Maintenance of grain quality during storage—prediction of the conditions and period of 'safe' storage

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Abstract

Retention of grain quality should be the major aim of designing any storage technology. Freedom from pests throughout storage and transport is an important part of this aim, but, in addition, we must ensure that there is no deterioration in the suitability of the stored product with respect to the requirements of the customer. In fact, there is also the possibility that some aspects of quality might be enhanced as a result of storage.

Ensuring quality retention requires a thorough understanding of the effects of all significant variables on quality, preferably in the form of a quantitative model. Such a model would take into account the original quality of the stored product and the expected storage conditions, particularly temperature, moisture and any treatment for pests. Given such information, it should be possible to predict the quality status of the stored material at any stage, or to determine the time of storage before some minimum acceptable level of quality is reached. A quantitative model could also be used to determine how the storage conditions might be manipulated (e.g. by cooling or drying) to extend this storage period, in turn permitting cost-benefit analyses to determine the most economic methods of extending storage life.

Examples of this approach to grain storage will be given for malting barley, milling-quality wheat, paddy and milled rice, and maize, together with the complicating factors of rain damage, fumigation and controlled atmospheres, considering quality in terms of germination (for seed use) and normal grain-specific utilisation by the customer (processor or householder).

Introduction

The grain family occupies a major place in our economy as a source of food and feed mainly because the grains can be stored and transported with general maintenance of good quality for long periods. This advantage for people and animals comes despite the fact that the seed is designed, not necessarily as a food/feed source for people, but as a plant's way of producing another plant. The requirement of this latter task is also good storage properties, with intact morphology and viability, so that sprouting can proceed when the seed eventually encounters conditions conducive to germination. This stage (germination), on the other hand, is also the point at which storage potential must inevitably be given up, and it is thus also a critical one for people to monitor in taking advantage of the storability of grains. Assessment of grain soundness (absence of even preliminary germination) is essential to the management of quality during storage.

An important characteristic of the excellent storability of grains is their low moisture content, compared with many other sources of food. This then, is a second factor to assess and control in maximising quality during storage, partly because it is the increase of grain moisture that is the trigger for the onset of germination.

The third factor, temperature of storage, is common to all chemical reactions. The very low level of respiration essential to all grains during storage must increase at higher temperatures, thereby reducing the expected period during which the grain will remain viable and be useful for many other purposes.

In addition, there is the ever-present risk that another grain eater will get to the food source before it can serve human purposes. Thus, the effects of pests and of pest-control measures on quality also need to be considered, or even used to enhance quality maintenance.

In this paper, we want to emphasise the importance of maintaining grain quality during storage, and to demonstrate how such maintenance requires an intimate knowledge of the role of these three factors — temperature of storage, grain moisture, and the soundness of the grain (generally in that order of importance) — presuming that pests are being controlled adequately.

Quality Retention is the Main Aim of Storage Technology

The economics of grain storage dictate that the market value of the grain must be as high as possible after storage and on delivery to the customer. This means that any possible deterioration in quality must at least be minimised. On the other hand, it may even be possible to manipulate the storage conditions so as to actually improve quality as a result of storage, and thus increase market value.

The possession of knowledge about how to optimise storage for quality maintenance implies an ability to also predict the effects of storage on quality and thus to also predict the length of time before grain quality has fallen below a critical market indicator, before which the grain should be delivered for processing. Developing the ability to do so requires:

(a) general knowledge about the specific grain (even the variety) and the quality attributes needed for its utilisation;
(b) an assessment of the soundness/condition of the grain lot in question (the test sample(s) must be representative of the whole);
(c) and (d) the moisture and temperature of the grain to be known throughout its past and future storage life;
(e) knowledge of the effects of pests and of pest control; and
(f) that there be a quantitative model to describe the interaction between all these factors.

With this set of information, it is possible to develop look-up tables or software programs that can be used to predict the

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period of time during which the grain will maintain adequate quality, or the extent to which moisture and/or temperature must be altered to extend the 'safe' storage period to meet storage-time and quality goals. In addition, this quantitative information can be used to assess the economics of marketing in relation to altering storage conditions.

The Meaning of 'Quality'

The word 'quality' means suitability for the specific process or utilisation for which it is destined. The word must thus be defined by the customer, who has the task of carrying out that process. It is obviously vital that the marketing and storage authorities are aware of the specific use to be made of the grain when they define the requirements for soundness, and storage conditions. This may not always be possible, requiring a wide view to be taken of the potential usage.

