Accelerating Malting: A Review of Some Lessons of the Past from the United Kingdom[1]

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ABSTRACT

Most English malting barleys are dormant to some extent when harvested. All malting schemes, but especially accelerated systems, must overcome dormancy and other facets of "immaturity." Warm water steeping, spray steeping, steeping with air rests, and steeping with aeration were already familiar techniques from 1870 to 1910, and were partially adopted in England. However, the use of air rests and steep aeration subsequently declined in the United Kingdom and it was accepted that, at least in some instances, using them produced malts of lower quality in lower yield. Air-rest steeping was successfully reintroduced when scientific studies defined "water sensitivity." Air rests also permit the use of slightly elevated steeping temperatures, which otherwise may induce water sensitivity. However, air rests and especially steep aeration, are not used by all British maltsters. Mechanical decortication was successful in accelerating malting but, unlike the milder process of abrasion, the process was not adopted. Abrasion is not used by all maltsters and its use seems to be declining. A newer low-moisture, squeezing treatment shows promise. The history of these processes shows that engineers have usually met maltsters' requirements. What has, and continues to limit acceleration of the malting process is an insufficient knowledge of the physiology of barley germination. Fundamental scientific studies are needed to give us the understanding to allow further advances in malting.

Key words: Accelerating malting, Warm steeping, Air rests, Aeration, Abrasion, Dormancy

The English harvest usually yields good malting-quality barleys. These are mostly two-rowed varieties. The grains are segregated by variety, width, and nitrogen content (7,10). Viabilities (determined by tetrazolium staining or hydrogen peroxide forced-germination tests) of 99% are common. Extract yields of 306–310 liter-degrees of extract per kilogram of dry malt (L°/kg dm, Institute of Brewing), roughly equivalent to 82% dm, are common (10). All these factors work in the maltster's favor. However dormancy, which varies from year to year and in grain from different localities, is common in most seasons. Samples of some barley varieties may remain dormant for months, until a sufficient period of storage has allowed the grain to "mature," causing great difficulties for the maltster (7,10,31). Probably dormancy or less obvious expressions of post-harvest immaturity are responsible for many of the problems encountered when attempts are made to use rapid malting processes. Over the years, the total times taken to produce top quality malts have declined. In the United Kingdom, the process took 15–32 days during the winter in old floor maltings. Air conditioning, which maintained steady ambient temperatures, allowed year-round malting, and process times of 12–14 days became common. Floor malting germination times were reduced by two days when gibberellic acid was used, but often potassium bromate was also used to reduce heat output in the pieces. In pneumatic maltings (compartment boxes, or drums), using interrupted air-rest steeping and perhaps applications of gibberellic acid with or without a soluble bromate, production times ranged between 6¾ and 10 days. In newer maltings, which are equipped to abrade grains and have temperature-regulated steeps, production times are between 5¾ and 7½ days. Not all malts are made using gibberellic acid, or abrasion, or soluble bromates. All the recent reductions in malting times have followed directly from fundamental scientific studies.

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MALT FAULTS AND MALTSTERS' OBJECTIVES

Malts may be obviously poor in quality because they fail to meet one or more conventional analytical criteria. However, some malts that meet their analytical specifications give problems in the brewhouse. Often problems have been traced to the presence of a small proportion of undermodified kernels. New analytical methods, such as the methylene blue or colored-varnish-penetration tests (8,19), the Calcofluor fluorescent-staining method (1), or the Friabilimeter (22) allow these undermodified kernels to be detected and the homogeneity of the malt assessed. In addition, the viscosities of worts prepared using small-scale 70°C mashes (6) and the extract differences between a mash made with a fine grist and a concentrated mash made with a coarse grist (6) are promising methods for detecting problem malts.

