FACTORS INFLUENCING THE RATE OF MOISTURE PENETRATION INTO WHEAT DURING TEMPERING

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ABSTRACT

Cereal Chem. 54(3): 627-637

Moisture penetration into wheat during tempering was investigated by an autoradiographic technique. The structure of the starchy endosperm, as determined by scanning electron microscopy, was found to be very significant in affecting the rate of moisture penetration, with the subaleurone region appearing to be rate limiting. The more ordered the endosperm structure became, the slower the rate of moisture movement. Protein content and distribution were also of significance, because they generally contributed to a more ordered endosperm structure. The time required after damping to reach an even distribution of moisture in the grain ranged from 6 hr to well over 24 hr, depending on variety and specific type of kernel (vitreous *vs.* mealy; high protein *vs.* low protein) chosen within a variety.

The factors involved in influencing the rate of moisture penetration into wheat during tempering are of considerable interest. The more rapid the rate of moisture penetration, the more quickly a wheat grain will attain its optimum state for milling. This involves the establishment of a moisture gradient decreasing in magnitude from the bran inward to the starchy endosperm. The considerations involved in this have previously been discussed (1,2).

When the penetration of water into wheat during tempering was investigated by autoradiography (3), the mode of entry was found to be essentially the same for different cultivars, but the rate of penetration varied widely and appeared to relate either to grain hardness or protein content. Protein content was also shown to be significant by Moss (4). Hinton (5) has indicated the importance of the endosperm structure, while the presence of hydrophilic components in the bran has also been implicated in affecting moisture movement (6).

In the present study, an assessment was made of the relative significance of grain hardness, protein content, and endosperm structure in influencing the rate of moisture penetration during tempering as determined by autoradiography. A range of wheat types typical of those currently grown in the U.K. was examined.

MATERIALS AND METHODS

Four winter wheat (*Triticum aestivum*) cultivars were examined: Maris Nimrod, Maris Widgeon, and Maris Huntsman, grown at a site in Buckinghamshire under a range of fertilizer conditions; and Pride, grown at a site in Wiltshire (Table I). Protein content was determined by the Kjeldahl method (N $\times$ 5.7) and grain hardness was measured as grinding resistance (7).

Vitreous and mealy grains were selected visually as being either completely vitreous or completely mealy. At the Buckinghamshire site, the vitreous and mealy grains were selected from high and low nitrogen fertilizer treatments, respectively. At the Wiltshire site, vitreous and mealy grains were selected from the same sample.

The rate of moisture penetration during tempering was followed by an autoradiographic technique as previously outlined (2,3). Grain (10 g) was tempered with tritiated water (100 m Ci/ml) to 16.0% moisture content and then allowed to lie for 3, 6, 12, 18, and 24 hr, respectively, before snap-freezing (liquid CO_2) to prevent any further movement of water. The grains were sectioned longitudinally through the center of the grain and placed in contact with stripping film (Ilford Type K2) for 72 hr at −30° C. The sections were then removed and the film developed, with exposed areas indicating the presence of water. All autoradiographs presented in the text are average representations of 25 repeat experiments.

Scanning electron microscopy (SEM) was carried out using a Coates and Welter (CWIKSCAN/100) instrument. Grains were fractured transversely and coated with a layer of gold (400 Å) before examination. All photographs are typical of a large number of grains.

RESULTS AND DISCUSSION

The autoradiographs of the mealy grains from each of the four cultivars (Fig. 1) showed marked variations in the rate of moisture penetration. The rate of water penetration into mealy grains of the cultivar Pride was very rapid indeed. In 3 hr (Fig. 1, A), there had been a considerable penetration of water into the central starchy endosperm, with movement from the germ region

TABLE I
The Grain Hardness, Protein Content, and Moisture Content of Vitreous and Mealy Grains from a Range of Winter Wheat Cultivars

