Northern Periphery and Arctic Programme

Northern Cereals – New Markets for a Changing Environment

METHODS USED WITHIN THE PROJECT FOR MALTING SMALL GRAIN QUANTITIES

Report

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1 Introduction

As a result of increasing consumer demand for high provenance alcoholic beverages across the project partner region, many beverage companies are interested in using locally grown barley to develop new products. A major constraint on this, however, is the need to convert barley into malt so that it can be used for beer or spirit production. During the 20th century there was a trend throughout Europe for small-scale local malting facilities to close down and to be replaced by a few large, commercial plants where minimum batch sizes may be as large as 200 t of grain. For producing specialist bottlings of beer or spirits using local barley, most SMEs often only require about 0.5 -5.0 t of malt, which is usually much too small a batch to be malted by the large malting companies. This lack of small-scale malting facilities not only constrains the range of products which beverage companies can produce, but it also limits the growing of malting barley in the project region, which is potentially a more valuable product than normal feed barley. In order to try to overcome this impasse, the project is seeking to pass on the skills and knowledge involved in making malt, using traditional floor malting methods which can be done without expensive equipment. One way in which this is being done is the provision of placements to associate partners at Highland Park Distillery in Orkney where they have the opportunity to learn the methods involved over a 4-day period. In parallel with this, some of the project partners are also working with associate partners to build on this new knowledge and develop local solutions for small scale malting.

This report summarises the methods which have been used in Orkney and Norway during the first half of the project to investigate small scale local malt production.

2 Small Scale Malting In Orkney

2.1 Introduction

Orkney is very fortunate in having a distillery, Highland Park (HP), which has its own on-floor malting facilities which it uses to produce malt for its own needs. As HP was an associate partner in the project, it agreed to carry out small scale malting of a one-off batch of barley for Orkney's Swannay Brewery, another associate partner in the project, and to allow the Agronomy Institute to monitor and record the process for the benefit of the project. For the malting which was done at HP, 7.5 t of grain was used because this was a convenient quantity for the equipment available at the distillery. The floor malting process is very flexible, however, and the scale can be reduced to suit the equipment and quantity of grain which is available. In Section 2.2, a general description is first given of the floor malting process and this is followed in Section 2.3 by a summary of the method which was used at HP to malt the grain for Swannay Brewery. A comprehensive set of photographs, illustrating the malting process at HP is presented in Appendix 1 at the end of the report.

Orkney also has a tradition of smaller scale malting for home brewing which was once widely carried out in rural areas. This was based upon use of Bere, an ancient type of Scottish barley which, for hundreds of years, was the only barley grown in Orkney. Small scale malting of Bere using traditional methods is still carried out at Barony Mill and is described in Section 2.4.

During the project a 5 t consignment of Bere was also sent away to Crisp Malt for small scale malting in their Pilot Vat at Great Ryburgh in England. This is described briefly in Section 2.5.

2.2 Floor Malting

2.2.1 Background

Up until the 20th century, most Scottish distilleries produced their own malt on-site using traditional floor malting. From then there was a gradual shift to less labour intensive methods like drum malting and Saladin box malting and eventually to abandoning distillery malting and using very large-scale centralised facilities instead. Consequently, there are now only about seven Scottish distilleries which still have their own facilities for malting barley and most of these use floor malting. Although this is a much more expensive process than purchasing malt from large malt suppliers, it has the major advantage of providing these distilleries with a unique malt which adds to the provenance of their whiskies. It also allows these distilleries to source locally grown barley and to produce whiskies with 100% local content. This can be a significant *unique selling point* in the whisky market where product differentiation is very important. In remote areas, the availability of malting facilities at distilleries raises the possibility of additional benefits to breweries and growers if these distilleries are prepared to malt local barley for brewing.

2.2.2 Stages In Floor Malting

Malting is the process whereby cereal grains are allowed to start to germinate so that the chemical changes necessary for brewing or distilling are started. Germination is then stopped, before it progresses too far, by drying the grains. This also creates a product which has good storage properties.

For malting, it is necessary to have good quality grain with a high germination percentage. Some varieties may need to pass through a period of dormancy to give maximum germination. The quality criteria for barley used for malting have been described in another project report (Martin, 2015).

The raw material for most malt is usually barley grains. These will normally have been dried down to about 13% moisture content for safe storage. To start the germination process, the moisture content of the grain needs to be raised and this is done by immersing or “steeping” it in water. For this, the barley is placed in a steeping vessel and immersed in water for several hours; the water is then drained away. Steeping and draining are then repeated several times over about a two-day period. At the end of this stage, the grain should be at a high moisture content (about 45%) and the coleorhiza or root sheath (“chit”) should be starting to appear at the base of the grain.