Ideally, the maltster achieves rapid and synchronous "chitting," growth and modification of all the grains in a batch, finishing with a homogeneous malt, i.e., one in which all the grains are equally well modified. By inducing faster chitting or modification in only a proportion of the grains in a batch during attempts to accelerate malting, a nonhomogenous malt is produced. The problem is acute when malting partly dormant grain. Germinative energy is usually assessed over a three-day period using petri-dish tests with 4 and 8

TABLE I
Some Factors That Influence Dormancy and Germination in Malting

Factor	Dormancy	Germination (malting)
Water supply		
Optimal (about 37%)	Minimized	Maximal rate
Excess, surface film or oversteeped	Enhanced	Delayed or prevented
Initial short, warm steep	Reduced	Initial check, then higher % germination
Elevated temperature (e.g. 25°C)	Exacerbated	Reduced, irregular
Germination temperature		
Optimal (7–15°C)	Reduced	Slow but regular
Warm (25–30°C)	Exacerbated	Rapid but irregular
State of grain		
Dried warm and stored	Finally eliminated	Accelerated, finally regular
Husk loosened	Reduced	Accelerated
Surface layers removed	Overcome	Extemely rapid
Surface layers sterilized	Sometimes reduced	Sometimes accelerated
Gases around grains		
Remove carbon dioxide	Not known	Accelerated
Aeration steep	Not known	Accelerated
Air-rest steep	Reduced	Accelerated
Oxygen-enriched atmosphere	Reduced	Accelerated (excess is toxic)
Additives		
Many chemical reagents (KNO_3, HCHO, Fe^{+++}, Hg^{++})	Reduced	(Many are toxic)
Hydrogen peroxide	Reduced	Accelerated in some cases, excess toxic
Gibberellic acid	Reduced	Accelerated (germination and modification)

ml of water (2,10). The extent to which the germination percentage is below the viability of the grain is a measure of the grains' dormancy or immaturity, under two arbitrarily chosen levels of stress (7,10). The difference in percentage germination between the 4- and 8-ml tests is termed "water sensitivity." These tests have been of immense value in deciding when batches of grain are sufficiently mature to be malted by conventional programs. However, grain is frequently exposed to more stressful conditions when rapid malting is the objective, and under these conditions only fully mature grains will chit and modify uniformly. I suggest that another higher-stress germination test should be developed, perhaps using 8 or 10 ml of water, over 2 or 3 days at 25° C, to distinguish grain with a residual degree of immaturity. Table I summarizes some of the many factors that influence the germination of dormant grains and hence the rate and uniformity of malting (7,10,31). The close agreement between the factors strongly suggests that the cause(s) of dormancy are also factors that influence the rate at which even mature grain will malt.

A few methods that have been tested for their usefulness in speeding up malting are listed below.

1. Selection and breeding of barleys that malt rapidly.
2. Selection of only the best samples of grain.
3. Correct drying and storage: this accelerates postharvest maturation and prevents deterioration.