Cultivar	Site	Grain Type	Grinding Resistance sec	Protein Content %	Moisture Content %	Conditioning Moisture Equilibration Time hr
Maris Widgeon	Buckinghamshire	Vitreous	33	17.0	13.3	>24
Maris Widgeon	Buckinghamshire	Mealy	28	9.0	13.3	24
Maris Nimrod	Buckinghamshire	Vitreous	28	14.2	13.0	18
Maris Nimrod	Buckinghamshire	Mealy	21	9.0	13.0	6
Maris Huntsman	Buckinghamshire	Vitreous	35	17.0	13.1	>24
Maris Huntsman	Buckinghamshire	Mealy	25	9.0	13.1	18
Pride	Wiltshire	Vitreous	48	11.7	12.7	>24
Pride	Wiltshire	Mealy	23	9.0	12.7	6

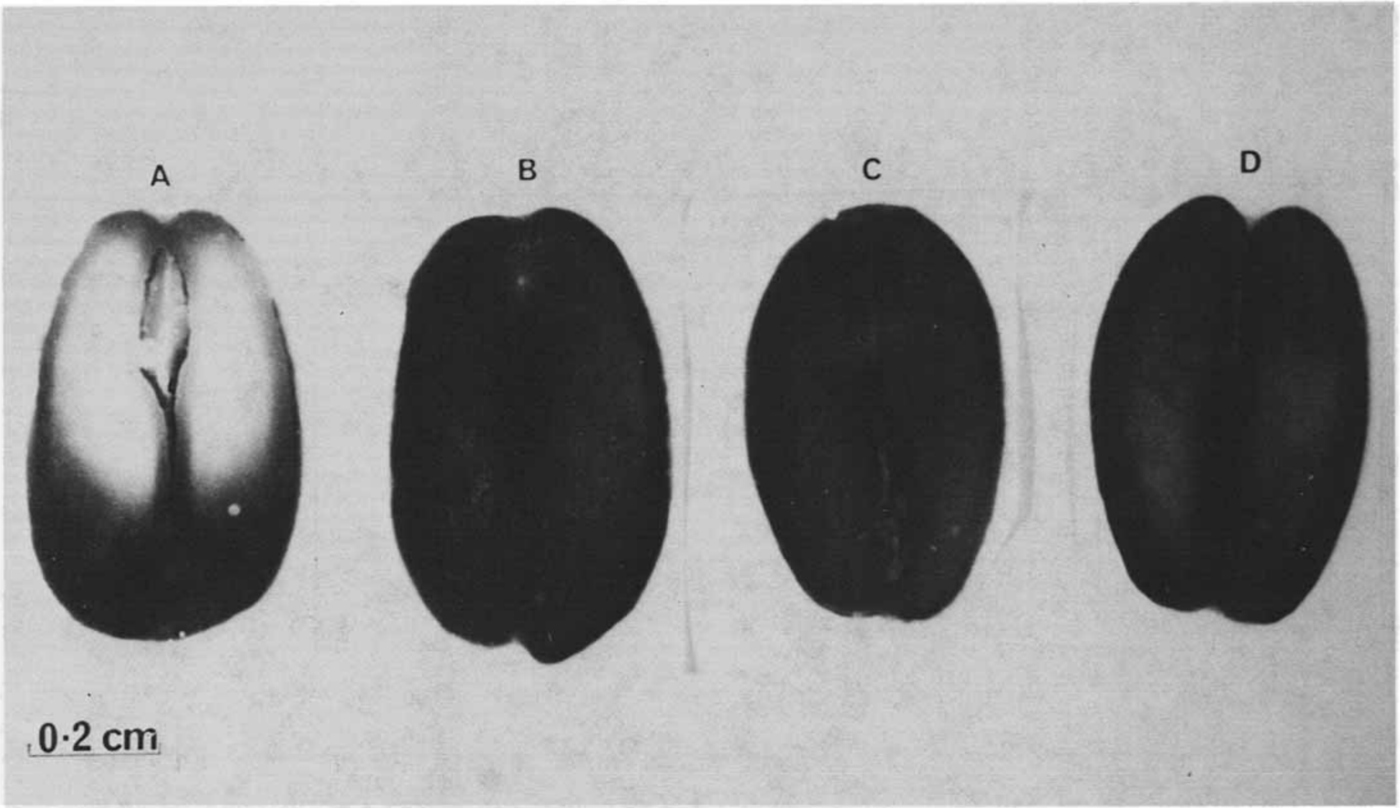


Fig. 1. The location of water in the central longitudinal sections of mealy grains from the cultivars: (A) Pride, 3 hr after damping; (B) Pride, 6 hr after damping; (C) Maris Huntsman, 18 hr after damping; and (D) Maris Widgeon, 18 hr after damping.

