Drought resistance in barley as related to color and screening tests
by Thomas Conrad Fink

A thesis submitted in partial fulfillment of the requirements for the degree of DOCTOR OF PHILOSOPHY in Crops and Soil Science
Montana State University

Abstract:
Color as it affects drought resistance in barley isogenes and screening tests for drought resistance in barley cultivars were investigated.

The greater reflection by the light isogene was related to its smaller water use early in the season. From mid-season on the higher stomatal resistances in the dark isogene more than compensated for its smaller reflection with the result being smaller water use by the dark isogene. Seasonal totals showed the light isogene used as much or more water than the dark isogene.

Osmotic potential does not appear to be useful as a screening test because of unreliability and inability to differentiate between cultivars.

Soil water use has good potential as a screening test. The best correlations with drought resistance occur at the shallow and deep depths. The less water used the larger the drought resistance.

Water loss after dry-down is also a potentially good screening test. The optimum drying interval was 24 hours, with whole plants being the best sample. The smaller the water loss, the larger the drought resistance.

Modulus of elasticity gave the highest correlations with drought resistance. However, the tediousness of the procedure makes it of questionable value in preliminary screening. The higher the modulus, the larger the drought resistance.

Plant height, percent plump kernels, and 100 kernel weights are all positively correlated with drought resistance.

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Chapter 1

INTRODUCTION

Drought Resistance Theory

The research for this thesis has involved two related, but separate, research problems. The first involved the influence of color as a drought resistance trait in barley isogenes. This is part of an ongoing research program at Montana State University in which different plant morphological features, such as color, awn length, and others, are evaluated in relation to drought resistance. The second area of research relates screening techniques to drought resistance of barley cultivars. These two areas will be treated separately throughout the thesis.

A brief introduction to drought resistance theory will follow in order to give a general background to the specific areas of drought resistance that were studied. Since this thesis research involved only plant characteristics and their relation to drought resistance, no discussion will be presented involving environmental factors and their relation to drought resistance.

Probably the simplest drought resistance classification scheme includes two categories, drought tolerance and drought avoidance. Drought tolerators include those plants capable of undergoing water stress (experiencing lowered water potential)[1] while still functioning normally. This is often referred to as desiccation resistance. Plant physiological characteristics that enhance this drought tolerance include: a) increased cell wall elasticity; b) the ability of the vacuole to gel or solidify; c) the production of sugars, polyols, peptides and proteins; and d) enlargement of cell walls (54). This thesis measured, as a screening test, osmotic potential, which should be a measure of the production of sugars, polyols, and other salts and, thus, of drought tolerance. Another screening technique researched, modulus of elasticity, measures cell wall elasticity and, consequently, also measures drought tolerance.

Drought avoiders are those plants that maintain a favorable internal water status (high water potential) when undergoing water stress or, such as is the case with desert ephemerals, maintain a high water potential by avoiding altogether any stressful situation. In order to maintain high water potential it is necessary that uptake, U,[2] of water be equal to or greater than the transpirational water loss.[3]

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[1]Throughout this thesis a water potential with a large negative value will be considered low.

[2]All symbols are defined in the text as well as Appendix Table 31.

[3]In some instances, such as with succulents, it is not precisely the uptake, but rather the retention of water in various plant organs that must equal or exceed transpiration.

Using an analogy of Ohm's Law it is possible to define the movement of water in soil and plants as

$$q = \Delta\Psi/r \quad (56) \qquad (1)$$

where q = water flux,

$\Delta\Psi$ = gradient of water potential across some component,

r = resistance across that component.

In a similar fashion to equation (1) we may write the uptake of water as being proportional to

$$U \propto \frac{\Psi_r - \Psi_s}{r_r + r_s} \qquad (2)$$

where U = uptake of water

Ψ_r = root water potential,

Ψ_s = soil water potential,

r_r = root resistance, and

r_s = soil resistance.

