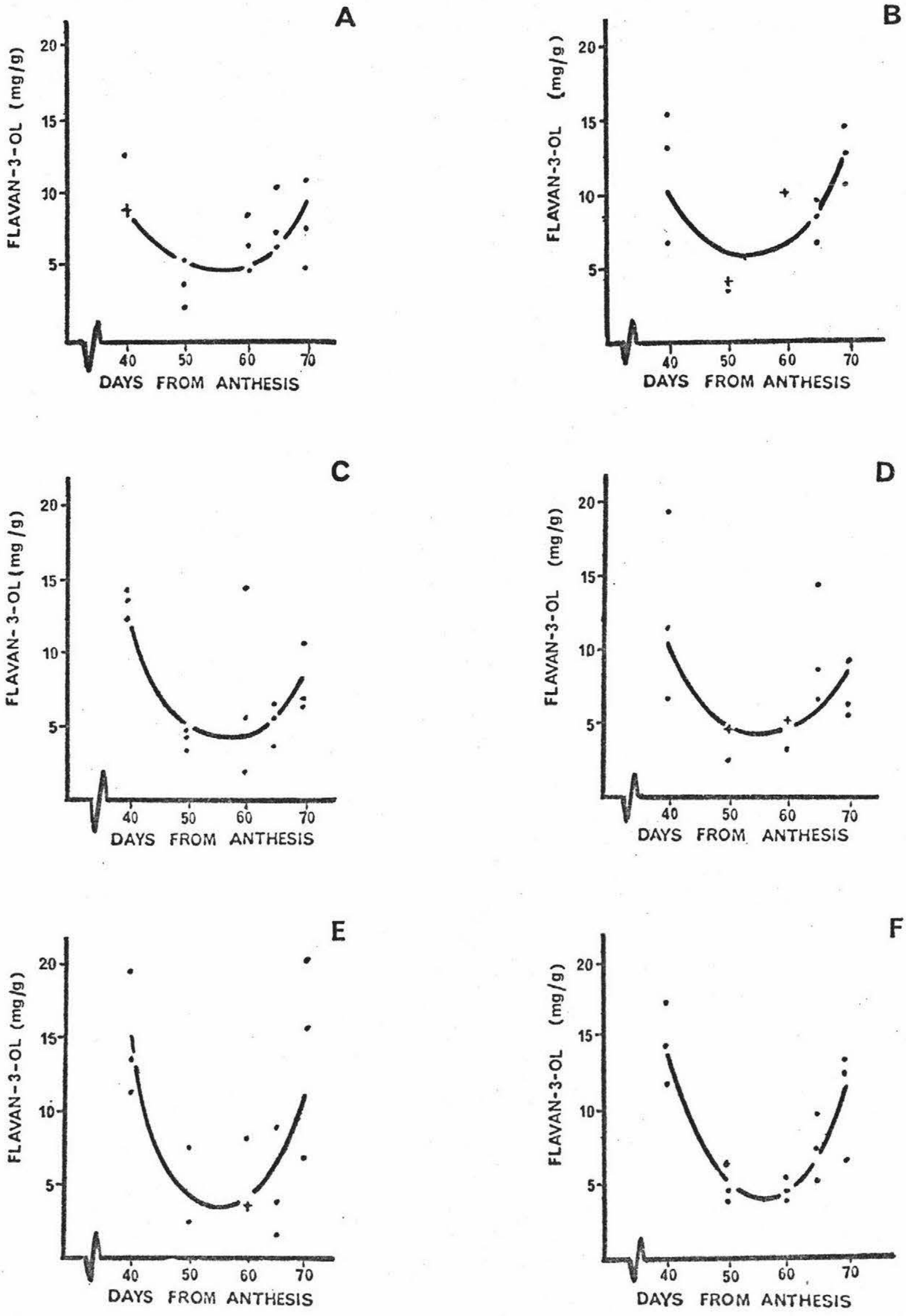

A
B
C
D
E
F
FLAVAN-3-OL (mg/g)
20
15
10
5
40
50
60
70
DAYS FROM ANTHESIS

Figure A1.4.2 Changes in flavan-3-ol concentration during grain development amongst six wheat cultivars in environment II (18-12°C; 0.4 kPa)

(A) Sonora

$R^2 = 0.6958$

(B) Timgalen

$R^2 = 0.8581$

(C) Pembina

$R^2 = 0.8021$

(D) Gamut

$R^2 = 0.8114$

(E) Sherbati-Sonora

$R^2 = 0.7750$

(F) Karamu

$R^2 = 0.6181$

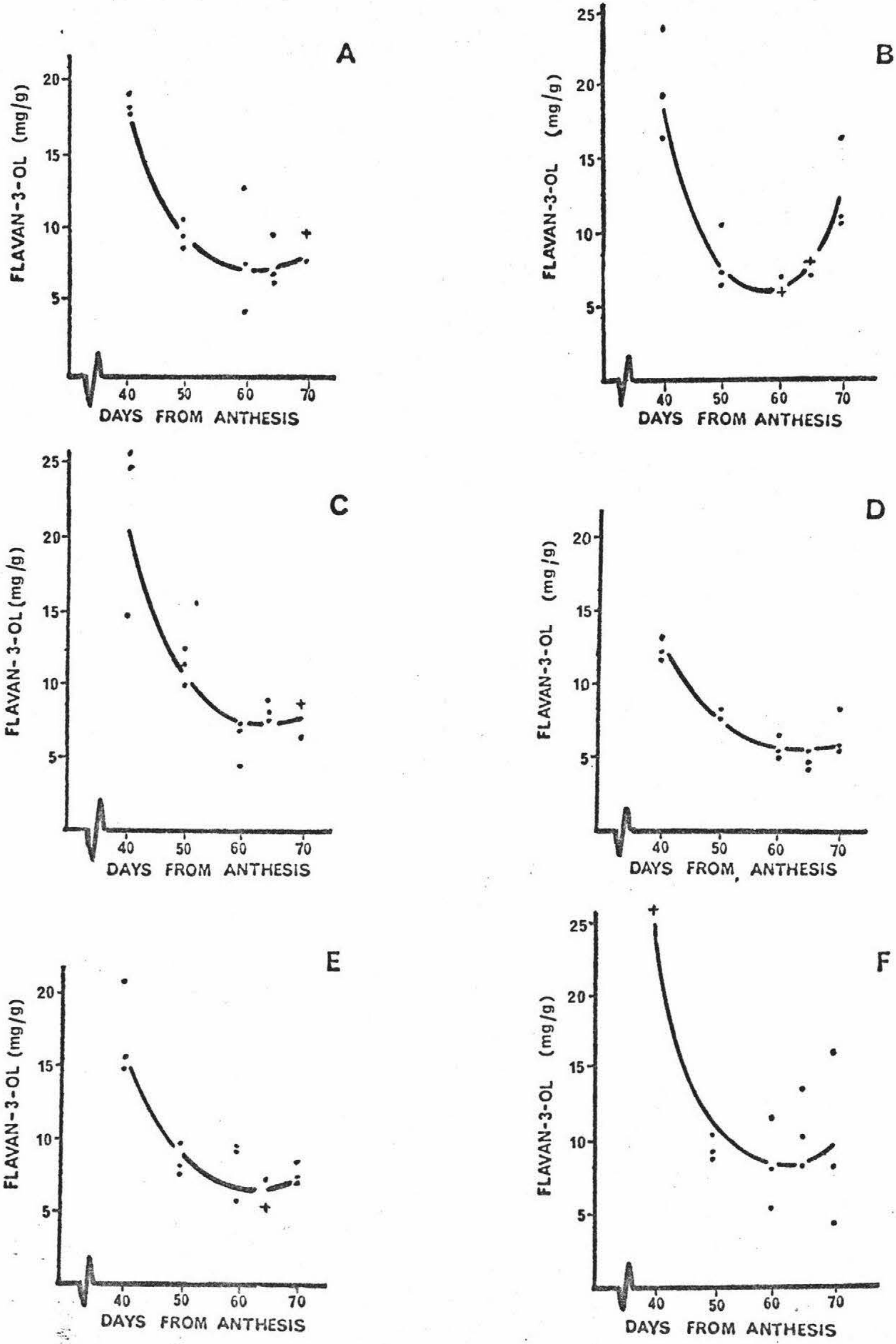

A
FLAVAN-3-OL (mg/g)
20
15
10
5
40
50
60
70
DAYS FROM ANTHESIS
B
FLAVAN-3-OL (mg/g)
25
20
15
10
5
40
50
60
70
DAYS FROM ANTHESIS
C
FLAVAN-3-OL (mg/g)
25
20
15
10
5
40
50
60
70
DAYS FROM ANTHESIS
D
FLAVAN-3-OL (mg/g)
20
15
10
5
40
50
60
70
DAYS FROM ANTHESIS
E
FLAVAN-3-OL (mg/g)
20
15
10
5
40
50
60
70
DAYS FROM ANTHESIS
F
FLAVAN-3-OL (mg/g)
25
20
15
10
5
40
50
60
70
DAYS FROM ANTHESIS

Figure A1.4.3 Changes in flavan-3-ol concentration during grain development amongst six wheat cultivars in environment

(A) Sonora

$R^2 = 0.9208$

(B) Timgalen

$R^2 = 0.9505$

(C) Pembina

$R^2 = 0.6959$

(D) Gamut

$R^2 = 0.6959$

(E) Sherbati-Sonora

$R^2 = 0.8187$

(F) Karamu

$R^2 = 0.6875$

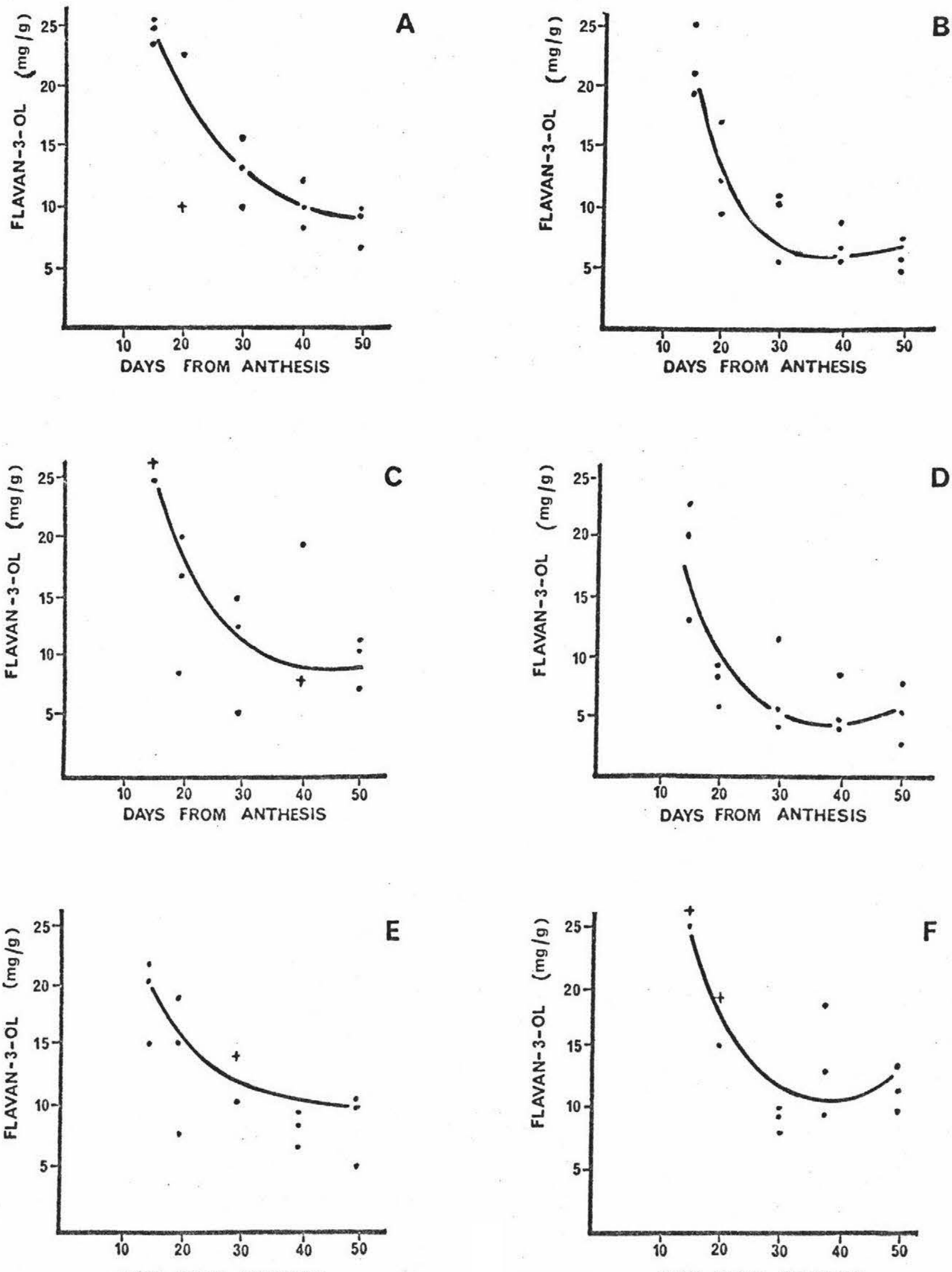

A
FLAVAN-3-OL (mg/g)
25
20
15
10
5
10
20
30
40
50
DAYS FROM ANTHESIS
B
FLAVAN-3-OL (mg/g)
25
20
15
10
5
10
20
30
40
50
DAYS FROM ANTHESIS
C
FLAVAN-3-OL (mg/g)
25
20
15
10
5
10
20
30
40
50
DAYS FROM ANTHESIS
D
FLAVAN-3-OL (mg/g)
25
20
15
10
5
10
20
30
40
50
DAYS FROM ANTHESIS
E
FLAVAN-3-OL (mg/g)
25
20
15
10
5
10
20
30
40
50
DAYS FROM ANTHESIS
F
FLAVAN-3-OL (mg/g)
25
20
15
10
5
10
20
30
40
50
DAYS FROM ANTHESIS

Figure A1.5.1 Changes in germination during grain development amongst six wheat cultivars in environment I (18-12°C; 1.0 kPa).

(A) Sonora

$R^2 = 0.8859$

(B) Timgalen

$R^2 = 8828$

(C) Pembina

No equation

(D) Gamut

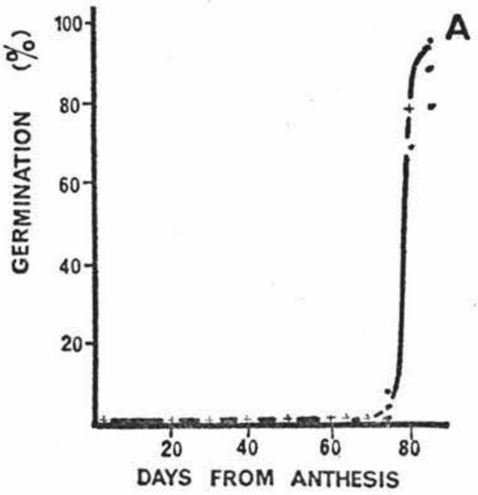
$R^2 = 0.9086$

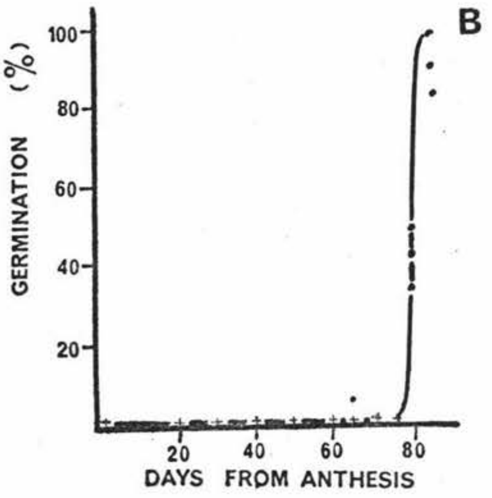
(E) Sherbati-Sonora

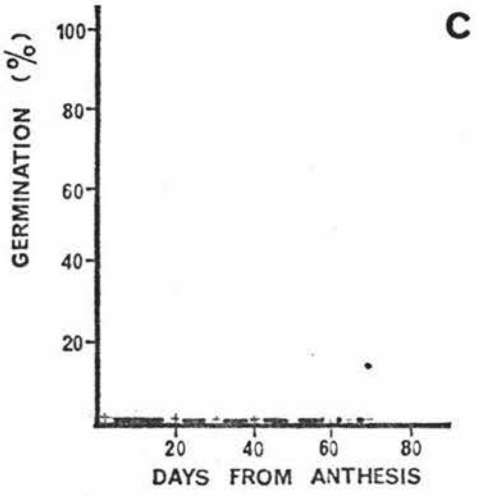
$R^2 = 0.8980$

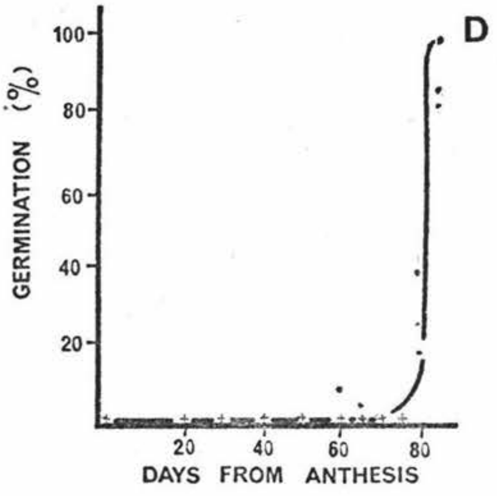
(F) Karamu

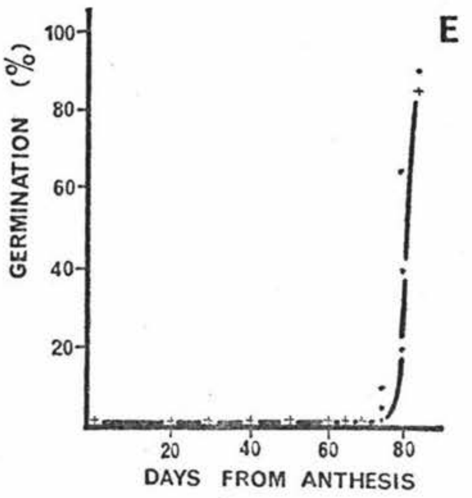
$R^2 = 0.5949$


A
GERMINATION (%)
100
80
60
40
20
20
40
60
80
DAYS FROM ANTHESIS


B
GERMINATION (%)
100
80
60
40
20
20
40
60
80
DAYS FROM ANTHESIS


C
GERMINATION (%)
100
80
60
40
20
20
40
60
80
DAYS FROM ANTHESIS


D
GERMINATION (%)
100
80
60
40
20
20
40
60
80
DAYS FROM ANTHESIS


E
GERMINATION (%)
100
80
60
40
20
20
40
60
80
DAYS FROM ANTHESIS

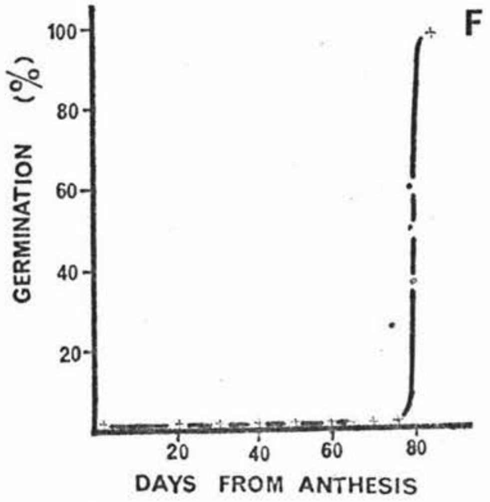

F
GERMINATION (%)
100
80
60
40
20
20
40
60
80
DAYS FROM ANTHESIS

Figure A1.5.2 Changes in germination during grain development amongst six wheat cultivars in environment II (18-12°C; 0.4 kPa)

