Kent, Geoff, McKenzie, Neil, Patrick, Darcy, Arzaghi, Ehsan, Plaza, Floren, Ryan, Kelly, Woods, Phil, & Parfitt, Roy
(2022)
Automation parameters for milling adjustments during processing of soft canes.
In *Proceedings of the 43rd Annual Conference of the Australian Society of Sugar Cane Technologists, ASSCT 2022.*
Australian Society of Sugar Cane Technologists (ASSCT), Australia, pp. 214-223.

Automation parameters for milling adjustments during processing of soft canes

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Abstract Concerns have been raised that many sugarcane varieties in the development pipeline, particularly in the Central and Southern regions, have fibre quality classified as soft, with some soft enough to cause processing problems in the factory. The main issues have been feeding of the cane through the milling train and high bagasse moisture contents causing subsequent combustion issues and low steam pressure at the boiler station. These cane varieties are usually designated as 'soft canes'. With soft canes in a factory's cane supply, there is a need to find a way to process them reliably at a reasonable rate, to extract the sucrose and produce reasonable quality bagasse for steam generation. This paper reports on a series of experiments at Isis mill to examine the effect of varying cane preparation, added water rate and added water temperature on the operation and performance of the factory, with the objective of providing the information necessary to develop an automated control strategy for handling the processing of soft canes without manual intervention. Changes to shredder speed to adjust cane preparation and changes to added water rate and temperature affect the operation and performance of the milling train. In particular, changing shredder speed influences #1 mill torque, changing added water rate influences #2 and #5 mill torque, and changing added water temperature influences #5 mill torque. Changing shredder speed and changing added water rate are proposed as strategies to address problems caused by the processing of soft canes.

Key words Soft cane, processing, preparation, added water

INTRODUCTION

Concerns have been raised that many sugarcane varieties in the development pipeline, particularly in the Central and Southern regions, have fibre quality classified as soft, with some soft enough to cause processing problems in the factory (Kent *et al.* 2017). The main issues have been feeding of the cane through the milling train and high bagasse moisture contents causing subsequent combustion issues and low steam pressure at the boiler station. These cane varieties are usually designated as 'soft canes', and their presence had been noted in Australia for over 60 years (Buzacott 1956; Sockhill 1958). An attractive trait of some soft canes is their relatively high sugar yield per hectare (Kent *et al.* 2019). Some other general characteristics have been noted as often (but not always) having relatively low fibre content, and being easier to prepare by the shredder, resulting in more smaller particles in the prepared cane. During the development of new cane varieties, Sugar Research Australia carries out tests for 'fibre quality' (Brotherton *et al.* 1986; Kent *et al.* 2014).

With soft canes in a factory's cane supply, there is a need to find a way to process them reliably at a reasonable rate to extract the sucrose and produce reasonable quality bagasse for steam generation. Mason *et al.* (1983) identified two potential strategies: reducing cane preparation by reducing shredder speed or increasing shredder grid setting, and reducing added water rate. While reducing added water rate was considered a more appropriate approach, this strategy clearly will not help with any processing problems at or before the first mill (which is not affected by added water).

Here, we report on a series of experiments at Isis Mill to examine the effect of varying cane preparation, added water rate and added water temperature on the operation and performance of the factory, with the objective of providing the information necessary to develop an automated control strategy for handling the processing of soft canes without manual intervention.

THE EXPERIMENTS

Overview

We conducted three experiments at Isis Mill using a randomised paired comparison design (Box *et al.* 1978). In each experiment, paired tests were conducted on a single rake of cane. In all experiments, one test was conducted at normal crushing conditions (treatment 1). In the other test, one factor was varied as shown in Table 1 (treatment 2). The order of the two tests was randomised. The shredder speed of 100% corresponded to a turbine speed of 5400 r/min. The added water rate of 49 t/h averaged 320% on fibre across all tests. Both of these factors could be easily adjusted with a parameter at the milling train console. In experiment 3, a plate heat exchanger was used to change the added water temperature using mixed juice as a coolant (Kent 2010).

Table 1. Details of experimental designs.