The process common to all species of grain is that a grain is the way of creating more grain. As already discussed, maintenance of seed viability thus comes at the top of any list of qualities, though in quantitative terms it is a relatively minor part of grain utilisation.

Wheat quality

Of the spectrum of grains, wheat has the widest and most exacting range of quality attributes, largely because of its unique ability to produce leavened bread products due to the viscoelastic properties of gluten. The quantity and quality of the protein are thus important aspects of 'quality' for this crop. These and other attributes must be tailored to the appropriate end-product.

A range of such products is listed in Table 1. The list reflects the range of products made from Australian wheat, both for the approximately 20% used domestically (about half used for pan breads) and for the remainder that is exported (Wrigley 1994). The table is an over-simplification, listing only three attributes. Protein content and dough strength together provide an indication of the dough that might be expected. Grain hardness is a determinant of milling properties, starch damage and water absorption. The segregation systems of many wheat-producing countries depend on the specification of variety to establish that specific grades have the appropriate hardness and dough strength, together with other important properties such as milling yield, starch-paste viscosity, dough-mixing tolerance and loaf-volume potential.

Receival standards are designed to exclude wheat of poor quality from specific grades. These poor-quality attributes include a range of contaminants, sources of physical and microbial damage and the important factor already discussed —preliminary germination. This last factor leads to processing problems for all the products in Table 1, especially for Chinese steamed breads and for noodles (Edwards et al. 1989). By way of contrast, sprouting of wheat grain may even be of benefit for animal feeding, but it is associated with the risk of mycotoxin contamination.

Barley quality

During the past decade, about 75% of Australia's barley crop has been exported, one quarter of this being used overseas for malting, the rest for feed. Within Australia, some 80% of domestic consumption goes to malting, over half of this being destined for value-added export. Food processing is a small but growing use of barley, but its requirements are so diverse that it is difficult to define a few essential quality attributes. Nevertheless, Table 2 is an attempt to summarise the desirable chemical composition for the three major uses of barley.

Table 2. Ideal chemical composition for barley, depending on end use.

Component	Malting	Feed	Food
Hydrolases	High	Not relevant	Not relevant
Protein content	Low	High	High
Starch content	High	High	High
Beta-glucan	Low	Low	High
Lipid content	[Low]	High	Not relevant
Lysine content	Not relevant	High	High
Phenolics	Low	[Low?]	Not relevant
Husk	Present, thin	Absent	Absent

Source: Adapted from Kasha et al. 1993.

The processing of barley for malting and brewing has exacting quality requirements (Bamforth and Barclay 1993). The main aim of the maltster is to produce malt from which a maximum of fermentable solids may be extracted. The achievement of this aim requires grain that germinates uniformly and at a high rate (>95% of grains germinated is the usual requirement), with a high level of diastase activity, moderately low protein content and a low level of beta-glucan (due

Table 1. Quality attributes preferred in wheats for specific products.

Product	Protein content	Grain hardness	Dough strength
Breads			
Pan bread	>13%	Hard	Strong
Flat bread	11–13%	Hard	Medium
Steamed-Nthn[a]	11–13%	Hard	Medium/strong
Steamed-Sthn	10–12%	Soft/medium	Medium
Noodles			
Alkaline	11–13%	Hard	Medium
White	10–12%	Medium/soft	Medium
Instant	11–12%	Medium	Medium
Biscuit/Cake	8–10%	Very soft	Weak
Starch/Gluten	>13%	Hard	Strong (soft preferred)

Source: Bread Research Institute of Australia, Inc. Reproduced with permission from Wrigley (1994).
[a] Northern and Southern China.

to the difficulty it causes during filtration later in the brewing process). Prolonged storage is unlikely to alter the composition of the grain (apart from the effects of significant pest infestation); it is more likely to alter biological attributes, such as enzyme activity, lipid composition and even lysine content (see Table 2).

A maximum of metabolisable energy is the major requirement for feed barley and for other feed grains such as oats, the assessment of this attribute varying depending on whether ruminants or non-ruminants are being fed (Bhatty 1993). Low beta-glucan is needed for the latter, particularly for chickens.

Rice quality

Any attempt to generalise on the quality attributes needed for rice is complicated by the diversity of tastes for the various rice-eating nations, but predominant attributes include grain appearance — the dimensions of the grains, their colour and translucency or chalkiness (associated with starch composition and amylose content) — and grade-specific factors such as aroma. Cooking characteristics, such as stickiness, water absorption, and grain elongation, also depend on starch properties (Juliano 1985).