(A) Sonora

$R^2 = 0.9873$

(B) Timgalen

$R^2 = 0.7961$

(C) Pembina

No equation

(D) Gamut

No equation

(E) Sherbati-Sonora

$R^2 = 0.8304$

(F) Karamu

$R^2 = 0.9991$

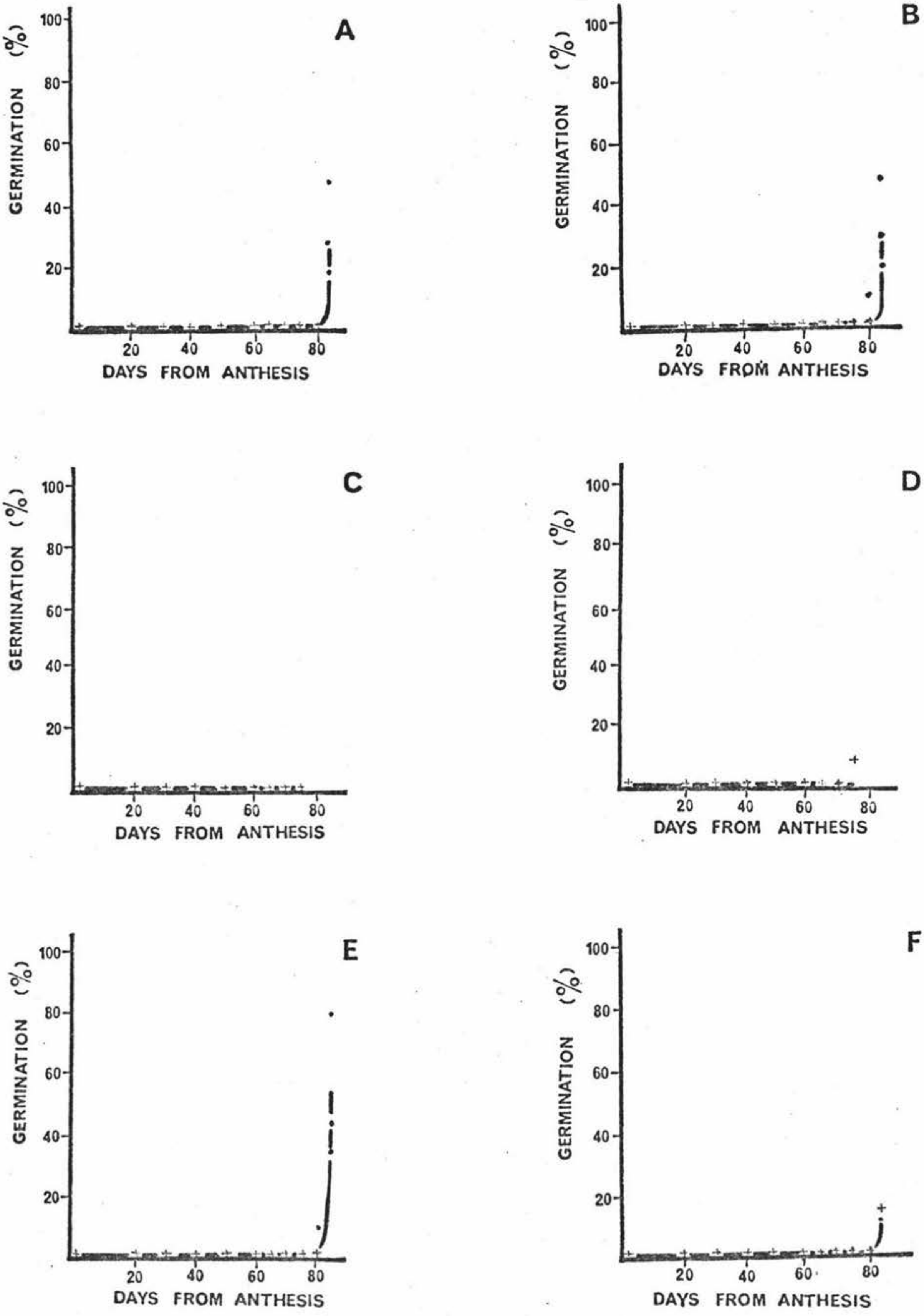

A
B
C
D
E
F
GERMINATION (%)
100
80
60
40
20
DAYS FROM ANTHESIS
20
40
60
80

Figure A1.5.3 Changes in germination during grain development amongst six wheat cultivars in environment III (30-20°C; 1.0 kPa)

(A) Sonora

$R^2 = 0.9747$

(B) Timgalen

$R^2 = 0.9431$

(C) Pembina

$R^2 = 0.9680$

(D) Gamut

$R^2 = 0.9165$

(E) Sherbati-Sonora

$R^2 = 0.9566$

(F) Karamu

$R^2 = 0.8245$

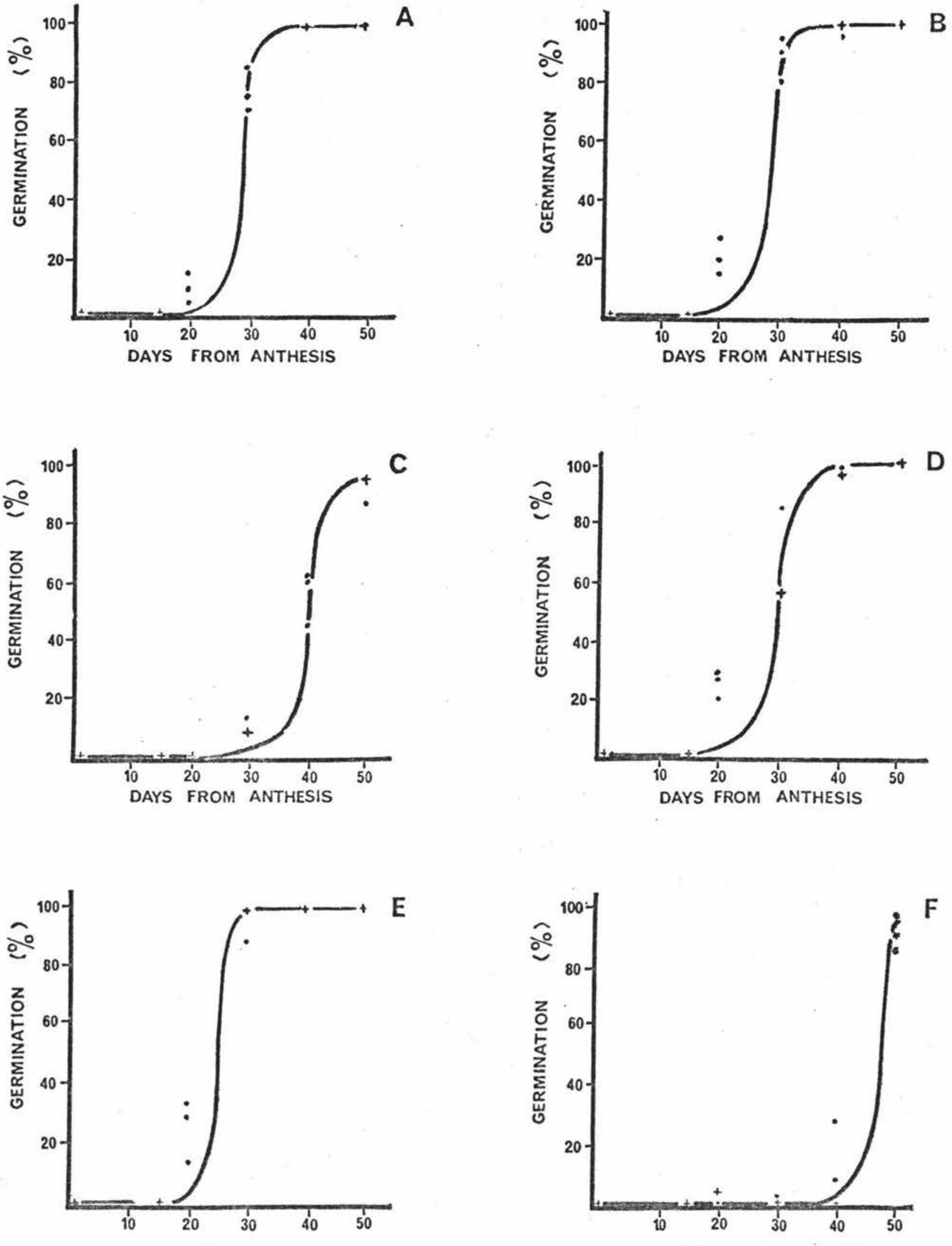

A
B
C
D
E
F
GERMINATION (%)
100
80
60
40
20
10
20
30
40
50
DAYS FROM ANTHESIS

Figure A1.6.1 Changes in embryo maturity during grain development amongst six wheat cultivars in environment I (18-17°C; 1.0 kPa)

(A) Sonora

$R^2 = 0.8999$

(B) Timgalen

$R^2 = 0.8999$

(C) Pembina

No equation

(D) Gamut

$R^2 = 0.8980$

(E) Sherbati-Sonora

$R^2 = 0.8501$

(F) Karamu

$R^2 = 0.9258$

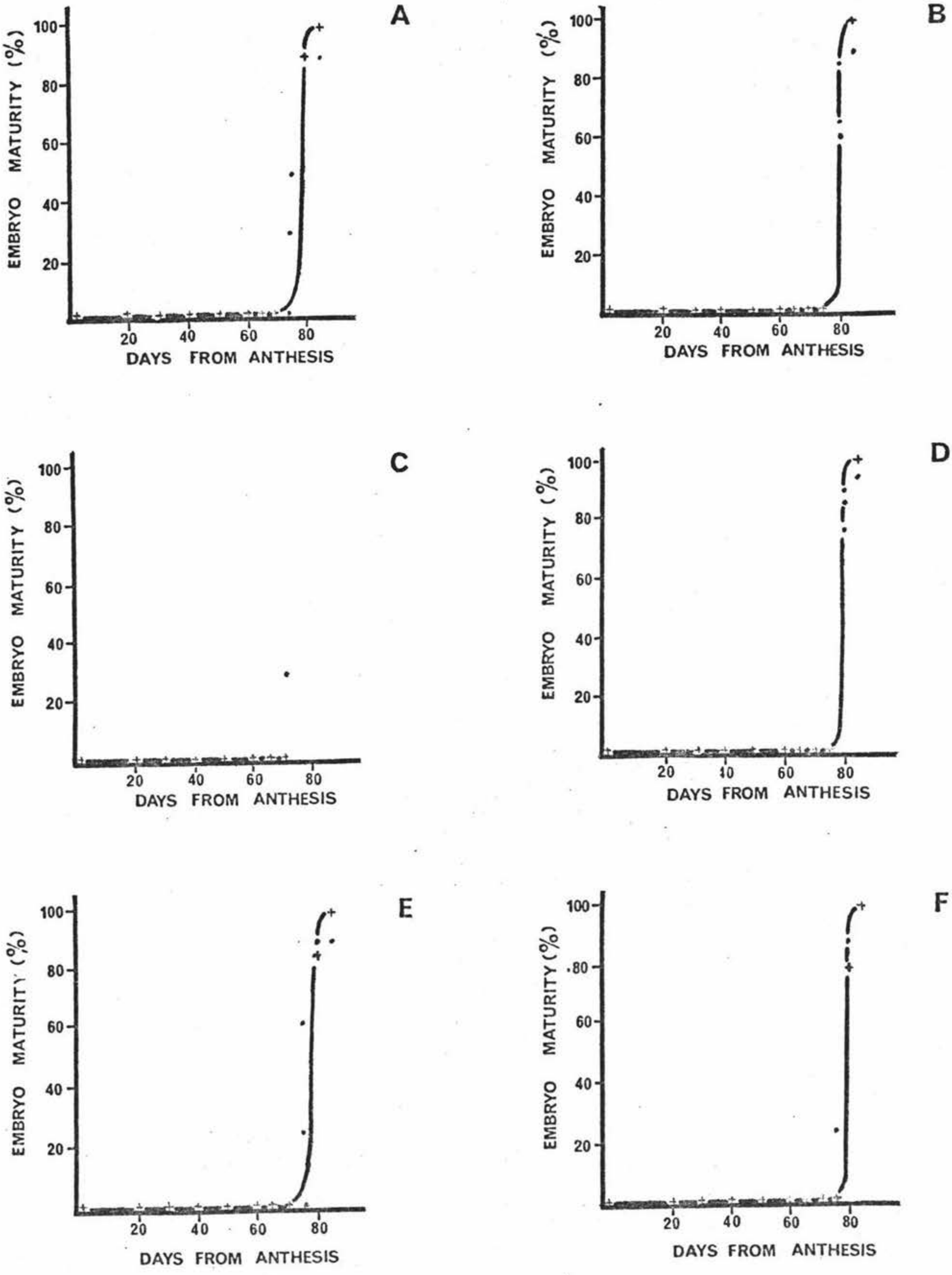

A
EMBRYO MATURITY (%)
100
80
60
40
20
20
40
60
80
DAYS FROM ANTHESIS
B
EMBRYO MATURITY (%)
100
80
60
40
20
20
40
60
80
DAYS FROM ANTHESIS
C
EMBRYO MATURITY (%)
100
80
60
40
20
20
40
60
80
DAYS FROM ANTHESIS
D
EMBRYO MATURITY (%)
100
80
60
40
20
20
40
60
80
DAYS FROM ANTHESIS
E
EMBRYO MATURITY (%)
100
80
60
40
20
20
40
60
80
DAYS FROM ANTHESIS
F
EMBRYO MATURITY (%)
100
80
60
40
20
20
40
60
80
DAYS FROM ANTHESIS

Figure A1.6.2 Changes in embryo maturity during grain development amongst six wheat cultivars in environment II (18-12°C; 0.4 kPa)

(A) Sonora

$R^2 = 0.9931$

(B) Timgalen

$R^2 = 0.7661$

(C) Pembina

No equation

(D) Gamut

No equation

(E) Sherbati-Sonora

$R^2 = 0.8360$

(F) Karamu

$R^2 = 0.9986$

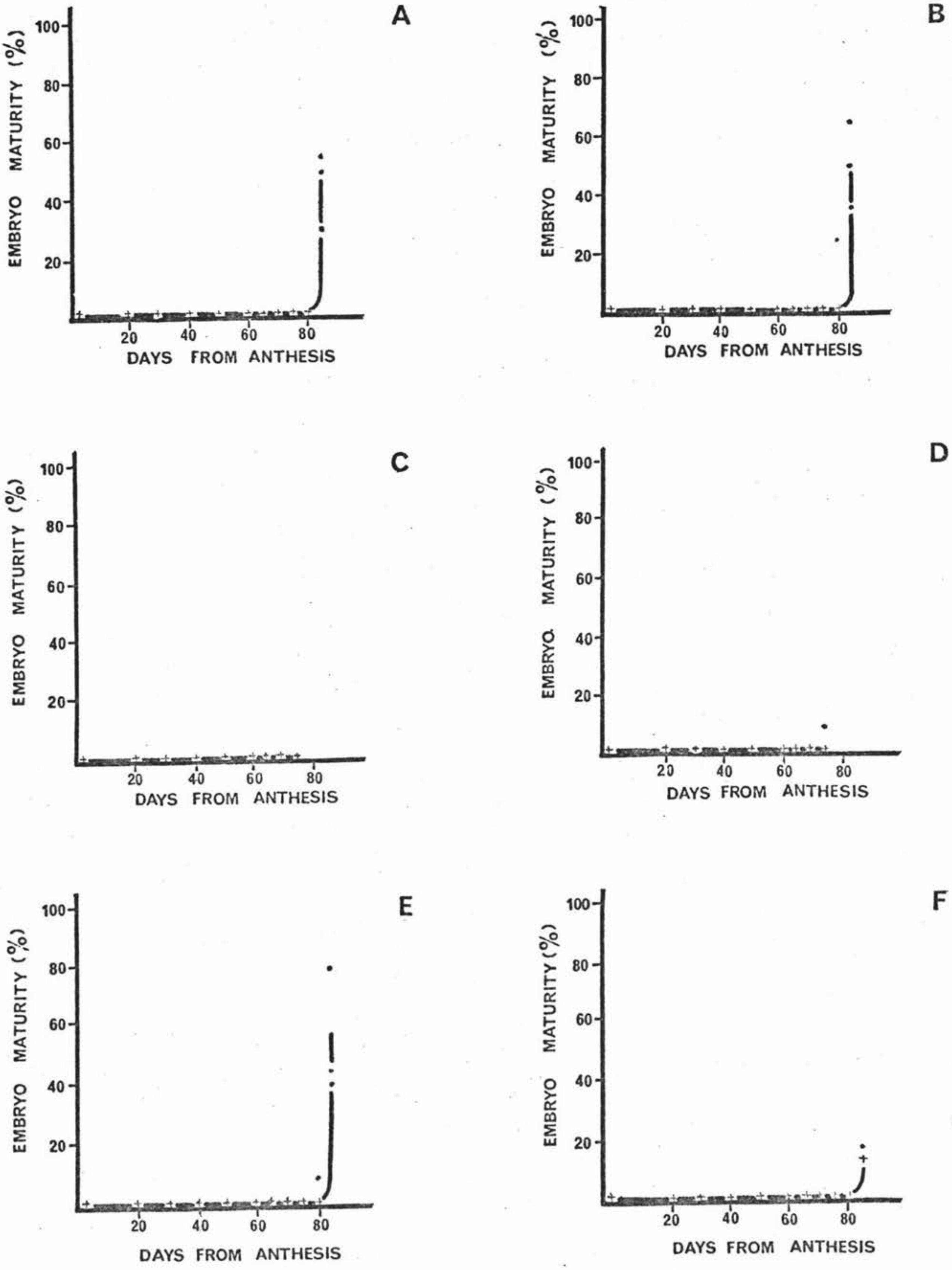

A
EMBRYO MATURITY (%)
100
80
60
40
20
20
40
60
80
DAYS FROM ANTHESIS
B
EMBRYO MATURITY (%)
100
80
60
40
20
20
40
60
80
DAYS FROM ANTHESIS
C
EMBRYO MATURITY (%)
100
80
60
40
20
20
40
60
80
DAYS FROM ANTHESIS
D
EMBRYO MATURITY (%)
100
80
60
40
20
20
40
60
80
DAYS FROM ANTHESIS
E
EMBRYO MATURITY (%)
100
80
60
40
20
20
40
60
80
DAYS FROM ANTHESIS
F
EMBRYO MATURITY (%)
100
80
60
40
20
20
40
60
80
DAYS FROM ANTHESIS

Figure A1.6.3 Changes in embryo maturity during grain development amongst six wheat cultivars in environment III (30-20°C; 1.0 kPa)