Plant morphological features that lower root potential and decrease root and soil resistances would increase uptake of water.

Potentials in the plant, including Ψ_r, consist of three components:

$$(\pm)\ \Psi = (-)\ \Psi_m\ (-)\ \Psi_o\ (\pm)\ \Psi_p \qquad (3)$$

where Ψ = total plant potential (root, leaf, etc.),

Ψ_m = matric potential,

Ψ_o = osmotic potential, and

Ψ_p = turgor or pressure potential.

Matric potential is due to the adsorptive qualities of the tissue matrix. Osmotic potential is due to the presence of salts or other solutes. Turgor potential is caused by vacuolar fluid pressure being greater than atmospheric.

Lowered root potential would likely include lowered osmotic potential caused by increased production of salts, sugars, etc. As mentioned above, osmotic potential was one of the screening tests studied. Soil resistances would be decreased by more extensive rooting systems, both deeper as well as more highly branched with finer root hairs. In both the color study and the screening tests study, soil water use was periodically monitored throughout the season. It was hypothesized that soil water use should give an indirect measure of the rooting patterns and, thus, of root resistance.

Again using an analogy to equation (1), we may define transpiration as being proportional to

$$E \propto \frac{\Psi_a - \Psi_1}{r_a + r_1} \qquad (4)$$

where E = transpiration,

Ψ_a = air potential,

Ψ_1 = leaf potential,

r_a = air resistance, and

r_1 = leaf resistance.

Any feature that lowers leaf potential or increases leaf resistance would decrease transpiration. One factor causing lowered leaf potential is lowered osmotic potential, as described above, which was measured in a screening test. Another plant feature, color, also exerts an influence on the leaf potential. A lighter colored plant reflects more visible radiation and, subsequently, maintains a cooler canopy temperature. This cooler temperature results in a lower leaf potential which in turn means a smaller transpiration rate. In simpler terminology, "cooler water will evaporate more slowly than warmer water". It is interesting to use Gates and Papian's (35) tables on the energy budgets of plant leaves to predict what a difference between plants of 16 percent in visible reflection (a realistic difference between a light and dark colored plant) would do to transpiration rates for a "typical" summer day. If this 16 percent difference in visible reflection results in a 16 percent difference in the radiation load, and if we assume other mean daily values of

leaf dimension along airflow: 5 cm,
leaf dimension across airflow: 1 cm,
internal diffusion resistance: 5 sec-cm^{-1},
windspeed: 20 cm-sec^{-1},
radiation absorbed - dark plant: .86 ly-min^{-1},
radiation absorbed - light plant: .72 ly-min^{-1},
relative humidity: 25 percent, and
air temperature: 20° C,

we find a predicted transpiration rate of 0.115 $ly\text{-}min^{-1}$ for the dark plant and 0.090 $ly\text{-}min^{-1}$ for the light plant. For a 10 hour day this represents 69.00 ly (1.19 mm) for the dark plant and 54.00 (0.93 mm) for the light plant. This is approximately a 22 percent difference between plants in transpiration rates. Plants can also reduce their temperature by sensible heat advection to the air. Morphological features, related to drought resistance, which accomplish this include thin leaves and stems, tall structures, and the presence of hairs or awns.

Leaf resistance depends upon cuticular resistance and stomatal resistance. Stomatal resistance is sometimes broken down into stomatal, sub-stomatal, and cell wall resistances. Plant morphological structures that would increase leaf resistance include a thick cutin, small density and size of stomata, rapid responsiveness of stomata to water stress, leaf rolling, and others. One screening test studied, dry-down or percent water loss, is probably at least partly a measure of leaf resistance. In the color study, stomatal diffusive resistances were monitored throughout the season.

This discussion on plant morphological features as they relate to drought resistance is not intended to be exhaustive. Rather, it is presented here to elucidate a few important drought resistance traits and, in particular, to show how this thesis research fits into the scope of drought resistance theory and research.