predominating. In 6 hr (Fig. 1, B), a state of moisture equilibrium (*i.e.*, an even distribution of moisture through the grain) had almost been established. The cultivar Maris Nimrod showed a similarly rapid rate of moisture penetration and had reached equilibrium conditions in 6 hr. A much slower rate of moisture penetration was evident with Maris Huntsman and Maris Widgeon. To attain equilibrium moisture conditions required 18 hr with Maris Huntsman (Fig. 1, C), but even at this time Maris Widgeon (Fig. 1, D) had moisture concentrated in the outer regions of the grain.

Since the mealy grains from the four cultivars examined were of similar protein and moisture contents and tempered to the same moisture level, other factors than these must be influencing the rate of moisture penetration. When wheat is tempered, water is initially held by the bran and germ and then diffuses into the starchy endosperm. Although there is an easy mode of entry around the germ region (3), the major proportion of the tempering water is held by the large

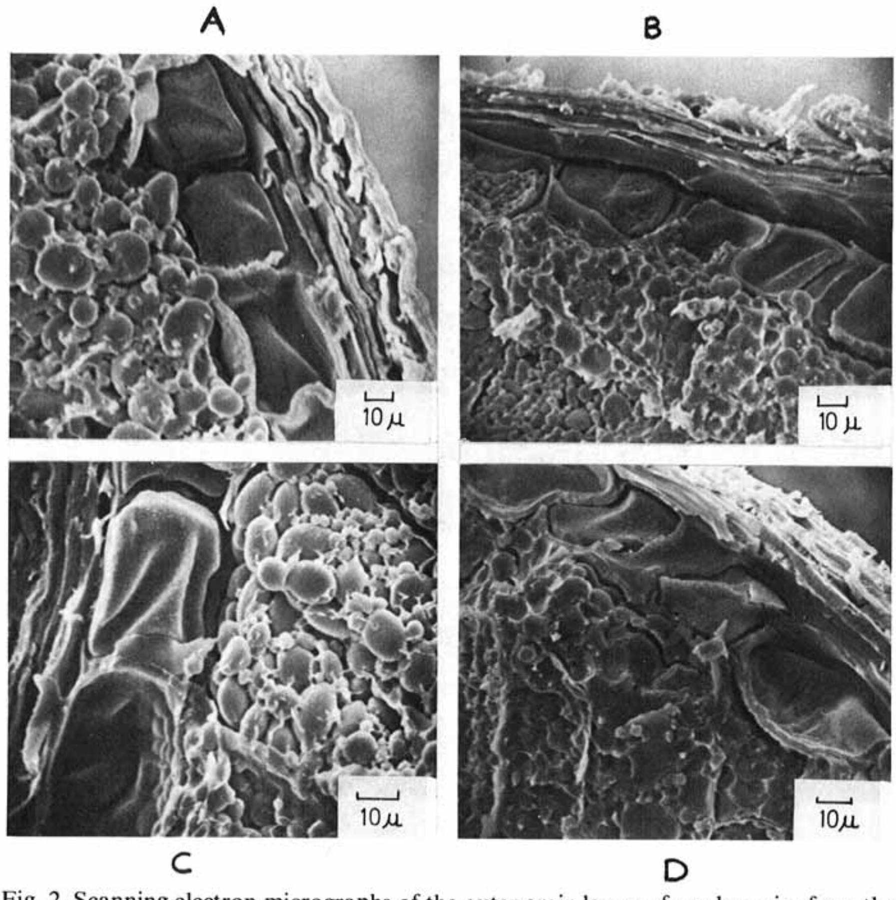


Fig. 2. Scanning electron micrographs of the outer grain layers of mealy grains from the cultivars: (A) Maris Nimrod; (B) Maris Huntsman; (C) Pride; and (D) Maris Widgeon.

bran surface area. Therefore, it is expected that diffusion into the starchy endosperm would primarily be influenced by the structure of the subaleurone region and subsequently by the structure of the central starchy endosperm. These regions were examined by SEM.

