PROJECT REPORT No. 325

DEVELOPING AND VALIDATING ON-FARM SAMPLING PROTOCOLS: SAMPLING IN STORE AND DURING OUT-LOADING

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DEVELOPING AND VALIDATING ON-FARM SAMPLING PROTOCOLS: SAMPLING IN STORE AND DURING OUT-LOADING

By

J D KNIGHT, D R WILKIN and J RIVETT

Imperial College London, Silwood Park Campus, Ascot,
Berkshire SL5 7PY

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Contents

Abstract

The aim of this project was to establish whether sampling of grain whilst in store provides a reliable method of determining the quality of a grain batch. The results of in-store sampling were compared with those obtained from sampling at intake and during out-loading.

Grain was sampled at a total of 9 farms starting from harvest 2002 through into 2003. The farms selected used a variety of drying methods (high and low temperature and ambient air) and storage methods (bin and on-floor). All sampling in the store was done using a 1.7m grain spear. Results for sampling and grain quality at harvest were from previous work investigating sampling at intake (HGCA Project Report 301).

The stored grain was sampled after approximately 1, 4 and 6 and, in one case, 10 months. In-store sampling was compared with sampling at out-loading by taking samples from the bulk to be loaded using a spear and then taking a litre of grain from each 2 tonne bucket as it was loaded into the lorry. The results of the quality analyses were then compared for the two sets of samples. The grain sampled at out-loading was also sampled at intake to the mill and the analyses done by the project were compared with the results obtained by the mill.

The quality parameters measured (protein, specific weight, moisture and hardness) did not vary markedly during the period of storage and sampling in store. Broadly similar values were obtained for the quality parameters compared with the samples taken at intake and at out-loading. However, because fewer samples are generally taken in store, it is unlikely that the whole range of variability was covered.

Results for mill samples were not statistically different from the results obtained on-farm but were sufficiently different to be commercially important. However, differences did not consistently favour or penalise either mill or supplier.

Despite its limitations, in-store sampling would appear to give a reasonable sample to determine the quality characteristics and obviously is essential for monitoring the quality of grain during storage.

Background

This research was done at the request of HGCA in response to the Treasury funding secured to undertake a two-year programme to improve and standardise grain sampling and analysis across the UK cereals industry. The first part was to develop and validate protocols suitable for collecting samples of grain on UK farms at harvest (HGCA Project Report 301) and to train farmers in their use. The second part, reported here, was to examine approaches to the collection of samples during storage and to compare the results obtained, wherever possible, with data collected as the store was filled.

Much of the background of this work was discussed in detail in HGCA Project Reports 34, 79 and 118. HGCA Project Report 301 dealt with the sampling of grain as it entered storage on farms. All previous investigations have indicated that any attempt to assess the commercial properties of grain by collecting samples during storage is likely to produce inferior results to sampling during the filling of the store. The major limitations to in-store sampling are that access may be difficult, dangerous or even impossible; it may be impossible to reach all parts of a bulk of grain and; very large numbers of samples are needed to cover the degree of variability. Nevertheless, there are occasions when it is necessary to sample grain during storage. The work discussed in this report aimed to provide some data to qualify the effectiveness of in-store sampling and to give an indication of the effectiveness of such an approach compared with an assessment done during filling or emptying.

The work was a continuation of that reported in Project Report 301 and most of the storage assessments were done at farms used during the earlier work. As a result, data were available for quality assessments during filling of the stores and this was used in comparison with the data collected during storage.

In addition, most of the grain was stored on drying floors so that some assessment of the ability of in-store sampling to assess changes in the properties of the grain during slow drying could be made.

Programme of work

i) Overall Aim

To assess the effectiveness of sampling grain during storage and to relate the results to those obtained by sampling during intake and on out-loading.

ii) Specific Objectives:

a) To relate the results of in-store sampling from this project with sampling during filling of farm stores and the sample results obtained by end users to ensure comparability of results.

b) To integrate work done during filling of farm stores with information collected during storage to improve storage strategies and consequently grain quality.

c) To assess methods for sampling at out-loading that will give reliable information about grain quality.

