A SIMPLE EQUATION FOR TOTAL REDUCING SUGARS (TRS) ESTIMATION ON SWEET POTATO AND ETHANOL YIELD POTENTIAL

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Abstract - Sweet potato is an attractive feedstock for ethanol production due to its high starch content and favorable agronomic characteristics. This paper proposes a simple equation to estimate the total reducing sugars (including glucose from starch) in sweet potatoes based on their moisture content (low cost and simple measurement). It allows the calculation of the ethanol production potential of a given sweet potato mash. According to the equation, the ethanol potential increases non-linearly with increasing concentrations of sweet potato mash in the fermenting medium (w/v), reaching a constant value for high concentrations (22 % of ethanol to 10 kg: L of a sweet potato with a moisture content of 66 %). Additionally, the ethanol yield potential is very sensitive to the sweet potato moisture, increasing linearly when the moisture decreases. We emphasize that the relations proposed in this paper can be used by other researchers, who can apply them to their specific cases.
Keywords: Sweet potato; Starch; Total Reducing Sugars; Ethanol.

INTRODUCTION

Fossil fuels supply around 82% of the current world energy demand (Gupta and Verma, 2015). Although it is expected that renewable energy presents the highest consumption growth rate (2.6%/year, 2012 – 2040), the forecast for 2040 is that fossil fuels will remain at 78% of the total energy usage according to the International Energy Outlook 2016 (EIA, 2016). Therefore, any promotion to increase the renewable energy participation is a significant contribution. Ethanol is not a new alternative, but its production is centered in two countries, USA ~ 60% and Brazil ~ 30%, and mainly from two feedstocks: corn (USA) and sugarcane (Brazil) (Gupta and Verma, 2015).

To increase the ethanol production, advantageous alternative feedstocks should be considered. Sweet potato roots have high starch content, 20 - 30% (w/w), which makes them a promising alternative (Srichuwong et al., 2012). Also, the sweet potato presents several agronomic advantages, such as the capability to grow in poor soils, drought resistance, high multiplication rate, short growth cycle, and low illness and plague incidence. In addition, the roots rapidly cover the soil and therefore they protect it from erosive rains, as well as against possible weed problems (Lareo et al., 2013).

Several studies have been done on ethanol production from sweet potatoes, such as Cao et al. (2011), Srichuwong et al. (2012), and Zhang et al. (2011), who carried out fermentations under high sweet potato concentrations, achieving an ethanol content of 15 – 16% (v/v) (including Zhang et al. (2011) who performed experiments on pilot and industrial scales). Schweinberger et al. (2016) found that it is better to let the sweet potato ripen, leaving its own amylases to act; the best post-harvest period was 25 days. Dewan et al. (2013) fermented a sweet potato broth using the bacterium *Zymomonas mobilis*. Other works related to sweet potato fermentation that may be cited are Duvernay et al. (2013), Lareo et al. (2013), and Huang et al. (2014).

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In our research group (GIMSCOP), we began studying alternative feedstocks for ethanol production in the Brazilian state of Rio Grande do Sul (RS), which does not have favorable conditions for sugarcane farming (the state produces less than 0.5% of the ethanol that is consumes) (Schweinberger, 2016). In GIMSCOP, Masiero (2012) studied three feedstocks: saccharine sorghum, cassava, and sweet potato, evaluating their finantial viability in an ethanol micro-plant. The results indicated that the sweet potato was the most promising alternative to sugarcane. Additionally, other sweet potato advantages are: (i) the state of RS leads the national production, i.e., around 30% of the Brazilian production (IBGE, 2016); (ii) the Embrapa (Brazilian Agricultural Research Corporation) branch office located in the city of Pelotas/RS has developed sweet potato cultivars with high productivity, e.g., the productivity can achieve 60 − 80 t/ha (the mean production is around 40 t/ha), and the starch content is also high (25 − 35%) (Betemps and Pinto, 2016; Castro and Becker, 2011a; b; c).