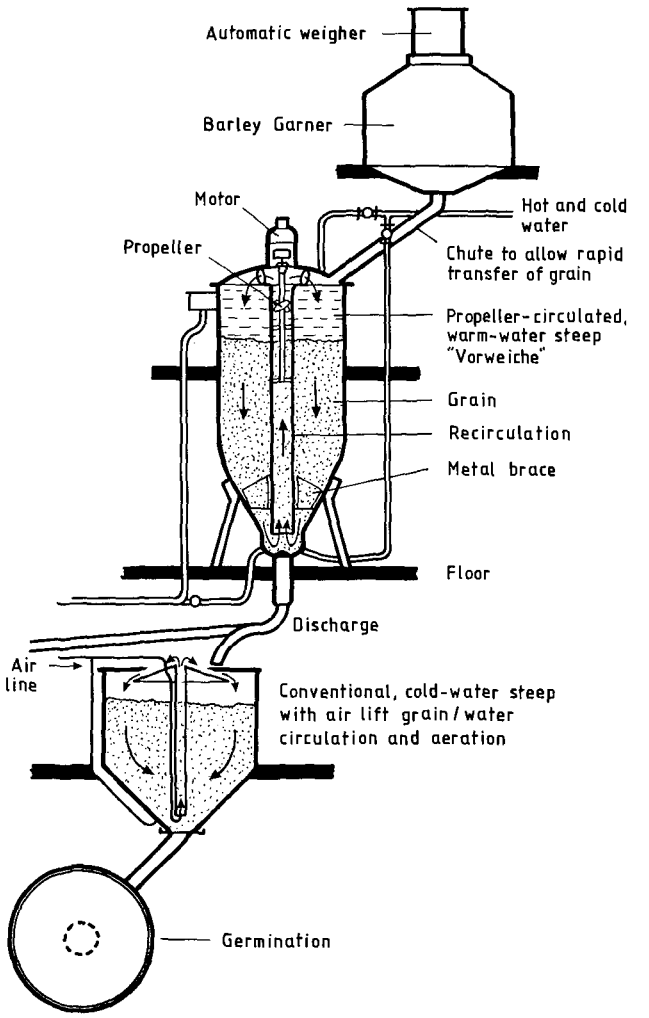


Fig. 1. Diagram of a system proposed by Wild in 1910 (41) for warm water steeping. Grain is rapidly loaded into the warm water steep and mixed by a propeller in the central lift tube. At the end of the warm period, the grain was rapidly discharged into a conventional steep and was mixed with cool water using aeration.

4. Abrasion (other physical treatments, decortication used with GA_3).
5. Steeping in running water, prewashing, steep aeration (by 1900), air rests (pre 1875), CO_2-extraction (by 1909), spray steeping (by 1875), warm water steeping (by 1905).
6. Additives: lime water, hypochlorites, sodium hydroxide, hydrogen peroxide, gibberellic acid (1940), $KBrO_3$, other growth regulators.
7. Resteeping—kills roots, modification rapid in wet grain.
8. Warm germination, finishing on kiln.
9. Rapid kilning programs.

Many of these are well known (10) and require no comment here. However, some steeping systems and the malting of physically treated (e.g., abraded) grains will be considered in more detail, because their histories demonstrate how a lack of knowledge of grain physiology has limited their acceptance and development.

HOT WATER STEEPING

Steeping in hot water (between 30 and 70° C) for various times was strongly championed in Germany during 1900–1910 (26). At elevated temperatures steeping times were shortened, and it was claimed that although chitting might be delayed, the grain was cleaned exceptionally well, higher germination percentages were achieved with partly dormant barleys, and good quality, uniform malts were produced. Furthermore, with some steeping schedules, rootlet growth was nearly prevented and malt yields improved. Controversy immediately occurred, because many maltsters had poor or disastrous results. Apparently, problems continued even after it had been pointed out (5,18): that fewer difficulties occurred if extreme temperatures (over 40° C) were avoided and if only the first immersion, of from about 1 to 1¼ hr at 40° C were hot; and that the grain and warm water should be mixed rapidly, preferably with aeration, and at the end of the warm period the grain should be rapidly drained and cooled to about 15° C by mixing with cool, aerated water. Apparently, the technical difficulties were overcome, for example, in the Wild system (41; Fig. 1).

Hot water steeping went out of use, and never spread to the United Kingdom, almost certainly because of the widely variable responses of different batches of grain. More recent reinvestigations (23) showed that warm water steeping could induce water sensitivity. However, this could be overcome by using air rests and gibberellic acid, and once again warm steeping seemed promising (10). Indeed, by steeping for 8 hr at 40° C, and then applying gibberellic acid, Pool (33) made malts with good analyses but with negligible rootlet growth and malting losses of only 3½% dm, compared to normal losses of about 7–11%. Yet, warm water steeping has not been adopted, and one major consideration has been the variations between different batches of grain. In a series of small-scale trials (unpublished) we have failed to make uniform malts of acceptable quality by steeping and germinating at 25° C despite the use of air-rest steeps, hydrogen peroxide, and gibberellic acid.