Next, the grain is removed from the steeping vessel and spread out or ‘cast’ on a malting floor (usually smooth concrete). Here, germination continues over several more days during which rootlets start to emerge. As germination progresses, the grain needs to be turned several times to provide uniform conditions and to prevent overheating and the rootlets from matting together. During germination the barley grains produce the enzymes which are needed later in the brewing process to convert starch and polysaccharides into sugars.

Underneath the husk of the grain, the coleoptile (or acrospire, which encloses the first leaf) starts to grow and the malt is usually ready when this is about the same length as the grain, but before it emerges. At this stage the germination process needs to be stopped.

This is done by moving the grain to a drying floor where it is exposed to hot air ("kilning") and drying it down to a very low moisture content (less than 6%). Dry malt is very stable and stores well in sealed plastic bags. Before the malt is used for brewing or distilling, however, it will need to be milled.

2.3 Floor Malting Of Orkney-Grown Barley At Highland Partk

The sections below describe the main steps which were taken to malt Orkney-grown barley at HP for the brewery.

2.3.1 Steeping

For steeping, about 7.5 t of grain were put in two vessels (c. 3.75 t in each) and steeping started at 12:00 on 10 March 2015. The temperature of the water going into the steeping vessel was raised to 14^{o} C but this was then allowed to drop (to about 11^{o} C) during steeping. The grain underwent 3 sessions of steeping as detailed in Table 1. By the end of steeping, grain moisture content reached 43.1%.

Table 1. *Cycles of steeping and draining for "Golden Promise" in the feasibility study.*

Activity	Start (time and date)	Duration of steeping (h)	Grain moisture (%) at end of steeping session
First steep	12:00 on 10/3/15	8	33.9
Drain	20:00 on 10/3/15		
Second steep	10:00 on 11/3/15	10	41.0
Drain	20:00 on 11/3/15		
Third steep	08:45 on 12/3/15	4	43.1
Drain	12:45 on 12/3/15		

Photos 1 to 4 show different stages in the steeping process.

2.3.2 Casting and floor germination

After the water had drained away at the end of the last steeping session, the grain was unloaded from the steeping vessel, cast on the floor and then spread out on the malting floor to a depth of about 10 cm (Photos 5 to 7). This required a floor space of about 220 m^2, indicating a space requirement of about 29.3 m^2 per tonne of grain. The grain was on the malting floor from 14:00 on 12 March until about 09:00 on 18 March and was turned (or ploughed) about 3-4 times daily using specialist equipment (Photos 8 and 9). In earlier times, wooden malt shovels would have been used. A general view of the malting floor is shown in Photo 10 while the extent of rootlet growth by the 18 March can be seen in Photo 11.

While the malt was being made on the floor, the temperature within the malt bed, and air temperature about 1.0 m above it, were recorded every 15 min using temperature sensors (TinyTag) at three locations. For comparison, air temperature outside the malt house was also monitored during this period. Average temperatures for the three environments are shown in Fig. 1. Over the malting period, the outside air temperature fluctuated from lows of 3-6^o C at night to day time highs of 5-8^o C. Air temperature within the malt house was more stable (7-9^o C). Malt temperature initially dropped from about 11^o C after leaving the steeping vessel to about 8.5^o C after several hours on the floor, but then gradually rose during malting to just over 14^o C on the last day. The dips in the trace of the malt temperature show where it was turned.