(A) Sonora

$R^2 = 0.9572$

(B) Timgalen

$R^2 = 0.9396$

(C) Pembina

$R^2 = 0.9295$

(D) Gamut

$R^2 = 0.9316$

(E) Sherbati-Sonora

$R^2 = 0.9745$

(F) Karamu

$R^2 = 0.9186$

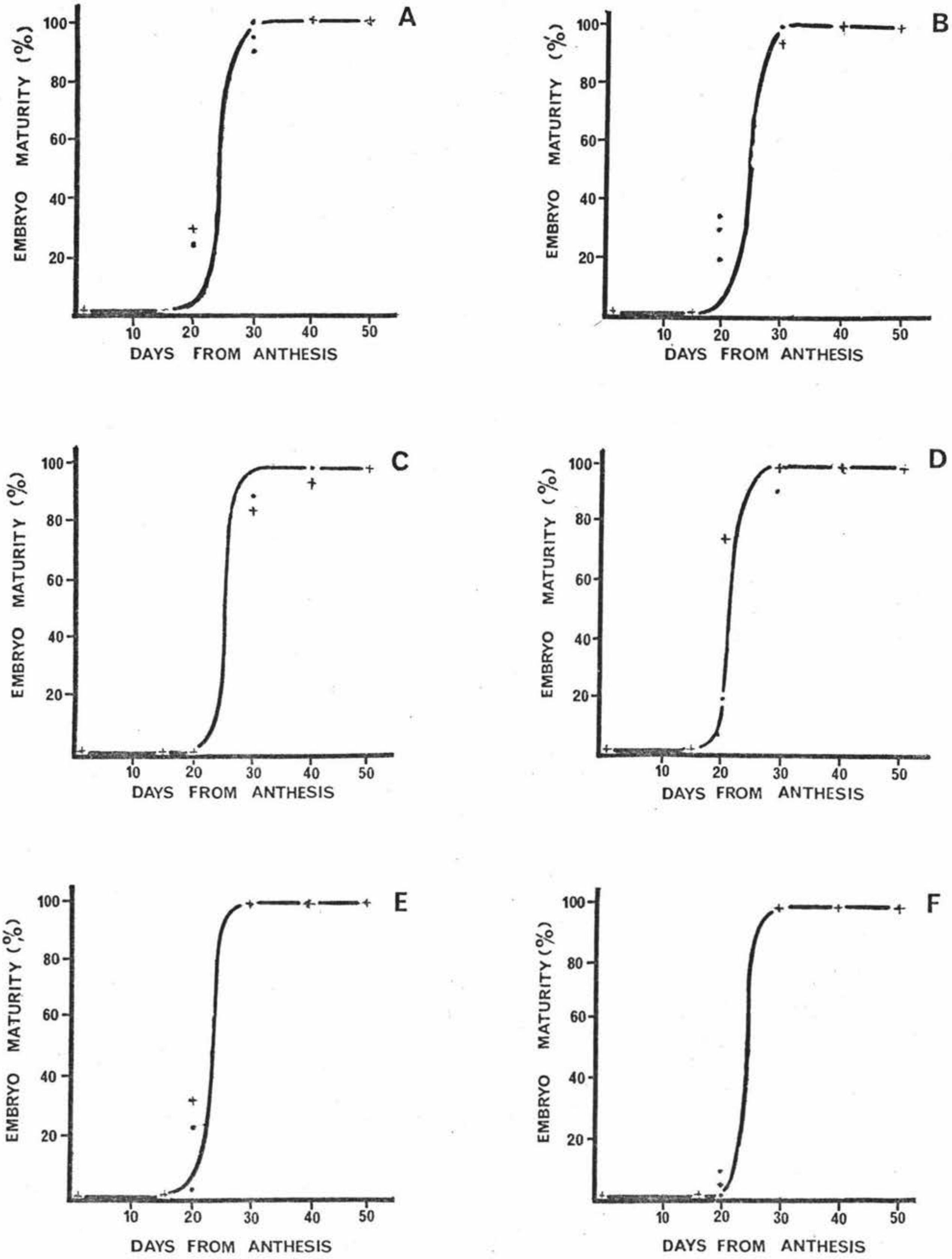

A
EMBRYO MATURITY (%)
20
40
60
80
100
10
20
30
40
50
DAYS FROM ANTHESIS
B
EMBRYO MATURITY (%)
20
40
60
80
100
10
20
30
40
50
DAYS FROM ANTHESIS
C
EMBRYO MATURITY (%)
20
40
60
80
100
10
20
30
40
50
DAYS FROM ANTHESIS
D
EMBRYO MATURITY (%)
20
40
60
80
100
10
20
30
40
50
DAYS FROM ANTHESIS
E
EMBRYO MATURITY (%)
20
40
60
80
100
10
20
30
40
50
DAYS FROM ANTHESIS
F
EMBRYO MATURITY (%)
20
40
60
80
100
10
20
30
40
50
DAYS FROM ANTHESIS

Figure A1.7.1 Changes in embryo dormancy during grain development amongst six wheat cultivars in environment I (18-12°C; 1.0 kPa)

(A) Sonora

$R^2 = 0.8680$

(B) Timgalen

$R^2 = 0.8800$

(C) Pembina

No equation

(D) Gamut

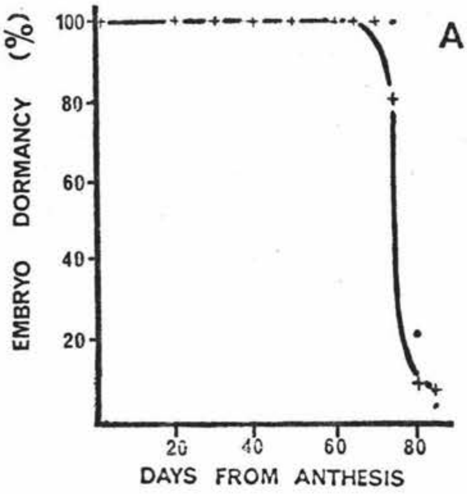
$R^2 = 0.9163$

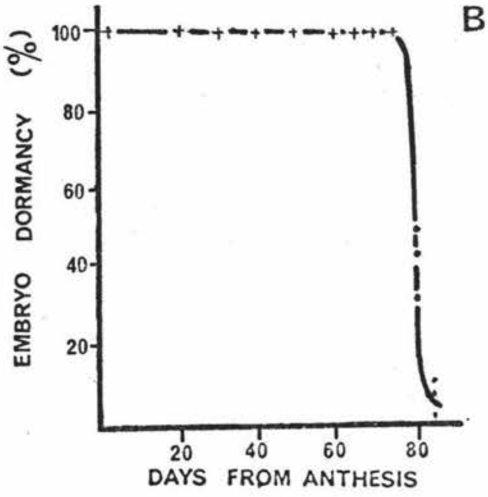
(E) Sherbati-Sonora

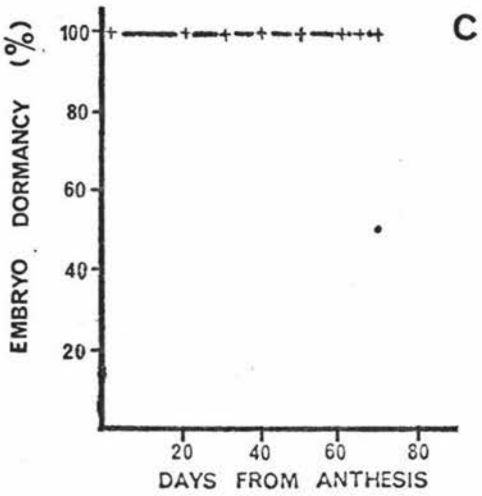
$R^2 = 0.8690$

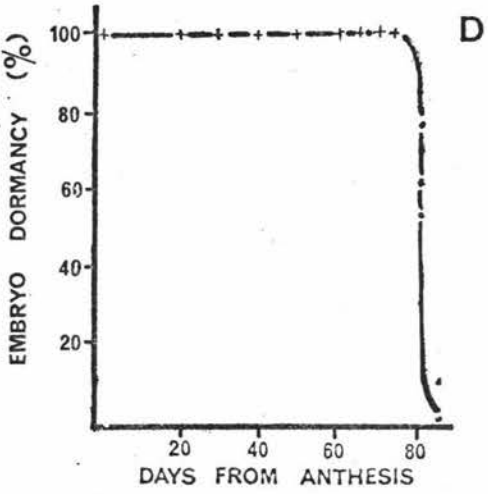
(F) Karamu

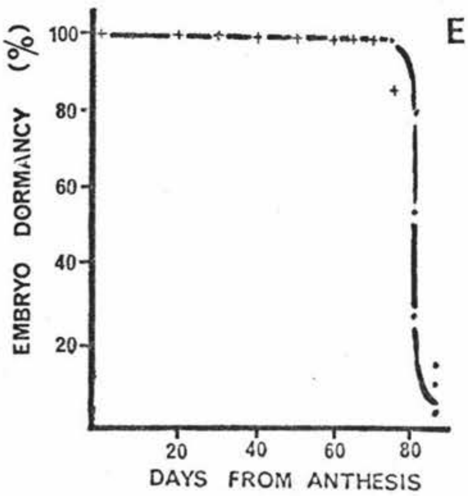
$R^2 = 0.6156$


A
EMBRYO DORMANCY (%)
100
80
60
40
20
20
40
60
80
DAYS FROM ANTHESIS


B
EMBRYO DORMANCY (%)
100
80
60
40
20
20
40
60
80
DAYS FROM ANTHESIS


C
EMBRYO DORMANCY (%)
100
80
60
40
20
20
40
60
80
DAYS FROM ANTHESIS


D
EMBRYO DORMANCY (%)
100
80
60
40
20
20
40
60
80
DAYS FROM ANTHESIS


E
EMBRYO DORMANCY (%)
100
80
60
40
20
20
40
60
80
DAYS FROM ANTHESIS

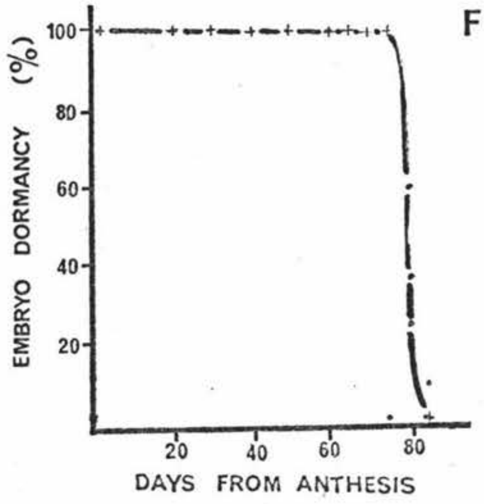

F
EMBRYO DORMANCY (%)
100
80
60
40
20
20
40
60
80
DAYS FROM ANTHESIS

Figure A1.7.2 Changes in embryo dormancy during grain development amongst six wheat cultivars in environment II (18-12°C; 0.4 kPa)

(A) Sonora

$R^2 = 0.8852$

(B) Timgalen

$R^2 = 0.7183$

(C) Pembina

No equation

(D) Gamut

No equation

(E) Sherbati-Sonora

$R^2 = 0.6116$

(F) Karamu

$R^2 = 0.9059$

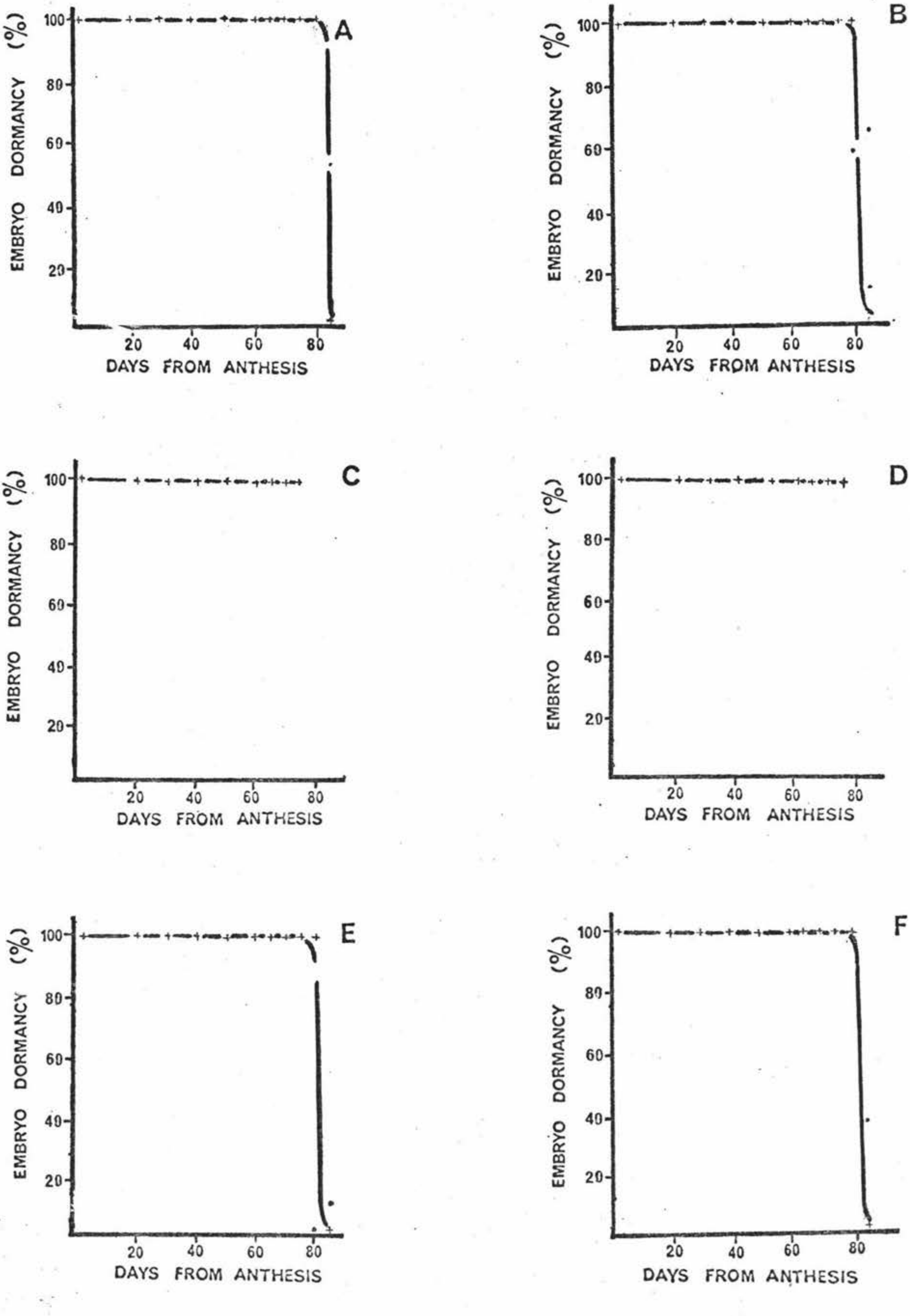

A
B
C
D
E
F
EMBRYO DORMANCY (%)
100
80
60
40
20
20
40
60
80
DAYS FROM ANTHESIS

Figure A1.7.3 Changes in embryo dormancy during grain development amongst six wheat cultivars in environment III (30-20°C; 1.0 kPa)

(A) Sonora

$R^2 = 0.9389$

(B) Timgalen

$R^2 = 0.7054$

(C) Pembina

$R^2 = 0.9572$

(D) Gamut

$R^2 = 0.7151$

(E) Sherbati-Sonora

$R^2 = 0.7959$

(F) Karamu

$R^2 = 0.6476$

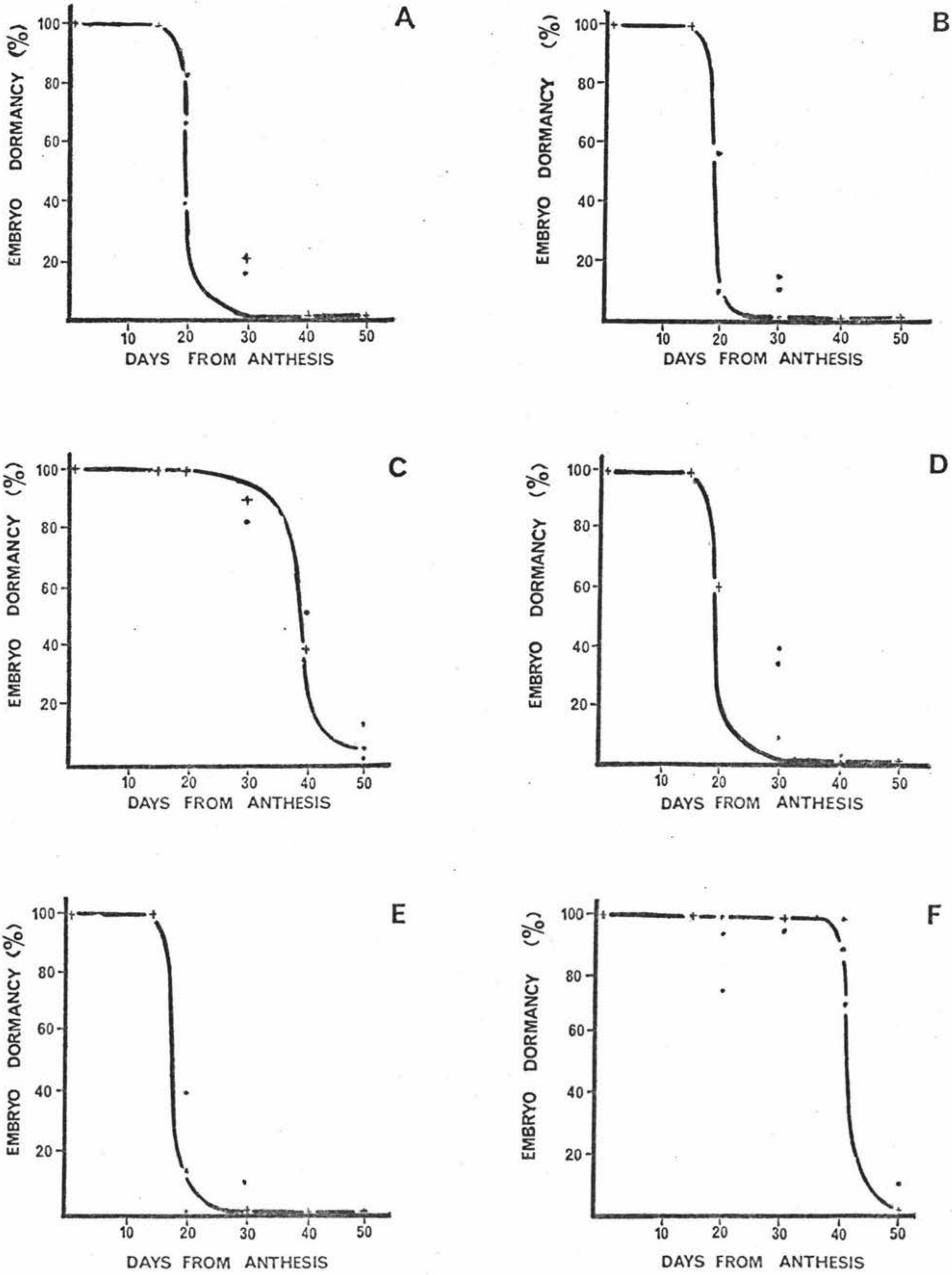

A
B
C
D
E
F
EMBRYO DORMANCY (%)
100
80
60
40
20
10
20
30
40
50
DAYS FROM ANTHESIS

Figure A1.8.1 Changes in basal alpha-amylase activity during grain development amongst six wheat cultivars in environment I (18-12°C; 1.0 kPa)

