Advances in barley quality. Experiences and perspectives

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Advances in barley quality Experiences and perspectives

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SUMMARY - After discussing the internal economy of the barley plant in the production of starch, protein and fat in relation to yield, a review on recent research on quality for malt and feed is given. A new method is described for the quantification of seed germination vitality of importance both for malt and for seed grain performance. New screening methods for malt quality such as malt modification and ß-glucan analysis as well as seed flotation for density are discussed in relation to plant breeding. In the field of feed quality improvement, promising results from breeding high-yielding high-lysine barley are reviewed. Finally, the eternal question of malt versus feed barley quality is discussed, concluding that in considering the quality demands from both the malt and the feed industries it should be possible with advantage to combine these two into one variety.

RESUME - "Progrès concernant la qualité de l'orge : résultats et perspectives". Après avoir fait le point sur l'économie interne de l'orge en ce qui concerne la production d'amidon, de protèines et de matière grasse par rapport au rendement, les recherches les plus récentes concernant la qualité pour la brasserie et l'alimentation du bétail son discutées. On présente une nouvelle méthode pour l'évaluation de la vitalité de germination des semences, d'importance aussi bien en brasserie qu'en alimentation du bétail. Des nouvelles méthodes d'étude de la qualité du malt, telles que les analyses de la modification du matl et de ß-glucanes, ainsi que la flottaison des graines pour estimer leur densité sont présentées dans le cadre de l'amélioration végétale. En ce qui concerne la qualité pour de l'alimentation du bétail, on discute les résultants prometteurs de l'amélioration des orges à bon rendement et haute teneur en lysine. Finalement, l'éternelle question de la qualité de l'orge de brasserie para rapport à l'orge comme aliment pour bétail est reprise, en concluant qu'une variété d'orge pourrait satisfaire à la fois aux exigences des brasseries et des industries d'alimentation du bétail.

Introduction

In this paper I will discuss, in the light of the recent advances in the quality concept of barley, the eternal question about quality of malt versus feed barley which might be looked upon as a confrontation or a happy reconciliation!. A clarification on this point is obviously of fundamental interest for both the plant breeders and the industries.

The potentials and the limits of productivity of the barley plant as related to composition

Compared to maize and sorghum which both display the C_4 photosynthetic pathway, C_3 plants like wheat and barley have less yield potential under ideal conditions (Mac Key, 1981). However, spring barley still wins in many environments due to its great adaptability under cold, hot/dry and saline conditions, while winter barley is not competitive with winter wheat under marginal winter conditions due to its inferior hardiness.

In plant production, the composition of the plant yield must be evaluated in order to make a fair comparison of yield in dry matter between crops. Thus, the energy costs of the plant are 1.20 glucose units for the synthesis of starch, 2.50 for protein and 3.03 for fat, a fundamental relationship which cannot be much changed by plant breeding efforts (Mac Key, 1981). A high-protein barley which yields as much as a low-protein barley is thus superior in yield to the latter as expressed in glucose units, which should be the criterion of choice to evaluate rightly the success of plant breeders. Similarly it is obvious that a high protein content in barley seeds measured on dry matter basis could be due to a relative decrease in the synthesis of other components such as starch giving still a low protein (and starch) yield per hectare. It is, therefore, not possible to breed for composition changes in seeds without simultaneously selecting for seed quality and high total yield.

Barley quality for malt and for the seed industry

The use of barley for malt and brewing has empirically gradually evolved through the last few thousand years, the processes of which have been interpreted and refined by new recent advances in science and technology.

It is of fundamental importance that barley for malt as well as for sowing is non-dormant, not pregerminated and microbiologically sound displaying a high level of vitality in germination.

Quantification of vitality and dormancy of barley seed lots

Seed vitality is an important production factor for both maltsters and farmers. Vitality, as measured by percentage of germinated kernels as a function of time, integrates like the factor seed yield/ha the complex performance of the different organs, tissues and cellular subsystems of the plant. This expression on the other hand is dependent on the unique gene composition of the barley variety in question in close interaction with environmental factors. Maltsters and farmers who like to utilize barley aiming at the production of malt for beer as well as for feed are interested in and dependent on regulatory concepts and devices based on environmental factors as well as regulator genes in order to optimize yield and vitality performance in relation to the costs of the inputs. One is here searching for the operational net effect and is not necessarily interested in a complete understanding of all the mechanisms behind especially if the research is elaborate and results take long time to obtain.

I will as an example of such an empirical approach discuss how we at the Carlsberg Research Laboratory have tackled the vitality and dormancy problems. At our institute we have devised (Aastrup *et al.*, 1989; Munck, 1989; Riis and Aastrup, 1989) an empirical method exactly to quantify dormancy and vitality, based on heat treatment of subsamples followed by germination. With this technique, it is possible with great precision to forecast dormancy and vitality in storage of barley as a function of seed moisture, temperature and storage time. It has also been possible to obtain the best compromise in heat treatment for removal of dormancy, avoiding the deleterious effect of heat treatment on vitality. There seems to be a variation between barley varieties in vitality and dormancy which could be bred for. It has also been shown by malting seeds that vitality has paramount importance for the modification of the malt and the malting time as well as for field performance and yield.