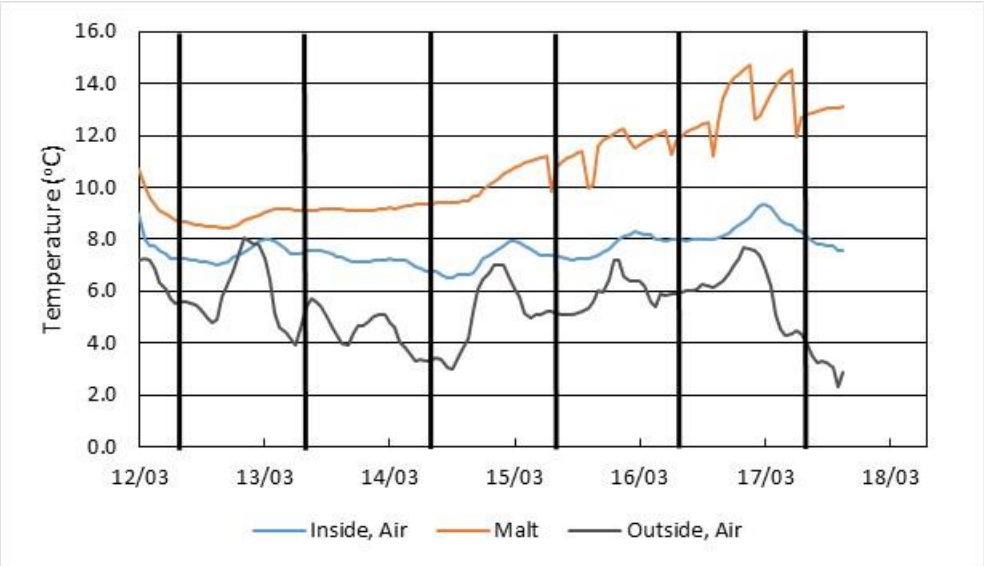

Fig 1. *Temperature during malting of i) the air inside the malt house, ii) the malt and iii) the outside air.*

2.3.3 Kilning

The grain was cleared from the malting floor on 18 March using a small plough blade which was pulled by a cable and winch system controlled by the operator (Photo 12). This pushed the grain to a hole in the floor where it fell onto an auger taking it up into the kiln on the first floor of the building. Here, it was discharged into barrows (Photo 13) and then spread over the drying floor made of wedge wire panels. The fuel used by the kiln fire (Photo 14) was smokeless anthracite and this was started at 11:00 on 18 March when the grain had a moisture content of 43.9%. Although some peat is often used by distilleries during the drying of malt, this was not used for the brewery's malt because peated malt is not liked for brewing. Initially, the kiln was set to give a grain temperature of 45-50^o C but this was raised to 65^o C from 23:30 on 18 March. The kiln fire was stopped at 18:30 on 19 March and the malt emptied from the kiln on the following morning. By the end of kilning, the moisture content of the malt was 3.8% which is lower than the distillery normally aims for, but is what the brewery had requested. While on the kiln floor the grain was turned mechanically by a large horizontal auger twice to even out the drying.

As the distillery does not normally produce malt for other organisations, a temporary solution had to be devised for taking the malt out of the kiln and it was therefore unloaded by emptying it through a window in the kiln room, via a metal chute, into tote bags supported by a telescopic loader (Photo 15).

2.3.4 Analysis Of Malt

An analysis of the malt using standard Institute of Brewing (IOB) methods is provided in Table 2 which also provides typical current-day minimum and maximum specifications for each analysis. While a number of the analyses of the malt are out of the range considered optimal in commercial malt, it is important to stress that the variety used had been grown for seed by the farmer and it was only after the harvest that it was decided to use it for malting. Also, the variety used (Golden Promise) was released in the 1960s and, although it is liked by specialist brewers, it has been long outclassed by more recent varieties. Amongst the analyses, glucan content is particularly high while extract, friability and homogeneity are low.

Table 2. *Laboratory analyses of malt made from Orkney-grown barley*

Analysis	Result	Minimum	Maximum
Colour on IOB 450g mash	2.0	3.5	5.0
Colour (quick check)	2.0	4.0	6.0
Moisture (%)	5.3		3.7
Extract Miag 7 “Dry” LDK	293.7	306.0	
Extract Miag 7 “As Is”	278		
Total nitrogen (dry %)	1.53		1.55
Total soluble nitrogen (% dry)	0.52	0.58	0.68
Soluble nitrogen ratio	34.0	38.0	44.0
Friability (%)	71	90	
Homogeneity	92	98	
Steely corns (%)	3.1		2.0
Glucan in wort (ppm) IOB	218		120
Diastatic power IOB “dry”	48	40	65
Diastatic power IOB “as is”	45		
Cold water extract (%)	16.6	16.0	

2.3.5 Discussion

The small scale malting study showed that there was no major difficulty in the distillery using its facilities to produce malt from Orkney-grown barley for a local brewery. Clearly for this to be repeated it would need to be viable financially for both parties and would need to be managed so that it results in minimal interference in the distillery's malting activities for its own purposes. The minimum quantity of grain which can be malted by the distillery for the brewery is about 7.0 t as this is the capacity of the steeping vessels and also corresponds to one load on the drying floor of the kiln. It is likely that this is a much larger quantity of grain than most microbreweries would initially want to malt.