Experiment	Factor	Treatment 1	Treatment 2	Number of tests
1	Shredder speed	100%	95%	24
2	Added water rate	49 t/h	42 t/h	22
3	Added water temperature	98 °C	70 °C	22

Test procedure

For each pair of tests, a rake of cane from a single block of at least 200 t was sought, to provide close to 30 minutes of crushing time. The 30 minutes was split in two so that typically 15 minutes was available for each test. The 15 minutes consisted of 10 minutes to allow the bagasse and juice flows to achieve a steady state following the change in factor treatment, with the remaining time available for data collection for the test.

While it was desirable to conduct these tests on soft cane, the Isis cane supply had a relatively low proportion of canes identified as soft enough to cause processing difficulties. To find long rakes of cane for the experiment, cane of any variety was considered acceptable. One pair of tests for experiment 2, however, was conducted on the soft cane variety SRA1[A]. Plaza *et al.* (2022) noted that in testing the response of different cane varieties, including a range of soft cane varieties, all varieties responded to preparation in the same way. Soft canes are part of a spectrum of varieties that include all other varieties. Consequently, the response in parameters to changes in shredder speed, added water rate and added water temperature in any variety is expected to be similar. What will change is the absolute value of the parameters.

The factory's sample tracker was used to identify the start and end of rakes. Samples of cane billets, prepared cane and first mill bagasse could be collected from the start to the finish of the test. First-mill bagasse samples were only collected during experiment 1, since no change was expected up to and including the first mill, due to the treatment change in experiments 2 or 3. Samples of final-mill bagasse were taken after the 10-minute settling period elapsed. First-expressed juice was sampled using the factory's automatic juice sampling system. The analyses conducted on the samples are shown in Table 2.

Table 2. Sample analyses.

Sample	Analyses
Cane billets	Impact resistance, shear strength and short fibre content
Prepared cane	Shear strength, short fibre content, fibre, brix, pol, moisture, pol in open cells
First mill bagasse	Pol, moisture
Final mill bagasse	Pol, moisture
First expressed juice	Brix, pol

In addition to the sample analysis, other parameters (Table 3) were recorded through the weighbridge system and the distributed control system.

Table 3. Automatically collected data.

Source	Parameters
Weighbridge	Tip time at start and end of test, and tonnes tipped
Shredder	Turbine steam flow, steam pressure and temperature at inlet and exhaust, speed
#1 and #5 mills	Flap position, top roll lift, pressure feeder and mill speed and torque, chute level
#2, #3 and #4 mills	Flap position, top roll lift, mill speed and torque, chute level
Added water	Flow rate, temperature

Cane supply

The cane varieties utilised in the three experiments are presented in Figure 1. Q240[A] was the main variety in each experiment, with KQ228[A] also well represented in experiments 1 and 3.

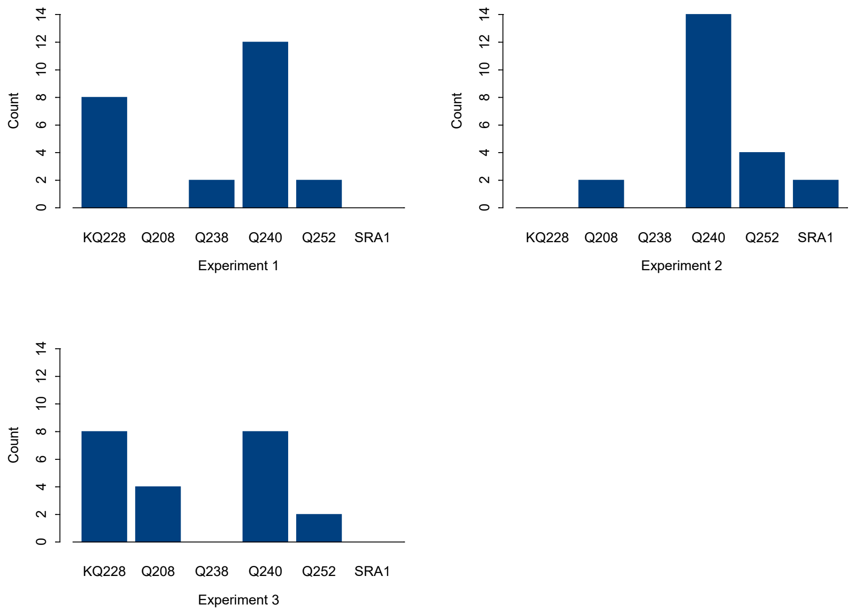

***Figure 1**.* Varieties used in the experiments.

The fibre content and fibre quality parameters for the cane supplies to each experiment are shown in Figures 2 to 4 for experiments 1 to 3, respectively. Q240[A] had relatively low fibre content but was one of the harder varieties (higher shear strength and impact resistance and lower short fibre content). KQ228[A] had relatively high fibre content and was also a harder variety.