Teory and models

The germination ability of most seed populations follows the process outlined in Fig. 1. In newly harvested barley a certain number of seeds expresses dormancy; then, during storage more and more seeds are able to germinate until maximal germination is achieved, whereafter the seeds start to die. The aging process takes years, days or only hours depending on the storage conditions. Like most natural events, dormancy and loss of vigour can be assumed to be normally distributed in a seed population. Thus, both break of dormancy and loss of vigour follow normal distribution curves at constant storage conditions. By mathematical transformation, using a probit scale, the distributions can be described by straight lines (Fig. 2). The points where the straight lines hit the y-axis are then a quantitative measure for the initial dormancy and the initial seed vigour, respectively.

In Fig. 3 and 4 the two models are illustrated. The point where the dotted line hits the y-axis in Fig. 3 is defined as the initial dormancy potential (DP_i) of a seed lot, the value being the *probit* (% dormant seeds in the

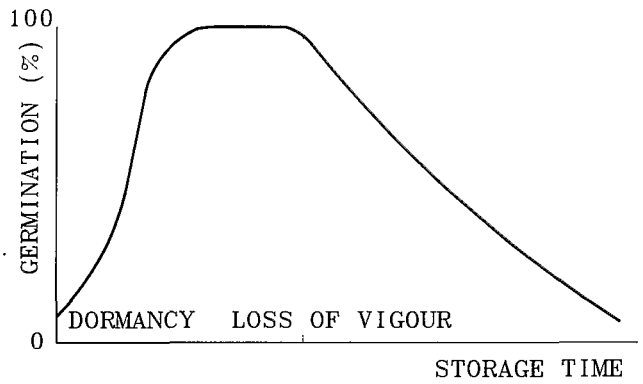

Fig. 1. Maximal germination as a function of storage time.

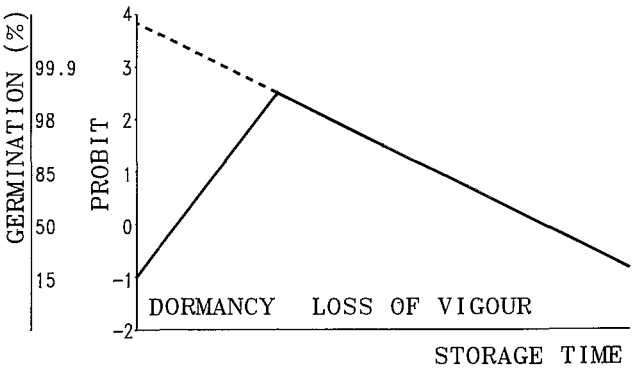

Fig. 2. Maximal germination as a function of storage time, plotted on probability paper.

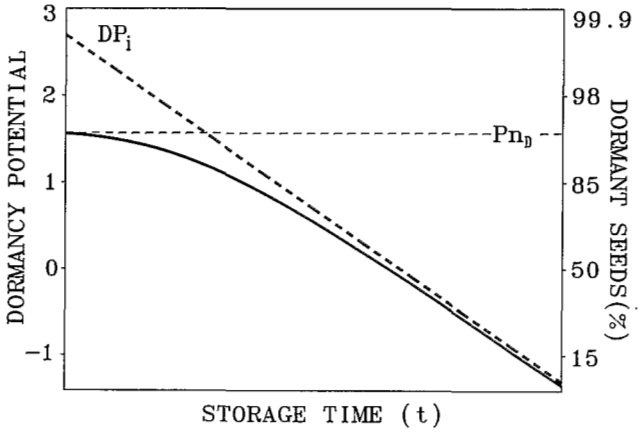

Fig. 3. Modified model for removal of dormancy as a function of storage time.

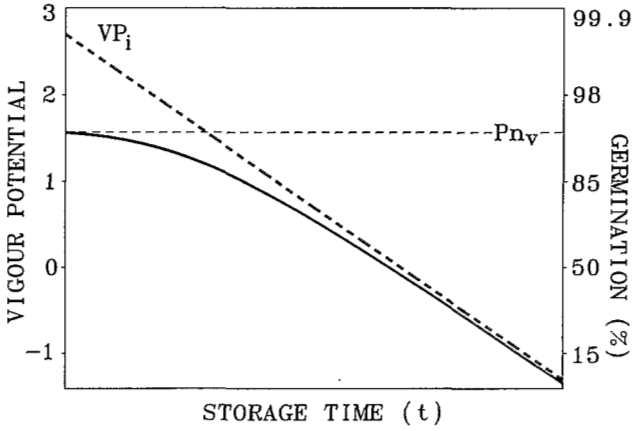

Fig. 4. Modified model for loss of vigour as a function of storage time.

part of the population with normal distributed dormancy). The point where the dotted line in Fig. 4 hits the y-axis is defined as the initial vigour potential (VP_i), the value being the *probit* (% viable seeds in the part of the population with normal distributed vigour). Dormancy and vigour are measured in dormancy and vigour potential units, respectively (1 unit = 1 unit on the probit scale) as seen in Table 1.

The influence on the rate of loss of vigour, a_V, has been intensively studied by Ellis and Roberts (1981), who experimentally demonstrated by accelerated aging treatments that the variation in a_v could be completely described as a function of seed moisture and storage temperature. For barley they found the following general empirical equation:

$$a_v = -d(VP)/day = 10^{(-9.98 + 5.90*\log(m) + 0.04*T + 0.00043*T^2)}$$

Table 1. Relationship between dormancy potential (DP) and vitality potential (VP) and germination percentage.