For partners in the Northern Cereals project, the test malting at HP was an important opportunity of documenting the steps which floor malting requires, but the partners will need to find their own solutions for developing the equipment required to carry out the process. A major factor influencing this will be the amount of malt required to be made in each batch – as this increases, so does the need for specialist equipment. The key items of equipment/facilities required are:

- Steeping vessels which can be easily filled and emptied of both grain and water
- A sufficiently large floor space for the floor malting
- Depending on scale, mechanical devices to assist with turning the malt and clearing the malt floor; these should also be suitable for use on the drying floor
- Drying facilities which allow the temperature of the malt to be controlled
- Bagging equipment, if the malt is to be stored. Air-tight bags are required for long-term storage
- Milling equipment for grinding the malt before it is used

It should be stressed that while floor malting is a fairly simple process, without appropriate machinery/equipment, it can be very labour intensive. Consequently, if project stakeholders are considering doing this on any scale, the design of the facilities and selection of equipment must take into account the need to reduce the labour input as much as possible.

Temperature could be an issue for partners in regions with more extreme temperatures than Orkney. Average monthly outside temperatures in Orkney can range from about 4^{o} C in the winter to 14^{o} C in the summer. This range of temperature does not present any major problem for floor malting in stone, unheated buildings although the process is quicker at the higher temperatures. In Orkney, the distillery gives the germinating barley an extra day to grow during the cold days of winter and all the windows and doors are closed in an effort to keep heat in. A portable gas space heater is also used occasionally when it is very cold. In other regions, floor malting in unheated buildings may not be possible over parts of the winter if temperatures are much lower than 4^{o} C. If a brewery is considering establishing a floor malting facility in a colder climate, it might be possible to use 'waste' heat from either the brewing and/or the kilning processes to warm the germinating floors. High summer temperatures could also make it more difficult to control the process and may result in a less uniform product.

2.4 Small Scale Malting At Barony Mill

Orkney's Barony Mill dates from 1873 and is the last operational mill in Scotland which still produces beremeal which is the flour of Bere, a very old type of Scottish barley. Although owned by Orkney Islands Council, the mill has been run since 1998 by Birsay Heritage Trust (BHT). In collaboration with a local farmer, the Trust grows its own Bere for milling and for seed, but is interested in developing new sources of income. There has always been a tradition in Orkney of home brewing and, in the past, this would have been based exclusively upon Bere which was once the only barley grown on the islands. There are still several keen home brewers in Orkney who are eager to source Bere malt but there are also a number of micro-distilleries and breweries in Scotland which have been made aware of Bere and are interested in sourcing Bere malt for speciality products. For BHT, therefore, the production of Bere malt is an attractive diversification option which is made feasible because of the mill's kiln and drying floor which can be used both for germinating the malt and drying it. Typically, the Mill malts batches of about 200-500 kg of grain at a time.

In producing Bere malt, the Mill follows closely the method which was used at Warsetter farm on the Orkney island of Sanday in the 1930s. This uses the same initial steps which have been described previously:

- The grain is steeped for 24-48 h and then drained.
- It is then spread out on the floor (10-15 cm deep) and turned daily.
- It may occasionally be sprinkled with water and should be turned twice a day once the coleoptile starts to emerge.

When the coleoptile is about 5 mm long, however, the malt is put into a "sweetbed" which is a traditional malting practice in Orkney and is reputed to produce a sweeter malt. For this the malt is dampened and then heaped into a mound and covered with sacks to heat up (Fig. 2). The malt is in a sweetbed for about 36 h, but is turned about half way through the process so that the malt on the outside of the heap goes into the inside. After the 36 h, the malt is spread out to cool down and then dried on the kiln floor.

Fig. 2. Bere malt heating up in two sweetbeds at Barony Mill.

2.5 Pilot Vat Malting Of Bere

In order to provide Bere malt for new product development at Swannay Brewery in Orkney and malt for continued brewing of Island Bere at Valhalla Brewery in Shetland, 5 t of Bere grain were sent to Crisp Malt in Great Ryburgh, Norfolk, England for malting in their Pilot Vat. This is a bespoke plant which was built by the company for producing small batches of malt. It allows all phases of the malting process to be completed in the same vat (Fig. 3). At the end of each phase the green malt is transferred through a conveyor system into a hopper above the vat. Whilst the malt is in the hopper, the following can be done to the vat:

- Add/drain water for the steeping process, as well as aerate the water
- Add humidification and air flow for the germination process.
- Direct fire as a kiln in order to dry.