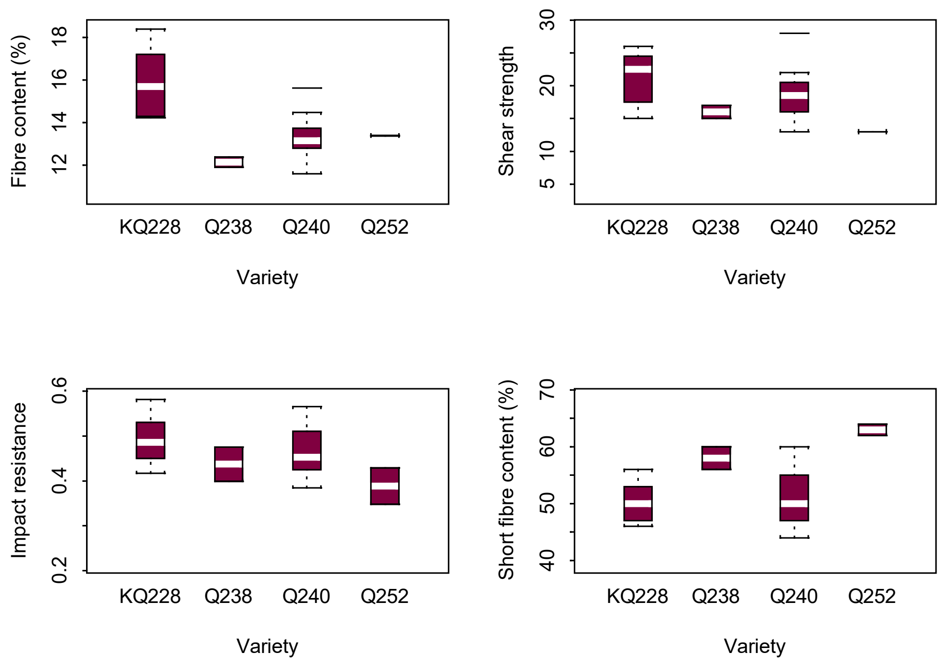

Figure 2. Fibre content and quality parameters for the varieties used in experiment 1.

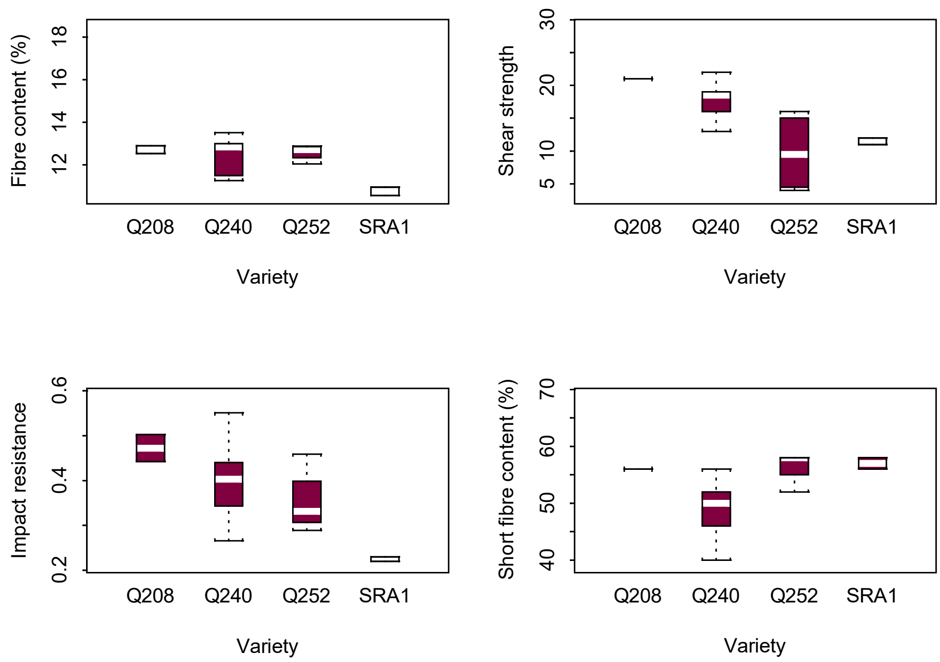

Figure 3. Fibre content and quality parameters for the varieties used in experiment 2.