DP/VP	Germination (%)
3	99.9
2	98.0
1	85.0
0	50.0
-1	15.0

where m = seed moisture (%) and T = storage temperature (°C).

As an example, one VP unit is removed by heating barley at 14% H_2O and 68 °C for 45 min.

The dormancy and vigour equations are illustrated in Fig. 5 and 6.

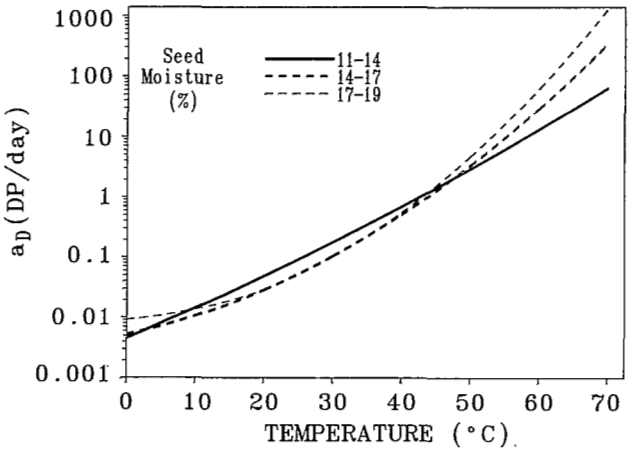

Fig. 5. Rate of dormancy removal as a function of temperature and seed moisture content.

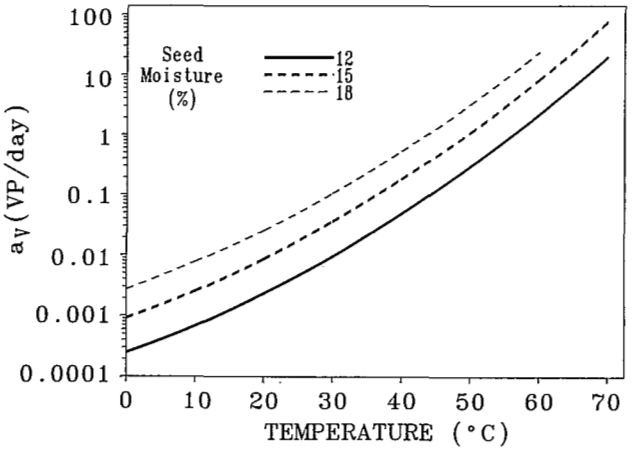

Fig. 6. Relationship between loss of vigour and storage temperature for three different moisture contents.

Both removal of dormancy and loss of vigour can be seen to be highly dependent on storage temperature, while vigour is by far the most sensitive element to seed moisture content. Thus, it is possible to remove dormancy within short period of time and with a minimum loss of vigour. To remove dormancy safely it is absolutely necessary to do it at low seed moisture content (11-13%) as can be seen from Fig. 7 where the dormancy is removed at 40 °C in barley lots of different moisture contents having a $VP_i = 3$ and a $DP_i = 2$.

Practice

The actual measurements of the DP and VP figures are based on germination results of heat-treated subsamples of the barley in question. Firstly, the seed moisture content is determined, whereafter the barley sample is divided into 8-12 subsamples which are heat treated for different times in closed containers. For the determination of DP, an appropriate temperature is chosen to provide subsamples treated different times representing the whole dormancy removal curve as indicated in Fig. 3. The same precautions are taken with regard to vitality testing to distribute differently treated subsamples to cover de VP curve in Fig. 4. The subsamples exhibit increasing and decreasing maximal germination in the DP and VP measurements, respectively. In the case of DP determination, the maximal germination is defined as the germination percentage after 7 days at 20 °C, and for VP determination as the germination percentage after 14 days at 17 °C. The germination results are finally put into the dormancy and vigour models and the DP and VP figures are computed.

Knowing the storage conditions (seed moisture and temperature) and the DP_i and VP_i figures, the DP and VP status at any time can be calculated using the models and equations, and the speed of the processes can be regulated by adjusting seed moisture and storage temperature to fit any need.

Our research has demonstrated a strong correlation between germination rate and vigour potential. In Fig. 8 the relationship between mean germination time and VP is shown for two cultivars, Ca 108725 and Klages, the latter showing a much shorter mean germination time at the same VP figure, which might be correlated to higher enzyme potential of Klages.

As could be expected from the mean germination time results, decreasing VP has a drastic effect on malting quality. Low vigour seeds (VP < 1.5) need twice the time of high vigour seeds (VP > 3) to produce an acceptable malt as indicated by the malt modification analysis.

Field experiments at Carlsberg Plant Breeding (J. Larsen) have shown that low vigour seeds are not able to penetrate the soil if they are sown too deep (5-10 cm), and if they do grow into plants these are 2-3 weeks behind the "high vigour plants" in development. How this fact influences the final yield is still under investigation.

We have found that 3 days germination at 20 °C gives a much better correlation to vitality than the present trade analysis of 5 days at 20 °C. Changing to the shorter germination analysis would guarantee the farmer a higher yield when buying certificated seed for sowing, and it would give the maltster a considerably better malting result especially when harvest weather has been difficult. The short germination method at 3 days could thus be used as a screening method for vitality supplementing the more exact but elaborate test involving accelerated ageing described above.