Constraints on the project

The ability to compare in-store sampling with intake sampling was limited to those farms assessed during earlier work (Report 301) where the grain remained in store and was accessible for further sampling. The farmers handled the storage and subsequent sale of the grain and the samplers were not necessarily informed before grain was sold. As a result the number of post-harvest assessments varied between farms. However, sufficient stored grain was available to fulfil the project requirements.

Methodology

Farms used

Grain on five farms used during the development of sampling protocols was sampled after being put into store. The storage period and the approach to sampling had to reflect the type of storage, accessibility and the farmer's marketing plans. At three farms grain was stored on drying floors. At one other farm the grain was stored in a bin after passing through a high-temperature drier. This grain was sampled both as it entered the store before drying and after passing through the drier as it was conveyed into the bin. Grain at the final farm was stored in a heap on a floor after being dried using a high temperature drier. Once again this grain was sampled as each trailer arrived at the store and then as it left the drier.

Farm number	Commodity	Farm location	Date of initial sampling
3	Wheat	Kent	Early August 02
4	Wheat	N. Lincolnshire	Mid August 02
5	Wheat	N. Lincolnshire	Mid August 02
7	Wheat	Yorkshire	Late August 02
8	Wheat	Yorkshire	Late August 02

Table 1. Farms where grain was sampled at intake and subsequently sampled during storage

In addition, wheat was sampled at a further 4 farms that were not included in the earlier work and so was not sampled as it entered store (Table 2). This grain was sampled in the store just before out-loading and then as it was loaded onto lorries for delivery to a mill. In most cases, further sampling was done of the lorry-loads on arrival at the mill.

Farm number	Commodity	Farm location	Date of harvest
11	Wheat	Essex	Not known
12	Wheat	Essex	Not known
13	Wheat	Essex	Not known
14	Wheat	Essex	Not known

Table 2. Farms not included in early intake sampling assessment but where the grain was sampled during storage and at the time of out-loading.

Collection of samples

The aim of the sampling was to collect samples from the same batch of grain that had been assessed as it entered storage (see Report 301 for details). Intake sampling involved collection of samples from incoming trailer loads with a pelican sampler or scoop during tipping or by spear from a heap. However, at farm 3, after drying, the farms own diverter sampler was used to give samples. At farm 7, a pelican sampler was used to collect samples of the grain after drying from a conveyer outlet as the wheat was discharged into a bin.

When grain was assessed during storage, a 1.7m, multi-compartmented sample spear was used to collect samples from the bulks of grain in store (Figure 1).

Figure 1. Multi-compartmented sampling spear.

Three sample points were used with each batch of grain stored on-floor or in bin. For on-floor bulks these were spread across the bulk and for the bin were arranged in a diagonal line across the centre. Five sample points were used for the larger (250 tonne) heap of grain and were arranged round the heap, half way up the slope (Figures 2 & 3).

In order to provide sufficient grain for an assessment with the Infratec, the spear had to be inserted twice at each point and the grain removed was mixed to give a single sample from each point.

Figure 2. Collection of samples from heap of grain.

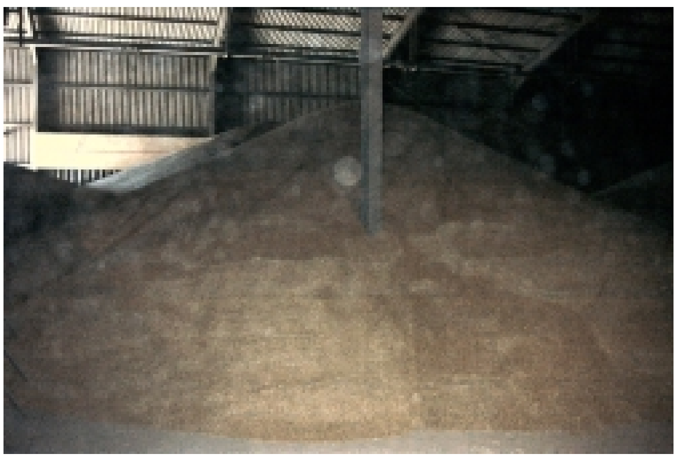

Figure 3. Heap of about 250 tonnes of wheat at farm 3.

Subsequently, grain at all the farms was sampled at intervals during storage. In the case of two batches of grain, farms 3 and 4, data-logging temperature sensors were placed in the grain at a depth of 0.5m to record temperatures over time to ensure that storage conditions were not abnormal.

