Effect of Process Conditions on Alcohol Yield of Wheat, Maize and Other Cereals

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ABSTRACT

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Past research has demonstrated the potential of a range of cereals in the production of grain whisky and ethanol. This paper describes further research that has been carried out to examine the role of processing conditions, the aim being to optimise alcohol yield and reduce processing problems. The first part of this study examined the impact of cooking temperature on alcohol yield and residue viscosity. Results showed that altering the cooking temperature had an effect on predicted spirit yield (PSY) in some, but not all, types of cereal. Hence, in order to obtain the maximum amount of alcohol, cooking regimes should be altered depending on the type of cereal being processed. Altering cooking temperature was also found to have an influence on residue viscosity. High residue viscosity can cause downstream processing problems and is a particular issue when processing wheat. The results of this research demonstrated how such problems could be lessened through changes to the cooking temperature. The second part of this research explored the optimisation of alcohol yield from Kipling, a "poor" quality variety of distilling wheat, through the use of commercial enzymes. A range of enzyme preparations were compared. Results demonstrated that some of these preparations have potential to increase the amount of alcohol that can be obtained from this wheat variety. However, results showed that optimum yields would only be achieved under controlled cooking temperatures.

Key words: Alcohol yield, commercial enzymes, residue viscosity, temperature, wheat.

INTRODUCTION

This study forms part of an ongoing programme of research at the Scotch Whisky Research Institute (SWRI), which examines the potential of wheat, maize, sorghum and millet for use in grain whisky and ethanol production. The aim is to gain more in-depth knowledge of differences in the physiology and also to develop further the earlier work carried out on these cereals, the results of which were communicated in this Journal[2]. The ultimate goal of this research is to allow distillers to optimise alcohol yields and processability by providing knowledge on the best cereal types, varieties and process conditions for particular applications, be it whisky or bioethanol production.

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Previous research[2] has demonstrated the potential of wheat, maize, sorghum and millet in the production of both grain spirit and ethanol. Wheat has been shown to be capable of producing alcohol yields comparable to those obtained from maize, though low nitrogen content is a prerequisite of a good distilling wheat. However, in comparison to maize, wheat consistently gives a much higher residue viscosity. This is of concern as it affects downstream processing of spent wash/spent grains, and therefore requires more study.

Research has also compared alcohol production from the starches extracted from these cereals in relation to yields obtained from whole grains. Extracted starches of maize and sorghum were found to produce more alcohol than those from wheat and millet. The reason for this difference is not fully understood. Observations were, however, linked to differences in the properties of maize/sorghum starches when compared with wheat/millet starches, and also the propensity of maize and sorghum starches to show a greater tendency for retrogradation, a property normally associated with amylose[5]. These assertions were confirmed in the results of the rapid-visco analysis (RVA) pasting properties of these cereals where, in contrast to wheat and millet, sorghum showed very similar characteristics to maize both in terms of lack of a well defined breakdown zone of the RVA pasting curves, as well as alcohol production and low residue viscosity of the processed samples[2]. These similarities observed for sorghum and maize gave more credence to the long established conclusion that both sorghum and maize have identical properties and are interchangeable[4]. Furthermore, lack of a well defined breakdown zone in the RVA pasting curves of both maize and sorghum suggest that some of the problems encountered while processing wheat are likely to be linked to the process conditions employed.

In the whisky industry, cereals normally undergo high temperature cooking in order to release the starch from the grain and to liquefy it. This is carried out to ensure that it can be broken down efficiently by the enzymes from the barley malt into fermentable sugar. Historically, maize was the primary raw material used in grain whisky production. Although more recently for economic reasons, wheat has virtually replaced maize. The high cook temperatures currently used in the grain whisky industry are still those originally developed for processing maize. The work reported in this paper investigates the impact of altering cook temperature on alcohol yield from wheat, maize, sorghum and millet. Cereals were processed at two different temperatures, using standard (high) and reduced (low) cooking temperature regimes. In addition to alcohol

Table I. Properties of the commercial enzymes used in this study.