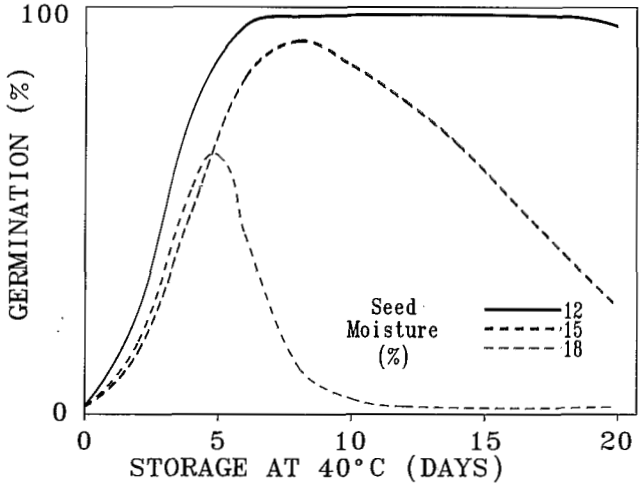

Fig. 7. The "life story" of a barley population stored at 40 °C with different moisture contents.

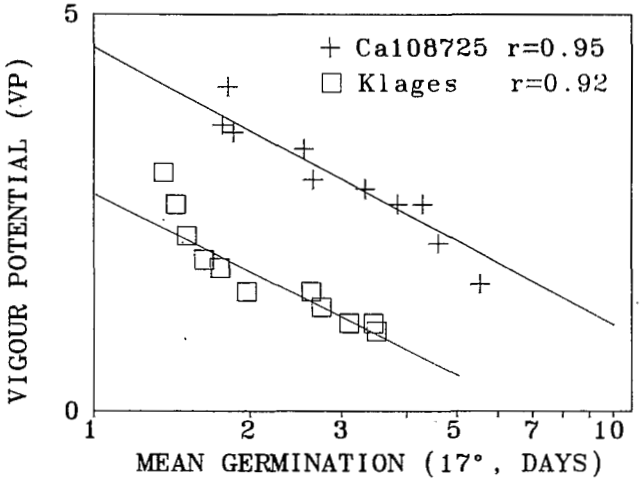

Fig. 8. Relationship between mean germination time and vigour potential.

Further quality criteria of importance for malting and brewing

We can thus conclude that by securing a vital barley seed for malting (VP > 4), more than half of the quality problematics is solved. In the following we shall dwell at the remaining quality considerations.

From a chemical point of view, the major aim of malting and mashing is to produce a brew (wort) containing all the appropriate nutrients for the yeast including fermentable sugars, amino acids, vitamins etc. The first phase in this process is the germination of barley grains activating important enzymes such as ß-glucanase, which degrades the endosperm cell walls, and α-amylase, which mainly exerts its action later in the mashing process degrading starch. In Table 2 it is seen that the crude composition of barley is comparatively little changed during malting with regard to starch, total lipids and crude protein, although the increases of free sugars and amino acids as expressed in percentages are about tripled but from a very low initial level. As for αß-glucan, which constitutes 2/3 of the substance of the endosperm cell walls, there is, however, a drastic decrease of 86% during malting. In order to explain this, we shall discuss the important structural changes during malting.

In Fig. 9 it is visualized by the Calcofluor fluorescence method (Aastrup *et al.*, 1981; Munck *et al.*, 1981; Jensen and Aastrup, 1985) how the endosperm cell walls are broken down during malting, starting in the scutellum/embryo end of the seed. We can also with immunotechniques (Gibbons, 1979) see how α-amylase diffuses into the areas where cell walls have been broken down, constituting the modified part of the endosperm. Aastrup (1983) produced a thin cell wall mutant, M 737, from the thick cell wall feed barley 'Minerva'. The mutant modified much faster than 'Minerva' in spite of similar levels of αß-glucanase and ß-amylase. The cell wall thickness (Aastrup and Munck, 1985) and the content of ß-glucan are thus critical factors in the modification of the endosperm, including the dissemination of the enzymes. However, to be able to attack the starch granules surrounded by a dense protein matrix, the α-amylase has to work in cooperation with many other enzymes besides ß-glucanase such as proteases and peptidases which can make the starch granules assessable. Another consideration which has been actualized is the findings in seeds of a range of proteins acting as enzyme inhibitors, e.g. α-amylase inhibitors such as ASI (Mundy *et al.*, 1983; Hejgaard *et al.*, 1983; Munck *et al.*, 1984).

Traditionally, the maltster tests the modification of the malt by squeezing the kernel between his nails. Today, we can evaluate the modification more exactly by the Malt Modification Analyser (Fig. 10) involving Calcofluor staining (Aastrup and Munck, 1981) or by the

Table 2. Changes in chemical composition (% DM) of European two-rowed barley and malt[1].