Storage

At the two farms using high temperature drying (farms 3 and 7), no further conditioning was done after drying. However, where the grain was stored in a bin (farm 7), it was moved into another bin after about 4 weeks of storage. This was done for operational reasons and not as an aid to storage.

At the other farms, grain was dried with on-floor drying systems. At one farm (farm 4) an automated, gas-powered heater designed to provide constant humidity was used. No records are available to show how much heat was used. One farm (farm 5) had a drier with a manually controlled electric heater bank but this was not used during the drying process. The drying process appeared to be completed successfully at these farms. The final farm (farm 8) used a motorised fan that added the heat from the engine to reduce the humidity of the drying air. This grain was sold before drying was completed.

Assessment of samples

Each sample was tested using a Foss Infratec grain analyser 1241 GA-TWM. This instrument measured moisture content, specific weight, protein in the case of wheat or nitrogen in the case of barley and made an assessment of hardness of wheat. As samples had to be transported to the location of the Infratec, delays of a maximum of 24 hours occurred between the collection and assessment of some samples. In these cases, samples were transported in a cool box to reduce the influence of temperature and moisture changes on the properties of the grain. Unfortunately, there was a change of instrument during the course of the work and the replacement instrument used different calibrations that affected the results given, in particular for specific weight. Some samples were tested on both machines so that there was an indication of the difference that could be attributed to the change of instruments.

The level of screenings was also assessed for each sample using a single sieve. This was only a comparative test and not done using standard slotted sieves due to constraints of time. The results simply provide an indication of the variability of the level of screenings or fines that occurs between samples.

Grain assessed as it entered storage:

The amount of grain assessed as it entered storage ranged between about 70 – 200 tonnes and was either held in a bin or formed an identifiable section of a bulk within a store. The total capacity of the stores ranged between 70 and 600 tonnes so that only in the case of the grain stored in a bin (70 tonnes on farm 7) was the entire lot sampled as it entered store.

At all farms a 1.7m multi-compartmented sampling spear was used to collect samples from the grain bulks. The spear was used to collect samples from three points in each batch of grain, arranged in a line across the bulk or bin.

Samples were collected at irregular intervals during the storage period**.**

Grain not assessed as it entered storage:

Milling wheat that had been stored at four farms for at least 6 months was sampled at the time of out-loading. All grain was stored in large bulks on-floor. It was outloaded using a front loader to fill lorries or trailers. Samples were collected from three points in the part of the bulk that was about to be out-loaded using the multi-compartmented spear. Then, as each bucket-load was collected by the front-loader, a 1 litre sample was collected from the surface of each bucket using a jug. These samples were added together to make a composite sample. This was mixed and then divided by coning and quartering and 3 sub-samples taken to give three samples for analysis.

On occasions, two loads were sampled from a farm, giving a total of 7 data sets. All loads were sampled with manual multi-compartmented spear by mill staff on arrival at the mill. This single sample was analysed in the mill laboratory using their equipment but often the results were made available to the project. In some cases, three additional samples were collected from loads at the mill and these were analysed using the same system as other samples collected during this work.

This work addressed specific objective (c) by providing comparisons between different methods of sampling grain as it was out-load from a store. However, it is acknowledged that the method of collecting a sample from each front loader bucket is not practical at a farm level and was used only to provide comparative data.

Results

In general, the weight of grain sampled at intake was about 100 tonnes so that this was the amount that was covered by in-store sampling. Standard commercial practice would probably be to take one sample from this amount of grain so that by taking 3 samples, the norm was exceeded. The maximum, minimum and mean values for intake and storage samples are given for each farm in the following tables.

Farm	Storage time and treatment of grain	Moisture content of samples		
		Max.	Min.	Mean
3	At intake	16.9	16.8	16.9
	After drying	14.6	14.4	14.5
	Discharge into heap	14.7	14.4	14.5
	1 month storage	14.7	14.5	14.6
	5 months storage*	15.8	15.1	15.3
4	At intake	17.4	16.2	16.9
	1 month storage	15.4	15.2	15.3
	4 months storage*	14.9	14.7	14.8
	6 months storage*	15.3	15.1	15.2
5	At intake	16.3	15.6	15.9
	1 month storage	15.4	14.9	15.1
	4 months storage*	14.8	14.6	14.7
	6 months storage*	14.8	14.7	14.7
7	At intake	16.6	14.6	15.3
	After cleaning	15.9	14.6	15.2
	After drying	13.0	11.3	12.4
	2 months storage	12.7	11.3	12.1
	4 months storage*	12.6	12.5	12.6
	10 months storage*	13	12.7	12.9
8	At intake	20.5	18.9	19.6
	1 month storage	19.6	19.3	19.4

Table 3. Moisture content of grain samples at harvest and during storage.