Name	Type	Microbial source	pH range	Optimum temp range	Activities
Bioglucanase ME 250	Endo-beta glucanase	*Penicillum emersonni* and *Bacillus subtilis*	5.0-6.5	50-65°C	Hydrolyses both 1,4 and 1,3 glucosidic linkage found in beta glucan
Bioprotease N100L	Proteolytic enzyme	*Bacillus subtilis*	5.5-6.0	45-53°C	Produces high level of FAN
Promalt 295	Beta glucanase, Protease and α-amylase	*Bacillus subtilis*	5.0-7.5 (glucanase) 5.0-8.5 (protease) 5.0-8.5 (amylase)	55-65°C (glucanase) 40-60°C (protease) 60-80°C (amylase)	Maximises extract recovery, reduces wort run off time, increases FAN in wort
Promalt 4TR	Mainly beta glucanase, but contains protease and α-amylase	*Bacillus subtilis* and *Trichoderma reesei*	5.0-7.5	55-65°C	Active on high beta glucan cereals

Table II. Enzyme combinations used during the study.

Sample designations		Enzyme combination
1	A	Termamyl (Control)
2	B	Termamyl + Bioglucanse ME250
3	C	Termamyl + Bioprotease NL100
4	D	Termamyl + Promalt 295
5	E	Termamyl + Promalt 4TR

production, the impact of processing temperature on residue viscosity was also studied.

Following extensive studies on wheat at SWRI for over a decade, some wheat varieties have been consistently identified as exhibiting poor distilling quality. The second part of this study examines the possibility of enhancing alcohol yield from one such "poor" quality wheat variety (Kipling) through the use of commercial enzyme preparations. Use of such enzymes is permitted in the bioethanol industry but not in the Scotch grain whisky industry, where enzyme activity is obtained solely from the addition of malted barley. However, success in achieving enhanced yields from "poor" quality wheat will not only benefit the bioethanol industry. The whisky industry could also potentially benefit by a reduction in competition for the good quality wheat.

MATERIALS AND METHODS

Cereal varieties

Cereal samples were obtained from a range of sources as described previously[2].

Total nitrogen determination

Total nitrogen of the cereals was determined on a Buchi Kjeldahl apparatus as described previously[2].

Alcohol yield analysis

The method was based on that of Brosnan *et al.*[3], which simulates the production process conditions in a "typical" Scotch whisky grain distillery. The detailed procedure for the determination of alcohol yield (high temperature process) has been described previously in this Journal[2]. When a low temperature (85°C) process was used in cooking the wheat samples, the process described for high temperature processing was applied, except that the step where wheat was transferred to the autoclave at 142°C was omitted.

Residue viscosity

Residue viscosity is a measure of the potential for processing problems arising from handling the distillation residues (spent wash co-products). The detailed procedure for the measurement of residue viscosity has been previously described in this Journal[2].

Measurement of residue colour

The colour of the distillation residue was determined using a Lovibond 2000 comparator (Hellige and Co., UK)[6].

Effect of commercial enzymes on poor quality wheat

The four commercial enzyme preparations used in this study were kindly supplied by Kerry Bio-Science. Details of these and their properties are shown in Table I. In addition to the Termamyl (Novozymes France S.A.) used for assessing cereal quality, other commercial enzymes were used to assess the quality of Kipling. Milled samples were processed as described previously[2], but this time the addition of commercial enzyme preparations (dose rate 25 μL/30 g grist) was applied, using the combinations shown in Table II.

RESULTS AND DISCUSSIONS

Effect of process temperature on low and high nitrogen wheat

Results for the predicted spirit yield and residue viscosity obtained for low nitrogen (1.24–1.53%) wheat cooked at high and low temperatures are shown in Table III, while those for high nitrogen wheat (1.83–2.14%) are shown in Table IV. Using the standard high cooking temperature (142°C), low nitrogen wheat samples gave good alcohol yields (average 465.8 LA/tonne). Under the same processing conditions, high nitrogen wheat gave much lower yields (430.5 LA/tonne). This gives further credence to the now well established relationship between wheat nitrogen content and alcohol yield[2,3].

Although 142°C is the standard temperature used in the Scotch Whisky industry for processing wheat, this study revealed that reducing this to 85°C will provide a significant increase in alcohol yield. In low nitrogen wheat samples, an average increase of 11.9 LA/tonne was observed across the 13 samples studied, while a similar increase of 11.5 LA/tonne was obtained for the high nitrogen wheat. Although a significant increase in alcohol yield was observed for all of the samples, precise gains varied from sample to sample, suggesting that wheat variety may have an influence. It should also be noted that nitrogen content was still the single biggest influence on average predicted spirit yield obtained from a low temperature cooking of a high nitrogen wheat (442.0 LA/tonne). This is still much lower than that obtained from the low nitrogen wheat, even under the less favourable high temperature processing conditions (465.8 LA/tonne). In spite of this, the gain of ~11 LA/tonne that can potentially be achieved through changes to the cooking temperature is important.