Maize quality

Like rice, maize quality largely relates to the pasting properties of the starch, reflecting in the case of maize the large proportion of the crop that is used for starch production. Grain hardness is a further aspect of maize quality critical for its use in food processing. The other major use of maize is for animal feed, for which freedom from mycotoxins and high metabolisable energy are important attributes. In many countries, maize is a staple food along with rice, or in place of it. In such cases, it is typically flint-type white maize that is milled into 'grits' which are then cooked like rice grains.

Negative (and Positive) Quality Changes During Grain Storage

There has been a natural obsession with the deleterious effects of storage pests in developing better storage technologies. Insects have been predominant in the range of pests to combat, obviously in the case of significant infestation because of the loss of the commodity, because of resultant hygiene problems, but also because even minor insect attack on grain leaves it particularly vulnerable to microbial attack. Furthermore, for minor infestation, the preference of insects for the germ portion of the grain is likely to reduce germination vigour in particular, and thus reduce the value of all grains for seed use and of barley for malting. Irrespective of these more obvious storage problems, there is the likelihood of storage gradually reducing many of the quality attributes that add up to form the basis of the grain's market value.

Malting barley, for example, is particularly at risk to any factors that reduce its rate of germination. Preliminary germination is important in this respect. Apparently (for many genotypes, at least), once the germination process has commenced, the storage lifetime of the grain is significantly reduced (Carn 1982). Quantitative assessment of the degree of pre-germination is thus essential to determining the storage lifetime of malting barley. Bason et al. (1993b,c) have described three procedures for rapid determination of sprout damage to barley, using either the Rapid Visco Analyser or the Falling Number instruments to determine the effects of amylase activity viscometrically, or by direct alpha-amylase assay. This estimate is the basis of the modelling exercise described below.

The deterioration of wheat quality is also established, but there is little information on the quantitative progress of this phenomenon. The most marked deterioration of sound wheat grain involves the loss of gluten properties, in a manner similar (but of course slower) to that encountered with heat denaturation. Better documented are the changes that accompany the ageing of milled flour, though this phenomenon is not necessarily related to the changes in stored whole grain.

During the storage of rice grain (paddy or milled) there is a gradual yellowing of the grain (Gras et al. 1989; Bason et al. 1990), a generally undesirable attribute, though in some cultures it is seen to be desirable since it is associated with the accompanying, desirable characteristic of a firmer and less sticky product when cooked. However, there is an optimum age of the product beyond which consumer preference declines (Gras et al.1990).

The improvement of rice quality during storage is one of the few examples of quality enhancement. Another is the reduction in hydrolase activity (particularly alpha-amylase) for sprouted wheat, providing it has been adequately dried before storage. In this case, however, there is the accompanying loss of other quality attributes, necessitating careful monitoring of the various aspects to determine whether there is an overall gain or loss in market value.

Developing a Model of Quality Changes During Storage

The rate at which quality changes during storage depends on the product, the quality parameter under question and the storage conditions. Defining the rate mathematically provides the possibility of defining the storage time and/or conditions that must not be exceeded if good quality is to be maintained. Such a process involves the construction of mathematical models, and several such models are available in the literature.

Thus, for example, Gras et al. (1989) and Bason et al. (1990) related the rate of yellowing in milled and paddy rice, respectively, to cultivar, storage temperature, water activity and storage atmosphere, using the model:

$$k = \alpha e^{\beta / T} a_w{}^{\gamma} [O_2]^{\delta} \tag{1}$$

which is

$$\mathrm{In}(k) = \mathrm{In}\alpha + \beta / T + \gamma \mathrm{In}(a_w) + \delta \mathrm{In}[O_2] \tag{2}$$

in logarithmic form, where *k* is rate of yellowing, *T* is absolute temperature, a_w is water activity and $[O_2]$ is oxygen concentration in mol/m^3, and α, β, γ and δ are constants.

Equation (1) was derived from chemical kinetics, indicating that the underlying process, non-enzymic browning, was following simple kinetic rules. Later work showed a high correlation between this yellowing and consumer evaluation of both raw and cooked rice (Gras and Bason 1990), and also that available lysine content similarly decreased, lysine being involved in the browning reactions.