This paper focuses on the Total Reducing Sugars (TRS) content of the sweet potato, i.e., glucose and fructose, which are the substrates converted into ethanol, assuming the ideal condition that all starch is hydrolyzed into glucose. Although every sweet potato is rich in starch, there is a significant content variation in the different types. Thus, to evaluate the ethanol potential of a given sweet potato, this work proposes correlating the TRS with the sweet potato moisture. This idea originated from collected literature data and the verification of the adequacy of the proposal.

Having a mathematical function relating TRS x moisture, it is possible to estimate the ethanol potential of a given sweet potato mash, and then evaluate the effects of the sweet potato moisture and its concentration in the medium on the ethanol potential. These are essential variables considering that it is desirable to concentrate as much as possible the ethanol content in the broth.

We also emphasize the fact that the proposal is based on the moisture, a cheap and simple analysis to perform.

THE PROPOSAL: EXISTENCE OF A RELATIONSHIP BETWEEN TRS AND MOISTURE IN SWEET POTATO

The sweet potato is mainly composed of starch and moisture; starch with a mean value around 20% and moisture 70% (Bradbury and Holloway, 1988). Thus, it was assumed that, with a small error, the sum of the other components could be considered constant. Then, the mass balance results in:

$$\text{Starch}\,(\%) = 100 - \text{Moisture} - \text{Constant} \qquad (1)$$

Coming up the relationship between only two variables, starch and moisture, this indicates that the higher starch contents occur in drier sweet potatoes.

In this sense, Eq. (1) was the core idea to develop an equation relating the TRS and the moisture. Due to the aldehyde group, all aldoses, including glucose, are reducing sugars. Concerning ketoses, some of them have reducing capability, such as fructose, which reduces Tollen's reagent, which occurs by a mechanism in which the fructose is isomerized to an aldose (Cui, 2005). Although the TRS concept is broad, in this work we took into account only the glucose and the fructose, assuming that other reducing sugars are negligible in the sweet potato composition. Thus, here the TRS concept includes: (i) free glucose and fructose, (ii) glucose from starch, and (iii) glucose and fructose from sucrose, since they are the available sugars to be converted into ethanol. To calculate the TRS, the stoichiometries presented in Figure 1 were considered.

According to the definitions, the starch x moisture and the TRS x moisture curves are similar, because the main contribution to the TRS is the glucose from the starch. Nevertheless, it is expected that the TRS x moisture relation is more accurate, because in the course of time the action of the amylases naturally present in the sweet potato occurs, reducing the starch content and increasing the glucose content (Zhang et al., 2002). These changes do not interfere when adopting the TRS concept since it accounts for both the free glucose and the glucose from the starch.

Another possible way to express the relationship presented is based on the dry basis, since the moisture and the dry basis are directly correlated (% dry basis = 100 - % moisture). As it is possible to choose between those variables to correlate with TRS, we chose the moisture basis by simple preference.
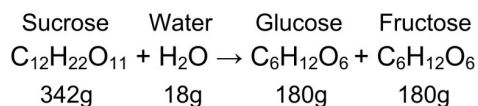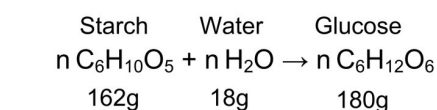
Hydrolysis

Starch   Water   Glucose
$$n\,C_6H_{10}O_5 + n\,H_2O \rightarrow n\,C_6H_{12}O_6$$
162g   18g   180g

Sucrose   Water   Glucose   Fructose
$$C_{12}H_{22}O_{11} + H_2O \rightarrow C_6H_{12}O_6 + C_6H_{12}O_6$$
342g   18g   180g   180g

Figure 1. Stoichiometry of the starch and sucrose hydrolysis reactions.

MATERIALS AND METHODS

Proposal Verification and Equation Obtained

The existence of a correlation between the TRS and the moisture was evaluated with data collected from the literature. Sources were sought with as many data as possible to validate the presumed relation.