Reduced alcohol yield with higher cook temperatures may be due to an increased occurrence of Maillard (browning) reactions. These involve the reaction of amide groups of amino acids with reducing sugars and are favoured at higher temperatures (>85°C). Maillard reactions result in the depletion of reducing sugars, which in turn will reduce the amount of fermentable sugars available for yeast conversion to alcohol during fermentation. A further impact of Maillard reactions is that depletion of the amide groups may result in a deficiency of yeast nutrients in the fermentation broth. This may affect the rate of fermentation, especially if the malt inclusion rate is not adequate during the processing of the wheat[2]. Analysis of residue colour provides (or indicates) a measure of the degree of Maillard reaction that has taken place. (This is discussed later in the section where commercial enzyme preparations were used to process Kipling–a poor quality wheat variety). When high cook temperatures were used, the residue colours ranged from between 12.5–14.0°EBC for both the low and high nitrogen wheat. In contrast, the residue colours obtained when wheat was processed at a lower temperature ranged from between 5.5–6.0°EBC for the same samples. Thus, differences in Maillard reactions may account for the observed differences in alcohol yield.

Reducing cooking temperature was found to have the added benefit of lowering residue viscosity in both low and high nitrogen wheat (Tables III and IV). The reason for this difference in residue viscosity is not clear at present, though it may relate to the properties of wheat starch[2]. Overall these results confirm the benefits of low temperature cooking of wheat, both in terms of an increase in the alcohol yield and reduced residue viscosity. The additional

Table III. Predicted spirit yield (PSY) of cook from lower nitrogen wheat processed using different methods.

Cereal type	TN % (dry)	PSY (LA/tonne) dry 142°C cook	PSY (LA/tonne) dry 85°C cook	Difference in alcohol yield	Residue viscosity (mPa) 142°C cook	Residue viscosity (mPa) 85°C cook	Difference in residue viscosity	Residue colour (°EBC) 142°C cook	Residue colour (°EBC) 85°C cook
Wheat 1	1.33	472.7	483.3	10.6	1.62	1.39	0.23	12.5	5.5
Wheat 2	1.24	471.5	481.2	9.7	1.55	1.37	0.18	12.5	5.5
Wheat 3	1.28	466.6	481.0	14.4	1.62	1.41	0.21	13.0	6.0
Wheat 4	1.37	456.8	465.6	8.8	1.78	1.49	0.29	13.5	5.5
Wheat 5	1.25	482.3	495.9	13.6	1.66	1.39	0.27	13.5	6.0
Wheat 6	1.26	461.1	474.6	13.5	1.89	1.56	0.33	13.0	6.0
Wheat 7	1.40	465.5	478.1	12.6	1.80	1.56	0.24	14.0	6.0
Wheat 8	1.39	467.7	480.2	12.5	1.67	1.38	0.29	14.0	5.5
Wheat 9	1.44	468.1	475.8	7.7	1.69	1.39	0.30	13.5	5.5
Wheat 10	1.50	462.0	474.6	12.6	1.68	1.50	0.18	13.5	6.0
Wheat 11	1.46	461.1	469.8	8.7	1.78	1.48	0.30	12.5	6.0
Wheat 12	1.46	469.4	482.0	12.6	1.50	1.33	0.17	12.5	5.5
Wheat 13	1.48	450.3	467.7	17.4	1.62	1.43	0.19	13.0	6.0
Mean	***1.37***	***465.8***	***477.7***	***11.9***	***1.68***	***1.44***	***0.24***	…	…

Range of increase in alcohol yield–8 to 17 LA/tonne.
Range of decrease in residue viscosity–0.17 to 0.33 mPa.

Table IV. Predicted spirit yield (PSY) of cook from higher nitrogen wheat processed using different methods.