It was immediately apparent (Fig. 2) that wide differences in the subaleurone structure existed for the various mealy grains. Both Maris Nimrod (Fig. 2, A) and Pride (Fig. 2, C), which exhibited a very rapid rate of water penetration, had a very open endosperm structure. The protein matrix was quite discontinuous and a large number of air spaces were present. This open, porous structure existed through the whole grain and is undoubtedly responsible for the rapid penetration which results in an early equilibration of moisture in the grain.

The much slower rate of water penetration evident with Maris Huntsman and especially Maris Widgeon (mealy kernels) could also be related to endosperm structure. Maris Huntsman (Fig. 2, B) showed a more continuous subaleurone structure, although this soon became more open, until in the central starchy endosperm (Fig. 3, A) it was again quite disordered. Apparently, the slightly more ordered subaleurone structure is capable of retarding the rate of moisture movement to such an extent that 18 hr were required to attain equilibrium. This effect was even more pronounced with Maris Widgeon. The subaleurone structure for this cultivar (Fig. 2, D) was continuous, with the protein matrix closely enveloping starch granules. Even though the central endosperm was again quite open (Fig. 3, B), the more dense subaleurone region appears able to markedly retard moisture movement, resulting in a concentration of water in the outer regions of the grain even after 18 hr.

Thus, in the mealy grains at the one protein level, it appears that the rate of moisture penetration is dependent on endosperm structure and is reflected in

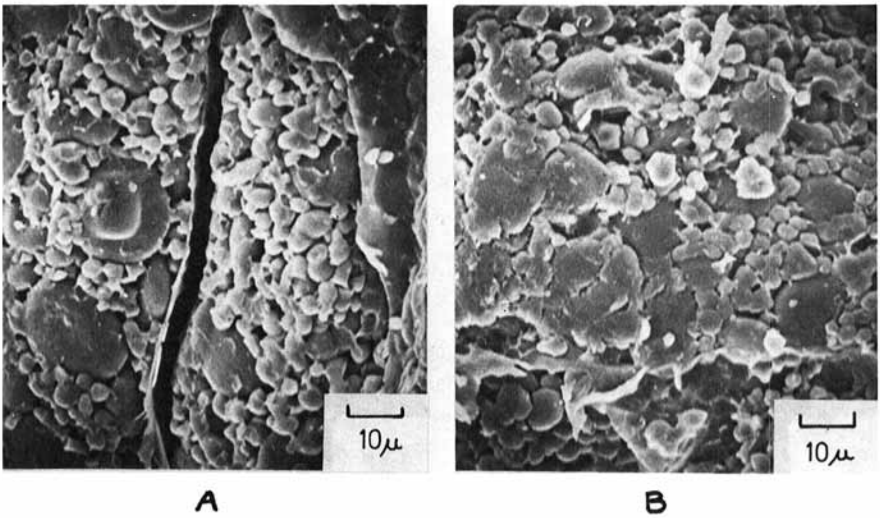


Fig. 3. Scanning electron micrographs of the central starchy endosperm of mealy grains from the cultivars: (A) Maris Huntsman and (B) Maris Widgeon.