In the works of Zhang et al. (2002), Oboh et al. (1989), and Bradbury and Holloway (1988), the linear relationship starch/carbohydrates/TRS x moisture was found. Here, a specific data subset from the work of Bradbury and Holloway (1988) was selected for the equation obtainment, because of the quantity and the quality of such data.

Bradbury and Holloway (1988) analyzed the chemical composition of seventy-three sweet potatoes (moisture, carbohydrates, proteins, lipids, fibers, and ashes), also quantifying the starch and sugars contents. The starch content was determined by the gelatinization at 100 ᵒC, and then the hydrolysis was carried out at 60 ᵒC catalyzed by an α-amylase and amyloglucosidase. The produced glucose was determined colorimetrically. For the sugars, the anthrone method was employed, which quantifies the sum of the glucose, the fructose (both expressed as sucrose), and the sucrose itself.

The study of Bradbury and Holloway (1988) was conducted in a project of the Australian Centre for International Agricultural Research. The sweet potatoes were obtained from agricultural research stations, farmer's fields or, in some cases, they were purchased in the market. The supplier countries were Fiji, Papua New Guinea, Solomon Islands, Tonga, and Western Samoa.

It is not expected that the sum of the sweet potatoes' composition matches 100% since there are errors associated with the chemical analysis. So, the sum $\geq$ 97.5% was determined as the criterion for selecting the points to estimate the parameters in Eq. (2). In the results of Bradbury and Holloway (1988) twenty-nine points did not achieve such a criterion. Also, the remaining data were analyzed with the Minitab software and, based on a significant standardized residual or a substantial leverage, eight samples removed. Then, from the seventy-three points of Bradbury and Holloway (1988), our final model was fitted with thirty-six, which we still consider a reasonable number to estimate the parameters.

TRS Equation Results and Comparison with Other Experimental Data

The results obtained by applying the equation are compared with experimental data from other authors (Zhang et al., 2002; Zhang et al., 2011; Srichuwong et al., 2012; Lareo et al., 2013; Dewan et al., 2013), i.e., different data from those used in the curve adjustment.

Additionally, we determined the TRS values by acid hydrolysis of five different sweet potatoes, three of which were developed by Embrapa: BRS Amélia, BRS Rubissol, and BRS Cuia (Figure 2). Another two sweet potato samples were purchased at a local market in the city of Porto Alegre/RS and they presented physical characteristics similar to those of BRS Cuia.

BRS Amélia   BRS Rubissol

BRS Cuia

Source: Castro and Becker (2011a;b;c).

Figure 2. Images of sweet potato cultivars developed by Embrapa.

The sweet potato moisture contents were determined thermogravimetrically (kiln at 105 ᵒC). For the TRS determination, the crushed fresh sweet potato, distilled water, and hydrochloric acid were heated in an autoclave at 1 atm for 2 h, as proposed by Masiero (2012).

The glucose and fructose quantification was performed by HPLC, using a Hi-Plex H column of Agilent Technologies, water as the mobile phase, and a Refractive Index Detector. The column temperature was 60 °C, the mobile phase flow rate 0.6 mL/min, and 20 μL of the sample was injected.

Sweet Potato Mash and Ethanol Potential Equation

The ethanol potential of a mash depends on the TRS content as well as on the sweet potato concentration in the medium. Thus, by applying the mass balance, the TRS x moisture relationship, and the hydrolysis and fermentation stoichiometry (Figure 1 and Figure 3), the equation for the ethanol potential of a given mash was deduced. Further details about this deduction are presented in the Results section "Sweet Potato Mash and Ethanol Potential Equation".
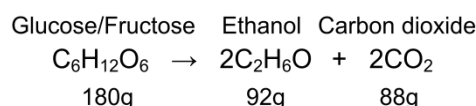
Fermentation

Glucose/Fructose   Ethanol   Carbon dioxide
$$C_6H_{12}O_6 \rightarrow 2C_2H_6O + 2CO_2$$
180g   92g   88g

Figure 3. Stoichiometry of the monosaccharide conversion into ethanol.