Cereal type	TN % (dry)	PSY (LA/tonne) dry 142°C cook	PSY (LA/tonne) dry 85°C cook	Difference in alcohol yield	Residue viscosity (mPa) 142°C cook	Residue viscosity (mPa) 85°C cook	Difference in residue viscosity	Residue colour (°EBC) 142°C cook	Residue colour (°EBC) 85°C cook
Wheat 1	2.10	435.8	444.3	8.5	1.63	1.28	0.35	13.0	5.5
Wheat 2	1.92	438.7	446.2	7.5	1.77	1.29	0.48	13.5	5.5
Wheat 3	2.14	415.1	429.4	14.3	1.83	1.37	0.46	12.5	5.5
Wheat 4	2.11	413.7	425.9	12.2	1.69	1.29	0.40	12.5	5.5
Wheat 5	2.07	429.6	443.0	13.4	1.71	1.26	0.45	13.0	6.0
Wheat 6	1.88	434.9	443.6	8.7	1.72	1.58	0.14	14.0	6.0
Wheat 7	1.90	429.8	442.4	12.6	1.69	1.65	0.04	14.0	6.0
Wheat 8	1.97	433.4	445.0	11.6	1.78	1.50	0.28	12.5	6.0
Wheat 9	1.95	436.2	448.8	12.6	1.78	1.50	0.28	13.0	5.5
Wheat 10	1.83	437.7	451.3	13.6	1.75	1.42	0.33	13.0	5.5
Mean	***1.99***	***430.5***	***442.0***	***11.5***	***1.74***	***1.41***	***0.32***	…	…

Range of increase in alcohol yield–8 to 14 LA/tonne.
Range of decrease in residue viscosity–0.04 to 0.48 mPa.

amount of alcohol gained in the low temperature process will, however, depend on the wheat variety under study.

Effect of process temperature on maize

Table V shows the alcohol yields and residue viscosities obtained when a range of maize samples were processed at low and high temperatures. The impact on alcohol yield of changing from high to low temperature cooking varied from sample to sample. For some varieties, a lower temperature gave an increased alcohol yield, while for others the same drop in temperature resulted in a poorer yield. Hence, the overall difference in yield was minimal, with an average increase of 2.3 LA/tonne across the seven samples. These results suggest that processing maize at different temperatures will not have a major impact on alcohol yield obtained. It was also noted that, unlike wheat, there was no clear relationship between alcohol yield and nitrogen content.

The residue viscosities obtained for maize were much lower than those of wheat. At cooking temperatures of 142°C the average residue viscosity for maize was 1.15 mPa, as opposed to 1.68 and 1.74 mPa for low and high nitrogen wheat respectively. Reducing cooking temperature for maize was found to result in lower residue viscosities, though the difference was small (average 0.08 mPa). Unlike alcohol yield, this reduction was observed for all samples/varieties. In combination, these observations further highlight physiological differences that have been previously observed between maize and wheat[2].

Effect of process temperature on sorghum and millet

Effect of process temperature on the alcohol yields and residue viscosities of sorghum and millet are shown in Table VI. When sorghum or millet was processed at a lower temperature, there was a significant reduction of alcohol yield (between 10 and 32 LA/tonne). These results are very interesting and highlight more latent physiological differences between the cereal samples studied. The results further highlight some unknown physiological differences between maize and sorghum, which were originally thought to be identical in all respects[4].

Residue viscosities were again found to reduce with reduced cooking temperature, though the differences observed for these cereals were minimal (average 0.04 mPa). Overall these results demonstrate that the high temperature cooking method is the most appropriate for sorghum and millet in order to obtain high alcohol yields.

Overall effects of altering process temperature on different cereal types

Reducing the cooking temperature from the standard 142°C to 85°C gives a beneficial decrease in residual viscosity for all of the cereals studied, though the effect is much greater in wheat due to its relatively high viscosity. The impact on alcohol yield is a key consideration, as the best temperature to give good alcohol yield varies from one type of cereal to another. Lowering the cooking temperature gave a significant increase in the yields for both high and lower nitrogen wheat. Conversely, the same reduction in cooking temperature had a detrimental effect on the amount of alcohol obtained from sorghum and millet. Finally, the impact of cooking temperature on the yield obtained from maize was not as clear cut, appearing to vary from sample to sample.

Effect of process conditions on poor quality wheat–Kipling

Processing Kipling at different temperatures. Predicted spirit yield and residue viscosity for the high and

Table V. Predicted spirit yield (PSY) of cook from maize processed using different methods.