Before malting, the Bere was screened over a 2.25 mm mesh, producing 9.4% of screening. The remaining grain produced 3.78 t of malt. The specifications for the malt are given in Table 3. All values are within the range which has been obtained with previous batches of Bere malt, except colour which has previously been between 5.1 and 7.0 ^{o}EBC.

Table 3. Specification for malt made from Bere by Crisp Malt in May 2016.

Parameter	Analysis
Moisture (%)	4.7
IOB Extract 0.7mm as is basis (l deg/kg)	281
IOB Extract 0.7mm dry basis (l deg/kg)	295
IOB Colour Visual (deg EBC)	9.5
Total Nitrogen dry basis (%)	1.99
IOB Total Soluble Nitrogen dry basis (%)	0.84
IOB Soluble Nitrogen Ratio (%)	42.2
Friability (%)	79.6
Homogeneity (%)	91.6
Diastatic Power as is basis (deg IOB)	133

Fig. 3. Bere being steeped in the Pilot Vat at Crisp Malt, Great Ryburgh.

3 Small-Scale Test Malting In Norway

3.1 Introduction

The background for this test was to perform an evaluation of the malting quality of seven varieties of barley grown in Northern Norway. We did regular cereal tests together with a test malting of the samples and test of malt quality. This test is part of Activity T4.1 “Small scale local malting of grain” which is aimed at testing methods for malting locally grown cereals with the goal of helping stakeholders to access malted local grain for high value beverage production. The results presented here are therefore preliminary and will be followed by further testing also of new samples.

3.2 Material and Methods

The Barley was grown in 2015 at NIBIO, Holt in Tromsø, Northern Norway. The seven varieties were selected for expected tolerance to the northern climate, except for Saana that was included for its qualities as a malting barley and was originally bred in Finland. The barley was then threshed, analysed for quality parameters and stored at the NIBIO research station at Apelsvoll in the southeastern part of Norway. Malting was started on April 1st 2016 after storage of the seeds from the end of August 2015. Malting as well as quality testing of the malt was done at The Norwegian University of Life Sciences at the Institute for Chemistry, Biotechnology and Food science.

3.2.1 Quality of seeds

After threshing in a small laboratory thresher, the barley samples were analysed at NIBIO Apelsvoll (Table 5). Germination was tested by placing 100 kernels in soil at 20ºC for 10-12 days. Protein, Hectolitre Weight (HL weight) and starch was determined using a INFRA-Tec machine by infrared transmission; for thousand kernel weight (TKW) an OPTO AGRI was used to count the number of kernels by picture analysis and water % was calculated from weight after harvest, weight after air drying and also using the Infrared transmission machinery.

3.2.2 Malting

3.2.2.1 Equipment.

Malting was performed in a micromalting plant (Fig. 3).

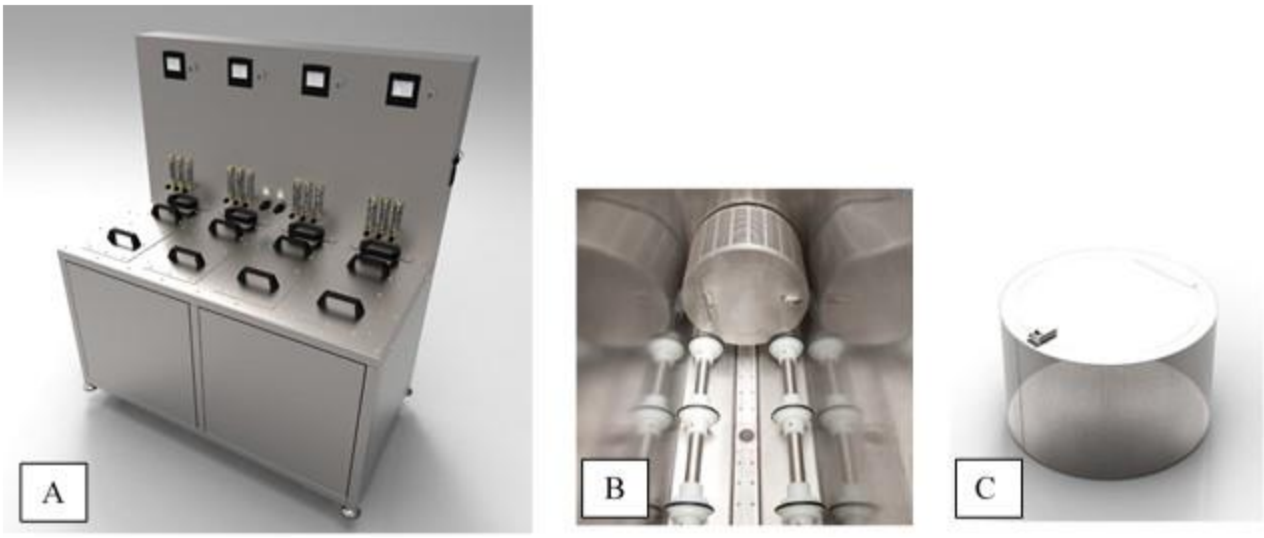

Fig. 3. A micromalting plant from Custom lab. (A) shows the malting machine with four chambers for malting. (B) A view of the malting chamber and (C) each chamber contains four malting vessels which each hold up to 0.5 kg of grain.