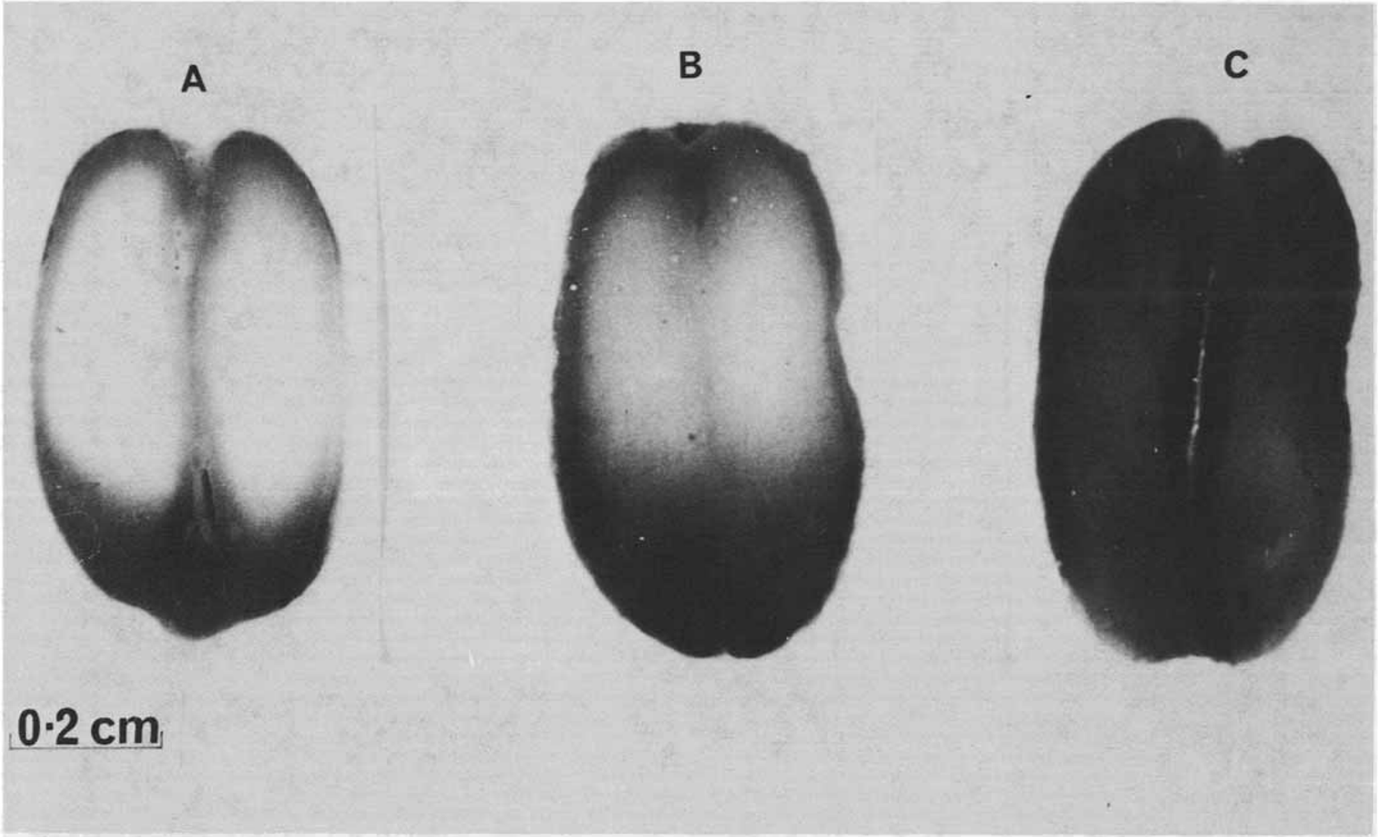


Fig. 4. The location of water in the central longitudinal sections of vitreous grains from the cultivar Pride at: (A) 3 hr after damping; (B) 6 hr after damping; and (C) 24 hr after damping.