Cereal type	TN % (dry)	PSY (LA/tonne) dry 142°C cook	85°C cook	Difference in alcohol yield	Residue viscosity (mPa) 142°C cook	85°C cook	Difference in residue viscosity	Residue colour (°EBC) 142°C cook	85°C cook
Yellow maize 1	1.38	467.0	474.7	−7.7	1.15	1.06	0.09	3.5	3.5
Yellow maize 2	1.35	467.5	475.2	−7.7	1.15	1.07	0.08	3.5	3.5
Yellow maize 3	1.42	472.0	472.0	0.0	1.14	1.07	0.07	3.5	3.5
Yellow maize 4	1.44	464.7	476.2	−11.5	1.15	1.07	0.08	3.5	3.5
Yellow maize 5	1.46	470.6	466.7	3.3	1.15	1.07	0.08	3.5	3.5
Yellow maize 6	1.54	474.1	473.1	1.0	1.13	1.08	0.05	3.5	3.5
White maize	1.41	468.0	469.0	1.0	1.16	1.06	0.10	3.5	3.5
Mean	***1.44***	***469.5***	***472.0***	***–2.3***	***1.15***	***1.07***	***0.08***	…	…

Table VI. Predicted spirit yield (PSY) of cook from other cereals (sorghum and millet) processed using different methods.

Cereal type	TN % (dry)	PSY (LA/tonne) dry 142°C cook	85°C cook	Difference in alcohol yield	Residue viscosity (mPa) 142°C cook	85°C cook	Difference in residue viscosity	Residue colour (°EBC) 142°C cook	85°C cook
White sorghum (HWU)	1.48	472.0	459.0	13.0	1.15	1.07	0.08	3.5	3.0
White sorghum (Nigeria)	1.70	480.0	448.0	32.0	1.09	1.07	0.02	3.5	3.0
Red sorghum (Nigeria)	1.53	471.0	441.0	30.0	1.08	1.07	0.01	3.5	3.0
Millet (Nigeria)	1.60	462.0	451.7	10.0	1.16	1.10	0.06	3.5	3.5
Mean	***1.58***	***471.0***	***449.9***	***21.0***	***1.12***	***1.08***	***0.04***	…	…

Table VII. Predicted spirit yield (PSY) of cook from Kipling using different combinations of commercial enzyme preparations.

Enzyme combination	PSY (LA/tonne) dry 142°C cook	PSY (LA/tonne) dry 85°C cook	Difference in alcohol yield	Residue viscosity (mPa) 142°C cook	Residue viscosity (mPa) 85°C cook	Difference in residue viscosity	Residue colour (°EBC) 142°C cook	Residue colour (°EBC) 85°C cook
Termamyl (control)	428.2	434.9	6.7	1.74	1.77	–0.03	12.5	5.5
Termamyl + Bioglucanase ME250	427.3	434.9	7.6	1.61	1.35	0.26	12.5	5.5
Termamyl + Bioprotease NL100	419.6	438.8	19.2	1.69	1.68	0.01	18.0	5.5
Termamyl + Promalt 295	423.4	433.0	9.6	1.68	1.69	–0.01	16.0	6.0
Termamyl + Promalt 4TR	426.3	431.1	4.8	1.65	1.65	0.00	13.0	6.0

low temperature processing of Kipling, a wheat variety known to have poor and variable distilling quality (total nitrogen 2.15%), are shown in Table VII. Results obtained using different combinations of commercial enzyme preparations are also shown in this table.

When Kipling was processed at a higher or lower temperature using Termamyl (control enzyme) the difference in alcohol yield (Table VII) was not as high as was observed for wheat samples of similar nitrogen content (see samples 3, 4, and 5 in Table IV). Also, the increase in alcohol yield gain, by reducing the processing temperature, was not as high (6.7 LA/tonne as opposed to 14.3, 12.2, and 13.4 LA/tonne achieved for samples 3, 4 and 5 respectively). Altering the cooking temperature also appeared to have a different effect on residue viscosity. The other wheat samples studied (see Tables III and IV) all gave a reduced residue viscosity at lower cooking temperature, while for Kipling the residue viscosity increased slightly. These results confirm that Kipling behaves differently, producing variable results. This goes further to confirm that Kipling is a poor quality distilling wheat.

Processing Kipling using different combinations of commercial enzyme preparations

Termamyl and Bioglucanase ME250. When Kipling was processed using a combination of Termamyl and Bioglucanase enzyme the alcohol yield was similar to that obtained by processing with only Termamyl (Table VII). However, some important changes were observed with regard to residue viscosity of the processed wheat. Here, the residue viscosity dropped in both the high and low temperature processed wheat when compared with the control, this drop being more dramatic when a low processing temperature was used. A possible explanation for this observation is that since Bioglucanase is a β-glucan degrading enzyme, the marginal drop in residue viscosity observed for the high temperature processed wheat suggests that the activity of this enzyme was limited at higher temperature. In contrast, the activity of this enzyme was enhanced when lower temperatures were used, causing a more significant drop in residue viscosity. Although the residue viscosity dropped dramatically when the Bioglucanase enzyme was combined with Termamyl at the low temperature process, the similar alcohol yield obtained for this wheat variety further shows that hydrolysis of β-glucan during processing of wheat makes only a minimal contribution to alcohol yield. This is not surprising as β-glucan accounts for only 0.1-0.5% of the wheat substrate[4,7,8].