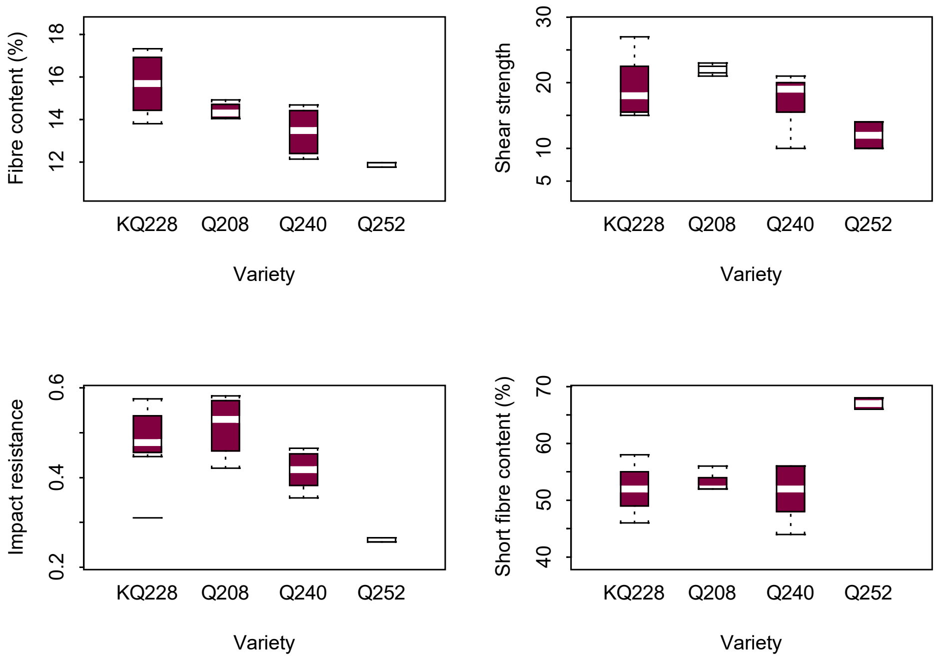

Figure 4. Fibre content and quality parameters for the varieties used in experiment 3.

Analysis of results

From the experimental results described in Table 2 and Table 3, means of parameters were calculated for each test for use in statistical analysis. The calculated parameters are presented in Table 4. For some parameters (designated by * in Table 4), the standard deviation was calculated, in addition to the mean. Note that, although data similar to that for #2 mill were collected for #3 and #4 mills, no analysis was undertaken on that data. It can be expected that #3 and #4 mill responses to changes will lie between the extremes identified for #2 and #5 mills. Some of the parameters listed in Table 4 are not widely used. Table 5 contains definitions or references to the less commonly used parameters.

Table 4. Parameters assessed in statistical analysis.

Source	Parameters
Factors	Shredder speed, added water rate % fibre, added water temperature.
Cane supply	Cane rate.
Shredder	Pol in open cells, specific power consumption.
#1 mill	Pressure feeder torque, flap position, top roll lift, mill torque*, pressure feeder to mill ratio*, chute level*; Extraction, delivery nip compaction, reabsorption factor multiplier, feed chute exit compaction.
#2 mill	Mill torque*, flap position*, chute level*, mill speed*; Delivery nip compaction, feed chute exit compaction.
#5 mill	Mill torque*, pressure feeder to mill ratio, chute level*, mill speed*, bagasse moisture content; Extraction, delivery nip compaction, reabsorption factor multiplier, feed chute exit compaction.

Table 5. Definitions and references to calculated parameters not widely used.

Parameter	Definition or reference
Specific power consumption	Ratio of power consumption to cane rate (kW.h/t)
Flap position	Feed chute flap position (%) with 0% being fully open
Pressure feeder to mill ratio	Ratio of pressure feeder speed to mill speed
Delivery nip compaction	Kent (2015)
Reabsorption factor multiplier	Kent (2015)
Feed chute exit compaction	Kent (2015)

To determine the statistically significant differences in each experiment, an analysis of variance was undertaken for each of the parameters listed in Table 4. Table 6 lists the parameters for which statistically significant differences at the 5% level were identified.