STEEP AERATION, AIR RESTS, AND SPRAY STEEPING

It has long been known that aeration or air rests during steeping accelerate germination. By 1875, some German maltsters were allowing grain contained in shallow, rectangular steeps to rest in air between immersions. These tanks had overhead sprinklers, so the grain could be spray steeped or the tanks could be filled with well-aerated water (36). In 1882, other maltsters were draining grain after a 12-hr immersion and turning it out onto the floor. After 12 hr, the grain was returned to the steep and the floor/steep process was repeated several times. Traditionally, Norwegian farmers steeped barley by immersing partly-filled sacks in running streams and taking them out at intervals to drain and rest. By 1900, Windisch (42) was strongly advocating aeration, blowing air through air-lift tubes in the steeps during periods of immersion, so

the grain would be well aerated, mixed, and cleaned. A range of steeps equipped with aeration tubes, both self-emptying conical-bottomed and flat bed patterns, was available by 1905 (36; Fig. 2). Similar effects were achieved by steeping in partly-filled, slowly rotating drums, a procedure that accelerates the onset of chitting (37). By 1909 a complex steep was available in which, as well as being aerated during immersion, the grain could be ventilated by suction during air rests (36; Fig. 3). Thus aeration, air rests, and ventilation (carbon-dioxide extraction) are scarcely novel.

At the start of the century, a few British maltsters were aerating grain, and all were fascinated by the German experience. Perhaps some were mesmerized by misleading comments about malting being a natural process and barley not being an aquatic plant. A number adopted the use of aeration during steeping, but gradually many ceased to aerate their grain at all. In the mid 1950s, an advance in our understanding of grain physiology led to the widespread readoption of air rests, because it was recognized that an air rest after grain had reached a water content of 35–37% overcame water sensitivity, and grain could then be steeped to the final moisture content, usually between 41 and 46% (7,10). Air-rest steeping, with CO_2 extraction, is now commonly used. In contrast, aeration of immersed grain is probably used less, and maltsters are strongly divided in their assessment of its value.

Why did air resting and steep aeration decline in the United Kingdom in the first place? Why is aeration not universally practiced? And, in an extreme form, what is wrong with spray steeping or spraying grain during germination? Aeration of steeps accelerates the rate at which grain chits, the rate at which diastatic power increases, and the rate at which modification occurs (7,10,31). Although some batches of grain made good malts after aeration, and with a saving of two days of germination time, others seem to have chitted and malted irregularly. Other batches grew excessively vigorously after aerated steeping, giving overgrown malts with low extracts and high malting losses. Experimentally sparging steeps with oxygen seems frequently to have had this effect. Indeed, about 1960 some trial results indicated that it would be beneficial to sparge steeps with carbon dioxide or nitrogen to prevent early chitting and to obtain more uniform malts in higher yields (10). Clearly, wholly conflicting views have been expressed, and at present it seems that only empirical trials can show what the effects of aeration will be in any particular case. Tentatively, one may ascribe harmful effects to several factors. For example, partly dormant, water-sensitive grains will not chit in aerated water or while kernels are covered with a film of moisture. Aeration of such grain in the steep will induce early chitting in the mature but not the water-sensitive grains, leading to irregular water uptake and chitting, and nonuniform malt. Conversely, over-aerating or spray steeping fully mature grains can give rise to early chitting, excessive water uptake, and overgrown malts, sometimes poorly modified, and usually with high malting losses (20,21,34,35). These results may be explained by reference to the ways in which water enters grains and redistributes itself both during steeping and subsequently. The entry and redistribution of water in steeping barley has been investigated by separating the parts of grains and

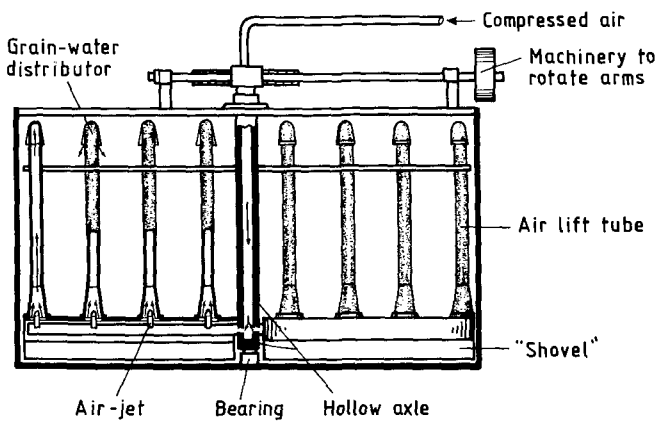


Fig. 2. Diagram of a flat-bed Doornkaat steep, in use before 1905, in which four radial arms carrying air lift tubes rotated and washed, mixed, and aerated the grain (36).