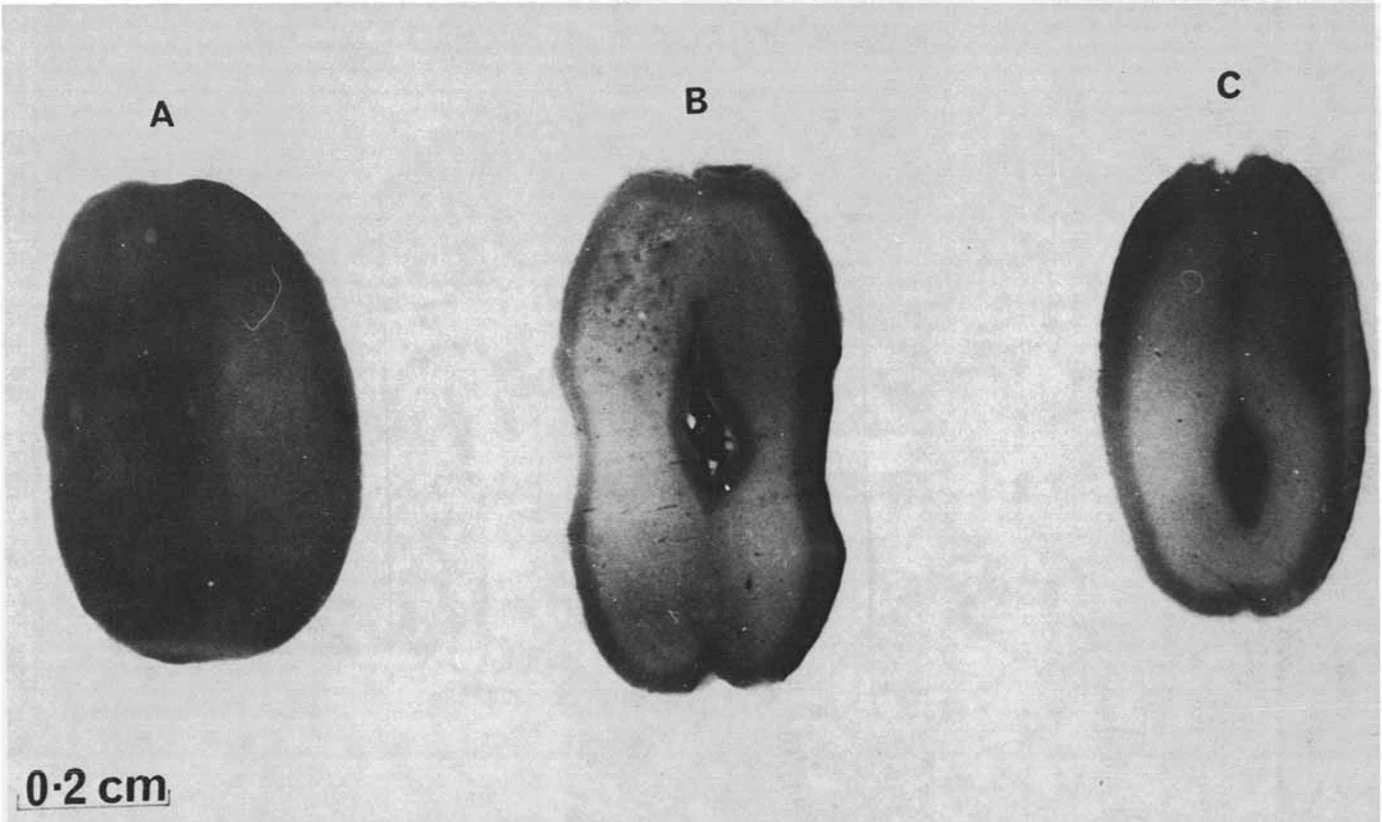


Fig. 5. The location of water in the central longitudinal sections of vitreous grains from the cultivars: (A) Maris Nimrod, 18 hr after damping; (B) Maris Huntsman, 24 hr after damping; and (C) Maris Widgeon, 24 hr after damping.

terms of overall wheat hardness (Table I) for these samples.

While the protein content of the subaleurone area *vs.* that in the central endosperm was not determined, the scanning electron micrographs (Fig. 2) tend to indicate that protein content of the subaleurone areas of Maris Huntsman and Maris Widgeon (mealy kernels) was relatively high, and related to the ordered structure observed and to the high resistance to water penetration. Additionally, a high protein content in the subaleurone areas would probably be related to an increased hardness of the subaleurone area. The existence of marked protein gradients in certain cultivars has previously been demonstrated by Moss (4) and Farrand and Hinton (8).

To further investigate the influence of endosperm structure on the rate of moisture penetration during tempering, but at varying protein levels, autoradiographs of the vitreous grains from the four cultivars were examined.