Table 6. Summary of statistically significant effects from analysis of variance.

Parameter	Experiment		
	1	2	3
Shredder speed	✓		
Added water rate		✓	
Added water temperature			✓
Shredder specific power consumption	✓		✓
Prepared cane shear strength	✓		
#1 mill torque	✓		
#1 mill reabsorption factor multiplier	✓		
#2 mill flap position		✓	
#2 mill speed	✓		
#5 mill torque standard deviation			✓
#5 mill pressure feeder to mill ratio		✓	✓
#5 mill speed			✓
#5 mill bagasse moisture content			✓
#5 mill reabsorption factor multiplier			✓
#5 mill feed chute exit compaction		✓	

It is noted that changing shredder speed caused changes mainly at #1 and #2 mills, changing added water rate caused changes at #2 and #5 mills and changing added water temperature caused changes only at #5 mill. The statistically significant effect of added water temperature on shredder specific power consumption was not expected since added water temperature should have no effect on shredder operation and the test order was randomised, but the actual change in power consumption, while statistically significant, was small.

The values of the parameters listed in Table 6 are presented in box plots in Figures 5 to 7 for experiments 1 to 3, respectively.

The experiment 1 results could be partially compared to those of Plaza *et al.* (2022) where the effect of changing shredder speed on the properties of prepared cane was assessed. While the experiment of Plaza *et al.* (2022) reduced shredder speed to 80%, experiment 1 only reduced shredder speed to 95%. The smaller change in shredder speed and smaller number of tests (24 compared to 43) made it more challenging for experiment 1 to identify the same results. Nonetheless, experiment 1 did confirm that the prepared cane shear strength was higher at lower shredder speed. Experiment 1 also measured lower POC and lower short fibre content at lower shredder speed, but the results were not statistically significant. All of these results were consistent with those of Plaza *et al.* (2022).

Experiment 2 was the only experiment where a rake of soft cane (SRA1^{A}) was processed as part of the experiment. In Figure 6, the SRA1^{A} results are superimposed on top of the box plots as blue dots. Figure 6 shows that the added water rate change for the SRA1^{A} tests was similar to that of the experiment average, although the rates were at the lower end in terms of magnitude, due to the usual manual control action taken at Isis to reduce added water rate when SRA1^{A} was processed. The #2 mill flap was close to its widest position for both tests, indicating that #2 mill was not able to maintain torque while processing this rake. Although not statistically significant, the mean of the #2 mill torque results indicates an increase in torque of 5% from the added water rate reduction. The #5 mill, however, was able to increase its pressure feeder to mill ratio to control torque. The increase in pressure feeder to mill ratio in response to the increase in added water rate was similar to that of the experiment average, while the values were high in terms of magnitude. The reduction in feed-chute exit compaction in response to the increase in added water rate, was also similar to that of the experiment average, while the values were low in terms of magnitude. These results support the conclusion from Plaza *et al.* (2022) that soft canes are similar to other canes in the way they respond to processing changes, although their parameter values are at one end of a spectrum. Here, #2 mill was unable to maintain torque control due to the feed chute flap not having enough control range, but #5 mill was able to maintain torque control due to available control range through the pressure feeder to mill ratio.