(A) Sonora

$R^2 = 0.8384$

(B) Timgalen

$R^2 = 0.8902$

(C) Pembina

$R^2 = 0.7839$

(D) Gamut

$R^2 = 0.6994$

(E) Sherbati-Sonora

$R^2 = 0.9281$

(F) Karamu

$R^2 = 0.9823$

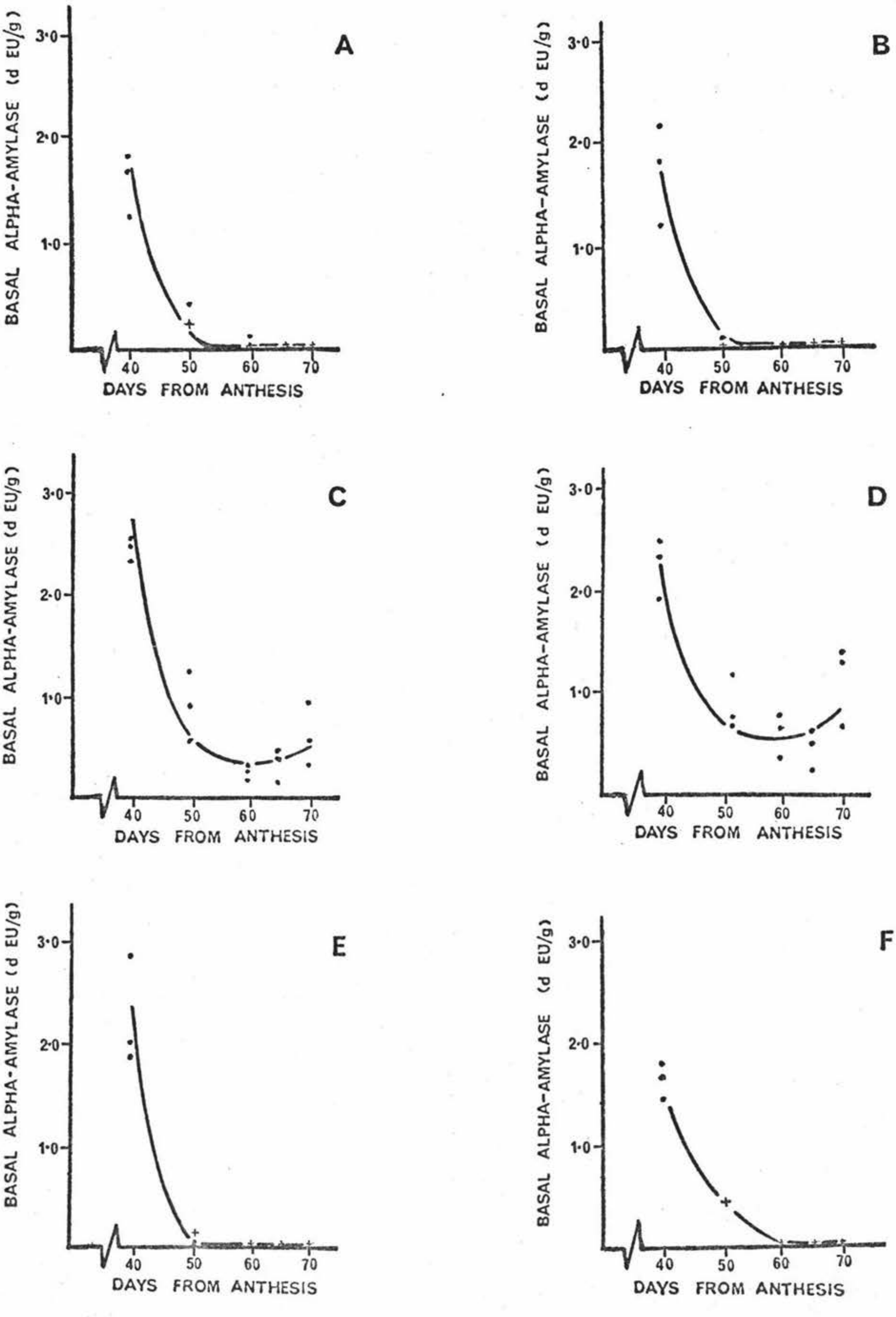

A
BASAL ALPHA-AMYLASE (d EU/g)
3·0
2·0
1·0
40
50
60
70
DAYS FROM ANTHESIS
B
BASAL ALPHA-AMYLASE (d EU/g)
3·0
2·0
1·0
40
50
60
70
DAYS FROM ANTHESIS
C
BASAL ALPHA-AMYLASE (d EU/g)
3·0
2·0
1·0
40
50
60
70
DAYS FROM ANTHESIS
D
BASAL ALPHA-AMYLASE (d EU/g)
3·0
2·0
1·0
40
50
60
70
DAYS FROM ANTHESIS
E
BASAL ALPHA-AMYLASE (d EU/g)
3·0
2·0
1·0
40
50
60
70
DAYS FROM ANTHESIS
F
BASAL ALPHA-AMYLASE (d EU/g)
3·0
2·0
1·0
40
50
60
70
DAYS FROM ANTHESIS

Figure A1.8.2 Changes in basal alpha-amylase activity during grain development amongst six wheat cultivars in environment II (18-12°C; 0.4 kPa)

(A) Sonora

$R^2 = 0.7687$

(B) Timgalen

$R^2 = 0.8328$

(C) Pembina

$R^2 = 0.7447$

(D) Gamut

$R^2 = 0.8138$

(E) Sherbati-Sonora

$R^2 = 0.9026$

(F) Karamu

$R^2 = 0.9227$

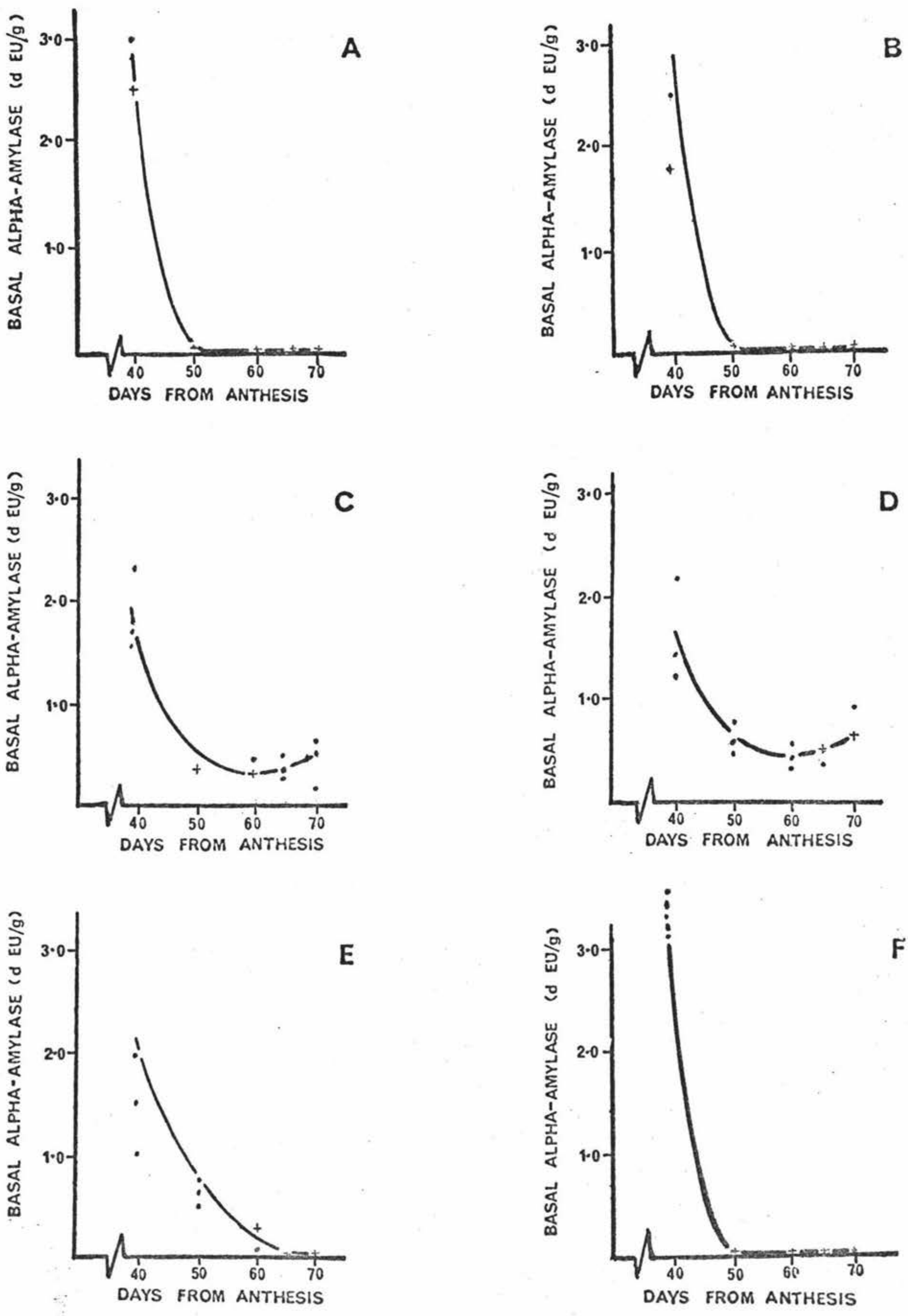

A
B
C
D
E
F
BASAL ALPHA-AMYLASE (d EU/g)
3·0
2·0
1·0
40
50
60
70
DAYS FROM ANTHESIS

Figure A1.8.3 Changes in basal alpha amylase activity during grain development amongst six wheat cultivars in environment III (30-20°C; 1.0 kPa)

(A) Sonora

$R^2 = 0.9056$

(B) Timgalen

$R^2 = 0.9386$

(C) Pembina

$R^2 = 0.8449$

(D) Gamut

$R^2 = 0.9825$

(E) Sherbati-Sonora

$R^2 = 0.9812$

(F) Karamu

$R^2 = 0.6623$

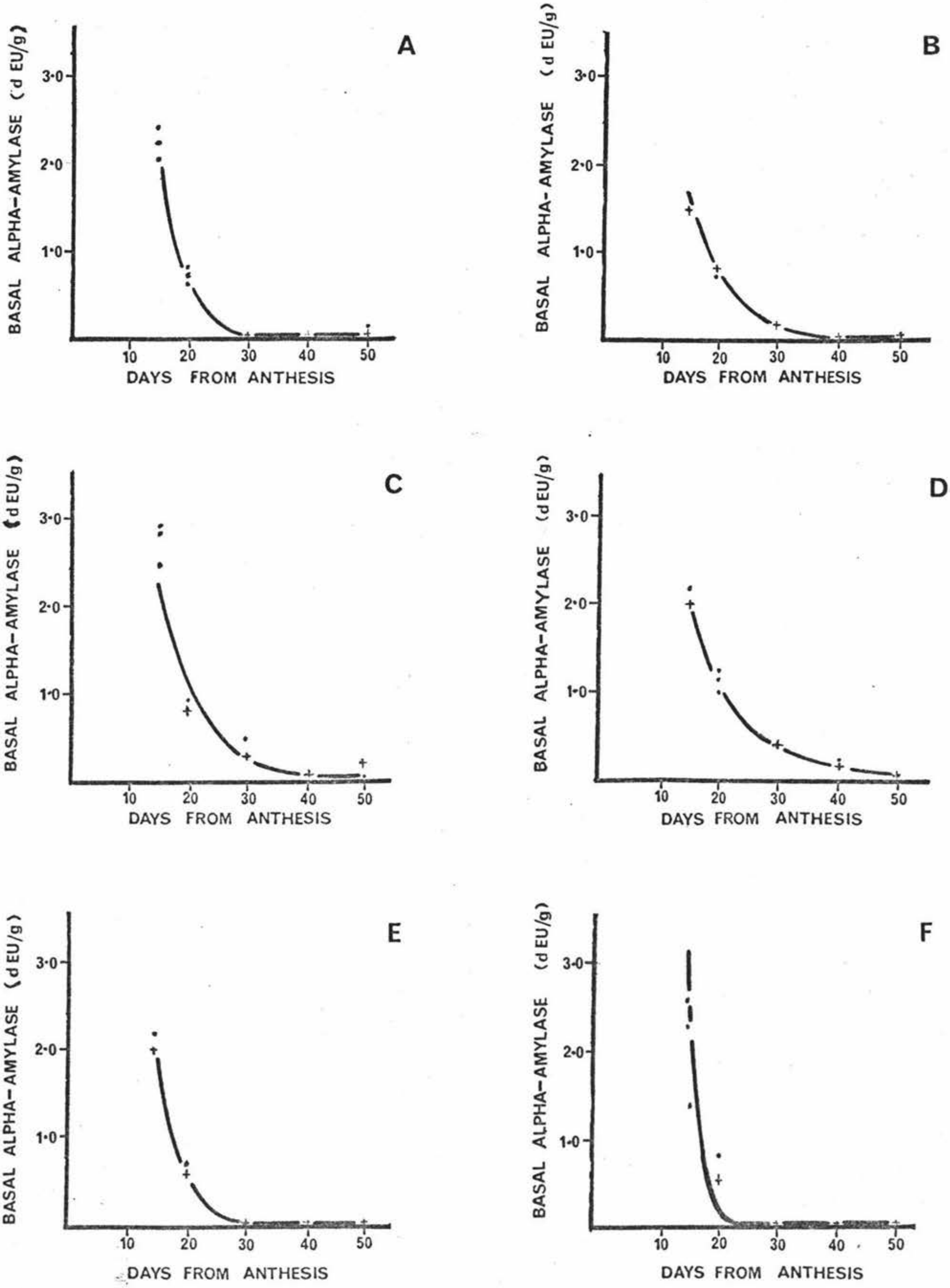

A
B
C
D
E
F
BASAL ALPHA-AMYLASE (d EU/g)
3·0
2·0
1·0
10
20
30
40
50
DAYS FROM ANTHESIS

Figure A1.9.1 Changes in alpha-amylase response during grain development amongst six wheat cultivars in environment I (18-12°C; 1.0 kPa)

(A) Sonora

$R^2 = 0.8343$

(B) Timgalen

$R^2 = 0.5747$

(C) Pembina

$R^2 = 0.1918$

(D) Gamut

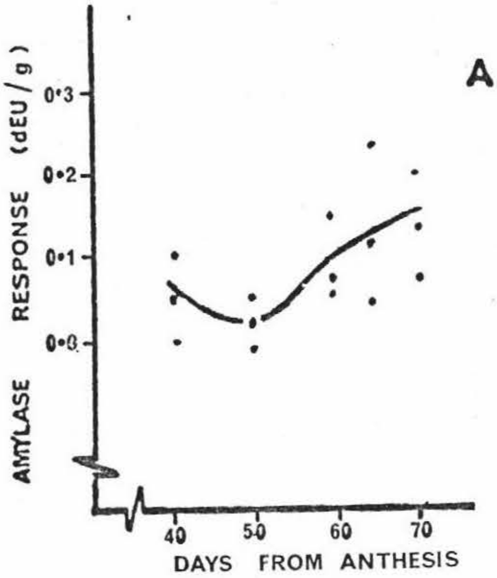
$R^2 = 0.8931$

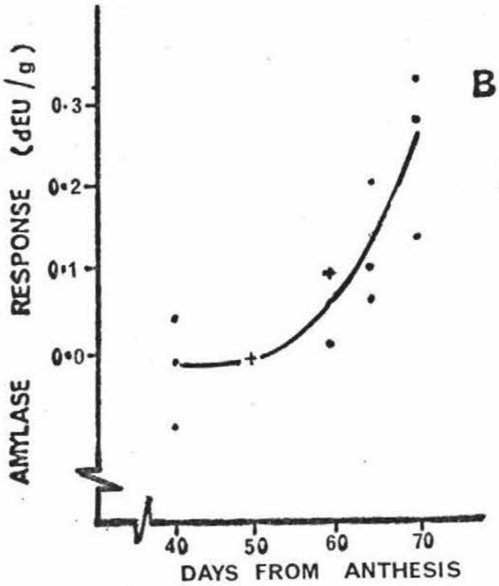
(E) Sherbati-Sonora

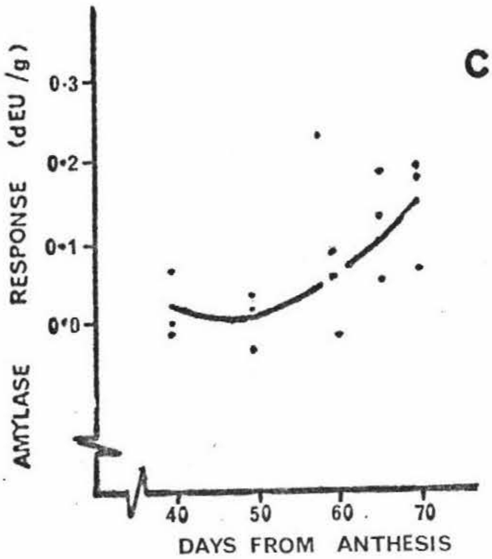
$R^2 = 0.4886$

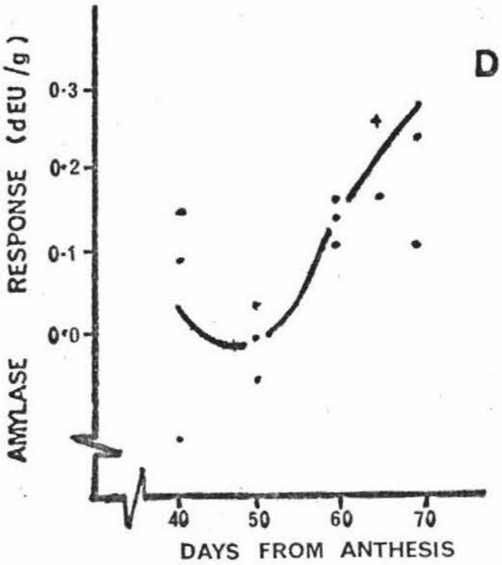
(F) Karamu

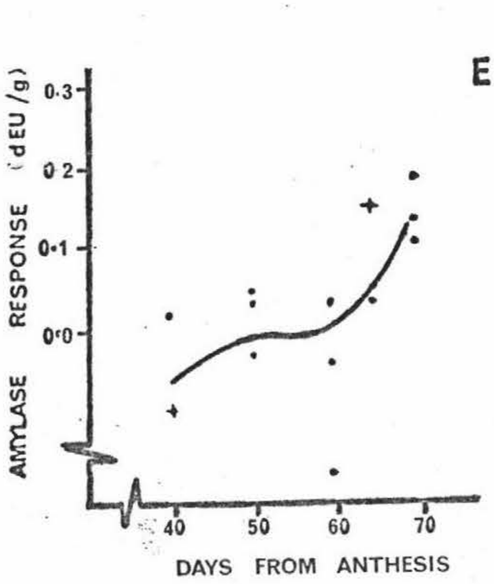
$R^2 = 0.8227$


A
AMYLASE RESPONSE (dEU/g)
0·3
0·2
0·1
0·0
40
50
60
70
DAYS FROM ANTHESIS


B
AMYLASE RESPONSE (dEU/g)
0·3
0·2
0·1
0·0
40
50
60
70
DAYS FROM ANTHESIS


C
AMYLASE RESPONSE (dEU/g)
0·3
0·2
0·1
0·0
40
50
60
70
DAYS FROM ANTHESIS


D
AMYLASE RESPONSE (dEU/g)
0·3
0·2
0·1
0·0
40
50
60
70
DAYS FROM ANTHESIS


E
AMYLASE RESPONSE (dEU/g)
0·3
0·2
0·1
0·0
40
50
60
70
DAYS FROM ANTHESIS

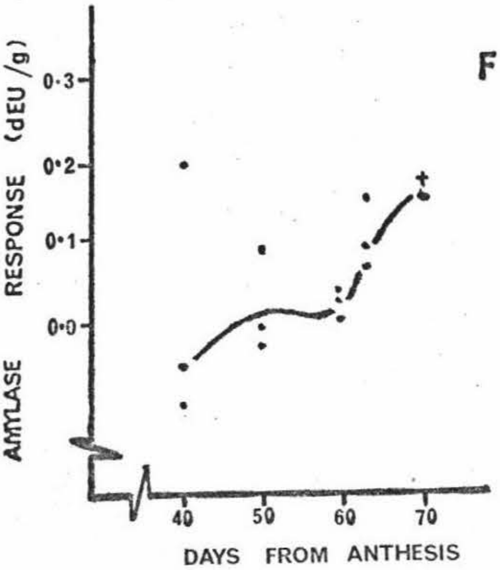

F
AMYLASE RESPONSE (dEU/g)
0·3
0·2
0·1
0·0
40
50
60
70
DAYS FROM ANTHESIS

Figure A1.9.2 Changes in alpha-amylase response during grain development amongst six wheat cultivars in environment II (18-12°C; 0.4 kPa)