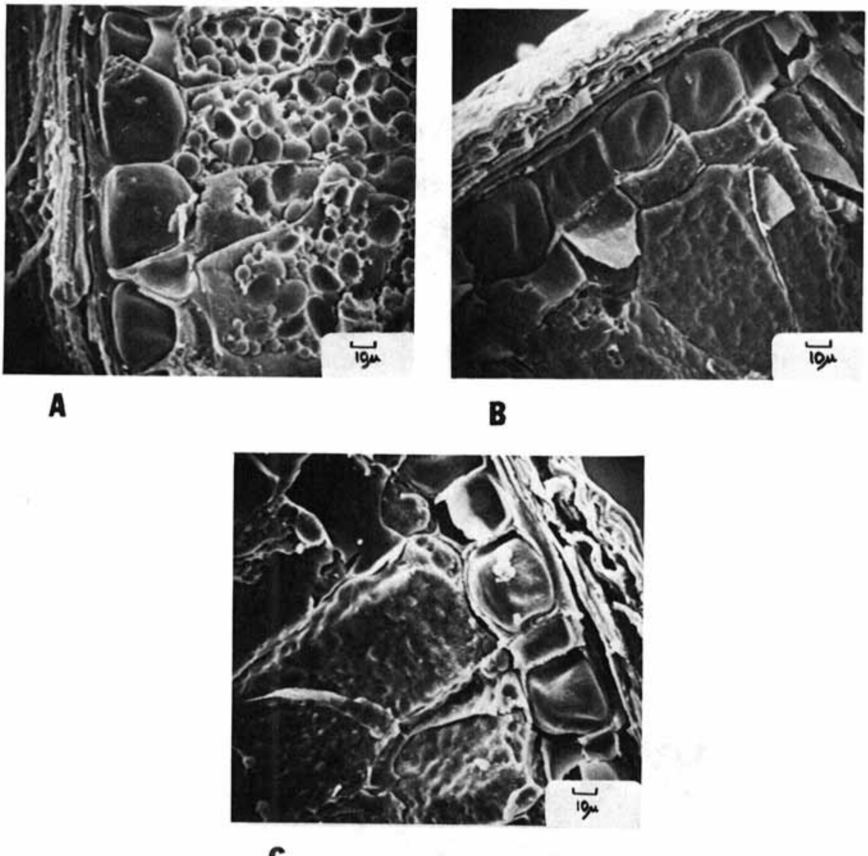
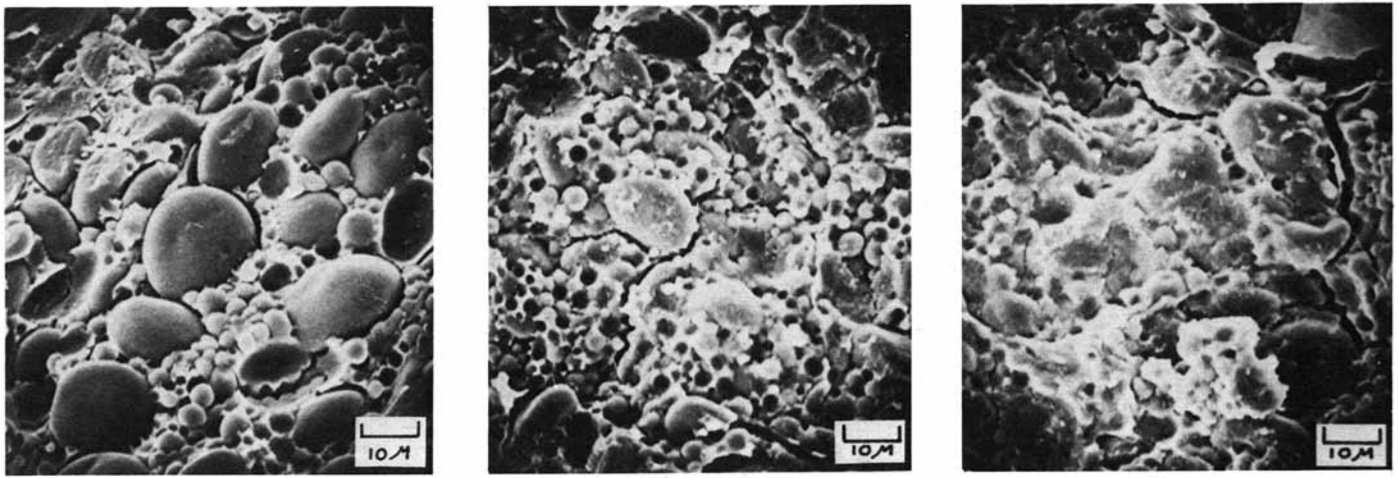