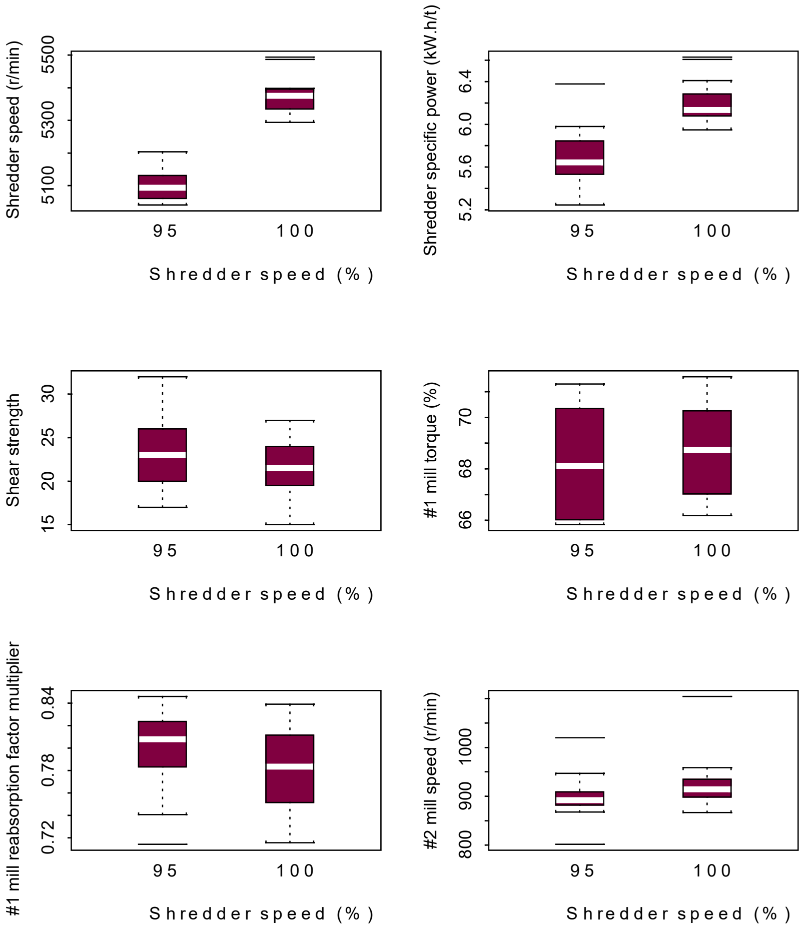

Figure 5. Box plots of statistically significant effects from experiment 1.

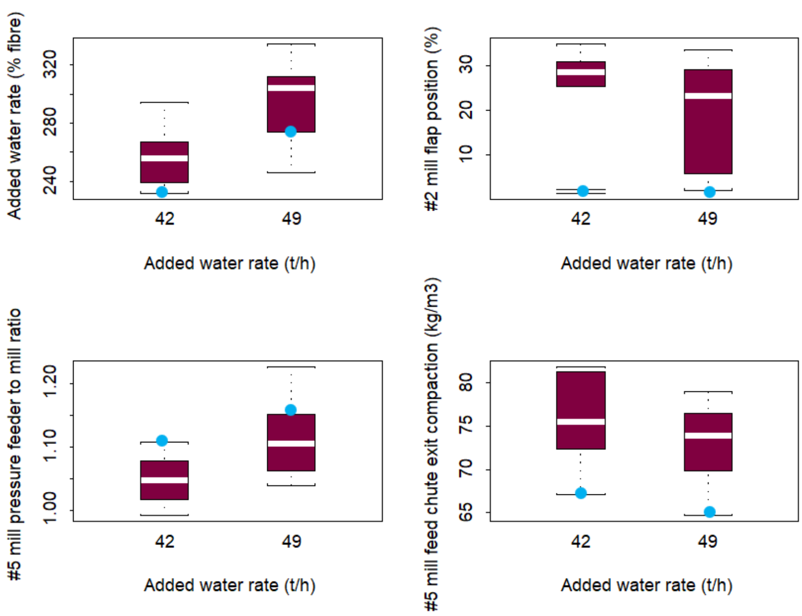

Figure 6. Box plots of statistically significant effects from experiment 2 (SRA1 results shown as blue dots).