	Barley	Malt	Change (% of barley)
Starch	64.0	60.0	– 6
ß-glucans[2]	3.5	0.5	– 86
Lipids	2.5	2.5	± 0
Crude protein	9.5	9.5	± 0
Amino acids and peptides	0.5	1.5	+ 200
Total free sugars	2.7	7.5	+ 178

[1] Approximation after Harris (1962)
[2] Data from K.G. Jørgensen, Carlsberg Research Laboratory

Friabilimeter (Chapon, 1978) which by milling separates the soft, modified parts of the malt from the unmodified hard parts. Both methods are approved as standard methods by the European Brewery Convention. We can now also rapidly measure ß-glucan in barley, malt, beer and wort quantitatively by Calcofluor (Jørgensen *et al.*, 1987; Jørgensen and Aastrup, 1988). Also this method (Munck *et al.*, 1989) has been proved by the European

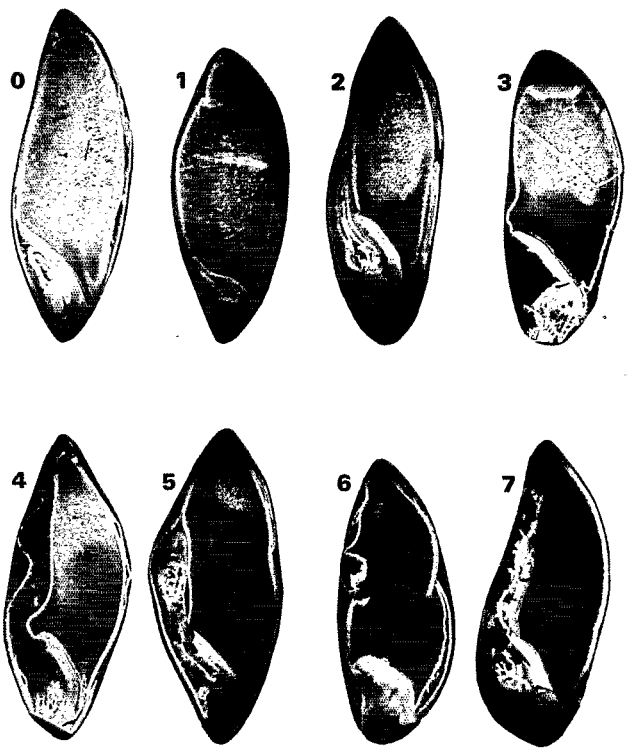

Fig. 9. Barley cell wall breakdown from 0-7 days as followed in the fluorescence microscope, stainig the endosperm cell walls (ß-glucan) with Calcofluor.

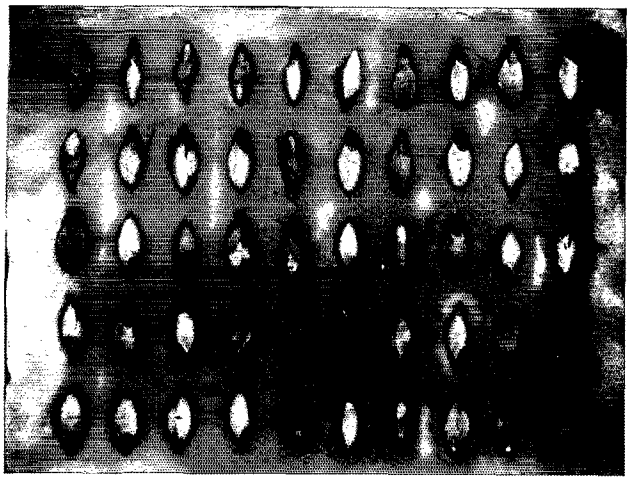

Fig. 10. Malt seed lot mixed with ungerminated barley as seen in the Malt Modification Analyser, visualizing the cell walls with Calcofluor which fluoresces in UV-light. The white spots mark unmodified barley endosperm with retained cell walls.

Table 3. Barley analyses on three fractions of 'Triumph' obtained by flotation in sodium nitrate.

	Barley fraction		
	"Mealy"	"Intermediate"	"Steely"
Hectoliter weight (kg)	64.85	69.41	70.66
Thousand corn weight (g)	40.13	41.85	43.08
Protein (% DM)	9.45	10.45	11.70
Starch (% DM)	65.70	61.90	60.10
Total ß-glucan (% DM)	4.04	4.34	4.36
Soluble ß-glucan (% DM)	0.43	0.63	0.74

Brewery Convention. The hulls of the barley act as a filtering aid in the lautering tank, the filtering being largely dependent on viscosity of the wort to which the high-molecular soluble ß-glucans significantly can contribute. ß-glucan may persist in wort because malt ß-glucanases are very sensitive towards temperature. This would cause significant delay in the processing time. Thus, the ß-glucans have double importance firstly as a resistance for modification in malting and secondary for lautering time. It is shown (Munck, 1987) that soluble ß-glucans in percentage of total ß-glucan in barley is well correlated with ß-glucans of the worts of the resulting malts. Soluble ß-glucan in barley is thus an efficient screening criterion in barley for malt quality and functions better as such than the total ß-glucan analysis of barley.