* Foss Infratec with different calibration was used for these samples. This change in calibration did not affect the measurement of moisture.

Analysis of variance revealed that the only statistically significant differences between samples (at P<0.01) were due to high temperature or on-floor drying having taken place between the different sampling dates. Overall there was little variation between the samples taken at different times during the project.

Farm	Storage time and treatment of grain	Specific weight of samples		
		Max.	Min.	Mean
3	At intake	69.5	68.3	68.7
	After drying	69.9	69.2	69.6
	Discharge into heap	71.0	70.1	70.5
	1 month storage	70.8	70.4	70.5
	5 months storage*	74.3	74.8	74.6
4	At intake	74.3	72.1	73.3
	1 month storage	73.3	72.8	73.0
	4 months storage*	77.6	78.4	77.7
	6 months storage*	77.2	78.1	77.7
5	At intake	74.0	72.3	73.0
	1 month storage	74.4	73.5	73.9
	4 months storage*	78.4	78.6	78.7
	6 months storage*	78.4	78.6	78.5
7	At intake	75.8	74.8	75.5
	After cleaning	77.1	76.2	76.7
	After drying	76.0	71.8	72.9**
	2 months storage	76.0	75.2	75.7
	4 months storage*	81.4	81.3	81.4
	10 months storage*	80.4	80.7	80.6
8	At intake	72.3	67.5	70.7
	1 month storage	71.8	71.9	71.8

Table 4. Specific weight of grain samples at harvest and during storage.

* Foss Infratec with different calibration was used for these samples. This change resulted in an increase in specific weight of about 7%. According to the manufacturer, the later calibration gave a more accurate assessment.

** this result is anomalous and emphasises the variability that can arise due to sampling.

Analysis of variance revealed that the only statistically significant differences between samples (at P<0.01) could be wholly attributed to the use of two different Foss instruments which had different calibrations for this parameter. Otherwise the values obtained were in close agreement throughout the sampling period.

Farm	Storage time and treatment of grain	Protein content of samples % DM		
		Max.	Min.	Mean
3	At intake	12.4	11.5	12.4
	After drying	12.6	12.4	12.5
	Discharge into heap	12.6	12.4	12.5
	1 month storage	12.6	12.4	12.5
	5 months storage*	14.3	12.5	13.1**
4	At intake	10.1	8.8	9.5
	1 month storage	9.3	9.0	9.2
	4 months storage*	9.5	9.0	9.3
	6 months storage*	9.2	9.5	9.3
5	At intake	12.3	10.8	11.8
	1 month storage	11.7	11.5	11.6
	4 months storage*	11.9	11.4	11.6
	6 months storage*	11.4	11.8	11.6
7	At intake	10.6	9.3	10.0
	After cleaning	10.4	9.4	9.9
	After drying	10.2	9.9	10.1
	2 months storage	10.1	10.2	10.1
	4 months storage*	9.9	10.0	9.9
	10 months storage*	10.0	10.0	10.0
8	At intake	12.6	12.0	12.2
	1 month storage	12	11.9	12.0

Table 5. Protein content of grain samples at harvest and during storage.

* Foss Infratec with different calibration was used for these samples. This change did not have a marked affect on measurement of protein.

** This result is anomalous and emphasises the variability that can arise due to sampling.

Analysis of variance revealed that there were no statistically significant differences between samples (at $P<0.01$) and protein content remained very similar throughout the storage period. However, the small differences could have financial consequences.