3.2.2.2 Malting procedure

The malting procedure followed the guidelines for a standard pale ale malt (Table 3). Germination was assessed as optimal when the shoot was 2/3 of the kernel length and we tried to reach this stage.

Table 3. *Program for steeping, germination and kilning (drying).*

1. Steeping Programme		
Treatment	Hours	Temp ºC
Wet	8	16
Dry	16	
Wet	8	
Dry	16	
Wet	2	
2. Germination Programme		
5 days at 16 ºC		
3. Drying		
Time, hours	Temp ºC	Airflow, m/s
16	65	6
2	85	5
2	90	5
2	95	5

3.2.2.3 Quality of mash

Mashing for the malt quality assessment followed the procedure for Congress mash which is a standardized small-scale mashing procedure. Fifty-gram samples of malt were milled and then extracted with four volumes of water in a regime that involved progressive temperature-raising in order to mimic temperature-programmed or decoction mashing (Table 4). After filtration, the resulting wort was tested for i) specific gravity for calculation of extract (Platon, Brix; Specific Gravity for estimating the strength of the beer by measuring the density of the wort before fermentation). ii) Saccharification (“iodine normality”, time taken for conversion of the starch to sugar), iii) colour (after: https://beerandbrewing.com/dictionary/EvJp0NBz6r/congress-mash/). Prior to extraction, we did a Friability test that gives a good idea of the homogeneity, degree of modification and how many of the grains were not malted or dead.

Table 4. *Temperature regime during extraction following the Congress Malt process*

Program stages for Congress Malt	Temperature, ºC	Time, min
1	0 ºC - 45 ºC	
2	45 ºC	30
3	45 ºC - 70 ºC	25
4	70 ºC	60
5	70 ºC - 20 ºC	

3.3 Results

3.3.1 Quality of seeds

The quality test showed a good germination of all samples and high 1000 kernel weight of all samples except Skumur (Table 5).

Table 5. *Quality parameters measured on seven barley varieties grown in Northern Norway.*

Variety	Weight after threshing (g)	Water (%)	Protein (%)	HL weight	Starch (% of DM)	TKW g	Germi-nation (%)
06 72	1454	9.3	8.5	73.3	65.2	41.6	99
Iskria	5876	9.4	10.4	72.5	63.8	43.0	98
NL 3	3665	9.5	9.4	69.7	63.5	46.1	99
Saana	1996	9.2	9.2	73.1	64.3	45.5	98
Skumur	2544	9.1	10.2	70.4	63.7	35.6	99
Teiste	5814	9.3	11.3	72.4	63.1	42.1	100
Tiril	8182	9.3	9.0	71.8	64.7	40.1	100

3.3.2 Malting

Germination took approximately twice the expected time. After 2.5 days in the germination procedure the length of the shoot was assessed in 30 kernels from each variety (Table 6).

Table 6. *Assessment of germination after 2.5 days.*

Variety	Number of kernels with shoot > 2/3 of the kernel length	Number of kernels with shoot < 2/3 of the kernel length
Tiril	10	20
Teiste	7	23
NL 3	12	18
06 72	12	18
Skumur	0	30
Iskria	3	27
Saana	15	15

Fig. 4 shows malted samples of the seven varieties.

Fig. 4. *Malted grains of the 7 varieties tested.*

3.3.3 Quality of Mash

The mash was tested in relation to a number of quality parameters (Table 7). There was a large variation in Friability, while % Plato was very similar except in Teiste which had a lower value then the remaining 6 varieties.