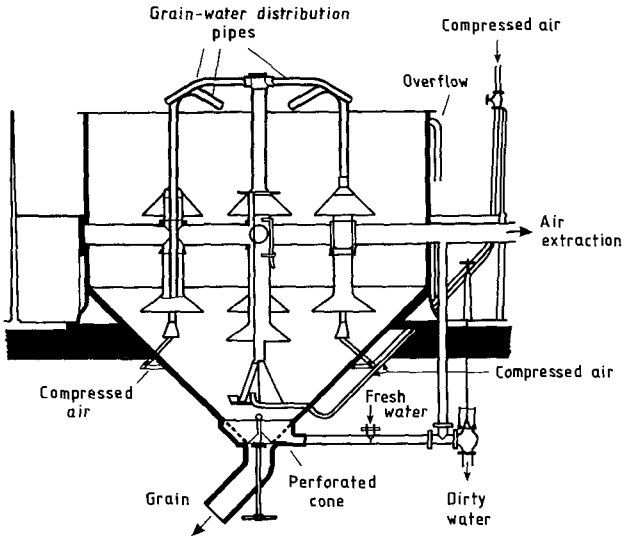
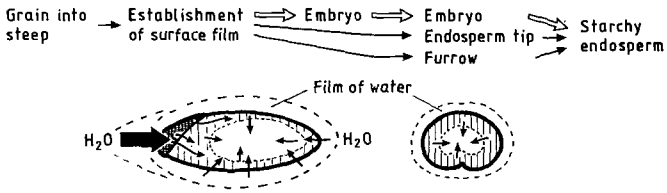


Fig. 3. A self-emptying Söding-Winde steep of 1909 equipped for rousing with air-lift tubes and downward ventilation by suction. The air-extraction tubes were of large diameter, fitted around the smaller aeration tubes, and terminated in downward-facing, open-ended cones. Air was also withdrawn at the bottom of the cone at the base of the steep (36).



Partly steeped grain (after Axcell, Jankovsky & Morrall). Embryo: fully hydrated. Outer endosperm: partly hydrated. Centre endosperm: dry.

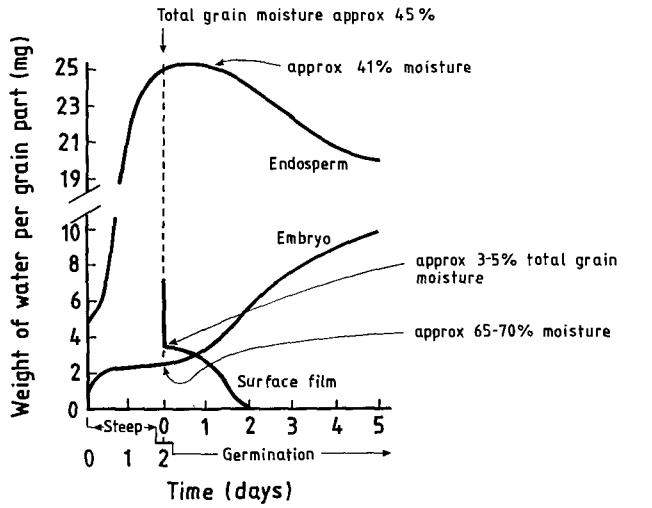


Fig. 4. Diagrams illustrating the routes by which water enters and spreads through a grain, and the redistribution of water during steeping and germination (after Axcell et al [3], Kirsop [20], and Reynolds and MacWilliam [35]).

measuring their moisture contents (35), by following the movement of radioactive, tritiated water using autoradiography (3), and by locating zones in the starchy endosperm where the moisture content exceeds some specific value (between 34% and 38%) by briefly heating grains to 100° C and noting which regions have become translucent because the starch has gelatinized (14).