(A) Sonora

$R^2 = 0.3597$

(B) Timgalen

$R^2 = 0.7514$

(C) Pembina

$R^2 = 0.5673$

(D) Gamut

$R^2 = 0.5544$

(E) Sherbati-Sonora

$R^2 = 0.5413$

(F) Karamu

$R^2 = 0.2401$

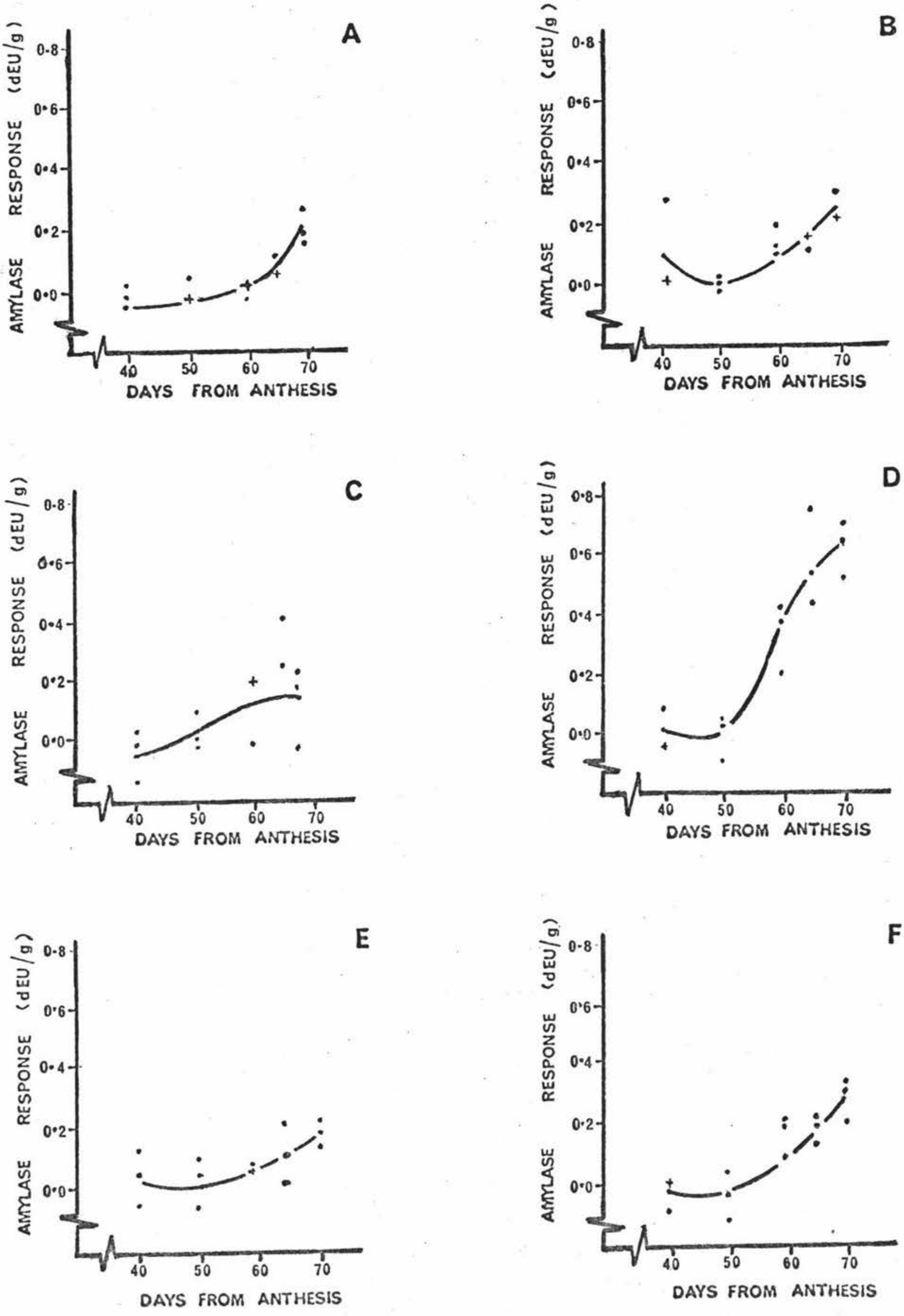

A
B
C
D
E
F
AMYLASE RESPONSE (dEU/g)
0·8
0·6
0·4
0·2
0·0
40
50
60
70
DAYS FROM ANTHESIS

Figure A1.9.3. Changes in alpha-amylase response during grain development amongst six wheat cultivars in environment III (30-20°C; 1.0 kPa)

(A) Sonora

$R^2 = 0.9090$

(B) Timgalen

$R^2 = 0.9720$

(C) Pembina

$R^2 = 0.4813$

(D) Gamut

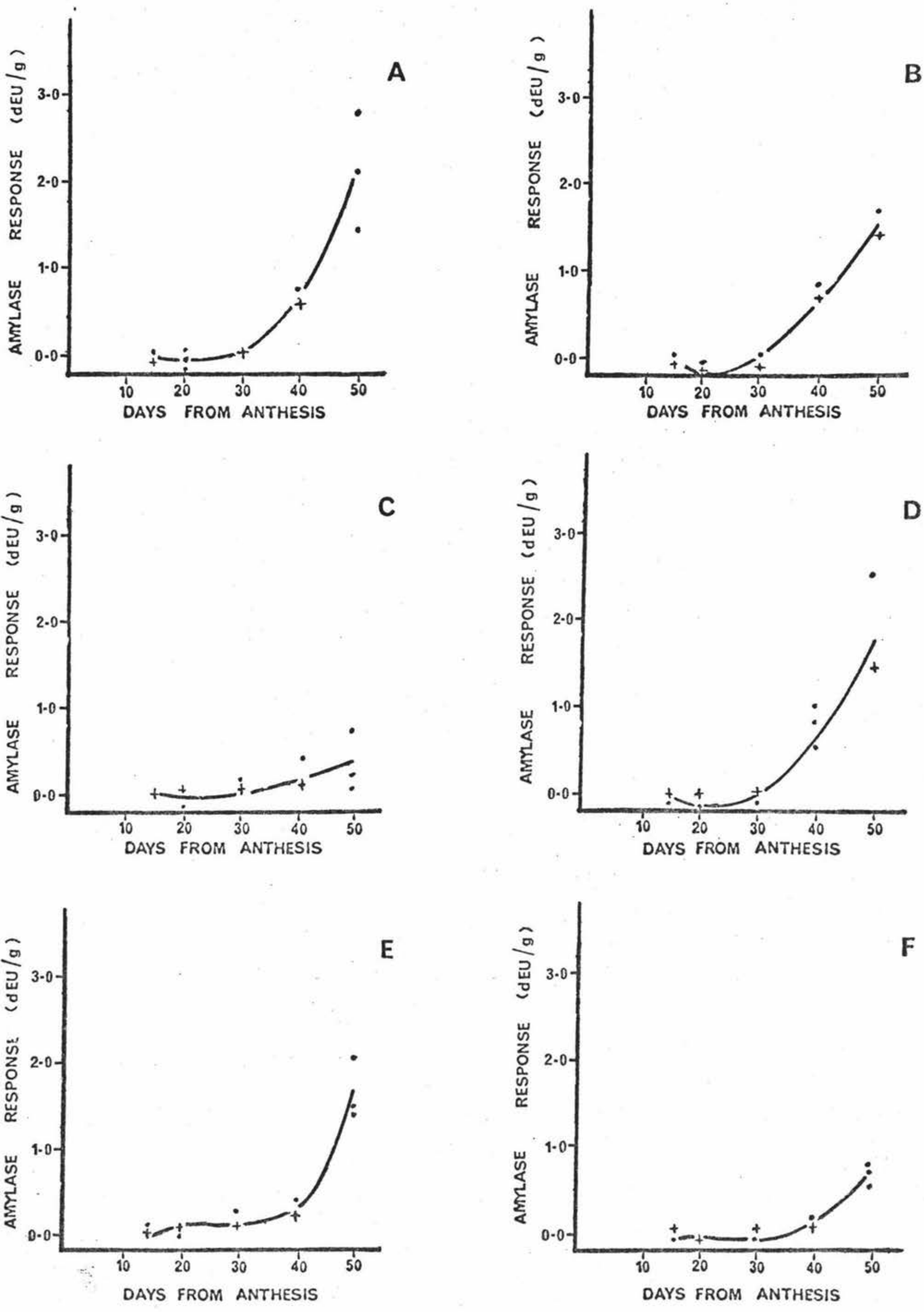
$R^2 = 0.8987$

(E) Sherbati-Sonora

$R^2 = 0.9320$

(F) Karamu

$R^2 = 0.9421$


A
B
C
D
E
F
AMYLASE RESPONSE (dEU/g)
0·0
1·0
2·0
3·0
10
20
30
40
50
DAYS FROM ANTHESIS

Appendix A2 : North Carolina State University Phytotron Nutrient as used by Plant Physiology Division, DSIR, Palmerston North.

	gm/litre STOCK SOLN.	p.p.m.	WORKING SOLN.
SOLN 'A'			
Ammonium nitrate $NH_4\ NO_3$	80.05	NH_4-N	28.0
Calcium nitrate $Ca(NO_3)_2 \cdot H_2O$	159.25	Ca N	54.8 37.6
Sequestrene 330 NaFe 7%	29.8	Fe	3.0
SOLN 'B'			
Potassium phosphate KH_2PO_4	12.5	K : P :	7.2 5.6
Potassium phosphate K_2HPO_4	5.5	K : P :	5.0 2.0
Potassium nitrate	63.9	K : N :	48.8 17.8
Magnesium sulphate $MgSO_4 \cdot 7H_2O$	30.81	Mg : S :	6.2 8.2
Sodium sulphate Na_2SO_4	35.50	Na : S :	13.8 19.2
Zinc sulphate $ZnSO_4 \cdot 7H_2O$	.025	Zn : S :	.012 .070
Manganous chloride $MnCl_2$	.26	Mn : Cl :	.113 .146
Copper sulphate $CuSO_4 \cdot 5H_2O$	.01	Cu : S :	.005 .003
Boric acid H_3BO_3	.35	B :	.127
Molybdic acid $MoO_3 \cdot 2H_2O$ MoO_3 - Anhydrous	.002	Mo :	.002

Notes :

1. Ammonium nitrate and sequestrene are combined in solution 'A', 200 grams of potassium hydroxide is added to bring the pH to 8, then calcium nitrate is added dropping the pH to 7.

Appendix A2 (cont)

2. The major salts of soln 'B' are dissolved, then the minor salts in solution are added slowly with stirring, the final pH is 5.2.

3. Stock solns. 'A' and 'B' are used at 1 to 500 or 200 ml stock per litre of water.

Appendix A3 : Theory and execution of curve fitting. The principles outlined below are based extensively on Bliss (1970).

1. Gompertz and related equations

The Gompertz equation may be expressed as :

$$Y = y\ A^{B^x}$$

where x = independant variate

y = upper asymptote

A = constant of curve location

B = constant of curvature

In linear terms, the Gompertz equation becomes :

$$\text{In } Y = \ln y + (\ln A)\ (B^x) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

which is a suitable form for linear multiple regression analysis (Bliss, 1970). To reduce the indices, the independant variate (x) may be reduced in dimension. In the present study, "x" was divided by seven. $\hat{B}$ may be estimated from an eye fit, or *a priori* knowledge. Initial estimates of $\hat{B}$ were obtained from Gordon (1975). Otherwise $\hat{B}$ would have been estimated from an eye fit curve using the equation :

$$\hat{B}_1 = \frac{Y_3 - Y_2}{Y_2 - Y_1} \qquad \text{(Bliss, 1970)}$$

where Y_1, Y_2, Y_3 are the dependant values of equally spaced points on the coded x axis; Y_1 being the closest, and Y_3 furtherest from the upper asymptote. Maximum likelihood iterations followed, using an auxillary variate to estimate the final $\hat{B}$. The first independant variate in the regression was : B_i^x where "i" is an index relating to the number of iterative $\hat{B}$ estimates. The auxillary variate for iterative improvement in $\hat{B}$ was the auxillary variate : $x\,B_i^{x-1}$.

The final equation for iterative improvement was therefore of the form :

$$\ln Y = a + b_1(B_i^x) + b_2\,(xB_i^{x-1}) \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Successive improvements in $\hat{B}$ were estimated from the equation :

$$B_k = B_{k-1} + \frac{b_{2(k-1)}}{b_{1(k-1)}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where k is the index of iteration of the new estimate,

(k-1) relates to the previous estimate,

and b_1 and b_2 are the regression coefficients relating to equation (1) (Bliss, 1970).

Iteration was stopped when either b_2 was not significantly different

(t test $H_o : b_2 = 0$)

to zero or when the increment in the new $\hat{B}$ was approximately 1% of the preceeding $\hat{B}$ (Bliss, 1970; Gordon, 1975).

The Makeham function introduces an additional constant (C) to the Gompertz, and has the form :

$Y = yC^xA^{B^x}$ (Bliss, 1970)

which in terms of natural logarithms is :

$$\ln Y = \ln y + \ln C + (\ln A)\ B^x$$

which is estimated by the multiple regression :

$\ln Y = a + b_1x + b_2B^x$ (Bliss, 1970).

Residual curvature in the Makeham may be accounted for by an additional quadratic term (quadratic Makeham)and is of the form :

$Y = y\ C^xD^{x^2}A^{B^x}$ (Gordon, 1975)

which in terms of natural logarithms becomes :

$$\ln Y = \ln y + (\ln C)\ x + 2\ (\ln D) + (\ln A)\ B^x$$

which is estimated by the multiple regression form of :

$$\ln Y = a + b_1x + b_2x^2 + b_3B^x .$$

2. Logistic and related functions

The logistic function relates rate of change in Y to a proportionate amount in x (the independant variate), according to the relationship :

$\frac{dY}{dx} = bY\ \frac{y-Y}{y}$ (Bliss, 1970)

where b = initial change rate, and

y = upper asymptote of Y,

which, in integrated form becomes :

$$Y = \frac{y}{1+e^{-(a+bx)}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

where a and b are constants, and e is the base of natural logarithms (Bliss, 1970).

From equation (1) :

$$y = Y\ (1 + e^{-(a+bx)}$$

$$= Y + Ye^{-(a+bx)} \quad \text{(Bliss, 1970)}$$

therefore :

$$y - Y = Y\ e^{-(a+bx)}$$, or equivalent to :

$$\frac{y - Y}{Y} = e^{-(a+bx)}$$

The reciprocal of this is :

$$\frac{Y}{y - Y} = e(a+bx)$$

which, in terms of matural logarithms is :

$$\ln .\ \frac{Y}{y - Y} = a+bx$$

Now the function ln. $\frac{Y}{y - Y}$ is defined as logit Y, so:

$$\text{logit } Y = a+bx \quad \text{(Bliss, 1970).}$$

Logits may be obtained from tables, or estimated as follows :

Let $P = \frac{Y}{y}$, ...(1)

which is the proportionate response of y attained by observations in Y, and $Q = \frac{y-Y}{y}$, which is the proportion of y left by P to be attained by an observation in Y.

Therefore Q=1-P ....(2)

So $\ln (\frac{P}{Q})$ = logit Y ....(3)

(Bliss, 1970)

Equations (1), (2), (3) were utilised with observed values of Y, and therefore estimated the upper asymptote (y). The regressed line is in logits, and cannot be transformed directly into original units of Y, as both P and Q are unknown. Antilogit tables were used to effect this transformation.

The loglogistic equation is one where rate of change in response (Y) is inversely proportional to change in the dependant variable (x), and is described as :

$$\frac{dY}{dx} = b\ Y\ \frac{(y-Y)}{(xy\ )} \qquad \text{(Bliss, 1970)}$$

where b is a constant.
Upon integration, this becomes :

$$Y = \frac{y}{1+e^{-a}x^{-b}}$$

$$= \frac{y}{1+e^{-(a+b\ \ln\ x)}} \qquad \text{(Bliss, 1970).}$$

Using similar derivations as to those given earlier, this equation becomes :

$\text{logit } Y = a + b\ (\ln\ x)$, and therefore of suitable form for linear regression analysis.

Remaining curvature in a logistic may be accounted for by using an additional quadratic term (quadratic logistic). In linear terms, this equation is :

$$\text{logit } Y = a + b_1x + b_2x^2$$

which may be fitted by multiple linear regression analysis. Where the upper asymptote (y) was unknown, it was estimated by an eye fit to the original data plot. This gave initial values to P and Q. Improved estimates were obtained using an auxillary maximum likelihood variate in a multiple regression fit. The auxillary variate was :

$$X = \frac{1}{Q} \qquad \text{(Bliss, 1970)}$$

so that the iterative equation was :

$$\text{logit } Y = a + b_1x + b_2X \quad \text{(Bliss, 1970).}$$

Iterative improvements in P and Q were obtained from the equation :

$$y_k = y_{k-1}\ (1+b_2)$$

where k is an index of the number of iterative improvements, and k-1 relates to the previous estimate. Iteration was stopped when either b_2 was not significantly different to zero (t test $H_o : b_2=0$), or when the increment in the upper asymptote estimate (y) over its preceeding estimate differed by approximately 1% (Bliss, 1970; Gordon, 1975).