RESULTS AND DISCUSSION

Proposal Verification and Equation Obtained

By performing a regression with the data from Zhang et al. (2002), we found a linear relationship between the TRS x moisture and the starch x moisture, both presenting R^2 = 0.93. Although this result

corroborates the proposed relationship, to estimate the curve parameters a larger number of data points should be used (the authors studied six sweet potato genotypes).

Oboh et al. (1989) analyzed the chemical composition of forty-nine varieties of sweet potatoes. They quantified moisture, proteins, lipids, fibers, and ashes, whereas the carbohydrates were calculated by simple difference. To calculate the TRS, the carbohydrate information alone is not enough to distinguish exactly what is starch and what are sugars. However, it was still possible to find a linear correlation between the carbohydrates and the moisture, as shown in Figure 4 ($R^2 = 0.95$), which reinforces the proposal of this work.

This previous analysis with the data found in the literature showed a linear relationship:

$$TRS(\%) = ax_{MST} + b \tag{2}$$

where x_{MST} is the moisture content. So, the quality of calculating TRS will depend on the estimation of the parameters a and b of Eq. (2).

Bradbury and Holloway (1988) analyzed the moisture, starch and sugars content of seventy-three sweet potatoes and, as outlined in more details in the Materials and Methods section (Proposal Verification and Equation Obtained), we removed thirty-seven points due to one of the following reasons: composition sum < 97.5%, large standardized residual or high leverage. Then, the final model was fitted with thirty-six points, as presented in Figure 5, and the resulting equation is given by Eq. (3).

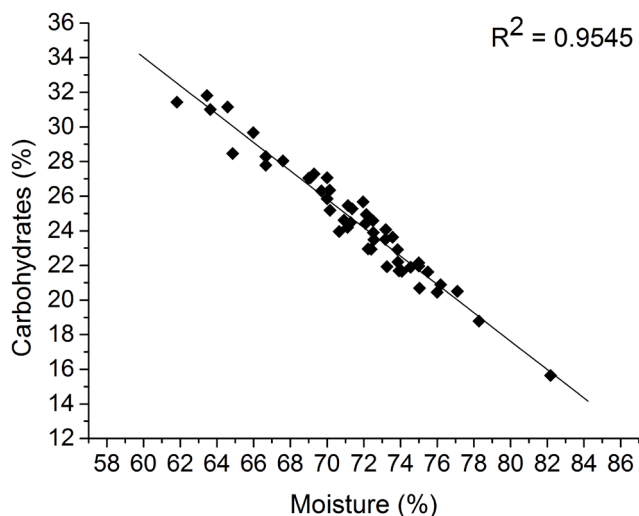$$TRS(\%) = -1.121x_{MST} + 105.4 \tag{3}$$

Figure 4. The linear correlation between the moisture and the carbohydrates, with data plotted from Oboh et al. (1989).
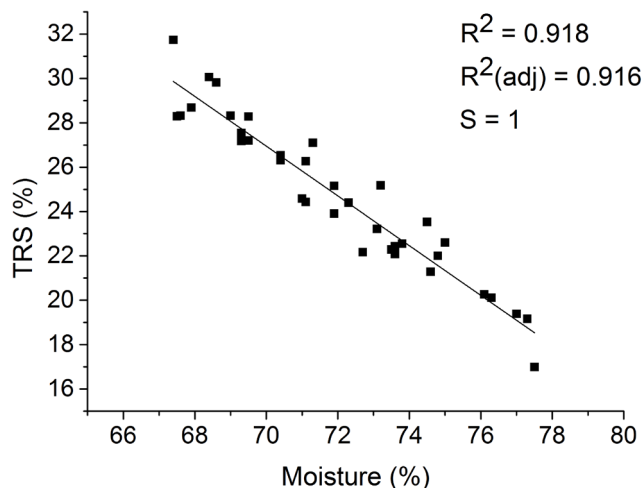
Figure 5. Linear correlation between the moisture and the TRS. Data plotted with the selected thirty-six points from Bradbury and Holloway (1988). R^2(adj) means the R^2 adjusted with degrees of freedom. S: standard deviation.