Fig. 5. *Mash of the 7 barley varieties being tested for filtration rate.*

Table 7. *Malt quality of seven varieties of barley*

Variety	Friability test	Sacchari-fication time, min	% Plato	Colour, EBC	Filtration rate	Total protein dry basis, %	Kolbach index (Soluble N ratio)
Optimal result	>80%	<12 min	10% = 4,5% alcohol	4.0 ±0.5	Normal/ Slow	10.5 – 12%	38-45%
NL3	44.03	15	8.3	5.3	S	8.52	37.04
Iskria	64.88	10	8.2	5.7	S	9.24	38.36
Tiril	60.08	10	8.3	5.4	S	7.96	36.38
Saana	75.60	10	8.4	4.8	S	8.32	37.1
06-72	79.38	10	8.6	4.9	N	7.73	41.16
Skumur	61.78	10	8.2	5.4	N	9.21	36.89
Teiste	33.48	15	7.8	3.7	S	10.25	27.52

After calculating the Friability the fraction left on the sieve was size fractioned on a 'Sortmat' (Falling Number, Sweden) (Table 8.)

Table 8. *Fraction size after Friability testing*

	% Left on sieve			
Variety	<0.22 mm	<0.25mm	<0.28mm	>0.28mm
NL3	51.4	22.0	21.6	5.0
Iskria	74.3	13.1	11.4	1.1
Tiril	58.1	25,9	13.2	2.9
Saana	84.2	13.,3	1.7	0.8
06_72	78.9	11.9	3.7	5.5
Skumur	70.4	20.9	6.6	2.0
Teiste	33.9	18.2	31.7	16.3

3.4 Conclusion

Quality testing of the cereal samples showed a general good quality. Germination were high in all the seven varieties. Protein content in malting barley is optimal at around 10.5%. Higher protein content may cause turbidity in the beer and too low may slow down the malting process or else affect the level of modification of starch during malting. The protein level in Iskria and Skumur were closest to 10.5% while the content in 06 72 was lower (8.5%) and the content in Teiste was high (11.3%). It has been found that location for cultivation has the most significant effect on protein content (Aasveen et al. 2015). Both HL weight and TKW were high. Only Skumur had a very low TKW, probably as a result of small or unevenly sized kernels. Large kernels are often associated with a higher alcohol output. This is debated, however, and it has been suggested that starch structure is a better measurement (Yu et al., 2017).

Malt quality was found to vary between varieties. Teiste and NL3 both showed a very low friability possibly also seen in the longer time for the starch to convert to sugar for these varieties. Plato values, were on the low side and will likely give a beer with a lower alcohol content, while EBC was high for all except Teiste. We have however, so far no reason to believe that it is not possible to grow malting barley in Northern Norway.

Acknowledgements

The UHI authors are very grateful to staff of Highland Park Distillery for agreeing to carry out the floor malting in Orkney and for providing information about the process, and access to the malting floors during the trial. It should be stressed that the malting of ‘Golden Promise’ at Highland Park Distillery was purely to produce malt for the brewery. This variety is not used by the distillery for whisky production and all steps were taken to ensure that grain of the variety did not enter the normal production stream.

We are also grateful to Birsay Heritage Trust for providing information about the malting at Barony Mill and to Daniel McManus at Crisp Malt for information about the Pilot Vat at Great Ryburgh.

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Appendix 1. Photographs

Photo 1. Transferring grain into the steeping vessel.

Photo 2. Steeping vessel during the third steep.

Photo 3. Grain after draining following the third steep.

Photo 4. Grains at the end of steeping. The white tip of the coleorhiza (root sheath) can be seen at the base of some grains.

Photo 5. Unloading grain from the steeping vessel.

Photo 6. Casting steeped grain on the malting floor.

Photo 7. Spreading out the grain on the malting floor.

