A model for predicting milling yield in wheat

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Abstract
Milling yield of wheat is a quality measure that defines the proportion of flour extracted from grain and is commercially important for domestic and international markets. Predicting milling yield using simulation models could be of benefit, where such models would allow the impact of environmental conditions, in particular climate change, on wheat quality to be tested. We used data from the Horsham Australian Grains Free Air CO_2 Enrichment (AGFACE) trial where wheat (*cv.* Yitpi) was grown under two water regimes (rain-fed and supplement irrigation) and two nitrogen (N) fertiliser levels at sowing (0 and 50 kg N/ha) for both ambient (365 ppm) and elevated (550 ppm) CO_2 conditions, to run a model, APSIM-7. Experimentally, there was no effect of CO_2 or N fertilisation on milling yield (mean: 73.7%), whereas for the water treatment, irrigated conditions produced a small but significant increase in milling yield (73.1 *vs.* 74.3%). We found that milling yield (Y) could be described by a crop water stress index (X) (r^2 = 77%) derived by the simulation model using a generalised logistic function: $Y = A+C/((1+T\times EXP(-B\times(X-M)))^2(1/T))$; where regression coefficients A, B, C, M and T were 70.45, -66.01, 5.476, 0.1009 and 0.2343, respectively. This implies that simulation models may be used to predict milling yield and provide extrapolated assessment of environmental conditions on wheat quality. Further experimental work and model testing is required to verify these initial assumptions and understand definitively whether elevated CO_2 (eCO_2) has any impact on milling yield.

Key words
climate change, grain quality, simulation models

Introduction

Quality attributes of wheat, such as milling yield, are commercially important metrics for determining the value of grain in domestic and international markets. Milling yield is the proportion of flour extracted from grain and is dependent on genetic and seasonal factors (Marshall *et al.* 1984). Laboratory determination of milling yield is tedious and alternative empirical rapid methods using grain morphological surrogates have been tested with reasonable success (Marshall *et al.* 1986; Berman *et al.* 1996). Within the cropping regions of south-eastern Australia it is anticipated that future climatic conditions of reduced growing season rainfall and increased temperature will have a variable effect on crop growth depending on agro-ecological region in Victoria (O'Leary *et al.* 2011), although it is unclear how a future climate will affect grain quality. Consequently, if a biophysical model could be developed that describes milling yield, this could be integrated into simulation models to predict milling yield. These coupled models would allow the impact of future weather conditions, such as those expected under climate change scenarios, to be tested on wheat quality. In this study, experimental data from the Australian Grains Free Air CO_2 Enrichment (AGFACE) experiment at Horsham, Victoria (Mollah *et al.* 2009) was used for model development. Down-scaled climate data (rainfall and temperature) projected for 2050 was calculated based on stochastic variation of 68 years of historical weather data (method B) described by Weeks *et al.* (2010). This paper reports on: a) a proposed model for describing wheat milling yield using a photosynthesis stress-based index (PSI); and b) estimates of the net effect of expected future elevated CO_2, temperature and rainfall conditions on milling yield of wheat in the Victorian Wimmera using simulation modelling.

Methods

A large (n = 736) database defining grain quality attributes of commercial wheat varieties and breeding lines, referred to as dataset 1 (J. Panozzo, unpublished data), was used to characterise milling yield and simple relationships with other quality attributes. A second dataset (2) from the AGFACE trial (2007, 2008, 2010 & 2011) was used to parameterize a crop simulation model (APSIM-Wheat (Version 7)) (Keating *et al.* 2002). The AGFACE experiment, evaluated wheat grown under mean day time ambient CO_2 (aCO_2) concentration (365 ppm) compared with elevated CO_2 (eCO_2) concentration (550 ppm) in accordance with the A1Fi scenario for atmospheric CO_2 (Nakicenovic *et al.* 2000) and data from both CO_2 treatments were used in this study. Two times of sowing (TOS) were also considered (TOS1: Jun & TOS2: Aug). The crop model was used to generate a photosynthesis stress index (PSI), which integrated soil water stress (ratio of soil water supply and demand) to photosynthesis from sowing to flowering. A generalised logistic function was used to define the relationship between PSI and observed wheat milling yield. Simulation runs of wheat growth for a Vertosol soil type (Isbell 1996) in the Victorian Wimmera was also conducted using three different climate data sets from Longerenong. Firstly, a long term recorded dataset (1935-2002), secondly the same data with

an increased CO_2 concentration to 550ppm (the same as that achieved in the AGFACE experiments) and thirdly, the increased CO_2 concentration and a modification to account for the change in climatic conditions predicted by the IPCC's A1Fi extreme climate change scenario model (2001; 2007) (using method B from Weeks *et al.* 2010). Briefly, method B determines the impact of climate at a single point in time (i.e. 2050) based on the outputs from CSIRO's global atmosphere model (CCAM-Mark3). For the simulations, wheat (*cv*. Yitpi) was sown on 1 June at 215 plants/m^2. Starting soil mineral N of 309 kg N/ha and soil water was reset annually at 10% of field capacity on the 1 June.