Farm	Storage time and treatment of grain	Hardness value of samples (0 – 100)		
		Max.	Min.	Mean
3	At intake	59.8	44.3	54.3[a]
	After drying	46.1	44.8	45.4[a]
	Discharge into heap	50.8	44.9	47.5
	1 month storage	50.8	45.0	47.5
	5 months storage*	56.6	49.3	53.9
4	At intake	55.0	40.5	46.5
	1 month storage	42.8	38.0	40.0[b]
	4 months storage*	52.5	40.8	47.2
	6 months storage*	55.0	49.5	52.9[b]
5	At intake	69.2	56.4	64.3
	1 month storage	63.5	67.9	65.3[d]
	4 months storage*	71.8	67.4	69.9
	6 months storage*	71.5	73.9	72.3[d]
7	At intake	53.9	43.0	48.9e
	After cleaning	57.0	53.2	55.1
	After drying	57.0	53.2	55.2
	2 months storage	55.1	53.2	54.4[ef]
	4 months storage*	60.5	58.8	59.4[f]
	10 months storage*	55.9	50.6	52.9
8	At intake	72.3	63.5	68.1
	1 month storage	73.6	68.1	71.0

Table 6. Hardness value of grain samples at harvest and during storage as calculated by the Infratec Foss Grain Analyser. Means followed by the same letter are significantly different at the P<0.01 level.

* Foss with different calibration was used for these samples.

Analysis of variance revealed some statistically significant differences between samples (at $P<0.01$). These differences in hardness values are shown above in Table 6. These results need to be viewed in terms of the very low number of samples taken which could lead to spurious significance being attributed to the findings.

Observations of storage practices

On-floor drying:

Observations were made over periods of between 1 and 4 months depending on the farm.

The multi-compartmented spear used to collect samples (Figure 1) only sampled the top half of the grain bulk because it was about 1.7m long and grain depths were always more than 2.5m. The grain collected was made up of 11 small sub-samples from different depths. Therefore the final sample represented the mean value for the top half of the bulk.

At two farms (4 and 5) the wheat was intended as feed and the target dry moisture content was <15%. In both cases this target was almost achieved after storage for 1 month and by 4 months the moisture content was below 15%. At farm 5 only ambient-air drying was used. At farm 4 a constant humidity heater was available but there are no records to show how much or if any heat was used.

At farm 8 the milling wheat was dried using a motorised fan unit where the waste heat from the engine was added to the drying air. Our observations suggested that little drying had occurred in the upper half of the bulk after 1 months storage, although drying may have occurred in the lower part. This grain was sold before more observations could be made and the farmer blended this grain with other, drier grain to achieve the intake moisture required by the mill.

Changes in other quality factors during drying and storage seemed small and, in general, were close to the values found during intake sampling. The apparent increase in specific weight seen in all samples after 4 months or more storage is attributable to the use of a different Foss Infratec. This instrument had a different calibration for specific weight that is likely to be more representative of the true value. Test samples checked with both instruments suggested that the calibration differences did not affect other parameters. There was some indication of a rise in hardness value by the ends of storage but the significance of this is unclear.

In general the in-store sampling results seemed to represent less variation than did the samples collected at intake.

High-temperature drying:

At farm 3, samples after drying were collected by a diverter sampler that collected a small trickle of grain from the main outflow from the drier. This grain was then deposited in a series of discrete heaps in a floor store (Figure 3). This heap was then sampled immediately after drying and at intervals during storage using a multi-compartmented sampling spear. The grain remained in this heap with no further treatment until it was sold in June 2003.

At farm 7 the grain was sampled on intake with a pelican sampler. This grain passed through a cleaner and into a holding bin. Samples were collected with a pelican sampler as the grain was discharged from a conveyer into the bin. Finally, the grain was moved into the drier and was sampled with a pelican as it was discharged into its storage bin. Following drying the grain received no further treatment except it was turned into another bin after about 3 months storage.

In both cases high-temperature drying was effective in removing moisture. However, at farm 7 the grain appeared to have been over-dried to some extent as the contract moisture content was 14.5% or less. There was little change in moisture content during the first months of storage at either farm. At farm 7, where the grain was stored in a bin, there was little change even after 10 months storage. The grain stored in a heap at farm 3 appeared to increase in moisture after 5 months of storage. This may be have been the result of the much larger area of the bulk exposed to atmospheric humidity.