For centuries, it has been well known that a hard and steely barley endosperm gives an inferior malt compared to a soft and mealy one. We have developed a flotation technique with sodium nitrate (Hallgren and Murty, 1983) on sorghum, which we also have used for selecting barley (Aastrup and Munck, 1985). A steely feed barley like 'Minerva' sinks while its mealy ß-glucan mutant, M 737, and the malting barley, 'Triumph', float. Aastrup and Thomsen (1986) have by flotation obtained three fractions of increasing hardness from a sample of 'Triumph' barley (Table 3). The steely grains contain less starch but more protein and slightly more ß-glucan than do the mealy ones. There is considerably more soluble ß-glucan in the steely, dense seed fractions compared to the mealy ones. This principle is valid in comparison between varieties as well as within varieties grown under different conditions where a dry weather causes a more steely endosperm with higher level of total and soluble ß-glucan. We now better can understand how the old empirical tests work with our new analytical methods. From a plant breeding point of view (Munck, 1987) it seems obvious that the flotation method combined with the malt modification and ß-glucan analyses would give new opportunities in rapid screening for the right endosperm structure and composition in barley for malting. However, as important as the endosperm structure is the power of enzyme dissemination from the embryo/scutellum and from the aleurone, which is a distinct varietal character, but also intimately coupled to the vitality potential and the handling of the grain. We thus arrive at the tentative formula:

$$M = F \times (E/C)$$

where M = modification rate, F = a numerical factor, E = enzyme activity, and C = cell wall thickness of barley as related to ß-glucan content.

The different *de novo* synthesized enzymes such as ß-amylase and ß-glucanase seem to be well correlated in activity, comparing varieties. By measuring barley cell wall thickness through ß-glucan analysis and modification at 3 and 5 days of germination in Petri discs at 15 °C, E could be estimated.

In the mashing process, almost all starch is converted into fermentable sugars while about 40% of the protein of the barley is dissolved in the wort as amino acids and peptides. The rest of the protein is left in the spent grains together with most of the fat, the hemicelluloses, and the husk material. A high content of starch is thus of paramount importance to a high extract yield. This implies a low protein content and a thin husk (low fiber content) of the malting variety.

Barley quality for feed

From an operational point of view, a feed barley for e.g. pig feeding should together with protein additives (soycakes), vitamins and minerals give an efficient meat production with due consideration to the meat/fat ratio. In Western Europe, energy (starch) is in fact economically limiting since cheap protein is imported from the U.S. without levies in the form of soycakes. As pointed out by Bach Knudsen and Munck (1981), available energy in barley should thus be a trait of national economical importance to breed for. This means that malting barley with the large, plump starchy seeds should be the ideal both for malt and for feed. The use of huskless barley purely for feed purpose could also be discussed if high-yielding varieties could be found which do not shatter. Official barley trials are evaluated by the Kjeldahl protein analysis but very seldom with regard to starch content. We have in field trials in Denmark (Haastrup Pedersen, 1987) used the NIR analysis for starch as well as a rapid enzymatic analysis to evaluate the variation of starch. There is a huge variation almost equally dependent on environment and variety (Table 4), confirming the values published in 1981 (Bach Knudsen and Munck). A more rigorous testing at the official certification of the variety would secure that an increase in yield of a new variety is due to available nutrients such as starch and protein and not husk and hemicelluloses. Similarly, a low content of ß-glucan which is favourable in malting is also good for the feed quality because ß-glucans can hardly at all be utilized by monogastric animals and high amounts causes wet faeces droppings in poultry feeding.

We have through the years been deeply involved in high-lysine barley breeding (Munck, 1972), since 1973 concentrating on improving the Risø 1508 mutant (Munck *et al.*, 1985; Bang-Olsen *et al.*, 1987) by crossing. Kirsten Bang-Olsen, my co-worker, has bred our new high-lysine lines. When we started, our target was to reach the yield of 'Zita', the reference variety of that time. We obtained that goal in 1985 by intensive selection for seed quality and yield using the pleiotropic large germ character of the M-1508 gene (*lys 3a*) for easy selection without the needs for chemical analysis. The improved lines such as Ca 700202, called 'Piggy', also display a higher starch content than the original M-1508. As pointed out in 1981 (Bach Knudsen and Munck), high-lysine barleys such as M-1508 tend to be low in starch and available energy. In Table 5 it is shown that the increase of fat balances the deficit in starch of the improved high-lysine 1508 line, Ca 700202 (in 'Triumph'), resulting in a combustion energy value of 18.4 kJ/g compared with 18.1 kJ/g for both 'Lami' and 'Triumph'. Digestible energy trials with rats indicate a level of Ca 700202 equal to the malting variety, 'Triumph', but significantly higher than the feed value of 'Lami'. The problem of low digestible energy in high-lysine barley seems thus to have been overcome.

We have verified the nutritive and economical value of Ca 700202 and M-1508 in feeding trials with pigs. Studies with the original 1508 variety (reported here (Table 6) and with Ca 700202 indicate that the daily growth of pigs, fed the high-lysine barley without protein supplement at 11.5% protein in the feed, approaches the growth rate on a full feed consisting of normal barley and soybean additives at 15.0% protein. There is thus an indication that the optimal protein content in pig feeding with high-lysine barley would be less than 15%; we are at present calculating on 12-13%. This would mean that about 20% less nitrogen pollution would be excreted from pig manure, which is a sizeable amount for the

Table 4. Grain yield, starch and crude protein percentages of five barley varieties grown on two different soil types in Jutland, Denmark (1984) (Haastrup Pedersen, 1987)[1].