The surface layers of the grain, the husk and the pericarp, hydrate rapidly and remain covered with a film of water for a period after the steep has been drained (Fig. 4). Within the testa, the embryo hydrates rapidly and reaches a moisture content of 65–70%. Most moisture spreads into the grain's interior through the embryo, although small amounts may slowly gain entry through the furrow and at the apex of the grain. Our limited experience indicates that water only enters at the apex when the surface layers have been physically damaged in this region. The central region of the starchy endosperm is the last to hydrate (Fig. 4), and when its moisture content is too low it fails to modify during germination (3). It appears that some steeping regimes, which produce bulk grain of the correct final moisture content, leave some of the individual grains inadequately hydrated. When these under-steeped kernels subsequently germinate they do not modify completely.

As a grain germinates, the water associated with it is redistributed (Fig. 4). After steep-out, the growing embryo absorbs the surface film and then abstracts water from the endosperm (20,21,35). As the latter becomes drier, modification is slowed and may even cease. Of course, small amounts of water are generated by the respiration of the living tissues, some is lost during the hydrolytic reactions which are occurring, and some is lost by evaporation. Spray steeping has never been popular in Britain. An acute form of poor water distribution can occur in spray-steeped grains (21,34) and by extrapolation might occur in excessively aerated, immersion-steeped grains that are fully mature. The results summarized in Figure 5 illustrate the problem. When grains were steeped by immersion, the moisture contained in the embryos plateaued and stayed constant as no growth occurred. After 48 hr, the grain mass reached 45% moisture and was regarded as fully steeped, and the endosperms were sufficiently hydrated. In contrast, during spray steeping the embryo grew strongly in the 24–48-hr period, and so the water contained in the embryos continued to increase; the grain mass achieved a moisture content of 45% after 36 hr. However, at this stage the endosperms were insufficiently hydrated. In this case, the embryos continued to grow vigorously, abstracting water from the endosperms and so reducing their moisture contents still more. Thus, an undermodified malt was produced with high malting loss. Many modern steeping schedules incorporate two air rests, and chitting begins before the final immersion is complete. Water enters grains more rapidly after chitting, so uneven chitting will lead to unevenly hydrated grains and irregularly modified malt.

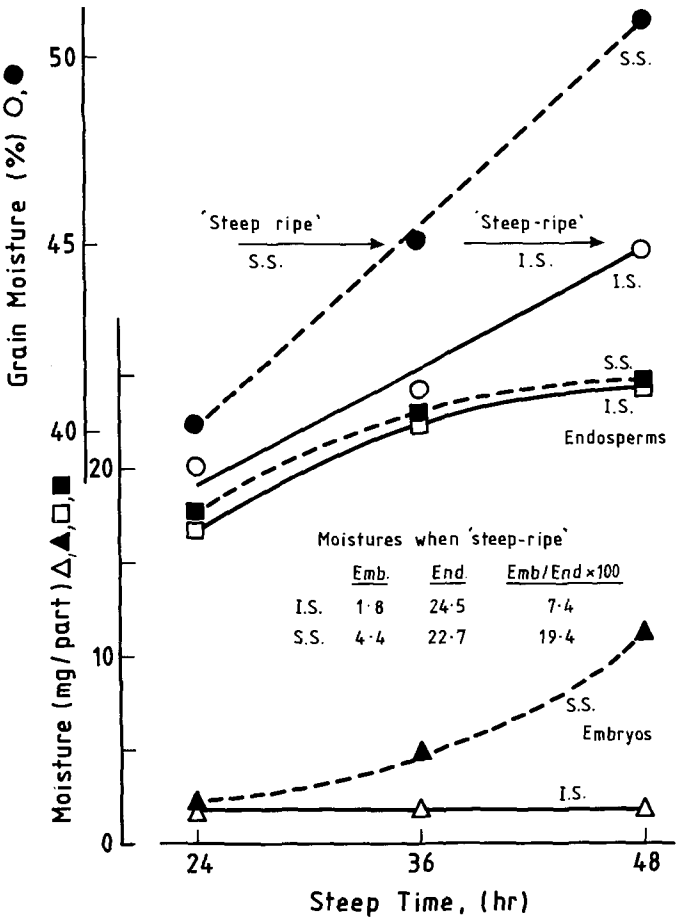


Fig. 5. Comparisons of water uptake and distribution in grains steeped by immersion (**I.S.**) and in spray-steeped grains (**S.S.**) (data of Kirsop et al [21]).