Results and Discussion

Wheat milling yield

For dataset 1, which defines a range of grain quality attributes for wheat, poor correlation existed between milling yield and kernel weight (r = 0.20), screenings (r = -0.08), grain hardness (r = -0.49) and protein (r = -0.13) and so limited utility of basic surrogates to milling yield exist. This highlights the limited utility of more routine measurements for predicting milling yield. When comparing dataset 1 with the AGFACE grain quality dataset (2), average milling yield was 73 and 74%, respectively, and in both cases usually ranged between 69 and 77% (Fig 1). In particular, poor agreement between milling yield and kernel size may be due to increasing size being linked with kernel length rather than with width or height, thus being insensitive to volume change and associated milling yield (Marshall *et al.* 1984). A model-derived photosynthesis stress index, which integrates seasonal conditions, may be useful in defining milling yield.

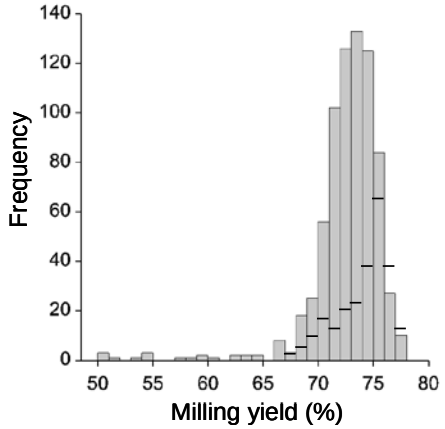

Figure 1. Frequency distribution of wheat milling yield from: a) dataset 1 - grain quality characteristics (grey bars *n* = 736); and b) dataset 2 - AGFACE trial (ambient and elevated CO2) in 2007, 2008, 2010 and 2011 (solid horizontal lines *n* = 238).

Crop growth

Elevated CO_2 (eCO_2) did not influence observed milling yield of wheat (*cv.* Yitpi) (73.7%). This is despite eCO_2 increasing grain number, kernel weight and yield by 16, 3 and 22%, respectively (Table 1). Similarly, milling yield was insensitive to variations in water supply, although under irritation, grain number and yield increased 25 and 16%, respectively. Kernel weight was significantly reduced (P<0.01) with a parallel increase in screenings where additional water was applied. Delaying the time of sowing (TOS2) caused milling yield to significantly drop compared with optimally sown (TOS1) crops. TOS2 also substantially reduced other yield components and increased screenings. There were no interactions between other factors on yield components.

Table 1. The effect of atmospheric CO_2 concentration, water supply and time of sowing on yield components of wheat (*cv.* Yitpi). Data is from the AGFACE trial, Horsham, Victoria for 2007, 2008, 2010, 2011.

	CO_2 concentration		Water supply		Time of sowing	
	Ambient	**Elevated**	**Rain-fed**	**Irrigated**	**1**	**2**
Milling yield (%)	73.8	73.6	73.4	74.0	74.3	72.9
lsd (P<0.01)	ns		ns		0.8	
Yield (t/ha)	3.29	4.02	3.38	3.93	4.68	2.11
lsd (P<0.01)	sd*		sd*		sd*	
Grain number (per/m^2)	9351	10842	8986	11207	12219	6913
lsd (P<0.01)	sd*		sd*		sd*	
Kernel weight (mg/1000)	34.3	35.5	35.9	33.9	37.7	30.7
lsd (P<0.01)	1.16		1.2		1.2	
Screenings (%)	2.7	2.6	2.0	3.2	1.1	4.9
lsd (P<0.01)	ns		sd*		sd*	

*data which required log(base10) transformation for ANOVA

Wheat milling yield and stress index

Six different PSI's were generated using the crop simulation model and cross referenced for agreement with observed wheat milling yield for dataset 2 (AGFACE). Milling yield could be best described by a PSI that described average water stress to photosynthesis between sowing and anthesis. The relationship was defined by a generalised logistic function: $Y = 70.45+5.476/((1+0.2343\times EXP(66.01\times (X-0.1009)))^2(1/0.2343))$ where 77% of the variation was explained (Fig 2). This model is applicable when wheat screenings are <4%. Where screenings are high (>6%) it appears that the milling yield becomes inflated relative to PSI due to the removal of the screenings prior to laboratory analysis and thus falls outside the descriptive capacity of the model. Milling yield can be effectively captured by the kernel volume per unit surface area (Marshall *et al.* 1984) and is linked to growing season moisture stress (Guttieri *et al*. 2001). The PSI generated by the model, integrates pre-anthesis water stress to photosynthesis, thus is likely to have utility in predicting milling yield.