Temperature monitoring

Figures 4 and 5 show the results of the temperature monitoring of the grain on f 3 and 4 respectively. farm 3 (Figure 4) shows the change in grain temperature associated with the change in ambient temperature over the storage period. The grain was in a 70 tonne bin which was located centrally in a cluster of similar bins so was subject to some thermal buffering.

On farm 4 (Figure 5) the temperature recording shows the large changes in temperature that occur when on floor drying systems operate as opposed to the slow changes in temperature created by ambient air ventilation. Unfortunately there are very few data on using such systems to cool grain and more information on both efficacy and cost effectiveness would be of value to the farmer.

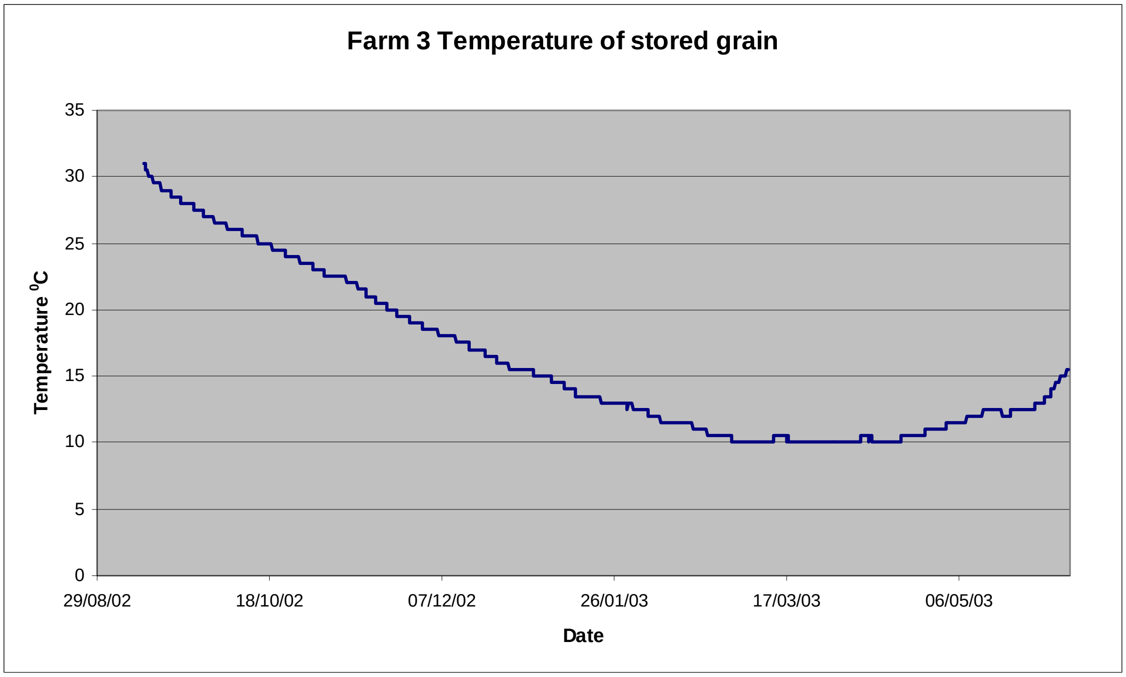

Figure 4. Temperature of stored grain on farm 3 (in bin)