Soil type[2]	Variety	Grain yield (t/ha) 15% moisture	Starch (% DM)	Nitrogen (% DM)
Clay	R-1508[3]	6.26	54.2	11.5
	Ca 700202[3]	7.06	58.2	10.6
	Triumph[4]	7.68	66.4	9.9
	Aramir[5]	6.72	62.3	11.1
	Lami[5]	7.27	60.0	9.5
Loamy sand	R-1508[3]	4.00	48.9	16.7
	Ca 700202[3]	4.84	51.3	16.3
	Triumph[4]	5.36	60.6	15.2
	Aramir[5]	5.04	53.6	15.8
	Lami[5]	5.39	51.2	16.5

[1] Means of four repetitions per variety are listed. Chemical analyses are performed in duplicates/repetition
[2] Soil classification according to U.S. Soil Survey
[3] High-lysine barley containing the lys 3a gene from the Risø mutant 1508
[4] Malting barley
[5] Fodder barley

Table 5. Chemical composition (% DM), energy content and energy utilization in rats of normal and high-lysine barleys.

Material	Ca 700202	Lami	Triumph
Protein	9.5	9.5	9.2
Fat	3.3	2.2	2.1
Starch	59.9	62.7	67.1
Fiber	4.5	5.0	3.9
Energy kJ/g	18.5	18.1	18.1
Digestible energy (rats) kJ/g	14.9	14.6	14.9

Table 6. Feed trial with pigh restrictive according to Danish norms[1].

	Without protein additive		With protein additive
	Normal feed barley	1508 barley	Full feed
Protein	10.5	11.5	15.0
Lysine g/16 g N	3.7	5.2	5.0
Lysine g/kg	3.8	6.0	7.5
Feed to obtain 90 kg live weight, kg	538.0	209.0	206.0
Daily growth, g	261.0	635.0	703.0

[1] According to Madsen and Mortensen (1980)

yearly Danish production of 14 million pigs for slaughter (Pedersen *et al.*, 1988). Added to that comes the sparing of imported protein additives as well as a higher consumption of barley which in Denmark and in the EC is a surplus cereal. The Ca 700202 variety is at present (1990) not competitive in yield with leading varieties (about 10% lower in yield compared to the controls, partly due to lack of mildew resistance). We have now obtained a new generation of high-lysine lines which under Danish conditions in three years constantly have had yields above the control, a mixture of the four best mildew-resistant, high-yielding varieties.

Communicating the message of quality to the plant breeders, comparing the production chains involving barley for malt and for feed

In the old subsistence society, all activities involving use of barley were integrated locally at the farm, including e.g. beer brewing and pig feeding. A skilled barley breeder/pig feeder/brewer could thus recover and coordinate experience from all the different productions, empirically and operationally. This is not possible straight away in the present complex, specialized productions chains (Fig. 11) where each step demands an