These examples demonstrate that at the end of the steeping period the grain should be clean and in the correct physiological state to germinate. It must germinate evenly, it should be at the correct moisture level, all the grains should be hydrated to the same extent, and the water should be correctly distributed within all the grains before substantial growth occurs. At present in U.K. commercial malting it is not known if these criteria are met, nor is it known if these are the only criteria of importance. It is virtually certain that some rapid steeping schedules have not met these criteria, and nonhomogenous malt has been produced, but in shortened malting time.

TRIALS WITH HYDROGEN PEROXIDE

Impressed with the way hydrogen peroxide can induce dormant grains to chit (2,10,31), we carried out small-scale trials (*unpublished*) in which sprays of hydrogen peroxide were used in attempts to accelerate malting in an economical way. When grains had been steeped by continuous immersion, spraying hydrogen peroxide at steep-out accelerated chitting and improved the response to gibberellic acid, especially when both agents were applied in the same solution. However, after steeping with air rests, hydrogen peroxide sprays were not of significant value, although applications of gibberellic acid were still beneficial. Guessing that the film of water around the grains at the start of an air rest might be detrimental, we tested the effects of applications of hydrogen peroxide at the start of the air rest (Table II). Hydrogen peroxide

TABLE II
Results of a Micromalting Trial Where Hydrogen Peroxide (H_2O_2) and Gibberellic Acid (GA_3) Were Sprayed onto the Grain at the Start of the Air-Rest Period[a]

Post-Steeping Period	Extract L°/kg dm[b] (malting loss, %)	
	H_2O_2 (0.75%) in Spray	
	0	+
2 days		
Water	246 (3.1)	256 (3.1)
GA_3 0.05 mg/kg	255 (3.2)	268 (3.1)
GA_3 0.25 mg/kg	267 (3.0)	265 (3.2)
GA_3 0.50 mg/kg	275 (3.2)	270 (3.4)
4 days		
Water	305 (7.8)	307 (8.2)
GA_3 0.05 mg/kg	308 (8.0)	308 (8.1)
GA_3 0.25 mg/kg	310 (8.4)	307 (8.1)
GA_3 0.50 mg/kg	313 (8.4)	309 (8.2)

[a] Steeping and germination, 16° C; air rests, 20° C. Data are from a study by J. Husain and D. E. Briggs, *unpublished*.
[b] L°/kg dm = Liter degrees of extract per kilogram of dry malt.

accelerated chitting and the initial rate of increase in hot water extract. However, moderate and, especially, heavy doses of gibberellic acid gave the best results in the absence of hydrogen peroxide. We do not know the effects of these treatments upon the relative levels of homogeneity in the finished malts.

PHYSICAL TREATMENTS OF GRAINS

It has been known for many years that loosening the husk, or removing it and the pericarp by physical or chemical means, reduces dormancy and accelerates the germination rate (4,7,10,31). When grain decorticated with sulfuric acid is micromalted, it grows and modifies exceptionally rapidly (38,39). Following this lead, methods were sought for dehusking grain mechanically on an industrial scale (15,17,25). Trials were moderately successful; malting times were reduced when 3–10% by weight of the grains were removed and gibberellic acid was used. This approach was not used on the commerical scale for various reasons. Among these were difficulties experienced in handling the treated grains, some of which were broken and tended to pack down in the steep vessels and germination compartments. The separated-husk fraction had to be remixed with the finished malt to assist wort separation from the brewer's grist. Brewers disliked the appearance of the finished product.