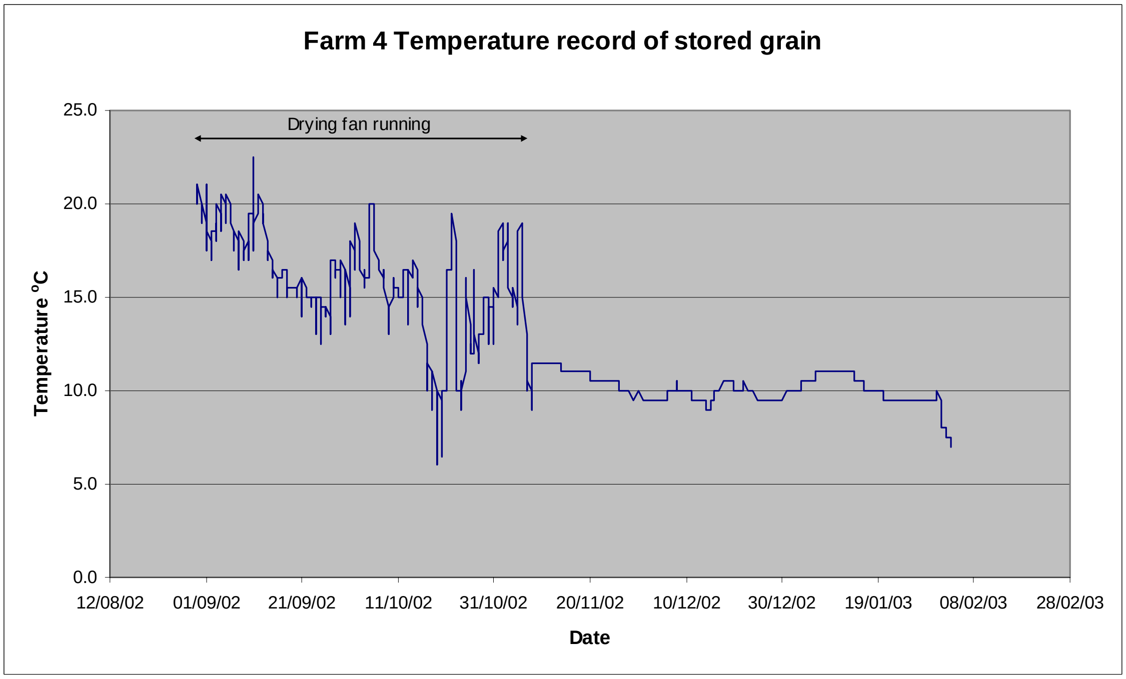

Figure 5. Temperature of stored grain on farm 4 (on-floor)

Results – out-loading for delivery to mill

Grain from 4 farms (11 – 14) was sampled once but in the case of farm 11, 4 loads of grain were sampled from the same heap. The sampling and assessment took place over a period of about 2 months and was controlled by the amount of grain needed at the mill from local farms. Whenever possible the loaded trailer or lorry was followed to the mill so that 3 spear samples could be extracted from the load before it was tipped. However, this was not always possible and in two cases, mill staff took a single sample that was retained for the project. The standard intake sampling done by the mill staff was to take a single, manual spear sample from each load.

The samples collected as part of this project were analysed using a Foss Infratec Grain Analyser. Samples at the mill were tested using the mill's own equipment.

A summary of the results of analysis of the samples collected from the farms during out-loading and on arrival at the mill is given in table 7. Where multiple samples were taken the average value is used.

Sample	Protein	Moisture	Hardness	Sp. Wt.
Farm1, load 1				
Spear form heap	13.4	13.4	73.2	77.5
Loader	13.7	14.0	67.9	76.8
Mill results	NA	NA	NA	NA
Farm 1, load 2				
Spear from heap	14.1	13.2	69.1	76.4
Loader	14.2	13.7	69.9	75.8
Mill results	13.9	13.9	5.8$	73.3
Farm 1, load 3				
Spear from heap	13.5	13.7	71.7	77.2
Loader	13.7	14.0	68.1	77.3
Samples at mill	13.7	14.1	67.2	77.2
Mill results	13.6	14.7	8.2$	79
Farm 1, load 4				
Spear from heap	13.6	13.0	68.6	77.6
Loader	13.4	13.1	69.3	78.0
Samples at mill	13.6	13.3	68.8	77.5
Mill results	13.2	11.9	8$	76.2
Farm 1, load 5				
Spear from heap	13.8	14.3	70.9	76.4
Loader	13.7	13.9	70.9	76.4
Samples at mill	14.1	14.5	71.5	76.4
Mill results	13.4	13.6	5.4$	75.1
Farm 1, load 6				
Spear*	NA	NA	NA	NA
Loader	13.6	14.1	72.5	76.4
Samples at mill	13.8	14.4	67.7	76.9
Mill results	13.8	14.5	5.7$	74.1

Farm 2, load 1				
Spear from heap	13.6	14.0	70.5	77.2
Loader	13.6	14.0	68.1	77.3
Samples at mill	13.7	14.1	68.8	77.2
Mill results	13.2	13.8	9.9[$]	79.4
Farm 3, load 1				
Spear from heap	13.4	14.9	58.0	81.9
Loader	12.8	15.0	55.3	82.1
Samples at mill**	12.9	14.9	54.3	82.3
Mill results	12.5	13.0	8.5[$]	80.2
Farm 4, load 1				
Spear from heap	13.4	14.1	53.6	77.9
Loader	12.8	14.0	53.2	78.1
Samples at mill**	12.9	14.9	54.3	82.3
Mill results	11.7	12.7	7[$]	76.8

*   Insufficient grain at store to spear.
** Sample collected by mill staff and only a single sample taken.
$ The mill used a different hardness scale, hence results cannot be compared with Infratec values.