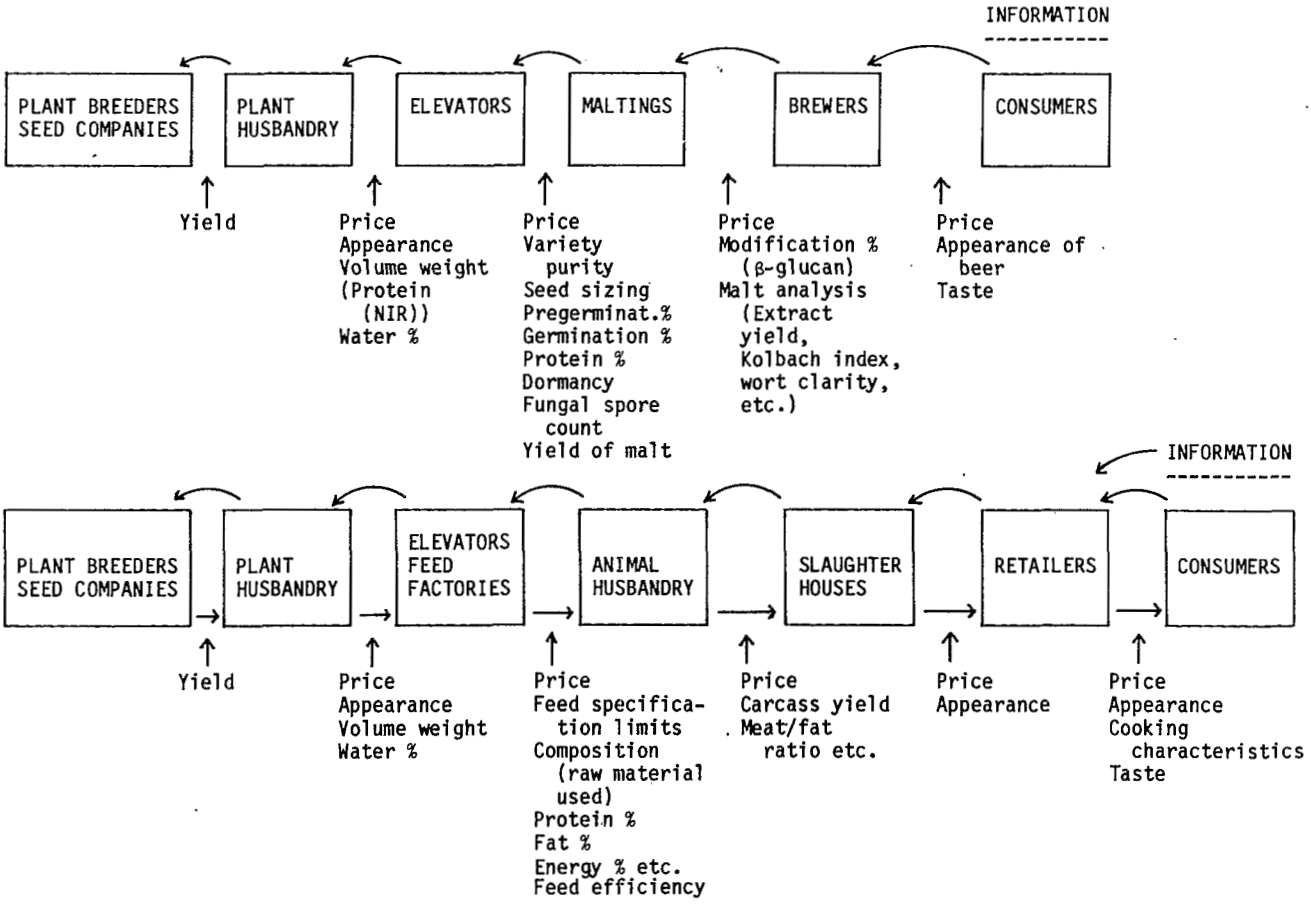

Fig. 11. The production chains of barley for malt and feed, criteria for exchange of goods and money, and the retrieval of information in the chains.

exchange of goods for money and where it at each such exchange, through specifications and analyses, must be secured that the commodities give value for money. Even within an integrated organization like Carlsberg which involves farms, plant breeders, maltsters, brewers, and trade specialists, the handling of the malting barley chain is quite complex.

Operationally the two production chains each constitutes a symbiosis between the three organisms, barley, yeast, and man - and barley, pigs, and man, where man (different men!) is not only the final consumer but also the controlling element and the profit/loss maker in each production step.

In comparison with the heavy barley/meat production chain, beer produces a higher incremental value which explains that it has been economical to introduce a higher sophistication in the quality control of the malt barley-to-beer chain compared to the feed barley-to-meat chain. In fact, in Western Europe the specifications of malting barley, involving a size assortment of seeds and a low protein content, have in the last 50 years dominated the spring barley market, being successful also due to the ease in plant breeding of obtaining a high yield with a high starch as opposite to protein content as discussed previously. In winter barley, plant breeding for quality has been less intense, and there is hence much more work to be done in this area to breed high quality malting (high extract) and feed (high metabolisable energy) barleys.

The control at the elevator level where farmers' harvest is received is much less rigorous compared to analyses at the intake of the malting and even of the feed industry. They thus have detailed specifications of what they need but due to exceeding costs, it is impossible to make all these analyses on each individual sample delivered from the farmer. The feed industry has nowadays an advanced feed optimization via computers based on the nutritional demands of the pigs which are quite well defined. The values put into the computer are, however, based mostly on mere table values which occasionally can be changed to suit the yearly average barley composition. The effect of this approximation is an over-supplementation of e.g. protein and lysine to be on the safe side statistically. It is also evident that the improvement of e.g. lysine in a high-lysine variety like Ca 700202 would not be recognized in the present system which considers protein before amino acid composition in selection. It is, however, fully possible to use the large germ character for qualitative grading and thus apply a corrected table value for the composition of this high- lysine barley. A quantitative estimate of lysine can conveniently be measured for all kinds of feed with the dye-binding method (Munck, 1983). As pointed out before, even the feed formulas have, however, to be changed to fully utilize the high-lysine barley option, lowering the optimal protein level in the feeds.

Another reason for the limited consensus in the quality concept of barley is the fact that there are always technical alternatives to the improvement of the barley raw material by breeding. Thus, supplementation with soybean protein or lysine and threonine is an alternative to feeding pigs with high-lysine barley. Polyvinylpyrolidone filtration in beer complexes the proanthocyanidins of barley, inhibiting haze being an alternative to proanthocyanidin-free barley (Wettstein *et al.*, 1984). Extract from barley malt can be exchanged with adjuncts such as sugar, starch, maize grits, etc. The uses of these options are not free but tied up with legislation, technical considerations, labelling of product, and company policy including traditions. This is the reason why the emphasis with regard to the quality complex of barley changes from country to country and appears so confusing for the plant breeders. We should never forget that beer brewing and animal production are well established, empirical and complex activities which have a firm cultural and historical background and which could still today be looked upon as a kind of art. It is theoretically possible to produce an artificial bacon with the help of spun soybean protein and aroma components. It is also possible to make a kind of artificial beer where the components never have been malted or fermented. The reason for these products being rather unsuccessful could besides problems with the taste be sought in their lack of cultural and sensoric foundation in the minds of the consumer and the legislators. Barley will, therefore, also in the future be used for malt and feed and as implied previously, we can see a general consensus coming up between the feed and the malt aspects, where a high starch level results in both a high potential malt extract yield and a high metabolisable energy for animals, and where vital seeds which might partly be genetically controlled give high performance, both in the malt house and in the farmer's field, lowering the production costs of both barley for malt and feed. The idea that we all should agree to a strictly defined barley quality definition once and forever is, however, not very realistic, firstly because conditions, including price, change and science develops, and secondly, we can not as professionals possibly be without this discussion. Arguing is the essential human activity without which human life would be boring and intolerable.

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