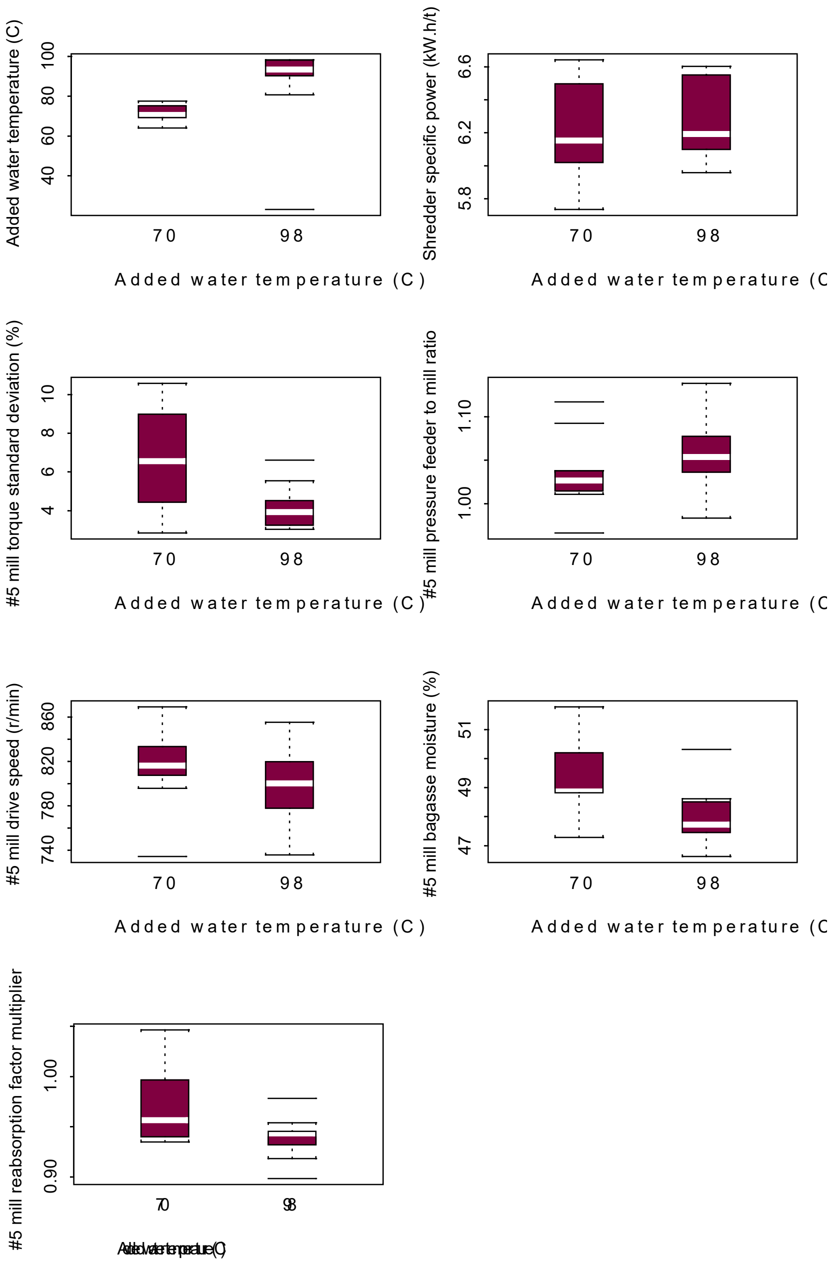

***Figure 7**.* Box plots of statistically significant effects from experiment 3.

The results of experiment 3 were consistent with the results of Kent (2010). The reduction in #5 mill pressure feeder to mill ratio, corresponding to an increase in #5 mill speed, was consistent with the observation of Kent (2010) that the reduction in added water temperature caused an increase in torque and also with the results of Kent (2010) that a reduction in added water temperature caused a decrease in delivery nip compaction. The increase in #5 mill bagasse moisture content and #5 mill reabsorption factor multiplier are consistent with most of the results of Kent (2010) that showed the reduction in added water temperature caused an increase in bagasse moisture content.

IMPLICATIONS FOR FACTORY CONTROL

Given that the purpose of the experiments was to identify strategies to automate the handling of soft canes, we reviewed the experimental results to identify strategies for handling soft canes.

Controllable parameters for soft cane handling

Using shredder speed

Adjusting the shredder speed caused a change in the shredder specific power consumption, #1 mill torque, #1 mill reabsorption factor multiplier and #2 mill speed. The change in shredder specific-power consumption was expected, since shredder specific-power consumption is an indicator of cane preparation and shredder speed was reduced specifically to change cane preparation. This parameter is not useful as a control response. Reabsorption factor multiplier is a performance parameter that cannot be calculated without online bagasse analysis (which is not available at Isis Mill). It is likewise not useful for control. The #2 mill speed is automatically varied to control #2 mill chute level. While it may be possible to utilise #2 mill speed for control, the best candidate for control is expected to be associated with the #1 mill torque.

The #1 mill control system at Isis Mill does have a control loop designed to control #1 mill torque by varying the pressure feeder to mill ratio (Kent 2019). That mill torque varied in response to a change in shredder speed indicates that the upper limit of the pressure feeder to mill ratio range was reached and, with no further control action available, the torque changed.