Table 7. A summary of the sample analysis results from the farms during out-loading and on arrival at the mill

Discussion

In the case of all grain assessed during this trial, there was safe, unlimited access to the grain surface so that it was possible to collect samples during storage. However, there were still practical limitations to the effectiveness of the process. The sampling spear used was only about 1.7m long so that sampling was restricted to that depth or less and this always represented less than 50% of the grain. Longer spears are available but they are difficult to insert and are difficult to use if headroom is restricted. By comparison with collecting a sample from a trailer during filling of the store, accessing the grain bulk and collecting samples was a time-consuming and laborious operation.

The amount of grain that was collected during each in-store-sampling (~1500g) was only about 15% of the amount collected when each incoming trailer was sampled. However, the mean results obtained from each approach were often very similar. The principal difference in the results given by the two methods was that the amount of variability (difference between the maximum and minimum values) was less with the in-store sampling. Therefore, it was less likely to show the extremes present in the grain and might result in an optimistic estimate of the consistency of the grain quality.

Other than moisture, the quality of grain did not appear to change to any great extent between intake sampling and the samples collected at the end of storage period. This provided further support for the concept of concentrating sampling effort on the grain as it enters storage. It is unfortunate that two different Infratec instruments had to be used and that their calibrations for specific weight were different. This has caused an apparent increase in specific weight in the latter part of the storage period. Samples tested on both instruments showed that this apparent increase could be attributed entirely to the change in instrument.

There were some slight changes in specific weight that were not attributable to the change in instrument. At farm 3, conveying and drying the wheat appeared to increase the specific weight but this was not the case at farm 7 that also used a high-temperature drier. However, at this last farm the specific weight seemed much more variable.

At two out of three farms where grain was dried on-floor the drying process was largely accomplished in a month, although some further drying was still required to meet contractual requirements. No obvious trend was apparent in changes in other quality parameters that occurred during drying. In the case of farm 8, samples taken 1 month after harvest did not indicate that any drying had occurred in the top 1.7m of grain. The grain was sold without problem but storage at this moisture content carries a high risk of some mould growth.

Sampling at the time of out-loading gives a clear indication of the difficulty in representing the variability of grain by collecting samples. There were always small differences in the results obtained from different sampling methods and these differences were often of commercial significance. In theory, the samples collected from the loader should have given the best estimate of quality because they were made up of the largest number of individual samples. However, although there were often small differences between the results from the two methods, there were no discernible trends. The results obtained by the mill staff using a single sample taken from the incoming load were often different from those obtained by sampling at the farm or by using the 3 samples collected from the load at the mill. Once again, although small, the differences were of commercial significance. The values obtained by the mill were mostly, but not always, lower than the values obtained with other samples. It is not clear how much if any of this difference can be attributed to measurement error caused by assessing samples with different equipment. The difference in equipment meant that the hardness values obtained by the mill are not comparable with those obtained by the Infratec.

This work suggests that sampling grain during storage can provide an effective estimate of its mean quality despite limitations to the approach. However, it is unlikely to give a full estimate of the variance contained within a bulk of grain. The work done on grain during out-loading and delivery shows the limitation of any approach to produce a sample that will give a consistent estimate of quality. It also shows that there are difficulties and dangers associated with attempting to apply precise values to commercially sensitive parameters. For example, the mean value for protein commonly varied by 0.4% depending on the sample. This represents an error of only about 3% yet it might affect the price of the grain by £4/tonne.

Recommendations

1. Consider drawing up some general guidelines for in-store sampling.
2. Develop an automated sampler that would collect samples from each bucket-load, as grain is out-loaded from a store.
3. Repeat in-store sampling work on bulks of grain that were sampled during intake but increase the numbers of samples taken to allow more detailed statistical analysis.

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