3. Other equations

Third and fourth degree polynomials (Steel and Torrie, 1960) were attempted for the alpha-amylase response plots. The x-variate was in days, and the Y-variate was in deci-enzyme units plus twenty (dEU + 20). The coding of the Y variate was necessary to effect positive values for regression analysis.

Appendix A4 : Wheat grain-colours standards

1	W 676*	*Tu. durum*, Russian, C.4458
2	W 1538	Stewart (*Tu. durum*)
3	W 2572	World collection 54/503 (*Tu. durum*)
4	Gamenya (*Tu. aestivum*)	
5	W 273	Indian dwarf, semi-bearded (*Tu. sphaerococcum*)
6	W 2607	IRN 59-88, Columbia, (*Tu. aestivum*)
7	W 2979	Nainari 60, IRN 63-462 (*Tu. aestivum*)
8	W 2530	Benzengubskaia, K 40583 (*Tu. aestivum*)
9	W 2906	*Tu. abyssinicum* var. arraseita
10	W 2888	(*Tu. durum* x *Ae. elongatum*) (2n = 14)

* W numbers are from the University of Sydney wheat collection

Appendix A5 : Significance symbols for all tests of hypotheses of comparisons amongst cultivars are as follows :

*	$0.05 > P > 0.01$
**	$0.01 > P > 0.005$
***	$0.005 > P$
NS	not significant at the 5% level

Appendix A5.1

Estimated t statistics for differences amongst pairs of Y-intercepts ($\hat{a}$) and regression coefficients ($\hat{b}$) relating to the curves for moisture content amongst six wheat cultivars, established within three environments.

Table A5.1.1 Environment I (18-12°C/1.0 kPa)

$\hat{a}$ differences / $\hat{b}$ differences	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	0.11 NS	4.14***	3.35**	0.04 NS	3.97***
Timgalen	1.18 NS	-	3.97***	3.23**	0.08 NS	3.93***
Pembina	6.00***	4.85***	-	0.71 NS	4.47***	1.36 NS
Gamut	2.10*	0.98 NS	3.74***	-	3.63**	1.83 NS
Sherbati-Sonora	0.36 NS	0.99 NS	6.08***	1.99 NS	-	4.09***
Karamu	3.94**	3.21**	0.31 NS	2.50*	3.89***	-

Appendix A5.1 (continued)

Table A5.1.2 Environment II (18-12°C/0.4 kPa)

$\hat{a}$ differences / $\hat{b}$ differences	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	2.99**	3.62**	2.67*	1.66 NS	0.00 NS
Timgalen	1.30 NS	-	0.36 NS	5.26***	1.39 NS	2.36 *
Pembina	1.67 NS	0.38 NS	-	5.80***	1.95 NS	2.72*
Gamut	1.76 NS	2.79**	2.75**	-	4.15***	2.36*
Sherbati-Sonora	1.69 NS	0.62 NS	1.02 NS	3.03**	-	1.34 NS
Karamu	0.08 NS	1.10 NS	0.97 NS	1.51 NS	1.44 NS	-

Appendix A5.1 (continued)

Table A5.1.3 Environment III (30-20°C/1.0 kPa)

$\hat{a}$ differences $\hat{b}$ differences	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	1.26 NS	1.78 NS	0.24 NS	0.83 NS	1.95 NS
Timgalen	1.03 NS	-	0.78 NS	1.11 NS	0.32 NS	0.95 NS
Pembina	1.44 NS	0.63 NS	-	1.67 NS	1.00 NS	0.14 NS
Gamut	0.15 NS	0.95 NS	1.39 NS	-	0.67 NS	1.85 NS
Sherbati-Sonora	0.73 NS	0.22 NS	0.78 NS	0.64 NS	-	1.17 NS
Karamu	1.38 NS	0.57 NS	0.05 NS	1.32 NS	0.72 NS	-

Appendix A5.2

Estimated t statistics for differences amongst pairs of Y-intercepts (a) and regression coefficients (b) relating to the curves for grain dry-weight amongst six wheat genotypes, established within three environments.

Table A5.2.1 Environment I (18-12°C/1.0 kPa)

$\hat{a}$ differences $\hat{b}$ differences	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	0.60 NS	1.11 NS	6.42***	2.06*	1.19 NS
Timgalen	2.90**	-	0.47 NS	6.00***	2.33*	1.63 NS
Pembina	3.58***	0.71 NS	-	6.34***	2.75*	2.12*
Gamut	3.08**	0.57 NS	1.39 NS	-	3.26**	5.45***
Sherbati-Sonora	0.03 NS	2.64*	3.27**	2.64*	-	1.06 NS
Karamu	0.44 NS	2.62*	3.33**	2.76**	0.41 NS	-

Appendix A5.2

Estimated t statistics for differences amongst pairs of Y-intercepts ($\hat{a}$) and regression coefficients ($\hat{b}$) relating to the curves for grain dry-weight amongst six wheat genotypes, established within three environments.

Table A5.2.1 Environment I (18-12°C/1.0 kPa)

$\hat{a}$ differences / $\hat{b}$ differences	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	0.60 NS	1.11 NS	6.42***	2.06*	1.19 NS
Timgalen	2.90**	-	0.47 NS	6.00***	2.33*	1.63 NS
Pembina	3.58***	0.71 NS	-	6.34***	2.75*	2.12*
Gamut	3.08**	0.57 NS	1.39 NS	-	3.26**	5.45***
Sherbati-Sonora	0.03 NS	2.64*	3.27**	2.64*	-	1.06 NS
Karamu	0.44 NS	2.62*	3.33**	2.76**	0.41 NS	-

Appendix A5.2 (continued)

Table A5.2.2 Environment II (18-12°C/0.4 kPa)

$\hat{a}$ differences $\hat{b}$ differences	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	2.75*	1.88 NS	7.98***	2.80**	1.20 NS
Timgalen	5.47***	-	6.18***	13.84***	6.40***	1.13 NS
Pembina	2.13*	4.78***	-	8.05***	1.43 NS	3.12**
Gamut	1.62 NS	5.18***	0.64 NS	-	5.23***	8.71***
Sherbati-Sonora	1.66 NS	4.19***	0.30 NS	0.23 NS	-	3.87***
Karamu	0.31 NS	4.68***	1.59 NS	1.13 NS	1.22 NS	-

Appendix A5.2 (continued)

Table A5.2.3 Environment III (30-20°C/1.0 kPa)

$\hat{a}$ differences $\hat{b}$ differences	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	1.20 NS	1.32 NS	4.63***	0.49 NS	1.29 NS
Timgalen	1.60 NS	-	0.02 NS	4.85***	1.72 NS	2.32*
Pembina	5.08***	2.85**	-	5.36***	1.91 NS	2.58*
Gamut	3.31**	0.73 NS	3.04**	-	5.54***	4.37***
Sherbati-Sonora	6.75***	3.33**	0.19 NS	4.57***	-	1.08 NS
Karamu	3.04**	0.53 NS	3.24**	0.34	4.87***	-

Appendix A5.3

Estimated t statistics for differences amongst pairs of Y-intercepts (a) and regression coefficients (b) relating to the curves for pigmentation amongst six wheat genotypes, established within three environments.

Table A5.3.1 Environment I (18-12^{o}C/1.0 kPa)

$\hat{a}$ differences $\hat{b}$ differences	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	2.67**	0.70 NS	2.15*	2.61*	0.60 NS
Timgalen	2.27*	-	2.76**	0.23 NS	0.14 NS	2.96**
Pembina	1.33 NS	2.92**	-	2.40*	2.70**	0.17 NS
Gamut	2.28*	0.60 NS	2.93**	-	0.33 NS	2.45*
Sherbati-Sonora	2.50*	0.15 NS	3.08**	0.50	-	2.90**
Karamu	0.25 NS	1.84 NS	1.45 NS	2.03*	2.03*	-

Appendix A5.3 (continued)

Table A5.3.2 Environment II (18-12°C/0.4 kPa)

$\hat{a}$ differences / $\hat{b}$ differences	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	2.23*	0.93 NS	2.41*	2.09*	0.36 NS
Timgalen	2.28*	-	3.07**	0.27 NS	0.04 NS	2.57*
Pembina	1.48 NS	3.50***	-	3.22**	2.88**	0.59 NS
Gamut	2.07*	0.29 NS	3.12**	-	0.21 NS	2.73**
Sherbati-Sonora	2.24*	0.14 NS	3.40**	0.16 NS	-	2.40*
Karamu	0.01 NS	2.26*	1.45 NS	2.06*	2.23*	-

Appendix A5.3 (continued)

Table A5.3.3 Environment III (30-20°C/1.0 kPa)

$\hat{a}$ differences $\hat{b}$ differences	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	2.58*	0.50 NS	2.91**	2.49*	0.34 NS
Timgalen	0.91 NS	-	3.10**	0.36 NS	0.11 NS	2.06*
Pembina	0.67 NS	1.62 NS	-	3.43**	2.97**	0.00 NS
Gamut	0.07 NS	1.02 NS	0.61 NS	-	0.22 NS	2.29*
Sherbati-Sonora	0.85 NS	0.02 NS	1.54 NS	0.95 NS	-	2.06*
Karamu	0.67 NS	1.62 NS	0.00 NS	0.61 NS	1.54 NS	-

Appendix A5.4

Estimated t statistics for differences amongst pairs of <u>Y-intercepts</u> ($\hat{a}$) relating to the curves for <u>flavan-3-ol</u> <u>concentration</u> amongst six wheat genotypes, established within three environments.

Table A5.4.1 Environments I (18-12°C/1.0 kPa) and II (18-12°C/0.4 kPa)

$\hat{a}$ (env. I) $\hat{a}$ (env. II)	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	189.39***	170.26***	149.10***	108.81***	191.61***
Timgalen	121.15***	-	15.66***	25.93***	78.95***	528.77***
Pembina	33.63***	168.63***	-	11.65***	61.49***	474.41***
Gamut	48.00***	209.57***	11.2***	-	45.23***	410.69***
Sherbati-Sonora	25.95***	93.49***	61.47***	79.54***	-	357.34***
Karamu	1.96 NS	101.74***	26.27***	36.82***	24.07***	-

Appendix A5.4 (continued)

Table A5.4.2 Environment III (30-20°C/1.0 kPa)

$\hat{a}$ (env. III)	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	103.61***	120.48***	141.44***	58.89***	338.50***
Timgalen	-	-	43.72***	97.42***	173.62***	279.57***
Pembina	-	-	-	68.61***	173.28***	196.85***
Gamut	-	-	-	-	171.08***	56.10***
Sherbati-Sonora	-	-	-	-	-	394.89***
Karamu	-	-	-	-	-	-

Appendix A5.5

Estimated t-statistics for differences amongst pairs of regression coefficients ($\hat{b}$) relating to the curves for flavan-3-ol concentration amongst six wheat genotypes, established within three environments.

Table A5.5.1 Environment I (18-12°C/1.0 kPa)

$\hat{b}_1$ differences $\hat{b}_2$ differences	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	0.85 NS	0.53 NS	0.53 NS	0.21 NS	1.45 NS
Timgalen	1.60 NS	-	0.43 NS	0.39 NS	1.33 NS	3.23**
Pembina	1.50 NS	0.27 NS	-	0.02 NS	0.91 NS	2.62*
Gamut	1.39 NS	0.45 NS	0.20 NS	-	0.89 NS	2.54*
Sherbati-Sonora	1.00 NS	1.29 NS	1.02 NS	0.80 NS	-	1.44 NS
Karamu	1.49 NS	4.75***	4.54***	4.28***	3.67**	-

Appendix A5.5 (continued)

Table A5.5.2 Environment II (18-12°C/0.4 kPa)

$\hat{b}_1$ differences $\hat{b}_2$ differences	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	1.95 NS	0.50 NS	0.82 NS	0.12 NS	0.06 NS
Timgalen	2.06*	-	2.66*	3.42**	2.10*	1.53 NS
Pembina	0.58 NS	2.91**	-	0.29 NS	0.38 NS	0.48 NS
Gamut	0.83 NS	3.55**	0.21 NS	-	0.69 NS	0.73 NS
Sherbati-Sonora	0.38 NS	1.36 NS	0.91 NS	1.13 NS	-	0.16 NS
Karamu	0.03 NS	1.79 NS	0.47 NS	0.67 NS	0.37 NS	-

Table A5.5.3 Environment III (30-20°C/1.0 kPa)

$\hat{b}_1$ differences / $\hat{b}_2$ differences	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	1.94 NS	1.08 NS	1.63 NS	0.48 NS	1.86 NS
Timgalen	0.69 NS	-	0.44 NS	0.78 NS	2.56*	0.89 NS
Pembina	2.53*	1.87 NS	-	0.96 NS	1.52 NS	1.08 NS
Gamut	0.76 NS	1.96 NS	3.02**	-	1.89 NS	0.00 NS
Sherbati-Sonora	2.89**	1.97 NS	1.25 NS	1.59 NS	-	2.14*
Karamu	1.31 NS	2.47*	1.31 NS	0.49 NS	2.12 NS	-

Appendix A5.6

Estimated t-statistics for differences amongst pairs of <u>Y-intercepts</u> ($\hat{a}$) relating to the curves for <u>germination</u> amongst six wheat cultivars, established within three environments.

Table A5.6.1 Environments I (18-12°C/1.0 kPa) and II (18-12°C/0.4 kPa)

$\hat{a}$ (env. I) $\hat{a}$ (env. II)	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	31.42***	-	38.94***	9.38***	17.72***
Timgalen	32.73***	-	-	4.68***	24.80***	35.19***
Pembina	-	-	-	-	-	-
Gamut	-	-	-	-	32.39***	38.82***
Sherbati-Sonora	22.73***	6.54***	-	-	-	22.82***
Karamu	42.75***	22.82***	-	-	12.89***	-

Table A5.6.2 Environment III (30-20°C/1.0 kPa)

$\hat{a}$ (env. III)	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	1.19 NS	6.97***	2.96**	5.14***	11.77***
Timgalen	-	-	4.23***	1.69 NS	5.47***	10.13***
Pembina	-	-	-	1.70 NS	11.01***	8.35***
Gamut	-	-	-	-	6.67***	8.25***
Sherbati-Sonora	-	-	-	-	-	14.27***
Karamu	-	-	-	-	-	-

Appendix A5.7

Estimated t-statistics for differences amongst pairs of regression coefficients ($\hat{b}$) relating to the curves for germination amongst six wheat cultivars, established within three environments.

Table A5.7.1 Environment I (18-12°C/1.0 kPa)

$\hat{b}_1$ differences $\hat{b}_2$ differences	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	2.08 NS	ND	2.57*	0.60 NS	1.16 NS
Timgalen	2.10 NS	-	ND	0.31 NS	1.66 NS	2.32*
Pembina	ND[1]	ND	-	ND	ND	ND
Gamut	2.60*	0.31 NS	ND	-	2.16 NS	2.55*
Sherbati-Sonora	0.59 NS	1.69 NS	ND	2.20 NS	-	1.49 NS
Karamu	1.17 NS	2.33*	ND	2.57*	1.48 NS	-

[1] ND = no data

Table A5.7.2 Environment II (18-12°C/0.4 kPa)

$\hat{b}_1$ differences / $\hat{b}_2$ differences	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	1.33 NS	ND	ND	0.91 NS	1.79 NS
Timgalen	1.33 NS	-	ND	ND	0.27 NS	0.91 NS
Pembina	ND[1]	ND	-	ND	ND	ND
Gamut	ND	ND	ND	-	ND	ND
Sherbati-Sonora	0.90 NS	0.28 NS	ND	ND	-	0.50 NS
Karamu	1.85 NS	0.90 NS	ND	ND	1.27 NS	-

[1] ND = no data

Appendix A5.7 (continued)

Table A5.7.3 Environment III (30-20^{o}C/1.0 kPa)

$\hat{b}_1$ differences $\hat{b}_2$ differences	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	0.31 NS	3.73**	1.14 NS	2.66*	5.69***
Timgalen	0.15 NS	-	2.73*	0.79 NS	2.62*	5.13***
Pembina	3.16**	2.42*	-	1.46 NS	5.99***	3.83**
Gamut	1.01 NS	0.79 NS	1.20 NS	-	3.17**	4.23***
Sherbati-Sonora	2.80*	2.59*	5.58***	3.15**	-	7.12***
Karamu	5.44***	4.98***	3.86**	4.10***	6.93***	-

Appendix A5.8

Estimated t-statistics for differences amongst pairs of Y-intercepts ($\hat{a}$) relating to the curves for embryo maturity amongst six wheat cultivars, established within three environments.

Table A5.8.1 Environments I (18-12°C 1.0 kPa) and II (18-12°C 0.4 kPa)

$\hat{a}$ (env. I) $\hat{a}$ (env. II)	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	23.16***	ND	20.13***	2.16 NS	18.32***
Timgalen	32.03***	-	ND	2.55*	23.37***	5.90***
Pembina	ND[1]	ND	-	ND	ND	ND
Gamut	ND	ND	ND	-	20.60***	3.11**
Sherbati-Sonora	27.59***	6.59***	ND	ND	-	18.88**
Karamu	67.34***	20.74***	ND	ND	14.28***	-

[1] ND = no data

Table A5.8.2 Environment III (30-20^{o}C/1.0 kPa)

$\hat{a}$ (env. III)	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	0.53 NS	2.36*	0.96 NS	3.47**	3.99**
Timgalen	-	-	1.61 NS	1.54 NS	3.90**	4.34***
Pembina	-	-	-	2.95**	5.24***	5.43***
Gamut	-	-	-	-	1.90 NS	2.87*
Sherbati-Sonora	-	-	-	-	-	1.67 NS
Karamu	-	-	-	-	-	-

Appendix A5.9

Estimated t-statistics for differences amongst pairs of regression coefficients ($\hat{b}$) relating to the curves for embryo maturity amongst six wheat cultivars, established within three environments.

Table A5.9.1 Environment I (18-12°C/1.0 kPa)

$\hat{b}_1$ differences $\hat{b}_2$ differences	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	1.52 NS	ND	1.33 NS	0.15 NS	1.22 NS
Timgalen	1.52 NS	-	ND	0.16 NS	1.54 NS	0.38 NS
Pembina	ND[1]	ND	-	ND	ND	ND
Gamut	1.33 NS	0.16 NS	ND	-	1.37 NS	0.20 NS
Sherbati-Sonora	0.16 NS	1.56 NS	ND	1.38 NS	-	0.01 NS
Karamu	1.23 NS	0.36 NS	ND	0.19 NS	1.29 NS	-

[1] ND = no data

Appendix A5.9 (continued)

Table A5.9.2 Environment II (18-12°C/0.4 kPa)

$\hat{b}_1$ differences $\hat{b}_2$ differences	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	1.30 NS	ND	ND	1.11 NS	2.81 NS
Timgalen	1.30 NS	-	ND	ND	0.27 NS	0.83 NS
Pembina	ND[1]	ND	-	ND	ND	ND
Gamut	ND	ND	ND	-	ND	ND
Sherbati-Sonora	1.11 NS	0.27 NS	ND	ND	-	0.56 NS
Karamu	2.89*	0.81 NS	ND	ND	0.53 NS	-

[1] ND = no data

Appendix A5.9 (continued)

Table A5.9.3 Environment III (30-20°C/1.0 kPa)

$\hat{b}_1$ differences / $\hat{b}_2$ differences	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	0.30 NS	1.76 NS	0.63 NS	1.68 NS	1.59 NS
Timgalen	0.25 NS	-	1.43 NS	0.87 NS	1.90 NS	1.77 NS
Pembina	1.96 NS	1.66 NS	-	2.17 NS	3.28**	2.90*
Gamut	0.70 NS	0.90 NS	2.42*	-	0.79 NS	0.97 NS
Sherbati-Sonora	1.72 NS	1.88 NS	3.53**	0.74 NS	-	0.44 NS
Karamu	1.60 NS	1.74 NS	3.07**	0.91 NS	0.40 NS	-

Appendix A5.10

Estimated t-statistics for differences amongst pairs of Y-intercepts ($\hat{a}$) relating to the curves for embryo dormancy amongst six wheat cultivars, established within three environments.