After Palmer's pioneering work (29,30), in which grains were abraded by passage through a cylinder past a rotating wire brush, several firms adopted the abrasion process (12,13,28), but they used machines that worked on different principles, either by impaction or by stirring the grain against itself and the walls of a container with rotating vanes. Such treated grains malt more rapidly than usual when treated with gibberellic acid. We achieved similar results in a laboratory tumbler (38) and more recently in a laboratory impacting machine. Palmer believes that abrasion works by creating faults in the pericarp layer that allow localized penetration of gibberelic acid, which in turn causes two-way modification, i.e., endosperm breakdown extending from the embryo *and* the apical lesions where extra gibberellic acid supposedly gains entry (9). We could find no evidence for significant quantities of two-way modification in grains malted after treatment in our tumbler or commercially abraded grains, although it certainly can occur if the surface layers of the grains are perforated (9,11,38). We believe that it is the testa, not the pericarp, that must be ruptured to allow the penetration of gibberellic acid (9). In grains treated in all these ways, modification occurs in the normal pattern, but it extends unusually quickly, immediately below the aleurone layer (9,11,38). In lightly treated grains, malting sometimes occurs faster than in the untreated controls when neither are dosed with gibberellic acid, indicating that at least one factor other than gibberelic penetration is important (9,29,38). We agree with Lyall and Stowell (24) that the physical treatments do not accelerate the uptake of externally applied gibberellic acid; they do, however, enhance the grains' response to the gibberellic acid, which continues to gain access to the living tissues in the region of the embryo in the usual way. Physical treatments also cause undesirable damage to grains. Indeed, commercial abrasion treatments, which normally remove 0.3–1.0% of the grain, have to be regulated to prevent extensive dehusking and grain breakage (12,13). We think that the benefits of physical grain treatments probably follow from improved access of oxygen to the living tissues (9,38). Oxygen availability is certainly one of the factors that limit enzyme production and modification in malting.

Despite its advantages, abrasion is not used by all British maltsters. Some of the reasons (12,13) may be: 1) The machines create a bottleneck in the process, as their rate of throughput is only 9–12 tons/hr. 2) The abrading conditions need to be optimized for each barley. 3) Abrasion creates dust, causes loss of dry matter, and can cause excessive husk-loosening and grain damage. 4) Abraded malts may be dark and uneven in appearance. It is improbable that all grains in a batch are evenly treated. Physical treatments might be widely adopted if new machines were developed with a high rate of through-put that treated grains more gently and evenly. Alternatively, other ways of allowing more oxygen to reach the living tissues might be sought.

In 1965, Sparrow (40) showed that when dry grains are cracked, water uptake is exceedingly rapid, and applications of gibberellic acid accelerate malting much more than in uncracked control grains. The process was not developed, probably because of the difficulties of handling cracked grains and problems with mold growth (9). However, the recently introduced "squeeze-malting" method of Pollock and Pool (32) is now being used (16,27), and it seems to have substantial advantages, including shortened steeping and kilning times. Barley, steeped for a short time to about 37% moisture, is "squeezed" and deformed by passage between smooth steel rollers. Gibberellic acid is applied, and the grain is germinated but, because it is relatively dry, root growth and probably heat output are reduced, permitting more grain to be held in the germination vessel. The green malt, having a relatively low moisture content, also can be dried rapidly, and kiln loading can be increased. Acceptable malts, low in nitrosodimethylamine and dimethyl sulfide precursor, can be produced in high yields in reduced times, with less water usage, less effluent production, and lower kilning costs (16,27,32). At present, one company is using this process.

CONCLUSIONS

Despite the arrival of dramatic new techniques and the progressive refinement and automation of malting plants, with all the consequent opportunities for more exact control over process parameters, it remains true that for British maltsters each new batch of barley gives, to a degree, problems in production. Consequently, malt could be made more rapidly and certainly if more were understood of grain physiology, particularly various aspects of immaturity and vigor, or dormancy. In particular, it would be an advantage if other methods, not involving prolonged periods of storage, could be found to hasten grain maturation immediately after harvest. At present, maltsters can only reliably overcome some of their problems by using longer processing times—e.g., longer periods of cool steeping or longer periods of germination. Better methods to characterize degree of maturity in grains will open the way to finding methods for achieving more uniform chitting and modification and hence more homogeneous malts. This knowledge will be used to shorten malting times, whether by warm water steeping, spray steeping, or other methods. These targets will only be met by using the understanding gained from fundamental scientific studies into the biological systems that operate in germinating grains. It is imperative, therefore, that these studies are done to allow further developments in malting.

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