Several models have been published relating storage viability to storage conditions for particular grains. These are more fully covered in the paper by Bason, Gras and Banks in these proceedings. In short, it has been found that rate of loss of grain viability in storage is largely dependent on the soundness of the grain, its temperature, and its moisture content or water activity. Modifying the atmosphere to control insects by lowering the oxygen or raising the carbon dioxide levels has a comparatively small effect. Ellis and Roberts (1980a,b) and later Dickie et al. (1990) showed that the viability of many seed species could be modelled using the equation

$$V = K_i - P / \delta \quad (3)$$

where $\log(\delta) = (\alpha - \beta \log M - \gamma T - \delta T^2$

and where V is probit viability (probit 50% = 0), K_i is the seed lot dependent constant (probit viability at time zero), P is storage period (days), M is moisture content (% as is), T is temperature (°C) and α, β, δ and γ are constants (different from those in Equations 1 and 2).

Gras et al. (unpublished data) showed that, for barley viability, the temperature terms of Equation (3) better described the data than the inverse temperature term of Equations (1) and (2). However, the water activity term (Equations 1 and 2) proved superior to the moisture term of Equation 3. This latter result has also recently been demonstrated for rice and maize viability.

Bason et al. (1993a) demonstrated that the Ki term provided a poor description of subsequent lifespan of barley that had been rain-damaged. An alternate equation was given in the form

$$\log(1 / t_{95}) = \alpha + \beta T + \gamma T^2 + \delta \log A_w + \varphi DI \quad (4)$$

where t_{95} is time to 95% viability (critical in barley), φ is a constant and DI, the damage index, was measured alternatively as the Falling Number, Stirring Number or probit waterbath score of the sample.

Models such as these allow estimation of the safe storage periods or conditions for particular grain lots. An example of predicted safe storage conditions for barley cv. Grimmett, stored for 15 months, is given in Figure 1. Similar graphs and tables or software can be generated by computer to help grain storage managers ensure the integrity of the commodity's quality. There is still considerable work to be done in creating such management tools for a variety of grains and relevant quality parameters. For example, little quantitative information is available to aid in the management of stored wheat destined for various end uses. Gras et al. (these proceedings) investigated quality changes in sprout-damaged and sound wheat. These experiments were conducted to model the progress of such changes. They have shown that Falling and Stirring Number values increase during storage for several wheat varieties. However, the baking quality of flour made from the wheat declined continuously throughout storage.

Practical Applications of Models

The provision of models to describe quality changes during storage provides important opportunities for better management of storage and transport with the aim of maximising market value. For example, our model describing malting barley has been incorporated into a software package 'Safestor' (Bason et al. 1993a,c). It permits the user to estimate the period of time before which stored barley will lose malting quality (i.e. < 95% germination), based on estimates of grain moisture and storage temperature, together with test results of soundness, using one of the tests mentioned above (Bason et al. 1993b). Use of this software is reported to have already saved the Australian barely industry large sums of money by ensuring that grain is used for malting before loss of quality below a critical level.

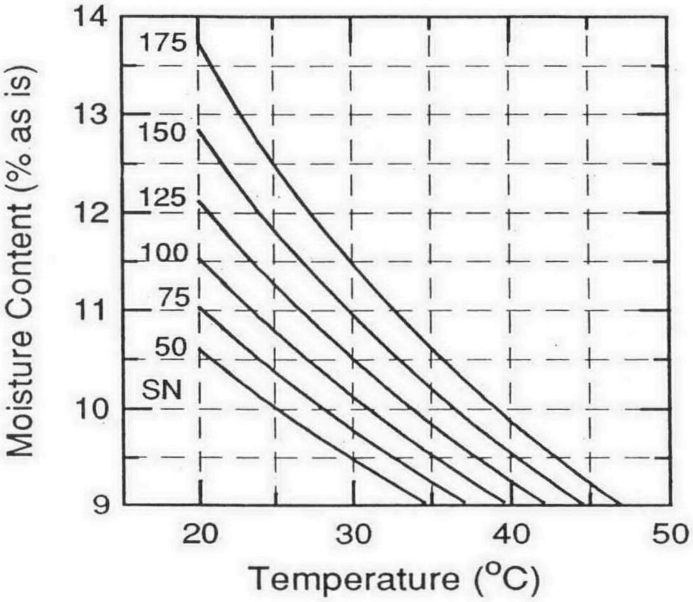

Fig. 1. Predicted maximum safe temperature and moisture content for storing malting barley cv. Grimmett for up to 15 months. The curves represent predicted maximum safe storage conditions for the grain at varying levels of soundness, as indexed by Stirring Number (SN). Conditions for safely storing the grain lie to the lower-left of the relevant curves.