Table A5.10.1 Environments I (18-12°C/1.0 kPa) and II (18-12°C/0.4 kPa)

$\hat{a}$ (env. I) $\hat{a}$ (env. II)	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	43.16***	ND	43.60***	12.67***	9.72***
Timgalen	27.09***	-	ND	7.26***	22.01***	9.11***
Pembina	ND	ND	-	ND	ND	ND
Gamut	ND	ND	ND	-	32.64***	13.58***
Sherbati-Sonora	27.30***	8.51***	ND	ND	-	3.26**
Karamu	1.07 NS	28.87***	ND	ND	28.40***	-

Appendix A5.10 (continued)

Table A5.10.2 Environment III (30-20°C/1.0 kPa)

$\hat{a}$ (env. III)	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	0.15 NS	5.07***	1.15 NS	2.78*	7.97***
Timgalen	-	-	2.72*	1.00 NS	1.56 NS	6.21***
Pembina	-	-	-	1.42 NS	7.43***	5.71***
Gamut	-	-	-	-	2.84*	5.31***
Sherbati-Sonora	-	-	-	-	-	9.25***
Karamu	-	-	-	-	-	-

Appendix A5.11

Estimated t-statistics for differences amongst pairs of <u>regression coefficients</u> ($\hat{b}$) relating to the curves for <u>embryo dormancy</u> amongst six wheat cultivars, established within three environments.

Table A5.11.1 Environment I (18-12^{o}C/1.0 kPa)

$\hat{b}_1$ differences $\hat{b}_2$ differences	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	2.14 NS	ND	2.88*	0.79 NS	0.70 NS
Timgalen	2.17 NS	-	ND	0.47 NS	1.47 NS	0.60 NS
Pembina	ND	ND	-	ND	ND	ND
Gamut	2.91*	0.47 NS	ND	-	2.17 NS	0.89 NS
Sherbati-Sonora	0.79 NS	1.51 NS	ND	2.20*	-	0.23 NS
Karamu	0.66 NS	0.60 NS	ND	0.89 NS	0.25 NS	-

Appendix A5.11 (continued)

Table A5.11.2 Environment II (18-12°C/0.4 kPa)

$\hat{b}_1$ differences $\hat{b}_2$ differences	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	1.11 NS	ND	ND	1.11 NS	0.04 NS
Timgalen	1.12 NS	-	ND	ND	0.28 NS	1.18 NS
Pembina	ND	ND	-	ND	ND	ND
Gamut	ND	ND	ND	-	ND	ND
Sherbati-Sonora	1.10 NS	0.28 NS	ND	ND	-	1.15 NS
Karamu	0.05 NS	1.19 NS	ND	ND	1.15 NS	-

Appendix A5.11 (continued)

Table A5.11.3 Environment III (30-20°C/1.0 kPa)

$\hat{b}_1$ differences / $\hat{b}_2$ differences	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	0.38 NS	2.95*	0.33 NS	1.29 NS	3.72**
Timgalen	0.51 NS	-	1.96 NS	0.55 NS	0.64 NS	3.21**
Pembina	2.70*	1.96 NS	-	1.26 NS	3.17**	2.39*
Gamut	0.22 NS	0.58 NS	1.26 NS	-	1.24 NS	2.70*
Sherbati-Sonora	1.42 NS	0.63 NS	3.16**	1.26 NS	-	4.07**
Karamu	3.55**	3.17**	2.34*	2.64*	4.02**	-

Appendix A5.12

Estimated t statistics for differences amongst pairs of Y-intercepts ($\hat{a}$) relating to the curves for basal alpha-amylase activity amongst six wheat genotypes, established within three environments.

Table A5.12.1 Environments I (18-12°C/1.0 kPa) and II (18-12°C/0.4 kPa)

$\hat{a}$ (env. I) $\hat{a}$ (env. II)	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	13.36***	18.53***	18.12***	5.36***	104.82***
Timgalen	7.79***	-	7.45***	6.64***	13.01***	135.96***
Pembina	20.69***	14.88***	-	1.28 NS	22.85***	144.64***
Gamut	23.43***	18.44***	4.78***	-	22.59***	149.72***
Sherbati-Sonora	84.67***	86.82***	87.96***	88.55***	-	153.51
Karamu	3.90***	12.97***	28.76***	32.36***	92.59***	-

Appendix A5.12 (continued)

Table A5.12.2 Environment III (30-20°C/1.0 kPa)

a (env. III)	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	41.58***	18.81***	47.33***	11.61***	57.88***
Timgalen	-	-	23.24***	0.37 NS	48.22***	73.0***
Pembina	-	-	-	27.46***	12.67***	65.33***
Gamut	-	-	-	-	73.58***	73.88***
Sherbati-Sonora	-	-	-	-	-	63.32***
Karamu	-	-	-	-	-	-

Appendix A5.13

Estimated t statistics for differences amongst pairs of regression coefficients ($\hat{b}$) relating to the curves for basal alpha-amylase activity amongst six wheat genotypes, established within three environments.

Table A5.13.1 Environment I (18-12°C/1.0 kPa)

$\hat{b}_1$ differences $\hat{b}_2$ differences	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	0.11 NS	0.46 NS	0.56 NS	0.82 NS	4.59***
Timgalen	0.58 NS	-	1.00 NS	1.22 NS	1.20 NS	7.16***
Pembina	0.87 NS	0.84 NS	-	0.22 NS	2.44*	7.02***
Gamut	0.87 NS	0.84 NS	0.01 NS	-	2.72*	7.02***
Sherbati-Sonora	0.11 NS	1.26 NS	2.32*	2.34*	-	8.47***
Karamu	4.80***	7.54***	7.39***	7.42***	8.36***	-

Appendix A5.13 (continued)

Table A5.13.2 Environment II (18-12°C/0.4 kPa)

$\hat{b}_1$ differences $\hat{b}_2$ differences	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	0.69 NS	2.18*	2.49*	6.30***	0.71 NS
Timgalen	0.73 NS	-	1.77 NS	2.18*	6.36***	1.58 NS
Pembina	2.04 NS	1.56 NS	-	0.55 NS	5.98***	3.47**
Gamut	2.31*	1.93 NS	0.48 NS	-	5.94***	3.89***
Sherbati-Sonora	6.45***	6.44***	6.13***	6.10***	-	7.26***
Karamu	0.50 NS	1.40 NS	3.07**	3.45**	7.13***	-

Appendix A5.13 (continued)

Table A5.13.3 Environment III (30-20°C/1.0 kPa)

$\hat{b}_1$ differences $\hat{b}_2$ differences	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	2.11*	1.11 NS	2.53*	0.27 NS	56.38***
Timgalen	2.30*	-	0.98 NS	0.19 NS	2.93**	57.06***
Pembina	1.01 NS	1.29 NS	-	1.31 NS	1.23 NS	56.61***
Gamut	2.53*	0.01 NS	1.47 NS	-	4.75***	57.75***
Sherbati-Sonora	0.60 NS	3.08**	0.74 NS	4.60***	-	58.13***
Karamu	3.09**	3.92***	3.50**	3.96***	3.38**	-

Appendix A5.14

Estimated t statistics for differences amongst pairs of <u>Y-intercepts</u> ($\hat{a}$) relating to the curves for alpha <u>amylase response</u> amongst six wheat genotypes, established within three environments.

Table A5.14.1 Environments I (18-12°C/1.0 kPa) and II (18-12°C/0.4 kPa)

$\hat{a}$ (env. I) $\hat{a}$ (env. II)	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	59.32***	20.61***	93.84***	39.81***	55.99***
Timgalen	40.47***	-	9.32***	39.07***	24.83***	11.35***
Pembina	20.39***	22.78***	-	34.40***	3.96***	3.33**
Gamut	9.05***	37.45***	23.22***	-	63.64***	51.87***
Sherbati-Sonora	50.20***	14.39***	34.98***	45.77***	-	15.36***
Karamu	19.98***	23.96***	21.89***	18.62***	25.49***	-

Appendix A5.14 (continued)

Table A5.14.2 Environment III (30-20°C/1.0 kPa)

$\hat{a}$ (env. III)	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	9.79***	1.40 NS	4.03***	7.98***	1.89 NS
Timgalen	-	-	13.05***	4.97***	26.65***	25.75***
Pembina	-	-	-	3.61**	13.15***	5.79***
Gamut	-	-	-	-	13.29***	7.71***
Sherbati-Sonora	-	-	-	-	-	10.93***
Karamu	-	-	-	-	-	-

Appendix A5.15

Estimated t statistics for differences amongst pairs of regression coefficients ($\hat{b}$) relating to the curves for alpha amylase response amongst six wheat genotypes, established within three environments.

Table A5.15.1 Environment I (18-12°C/1.0 kPa)

$\hat{b}_1$ differences $\hat{b}_2$ differences	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	1.74 NS	0.51 NS	2.84*	1.21 NS	1.69 NS
Timgalen	1.75 NS	-	0.16 NS	1.22 NS	0.69 NS	0.29 NS
Pembina	0.75 NS	0.14 NS	-	1.00 NS	0.13 NS	0.04 NS
Gamut	2.87**	1.25 NS	0.95 NS	-	1.91 NS	1.57 NS
Sherbati-Sonora	1.28 NS	0.66 NS	0.22 NS	1.92 NS	-	0.46 NS
Karamu	1.74 NS	0.27 NS	0.01 NS	1.59 NS	0.44 NS	-

Table A5.15.1 (continued)

$\hat{b}_3$ differences (env. I)	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	69318***	43841***	56599***	69318***	69318***
Timgalen	-	-	0.07 NS	1.26 NS	0.69 NS	0.24 NS
Pembina	-	-	-	0.89 NS	0.31 NS	0.06 NS
Gamut	-	-	-	-	1.96 NS	1.56 NS
Sherbati-Sonora	-	-	-	-	-	0.52 NS
Karamu	-	-	-	-	-	-

Appendix A5.15 (continued)

Table A5.15.2 Environment II (18-12°C/0.4 kPa)

$\hat{b}_1$ differences / $\hat{b}_2$ differences	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	1.22 NS	0.61 NS	0.26 NS	1.49 NS	0.51 NS
Timgalen	1.26 NS	-	0.68 NS	1.11 NS	0.41 NS	0.63 NS
Pembina	0.62 NS	0.71 NS	-	0.68 NS	1.03 NS	0.57 NS
Gamut	0.24 NS	1.11 NS	0.66 NS	-	1.34 NS	0.48 NS
Sherbati-Sonora	1.50 NS	0.40 NS	1.03 NS	1.33 NS	-	0.68 NS
Karamu	0.45 NS	0.57 NS	0.50 NS	0.41 NS	0.61 NS	-

Table A5.15.2 (continued)

$\hat{b}_3$ differences (env. II)	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	1.27 NS	0.66 NS	0.21 NS	1.52 NS	0.57 NS
Timgalen	-	-	0.70 NS	1.10 NS	0.40 NS	0.72 NS
Pembina	-	-	-	0.66 NS	1.03 NS	0.64 NS
Gamut	-	-	-	-	1.32 NS	0.54 NS
Sherbati-Sonora	-	-	-	-	-	0.76 NS
Karamu	-	-	-	-	-	-

Appendix A5.15 (continued)

Table A5.15.3 Environment III (30-20°C/1.0 kPa)

$\hat{b}_1$ differences $\hat{b}_2$ differences	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	1.55 NS	0.27 NS	0.57 NS	1.11 NS	0.21 NS
Timgalen	1.70 NS	-	2.22*	0.82 NS	4.52***	6.55***
Pembina	0.44 NS	2.17*	-	0.44 NS	1.93 NS	0.86 NS
Gamut	0.61 NS	0.93 NS	0.30 NS	-	1.86 NS	1.03 NS
Sherbati-Sonora	1.12 NS	4.80***	2.20*	1.93 NS	-	1.59 NS
Karamu	0.13 NS	7.05***	1.06 NS	1.01 NS	1.75 NS	-

Table A5.15.3 (continued)

$\hat{b}_3$ differences (env. III)	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	1.73 NS	0.77 NS	0.67 NS	0.29 NS	0.10 NS
Timgalen	-	-	1.44 NS	0.93 NS	1.23 NS	3.61 NS
Pembina	-	-	-	0.04 NS	0.73 NS	1.25 NS
Gamut	-	-	-	-	0.71 NS	0.84 NS
Sherbati-Sonora	-	-	-	-	-	0.37 NS
Karamu	-	-	-	-	-	-

Appendix 6 : Significance symbols for tests of hypothesis of environmental comparisons are as follows :

*	$0.05 > P > 0.01$
**	$0.01 > P > 0.005$
***	$0.005 > P$
NS	not significant at the 5% level

Table A6.1 Estimated t statistics for differences amongst pairs of Y-intercepts ($\hat{a}$) and regression coefficients ($\hat{b}$) between three environments relating to the curves for moisture content amongst six wheat cultivars.

	Paired environmental comparison					
	I, II		II, III		I, III	
	$\hat{a}$ diff.'s	$\hat{b}$ diff.'s	$\hat{a}$ diff.'s	$\hat{b}$ diff.'s	$\hat{a}$ diff.'s	$\hat{b}$ diff.'s
Sonora	1.17 NS	0.20 NS	1.50 NS	4.16***	0.92 NS	4.16***
Timgalen	1.88 NS	2.77**	1.66 NS	5.46***	0.82 NS	4.77***
Pembina	6.97***	7.56***	2.16 NS	4.41***	0.00 NS	2.84**
Gamut	1.11 NS	0.33 NS	3.24**	3.78***	2.66*	4.19***
Sherbati-Sonora	0.67 NS	2.65**	0.53 NS	4.63***	0.30 NS	4.16***
Karamu	2.84**	3.40***	1.19 NS	4.06***	0.57 NS	2.82**

Environment I = 18-12°C; 1.0 kPa
Environment II = 18-12°C; 0.4 kPa
Environment III = 30-20°C; 1.0 kPa

Table A6.2 Estimated t statistics for differences amongst pairs of Y-intercepts ($\hat{a}$) and regression coefficients ($\hat{b}$) between three environments relating to the curves for grain dry-weight amongst six wheat genotypes.

	Paired environmental comparison					
	I, II		II, III		I, III	
	$\hat{a}$ diff.'s	$\hat{b}$ diff.'s	$\hat{a}$ diff.'s	$\hat{b}$ diff.'s	$\hat{a}$ diff.'s	$\hat{b}$ diff.'s
Sonora	0.51 NS	0.05 NS	7.76***	10.01***	7.69***	11.13***
Timgalen	1.28 NS	1.95 NS	6.32***	3.33**	6.23***	4.25***
Pembina	3.32**	2.08*	11.01***	3.31**	6.02***	0.79 NS
Gamut	3.13**	1.52 NS	16.67***	9.73***	13.18***	7.90***
Sherbati-Sonora	1.05 NS	1.60 NS	12.95***	4.57***	9.65***	5.57***
Karamu	1.85 NS	0.06 NS	5.81***	7.74***	9.85***	10.37***

Environment I = 18-12°C; 1.0 kPa
Environment II = 18-12°C; 0.4 kPa
Environment III = 30-20°C; 1.0 kPa

Table A6.3 Estimated t statistics for differences amongst pairs of Y-intercepts ($\hat{a}$) and regression coefficients ($\hat{b}$) between three environments relating to the curves for pigmentation amongst six wheat cultivars.

	Paired environmental comparison					
	I, II		II, III		I, III	
	$\hat{a}$ diff.'s	$\hat{b}$ diff.'s	$\hat{a}$ diff.'s	$\hat{b}$ diff.'s	$\hat{a}$ diff.'s	$\hat{b}$ diff.'s
Sonora	0.25 NS	0.19 NS	1.15 NS	1.66 NS	1.53 NS	1.75 NS
Timgalen	0.15 NS	0.11 NS	1.88 NS	2.34*	2.08*	2.30*
Pembina	0.02 NS	0.19 NS	1.52 NS	1.73 NS	1.40 NS	1.78 NS
Gamut	0.11 NS	0.18 NS	1.91 NS	2.76**	0.56 NS	2.87**
Sherbati-Sonora	0.31 NS	0.13 NS	1.68 NS	2.10*	2.09*	2.12*
Karamu	0.40 NS	0.41 NS	0.66 NS	2.35*	0.91 NS	2.51*

Environment I = 18-12°C; 1.0 kPa
Environment II = 18-12°C; 0.4 kPa
Environment III = 30-20°C; 1.0 kPa

Table A6.4 Estimated t statistics for differences amongst pairs of Y-intercepts between three environments relating to the curves for flavan-3-ol concentration amongst six wheat genotypes.

	Paired environmental comparison		
	I, II	II, III	I, III
Sonora	228.96***	14.26***	241.46***
Timgalen	36.33***	92.49***	14.21***
Pembina	84.76***	101.47***	8.07***
Gamut	91.37***	162.96***	28.09***
Sherbati-Sonora	107.44***	91.66***	155.85***
Karamu	588.41***	223.14***	485.14***

Environment I = 18-12°C; 1.0 kPa
II = 18-12°C; 0.4 kPa
III = 30-20°C; 1.0 kPa

Table A6.5 Estimated t statistics for differences amongst pairs of regression coefficients ($\hat{b}$) between three environments relating to the curves for flavan-3-ol concentration amongst six wheat genotypes.

	Paired environmental comparison					
	I, II		II, III		I, III	
	$\hat{a}$ diff.'s	$\hat{b}$ diff.'s	$\hat{a}$ diff.'s	$\hat{b}$ diff.'s	$\hat{a}$ diff.'s	$\hat{b}$ diff.'s
Sonora	1.27 NS	1.86 NS	1.29 NS	0.24 NS	1.79 NS	1.91 NS
Timgalen	0.74 NS	0.60 NS	2.91**	5.31***	0.82 NS	2.45* NS
Pembina	1.41 NS	1.47 NS	0.17 NS	1.57 NS	1.36 NS	0.15 NS
Gamut	1.50 NS	1.64 NS	1.29 NS	1.90 NS	0.41 NS	0.39 NS
Sherbati-Sonora	1.98 NS	1.70 NS	1.53 NS	1.23 NS	2.80**	2.51*
Karamu	3.81***	5.19***	0.57 NS	1.96 NS	3.39**	3.47**

Environment I = 18-12°C; 1.0 kPa
Environment II = 18-12°C; 0.4 kPa
Environment III = 30-20°C; 1.0 kPa

Table A6.6 Estimated t-statistics for differences amongst pairs of Y-intercepts ($\hat{a}$) between three environments relating to the curves for germination amongst six wheat cultivars.