Fig. 6. Scanning electron micrographs of the outer grain layers of vitreous grains from the cultivars: (A) Maris Nimrod; (B) Maris Widgeon (also typical of Maris Huntsman); and (C) Pride.



A B C

Fig. 7. Scanning electron micrographs of the central starchy endosperm of vitreous grains from the cultivars: (A) Maris Nimrod; (B) Maris Widgeon (also typical of Maris Huntsman); and (C) Pride.

The vitreous grains from Pride showed a much slower rate of moisture penetration (Fig. 4) than the corresponding mealy grains. In 3 hr (Fig. 4, A), the moisture was primarily concentrated in the outer layers; in 6 hr (Fig. 4, B), some penetration into the central endosperm had occurred; but, even at 24 hr (Fig. 4, C), the grain had not reached equilibrium.

The vitreous grains from Maris Nimrod (Fig. 5, A) also exhibited a slower rate of moisture penetration and did not approach equilibrium until 18 hr after damping. Both Maris Huntsman (Fig. 5, B) and Maris Widgeon (Fig. 5, C) showed a very definite concentration of water in the subaleurone region, even after 24 hr.

To ascertain the reasons for the variations in water penetration for the vitreous grains from these cultivars, the interactions of protein content, endosperm structure, and grain hardness must be considered. The vitreous grains of Pride, which were selected from the same sample as the mealy grains, were of a higher protein content and extremely hard. It was apparent (Fig. 6, C) that the subaleurone endosperm for these grains was completely continuous and very ordered, and that this structure continued into the central endosperm (Fig. 7, C), as is typical for very hard wheats. The slower rate of moisture penetration could then be primarily attributed to the existence of a more coherent and consequently harder endosperm structure.

The vitreous grains from Maris Nimrod were of a considerably higher protein content than the mealy grains and were slightly harder. This is reflected in a more ordered endosperm structure both in the subaleurone region (Fig. 6, A) and in the central starchy endosperm (Fig. 7, A). The protein in this normally soft cultivar appears to have filled up the air spaces present in the mealy, low-protein grains, but does not tightly entrap the starch granules as evident with the hard vitreous grains of Pride. Nevertheless, the rate of water penetration is significantly retarded. Maris Widgeon and Maris Huntsman both had vitreous grains of extremely high protein content, but were only of intermediate hardness. From the surface of the cells, the subaleurone appears to have an extremely high protein content (Fig. 6, B), with very little evidence of starch granules near the surface. Both displayed strong resistance to water penetration with equilibration requiring over 24 hr. Examination of the autoradiographs at various tempering times shows for both these cultivars that there are heavy concentrations of water in the subaleurone regions. The extremely high protein levels do not persist into the central endosperm (Fig. 7, B), although it is evident that the structure in the central endosperm is quite ordered.

CONCLUSIONS

Endosperm structure has been shown to be of primary importance in water penetration during tempering. A typically soft porous structure allows a very rapid penetration of water into the starchy endosperm and raises the point that, in some instances, to maintain a moisture gradient before milling a lying time of 3–4 hr should not be exceeded. The presence of a more ordered structure strongly retards the rate of moisture penetration. At one protein level (9.0% in this study), this difference in structure appears to be reflected by the hardness of the grain. The more closely the protein matrix occludes the starch granules, the harder the endosperm and the slower the rate of moisture penetration.

Acknowledgments

Thanks are due to M. R. Williams and R. E. Angold for carrying out the scanning electron microscopy and for helpful discussions, and to D. Gedye for preparing the wheat samples at different fertilizer levels.

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[Received May 19, 1975. Accepted November 22, 1976]