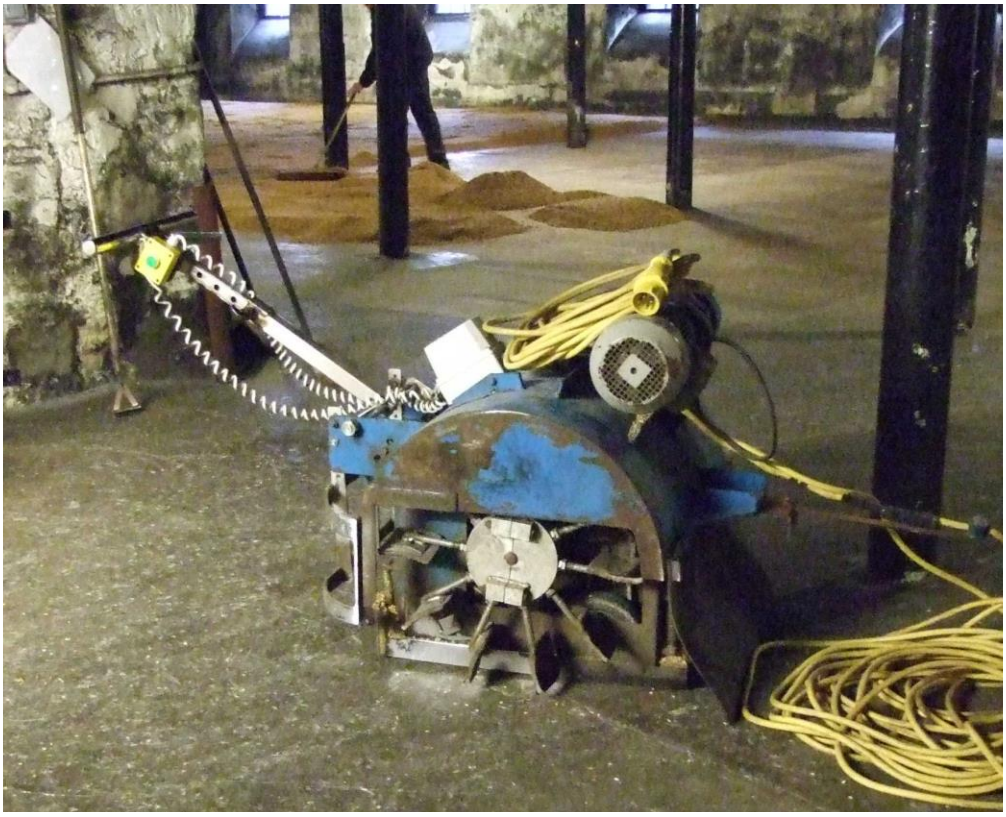

Photo 8. Machine used for turning malt

Photo 9. Manual rake used for ploughing the malt.

Photo 10. General view of the ‘Golden Promise’ spread on the malting floor.

Photo 11. 'Golden Promise' grains on the last day on the malt floor, just before kilning.

Photo 12. Clearing the malt floor

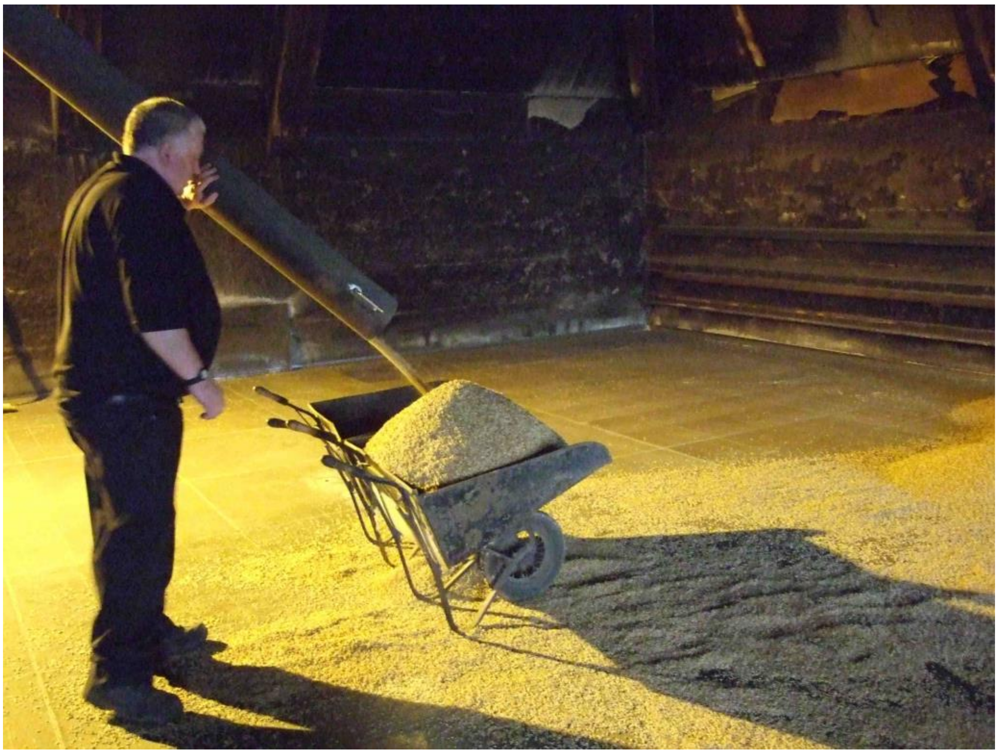

Photo 13. Spreading the green malt on the kiln floor.

Photo 14. Kiln fire.

Photo 15. Unloading malt from the kiln.