Genotype	Paired environmental comparison		
	I, II	II, III	I, III
Sonora	76.05***	247.12***	21.42***
Timgalen	11.28***	29.44***	22.58***
Pembina	[1]ND	ND	ND
Gamut	ND	ND	32.13***
Sherbati-Sonora	38.50***	38.04***	9.30***
Karamu	65.12***	336.16***	29.07***

Environment I = 18-12°C; 1.0 kPa
II = 18-12°C; 0.4 kPa
III = 30-20°C; 1.0 kPa

[1]ND = no data

Table A6.7 Estimated t-statistics for differences amongst pairs of <u>regression coefficients</u> ($\hat{b}$) between three environments relating to the curves for <u>germination</u> amongst six wheat cultivars.

	Paired environmental comparison					
	I, II		II, III		I, III	
	$\hat{a}$ diff.'s	$\hat{b}$ diff.'s	$\hat{a}$ diff.'s	$\hat{b}$ diff.'s	$\hat{a}$ diff.'s	$\hat{b}$ diff.'s
Sonora	6.94***	6.82***	11.00***	11.51***	0.95 NS	0.52 NS
Timgalen	0.48 NS	0.43 NS	1.37 NS	1.53 NS	1.89 NS	2.25*
Pembina	ND[1]	ND	ND	ND	ND	ND
Gamut	ND	ND	ND	ND	2.53*	2.83**
Sherbati-Sonora	1.68 NS	1.70 NS	1.78 NS	2.07*	0.07 NS	0.89 NS
Karamu	4.16***	4.06***	31.19***	17.44***	1.91 NS	2.06*

Environment I = 18-12°C; 1.0 kPa
Environment II = 18-12°C; 0.4 kPa
Environment III = 30-20°C; 1.0 kPa

[1] ND = no data

Table A6.8 Estimated t statistics for differences amongst pairs of <u>Y-intercepts</u> ($\hat{a}$) between three environments relating to the curves for <u>embryo maturity</u> amongst six wheat cultivars.

Genotype	Paired environmental comparison		
	I, II	II, III	I, III
Sonora	100.54***	322.31***	7.80***
Timgalen	8.00***	24.31***	24.27***
Pembina	ND[1]	ND	ND
Gamut	ND	ND	20.15***
Sherbati-Sonora	36.19***	39.34***	9.01***
Karamu	93.31***	372.43***	18.97***

Environment I = 18-12°C; 1.0 kPa
II = 18-12°C; 0.4 kPa
III = 30-20°C; 1.0 kPa

[1] ND = no data

Table A6.9 Estimated t statistics for differences amongst pairs of regression coefficients ($\hat{b}$) between three environments relating to the curves for embryo maturity amongst six wheat genotypes.

	Paired environmental comparison					
	I, II		II, III		I, III	
	$\hat{a}$ diff.'s	$\hat{b}$ diff.'s	$\hat{a}$ diff.'s	$\hat{b}$ diff.'s	$\hat{a}$ diff.'s	$\hat{b}$ diff.'s
Sonora	6.03***	5.82***	15.17***	15.87***	0.00 NS	0.59 NS
Timgalen	0.32 NS	0.27 NS	1.17 NS	1.37 NS	2.08*	2.62*
Pembina	ND[1]	ND	ND	ND	ND	ND
Gamut	ND	ND	ND	ND	1.85 NS	2.47*
Sherbati-Sonora	1.69 NS	1.67 NS	1.85 NS	2.18*	0.10 NS	0.52 NS
Karamu	3.79**	3.50**	31.25***	25.13***	1.92 NS	2.76*

Environment I = 18-12°C; 1.0 kPa
Environment II = 18-12°C; 0.4 kPa
Environment III = 30-20°C; 1.0 kPa

[1] ND = no data

Table A6.10 Estimated t-statistics for differences amongst pairs of Y-intercepts ($\hat{a}$) between three environments relating to the curves for embryo dormancy amongst six wheat cultivars.

Genotype	Paired environmental comparison		
	I, II	II, III	I, III
Sonora	84.11***	79.42***	27.67***
Timgalen	18.15***	26.25***	17.80***
Pembina	ND[1]	ND	ND
Gamut	ND	ND	31.65***
Sherbati-Sonora	10.51***	8.45***	11.22***
Karamu	59.54***	86.38***	2.44*

Environment I = 18-12°C; 1.0 kPa
II = 18-12°C; 0.4 kPa
III = 30-20°C; 1.0 kPa

[1] ND = no data

Table A6.11 Estimated t-statistics for differences amongst pairs of regression coefficients $(\hat{b})$ between three environments relating to the curves for embryo dormancy amongst six wheat cultivars.

	Paired environmental comparison					
	I, II		II, III		I, III	
	$\hat{a}$ diff.'s	$\hat{b}$ diff.'s	$\hat{a}$ diff.'s	$\hat{b}$ diff.'s	$\hat{a}$ diff.'s	$\hat{b}$ diff.'s
Sonora	3.65**	3.70**	3.39**	3.56**	1.40 NS	0.97 NS
Timgalen	0.77 NS	0.77 NS	1.20 NS	1.34 NS	1.66 NS	2.11*
Pembina	ND[1]	ND	ND	ND	ND	ND
Gamut	ND	ND	ND	ND	2.63*	2.94**
Sherbati-Sonora	ND	ND	0.44 NS	0.57 NS	0.15 NS	0.57 NS
Karamu	2.99**	2.98**	3.61**	3.53**	0.14 NS	0.25 NS

Environment I = 18-12°C; 1.0 kPa
Environment II = 18-12°C; 0.4 kPa
Environment III = 30-20°C; 1.0 kPa

[1] ND = no data

Table A6.12 Estimated t statistics for differences amongst pairs of Y-intercepts between three environments relating to the curves for basal alpha-amylase activity amongst six wheat genotypes.

Genotype	Paired environmental comparison		
	I, II	II, III	I, III
Sonora	0.70 NS	4.27***	3.20**
Timgalen	7.88***	24.65***	19.88***
Pembina	0.20 NS	8.47***	8.18***
Gamut	6.06***	20.92***	20.63***
Sherbati-Sonora	96.05***	99.23***	7.10***
Karamu	126.01***	48.99***	123.25***

Environment I = 18-12°C; 1.0 kPa
II = 18-12°C; 0.4 kPa
III = 30-20°C; 1.0 kPa

Table A6.13 Estimated t statistics for differences amongst pairs of regression coefficients ($\hat{b}$) between three environments relating to the curves for basal alpha-amylase activity amongst six wheat genotypes.

	Paired environmental comparison					
	I, II		II, III		I, III	
	$\hat{a}$ diff.'s	$\hat{b}$ diff.'s	$\hat{a}$ diff.'s	$\hat{b}$ diff.'s	$\hat{a}$ diff.'s	$\hat{b}$ diff.'s
Sonora	1.08 NS	0.21 NS	1.70 NS	0.80 NS	1.28 NS	0.28 NS
Timgalen	0.69 NS	0.74 NS	3.84***	2.49*	2.59*	2.12*
Pembina	0.26 NS	0.09 NS	0.52 NS	0.23 NS	0.74 NS	0.16 NS
Gamut	0.58 NS	0.58 NS	2.41*	2.07*	2.24*	2.04 NS
Sherbati-Sonora	7.06***	6.94***	6.37***	6.64***	2.64*	1.46 NS
Karamu	7.86***	8.23***	53.84***	2.46*	51.56***	6.45***

Environment I = 18-12°C; 1.0 kPa
Environment II = 18-12°C; 0.4 kPa
Environment III = 30-20°C; 1.0 kPa

Table A6.14 Estimated t statistics for differences amongst pairs of Y-intercepts between three environments relating to the curves for alpha amylase response among six wheat genotypes.

Genotype	Paired environmental comparison		
	I, II	II, III	I, III
Sonora	75.11***	16.72***	13.19***
Timgalen	40.64***	28.16***	16.07***
Pembina	2.58*	7.82***	6.62***
Gamut	28.49***	17.12***	42.47***
Sherbati-Sonora	31.79***	7.09***	19.76***
Karamu	20.73***	23.36***	32.40***

Environment I = 18-12°C; 1.0 kPa
II = 18-12°C; 0.4 kPa
III = 30-20°C; 1.0 kPa

Table A6.15 Estimated t statistics for differences amongst pairs of regression coefficients (b) between three environments relating to the curves for alpha amylase response amongst six wheat genotypes.

	Paired environmental comparison								
	I, II			II, III			I, III		
	b_1	b_2	b_3	b_1	b_2	b_3	b_1	b_2	b_3
Sonora	1.91 NS	1.99 NS	6.9E4***	0.95 NS	0.85 NS	0.34 NS	0.76 NS	0.31 NS	3.7E4***
Timgalen	1.17 NS	1.15 NS	0.92 NS	2.00 NS	3.18**	2.24*	0.02 NS	1.04 NS	1.32 NS
Pembina	0.10 NS	0.17 NS	0.20 NS	0.22 NS	0.02 NS	0.09 NS	0.16 NS	0.18 NS	0.12 NS
Gamut	1.73 NS	0.89 NS	0.78 NS	0.54 NS	0.30 NS	0.28 NS	1.57 NS	1.21 NS	0.86 NS
Sherbati-sonora	0.50 NS	0.94 NS	0.68 NS	0.26 NS	1.09 NS	1.28 NS	1.58 NS	2.23*	1.83 NS
Karamu	0.54 NS	0.47 NS	0.61 NS	0.62 NS	0.59 NS	0.80 NS	1.26 NS	1.56 NS	0.88 NS

Appendix 7 : Significance symbols for tests of hypothesis amongst comparisons of regressed estimates are as follows :

*	$0.05 > P > 0.01$
**	$0.01 > P > 0.005$
***	$0.005 > P$
NS	not significant at the 5% level

Appendix A7.1

Estimated t-statistics for differences amongst pairs of <u>regressed estimates</u> of days to <u>harvest ripeness</u> within three environments amongst six wheat cultivars.

Table A7.1.1 Environments I (18-12^{o}C; 1.0 kPa) and II (18-12^{o}C; 0.4 kPa)

Env. I Env. II	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	4.21***	37.88***	0.64 NS	2.40*	2.51*
Timgalen	2.14 NS	-	5.53***	3.19**	2.33*	0.12 NS
Pembina	2.64*	0.38 NS	-	8.36***	13.22***	3.56**
Gamut	0.03 NS	1.64 NS	1.93 NS	-	1.71 NS	2.39*
Sherbati-Sonora	0.98 NS	3.36**	4.02**	0.75 NS	-	2.85**
Karamu	0.30 NS	1.63 NS	2.03 NS	0.28 NS	1.23 NS	-

Appendix A7.1 (continued)

Table A7.1.2 Environment III (30-20°C; 1.0 kPa)

Env. III	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	0.03 NS	0.09 NS	0.07 NS	0.06 NS	0.43 NS
Timgalen	-	-	0.06 NS	0.04 NS	0.09 NS	0.41 NS
Pembina	-	-	-	0.03 NS	0.15 NS	0.31 NS
Gamut	-	-	-	-	0.13 NS	0.39 NS
Sherbati-Sonora	-	-	-	-	-	0.48 NS
Karamu	-	-	-	-	-	-

Appendix A7.2

Estimated t-statistics for differences amongst pairs of regressed estimates of days to 50% pigment formation within three environments amongst six wheat cultivars.

Table A7.2.1 Environments I (18-12°C; 1.0 kPa) and II (18-12°C; 0.4 kPa).

Env. I Env. II	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	0.81 NS	0.70 NS	0.29 NS	0.42 NS	1.00 NS
Timgalen	0.42 NS	-	0.12 NS	0.79 NS	0.40 NS	1.99 NS
Pembina	0.52 NS	0.00 NS	-	0.64 NS	0.29 NS	1.88 NS
Gamut	0.43 NS	0.05 NS	0.07 NS	-	0.26 NS	1.85 NS
Sherbati-Sonora	0.28 NS	0.14 NS	0.18 NS	0.97 NS	-	1.54 NS
Karamu	0.40 NS	0.84 NS	1.05 NS	0.91 NS	0.69 NS	-

Appendix A7.2 (continued)

Table A7.2.2 Environment III (30-20°C; 1.0 kPa)

Env. III	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	1.28 NS	0.49 NS	0.76 NS	1.28 NS	0.51 NS
Timgalen	-	-	1.78 NS	1.90 NS	0.19 NS	1.84 NS
Pembina	-	-	-	0.33 NS	1.70 NS	0.00 NS
Gamut	-	-	-	-	1.84	0.34 NS
Sherbati-Sonora	-	-	-	-	-	1.74 NS
Karamu	-	-	-	-	-	-

Appendix A7.3

Estimated t-statistics for differences amongst pairs of <u>regressed</u> <u>estimates</u> for germination at harvest ripeness within three environments amongst six wheat genotypes.

Table A7.3.1 Environments I (18-12°C/1.0 kPa) and II (18-12°C/0.4 kPa)

Env. I Env. II	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	6.50***	ND	3.62**	4.16***	2.43*
Timgalen	0.23 NS	-	ND	3.82**	3.74**	1.11 NS
Pembina	ND[1]	ND	-	ND	ND	ND
Gamut	ND	NS	ND	-	0.28 NS	0.96 NS
Sherbati-Sonora	6.09***	4.57***	ND	ND	-	0.87 NS
Karamu	4.13**	0.54 NS	ND	ND	6.95***	-

[1] ND = no data

Appendix A7.2 (continued)

Table A7.2.2

Env. III	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	0.77 NS	16.21***	2.00 NS	1.93 NS	11.87***
Timgalen	-	-	11.34***	1.15 NS	4.74***	10.44***
Pembina	-	-	-	8.52***	18.60***	4.07***
Gamut	-	-	-	-	5.46***	9.02***
Sherbati-Sonora	-	-	-	-	-	14.14***
Karamu	-	-	-	-	-	-

Appendix A7.4

Estimated t-statistics for differences amongst pairs of regressed estimates for embryo maturity at harvest ripeness within three environments amongst six wheat cultivars.

Table A7.4.1 Environments I (18-12°C/1.0 kPa) and II (18-12°C/0.4 kPa)

Env. I Env. II	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	6.66***	ND	2.23*	2.59*	6.81***
Timgalen	0.60 NS	-	ND	4.73***	3.98***	0.36 NS
Pembina	ND[1]	ND	-	ND	ND	ND
Gamut	ND	ND	ND	-	0.55 NS	4.70***
Sherbati-Sonora	5.76***	4.18***	ND	ND	-	3.87***
Karamu	3.42**	0.17 NS	ND	ND	6.34***	-

[1] ND = no data

Appendix A7.4 (continued)

Table A7.4.2 Environment III (30-20°C/1.0 kPa)

Env. III	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	0.77 NS	4.49***	1.30 NS	3.02**	1.14 NS
Timgalen	-	-	3.48**	1.83 NS	3.36**	1.63 NS
Pembina	-	-	-	5.00***	6.94***	4.46***
Gamut	-	-	-	-	0.97 NS	0.05 NS
Sherbati-Sonora	-	-	-	-	-	0.74 NS
Karamu	-	-	-	-	-	-

Appendix A7.5

Estimated t-statistics for differences amongst pairs of regressed estimates for embryo dormancy at harvest ripeness within three environments amongst six wheat cultivars.

Table A7.5.1 Environments I (18-12°C/1.0 kPa) and II (18-12°C/0.4 kPa)

Env. I Env. II	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	6.57***	ND	4.33***	3.63**	2.73*
Timgalen	0.67 NS	-	ND	3.56**	3.91***	0.83 NS
Pembina	ND[1]	ND	-	ND	ND	ND
Gamut	ND	ND	ND	-	0.57 NS	1.05 NS
Sherbati-Sonora	1.05 NS	1.36 NS	ND	ND	-	1.26 NS
Karamu	1.19 NS	0.11 NS	ND	ND	1.62 NS	-

[1] ND = no data

Appendix A7.5 (continued)

Table A7.5.2 Environment III (30-20°C/1.0 kPa)

Env. III	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	0.98 NS	11.98***	0.31 NS	2.92**	7.05***
Timgalen	-	-	6.71***	1.00 NS	1.15 NS	6.19***
Pembina	-	-	-	5.51***	10.37***	1.83 NS
Gamut	-	-	-	-	2.29*	5.30***
Sherbati-Sonora	-	-	-	-	-	8.04***
Karamu	-	-	-	-	-	-

Appendix A7.6

Estimated t-statistics for differences amongst pairs of regressed estimates for basal alpha-amylase levels at harvest ripeness within three environments amongst six wheat cultivars.

Table A7.6.1 Environments I (18-12°C/1.0 kPa) and II (18-12°C/0.4 kPa)

Env. I Env. II	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	0.04 NS	0.63 NS	5.14***	0.14 NS	0.02 NS
Timgalen	2.54*	-	0.98 NS	7.12***	0.15 NS	0.08 NS
Pembina	1.83 NS	1.43 NS	-	8.93***	0.76 NS	1.24 NS
Gamut	0.05 NS	5.63***	7.44***	-	7.34***	8.58***
Sherbati-Sonora	1.88 NS	0.20 NS	1.02 NS	3.30**	-	0.25 NS
Karamu	2.32*	0.21 NS	1.32 NS	4.44***	0.03 NS	-

Appendix A7.6 (continued)

Table A7.6.2. Environment III (30-20°C/1.0 kPa)

Env. III	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	0.15 NS	0.46 NS	0.79 NS	0.17 NS	0.05 NS
Timgalen	-	-	0.72 NS	1.33 NS	0.00 NS	0.00 NS
Pembina	-	-	-	0.23 NS	0.82 NS	0.21 NS
Gamut	-	-	-	-	1.86 NS	0.27 NS
Sherbati-Sonora	-	-	-	-	-	0.00 NS
Karamu	-	-	-	-	-	-

Appendix A7.7

Estimated t-statistics for differences amongst pairs of regressed estimates for amylase response at harvest ripeness (12½% moisture content) within three environments amongst six wheat cultivars.

Table A7.7.1 Environments I (18-12°C/1.0 kPa) and II (18-12°C/0.4 kPa)

Env. I Env. II	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	7.70***	3.16**	5.91***	1.51	1.09
Timgalen	2.70*	-	2.20*	0.77	8.30***	6.41***
Pembina	0.66	4.03***	-	2.42*	3.96***	2.41*
Gamut	1.44	0.30	1.97	-	6.54***	5.16***
Sherbati-Sonora	5.35***	3.48**	6.48***	2.72*	-	2.39*
Karamu	7.25***	5.91***	8.05***	5.00***	3.05**	-

Appendix A7.7 (continued)

Table A7.7.2 Environment III (30-20°C/1.0 kPa)

	Sonora	Timgalen	Pembina	Gamut	Sherbati-Sonora	Karamu
Sonora	-	0.90 NS	4.46***	0.51 NS	1.82 NS	6.07***
Timgalen	-	-	8.78***	1.63 NS	4.18***	14.71***
Pembina	-	-	-	4.04***	3.53**	1.91 NS
Gamut	-	-	-	-	1.29 NS	5.73***
Sherbati-Sonora	-	-	-	-	-	6.06***
Karamu	-	-	-	-	-	-