Using added water rate

Adjusting the added water rate caused a change in the #2 mill flap position, the #5 mill pressure-feeder-to-mill ratio and the #5 mill feed chute exit compaction. The #5 mill feed-chute exit compaction is a calculated parameter and not useful for control. The #2 mill flap position and the #5 mill pressure-feeder-to-mill ratio, however, are the mechanisms for control of #2 mill torque and #5 mill, respectively. Both of these parameters are ideal for use in a control system.

Using added water temperature

Adjusting the added water temperature caused a change in the #5 mill torque standard deviation, the #5 mill pressure-feeder-to-mill ratio, the #5 mill speed, the #5 mill bagasse moisture content and the #5 mill reabsorption factor multiplier. All of these parameters relate to #5 mill. Figure 7 shows that the torque standard deviation was less at higher temperature, but this result is not useful for control. Bagasse moisture content and reabsorption factor multiplier are also not useful for control due to the lack of online bagasse analysis. The #5 mill pressure-feeder-to-mill ratio and #5 mill speed are essentially the same parameter, since changing the pressure-feeder-to-mill ratio effectively changes the mill speed (Kent *et al.* 2004).

Concluding remarks

We conclude from this review of responses to the control actions of changing shredder speed, added water rate and added water temperature that the most suitable response to changing all parameters is a change in torque or the parameter responsible for controlling torque. Our analysis showed that #1 mill torque changes with shredder speed, #2 mill torque changes with added water rate and #5 mill torque changes with both added water rate and temperature.

From this review, we hypothesised that change in torque, or the control system response to change in torque, is the most promising indicator of soft cane behaviour. Furthermore, we hypothesised that if shredder speed, added water rate and/or added water temperature can be adjusted to maintain torque, soft canes should cause minimal processing problems through the milling train.

Our analysis of results showed that, of the three controllable parameters for soft cane processing, #1 mill torque is only one affected by shredder speed. Consequently, shredder speed is the parameter that should be used to manage soft canes through #1 mill. Similarly, only added water rate was shown to have a substantial effect on #2 mill torque. Consequently, added water rate is the parameter that should be used to manage soft canes through #2 mill. We note, however, that there will be a lag of typically 5 minutes between a change in added water rate at the final mill and a change in imbibition rate at #2 mill. If this lag proves to be too much, it might be necessary to divert some of the imbibition flow directly to #2 mill expressed juice to reduce the imbibition flow at #2 mill faster.

If soft canes are causing problems at #5 mill but not at the earlier mills, added water temperature could be adjusted since it has minimal effect at the earlier mills, but it does cause an increase in bagasse moisture content. Consequently, it is probably best to adjust the added water rate, as for #2 mill. Although no analysis was done at #3 or #4 mills, we assume that added water rate will have a substantial impact on their torque as well.

Experience processing soft canes at Isis has shown that processing problems typically occur at #1 and #2 mills. Consequently, the use of shredder speed to maintain torque on #1 mill and added water rate to maintain torque on #2 mill are proposed as the appropriate control strategies.

Given that an independently driven pressure feeder gives greater torque control capability than the feed chute flap, it can also be expected that soft cases will be better handled by mills with independently driven pressure feeders.

CONCLUSIONS

Changes to shredder speed to adjust cane preparation and changes to added water rate and temperature affect the operation and performance of the milling train. In particular, changing shredder speed influences #1 mill torque, changing added water rate influences #2 and #5 mill torque and changing added water temperature influences #5 mill torque. Changing shredder speed and changing added water rate are proposed strategies to address problems caused by the processing of soft canes.

Further work is required to provide confidence that these strategies will indeed minimise problems caused by the processing of soft canes. Updates to the Isis milling train control system have been made to test these strategies and provide evidence as to their success in minimising problems in processing soft canes.

ACKNOWLEDGEMENTS

We acknowledge Isis Central Sugar Mill Co for hosting the project. The support of Jenny Magdalinski and the Isis mill factory and laboratory staff, are acknowledged for the sample collection and analysis. Michelle Miedecke and the SRA staff are acknowledged for the fibre-quality analyses. The funding support of Sugar Research Australia is gratefully acknowledged. Peter Samson and Stephen Mudge are acknowledged as project funding liaison.

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