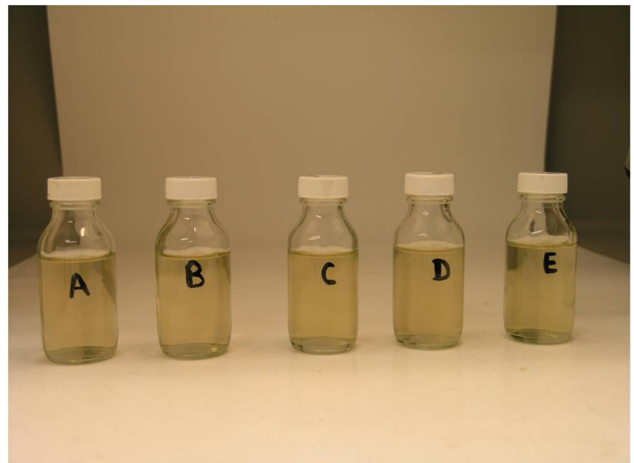

Fig. 1. Residue obtained after processing Kipling at a lower temperature. (See Table II for enzyme combinations.)

Termamyl and BioproteaseNL100 or Promalt 295 or Promalt 4TR. In contrast to the observations made when Kipling was processed using a combination of Termamyl and Bioglucanse commercial enzymes, more important changes were observed when a combination of Termamyl and a neutral Bioprotease was used. Here, significant differences were observed in alcohol yield, with more alcohol being produced with a low temperature cook. A possible explanation is that Bioprotease will not only hydrolyse the proteins embedded in the starch, its actions will also expose the starch to Termamyl enzyme attack. A combination of these hydrolytic enzyme activities on the different substrates will result in the production of more reducing sugars and soluble nitrogen, the precursor for Maillard reactions. Therefore, processing wheat using this enzyme combination and applying a high temperature process will favour increased Maillard reactions, which will cause a reduction in alcohol yield and an increase in residue colour. Colour analysis of these samples confirmed this hypothesis (see Figs. 1 and 2 and also Table VII). Conversely, when Kipling was processed at a lower temperature using these enzyme combinations, the advantage of producing more reducing sugars and soluble nitrogen from the activities of Termamyl and neutral Bioprotease gave an enhanced advantage for higher alcohol production. It is also important to note that the use of neutral Bioprotease did not have a noticeable influence on the residue viscosity regardless of processing temperatures used. In general, the use of a combination of Termamyl

Fig. 2. Residue obtained after processing Kipling at a higher temperature. (See Table II for enzyme combinations.)

and Promalt commercial enzymes in processing Kipling increased alcohol yield in the low temperature process. These results demonstrate that through the use of enzyme preparations, this "poor" quality variety may have potential for ethanol production.

CONCLUSIONS

The results of this study have shown that changing the cooking temperature during cereal processing can have a significant effect on alcohol yield. However, not all cereals behave in the same way. The influence of temperature is greater for some cereals than for others. For example, cooking temperature has minimal influence on the yields obtained from maize. For wheat, on the other hand, the influence is large, with a reduction in temperature giving a large increase in potential alcohol production. This was observed for both low and high nitrogen wheat and is thought to be due to the reduced level of Maillard reactions observed at the lower temperatures. Sorghum and millet performed quite differently from either maize or wheat, with the predicted spirit yield dropping dramatically when the cooking temperature was reduced. These results demonstrate that in order to optimise alcohol production, the cooking temperature should be specifically tailored to suit the type of cereal being processed. Residue viscosity is also an important consideration, particularly for wheat, which has a high residue viscosity, which can in turn cause processing problems. However, residue viscosity can be considerably reduced by lowering the cooking temperature.

This study also demonstrated the potential of improving alcohol yield from "poor" wheat varieties such as Kipling, through the addition of commercial enzyme preparations. The amount of alcohol obtained could be increased using a combination of Termamyl with Bioprotease. However, this was only successful if the cooking temperature was kept low, as these enzymes are heat sensitive. Although use of these enzymes is only permitted in the bioethanol industry and not in grain whisky production, the latter could reap the benefits of reduced competition for good quality wheat.

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