Possession of this predictive capability also permits various management scenarios to be modelled and subjected to cost-benefit analysis. For example, if grain is estimated to be too hot or too moist for quality–time goals to be achieved, the reductions in temperature and moisture needed to achieve the goals can be determined. Furthermore, the costs involved in doing so can be compared with the potential benefits of quality maintenance.

As these systems are put into practice, the considerable benefits will become clear, and this approach will be extended to the range of commodities for which market value is sensitive to quality attributes.

References

Bamforth, C.W. and Barclay,A.H.P. 1993. Malting technology and the uses of malt. In: MacGregor, A.W. and Bhatty, R.S.ed., Barley chemistry and technology. St Paul, MN, USA, American Association of Cereal Chemists, 297—354.

Bason, M.L., Gras, P.W., Banks, H.J. and Esteves, L.A. 1990. A quantitative study of the influences of temperature, water activity and storage atmosphere on the yellowing of paddy endosperm. Journal of Cereal Science, 12, 193—201.

Bason, M.L., Ronalds, J.A. and Wrigley, C.W., 1993a. Prediction of safe storage life for sound and weather-damaged malting barley. Cereal Foods World, 38, 361—363.

Bason, M.L., Ronalds, J.A., Wrigley, C.W. and Hubbard, L.J. 1993b. Testing for sprouting damage in malting barley using the Rapid Visco Analyser. Cereal Chemistry, 70, 247-251.

Bason, M.L., Wrigley, C.W. and McCleary, B.V. 1993c. Modeling the effects of sprouting damage on malting barley, based on viscometric or amylase analyses. In: Walker-Simmons, M. K. and Ried, J.L. ed., Pre-harvest sprouting in cereals, 1992. St. Paul, MN, American Association of Cereal Chemists, 417-425.

Bhatty, R.S. 1993. Nonmalting uses of barley. In: MacGregor, A.W. and Bhatty, R.S. ed., Barley chemistry and technology. St. Paul, MN, American Association of Cereal Chemists, 355–417.

Carn, J.D. 1982. Alpha amylase indicates problems with malting of stored barley. Food Technology in Australia, 34, 82–83.

Dickie, J.B., Ellis, R.H., Kraak, H.L., Ryder, K. and Tompsett, P.B. 1990. Temperature and seed storage longevity. Annals of Botany, 65, 197–204.

Edwards, R.A., Ross, A.S., Mares, D.J., Ellison, F.W. and Tomlinson, J.D. 1989. Enzymes from rain-damaged and laboratory-germinated wheat. I Effects on product quality. Journal of Cereal Science, 10, 157–167.

Ellis, R.H. and Roberts, E.H. 1980a. Improved equations for the prediction of seed longevity. Annals of Botany, 45, 13–30.

Ellis, R.H. and Roberts, E.H. 1980b. The influence of temperature and moisture on seed viability period in barley (Hordeum distichum L.). Annals of Botany, 45, 31–37.

Gras, P.W., Banks, H.J., Bason, M.L. and Arriola, L.P. 1989. A quantitative study of the influences of temperature, water activity and storage atmosphere on the yellowing of milled rice. Journal of Cereal Science, 9, 77–89.

Gras, P.W. and Bason, M.L. 1990. Biochemical effects of storage atmospheres on grain and grain quality. In: Champ, B.R., Highley, E. and Banks, H.J., ed., Fumigation and controlled atmosphere storage of grain: proceedings of an international conference, Singapore, 14–18 February 1989. ACIAR Proceedings No 25, 83–91.

Gras, P.W., Bason, M.L., Esteves, L.A. and del Mundo, A.M. 1990. Relating sensory evaluation to other quality factors in stored rice. In: Champ, B.R., Highley, E. and Banks, H.J. ed., Fumigation and controlled atmosphere storage of grain: proceedings of an international conference, Singapore, 14–18 February 1989. ACIAR Proceedings No. 25, 261–264.

Juliano, B.O. 1985. Criteria and tests for grain qualities. In: Juliano, B.O., ed., Rice chemistry and technology, 2nd ed. St Paul, MN, USA, American Association of Cereal Chemists, 443–524.

Kasha, K.J., Falk, D.E. and Ziauddin, A. 1993. Potential improvement of barley quality through genetic engineering. In: MacGregor, A.W. and Bhatty, R.S. ed., Barley chemistry and technology. St Paul, MN, USA, American Association of Cereal Chemists, 419–435.

Wrigley, C.W. 1994. Developing better strategies to improve grain quality for wheat. Australian Journal of Agricultural Research, 45, 1–17.