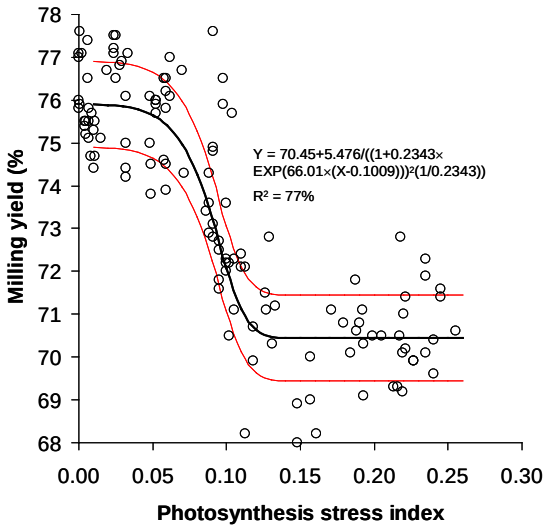

Figure 2. Relationship between photosynthesis stress index (PSI) and milling yield of wheat. The PSI was derived from a mechanistic crop model output. Outer boundary lines indicate a *ca.* 1.5% deviation around the model function.

Crop simulation for future climate

For a simulation run over 68 years, average grain number and yield of wheat (sown 1 June) under a current climate was 8093 grains/m^2 and 3.21 t/ha, respectively (Table 2). The simulated effect of eCO_2 (FACE conditions) was to increase both these yield components by 26%, where the model assumes increased crop RUE and TE under eCO_2. In comparison, when both eCO_2 and Mark3 2050 climate were combined, the average grain number and yield decreased by 3 and 5% respectively, due to drier Spring conditions, compared with the current climate. There was no effect of climate on simulated kernel weight.

Table 2. Simulated effect (main and combined) of elevated CO_2 and IPCC climate scenario A1Fi for 2050 on wheat (*cv.* Yitpi) yield components, grain number, yield and kernel size for 01 Jun sowing only. Photosynthesis stress indices (PSI) are also defined for two times of sowing.

Climate	365 ppm CO_2/historic	550 ppm CO_2/historic	550 ppm CO_2/2050
Grain number (per/m^2)	8093	10195	7885
Yield (t/ha)	3.21	4.03	3.06
Kernel weight (mg/1000)	0.04	0.04	0.04
PSI (01 June sowing)	0.022	0.025	0.023
PSI (01 August sowing)	0.089	0.097	0.105

Despite a substantial shift in grain set and yield of wheat under different simulated climate scenarios, the corresponding photosynthesis stress index (PSI), which appears to adequately explain milling yield, did not change markedly over climate scenarios (Fig 3). These results indicate that under a future climate, milling yield of wheat is unlikely to change, but absolute yield will be affected. Delayed sowing (1 August) caused PSI to increase in absolute terms and also with a future climatic scenario. This suggests agronomic management strategies, such as early sowing (pre-June), provide options for avoiding impacts of future climate on quality attributes such as milling yield. Further verification of these initial results will be conducted by testing alternative stress indices against milling yield and conducting simulations across different agro-ecological environments.

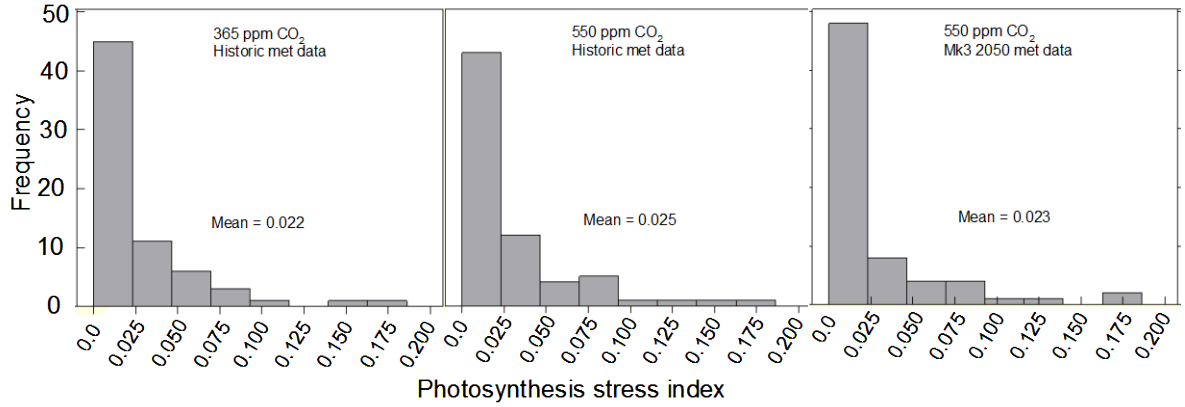

Figure 3. Simulated effects (main and combined) of elevated CO_2 and IPCC climate scenario A1Fi for 2050 on wheat (*cv.* Yitpi) photosynthesis stress index (PSI) *n* = 68.

Conclusions

Milling yield is an important wheat quality attribute that appears to be well described by a photosynthesis stress index (PSI) generated by a crop simulation model. Consequently, potential exists for predicting milling yield using crop simulation models and estimating the effects of a future climate. We found that despite future growing conditions causing a slight net decrease in grain set and yield, PSI and wheat milling yield are unlikely to be affected. We also demonstrated, using simulation modelling, that delayed sowing caused PSI to increase, which is likely to translate into reduced milling yield.

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