TRS Equation Results and Comparison with Other Experimental Data

To evaluate the estimation capability of Eq. (3), its results were compared with the experimental data that was not used in the calibration stage. The comparison is presented in Table 1.

In Table 1, some differences between the estimates with the proposed equation and the experimental results can be seen. Nevertheless, one should note that Eq. (3) is a first approximation, constructed with a global approach that includes different types of sweet potatoes. For a more accurate estimation, a specific equation for a particular kind of sweet potato is necessary. To obtain such equations, it would be necessary to quantify the TRS for the various samples of the sweet potato under study and then perform the equation readjustment (please note that for the equation quality it is also important to have a reliable analytical method to obtain the new experimental points).

However, when there is no specific equation, Eq. (3) is a reasonable tool to get an idea of the expected TRS value, calculated quickly and easily. For example, taking the extreme cases from Table 1, the sweet potato Chao1 presented a TRS_{Exp} value of 14.62% and TRS_{Eq} value of 18.65%. Although there is a 4.03% difference between them, with only a moisture analysis and Eq. (3) it is known that the TRS value should not be between 25 – 35%. Similarly, the DCY sweet potato variety presented a TRS_{Exp} value of 33.37% and TRS_{Eq} value of 38.83% (difference 5.46%), which implies that the TRS should not be expected between 15 – 25%.

There will always be differences between TRS_{Exp} and TRS_{Eq}, because of assumption errors when elaborating the TRS x moisture concept, variability

Table 1. Comparison between the estimates with Eq. (3) (TRS_{Eq}) and the experimental results (TRS_{Exp}). Standard deviations are also given (S_{Exp} and S_{Eq}).

Authors	Starch quantification method	Sweet potato	%				
			Moisture	TRS$_{Exp}$	TRS$_{Eq}$	S$_{Exp}$	S$_{Eq}$
Present work	Acid hydrolysis and HPLC quantification	Amélia	70.57	21.92	26.31	0.48	
		Rubissol	70.69	26.95	26.17	0.57	
		Cuia	62.34	29.09	35.53	0.07	
		Market 1	67.83	25.60	29.38	2.42	
		Market 2	69.30	22.65	27.73	0.68	
Zhang et al. (2002)	Megazyme total starch assay kit	Hi-dry	66.5	29.01	30.87	0.31	
		Yan1	70.7	20.88	26.16	0.32	
		Chao1	77.4	14.62	18.65	0.69	
		Yubeibai	72.1	18.81	24.59	0.57	
		Guang7	73.1	20.32	23.47	1.10	
		Guang16	75.7	16.00	20.56	0.47	
Zhang et al. (2011)	Acid hydrolysis and HPLC quantification	-	61.5	35.94	36.47	-	1
Srichuwong et al. (2012)	Megazyme total starch assay kit	K159	59.5	32.39	38.72	0.57	
		DCY	59.4	33.37	38.83	1.11	
Lareo et al. (2013)	Hydrolysis with Megazyme's enzymes and HPLC quantification by NREL method (Sluiter and Sluiter, 2005)	-	73.1	20.18	23.47	1.64	
Dewan et al. (2013)	Hydrolysis with Megazyme's enzymes and HPLC quantification by NREL method (Sluiter and Sluiter, 2005)	-	78.4	20.08	17.53	1.07	

between the sweet potatoes used for the curve construction and for the TRS prediction, and due to experimental errors when determining TRS_{Exp}. Despite these points, the TRS x moisture relation is a valid and interesting proposal for estimates. In addition, other researchers can take advantage of the idea and determine the parameters a and b (Eq. (2)) for their specific cases, thus increasing the estimation accuracy. Once one has the proper equation, the work becomes simpler, requiring only the moisture analysis.

The moisture analysis may be performed by a thermogravimetric technique, which is easy, cheap and does not generate chemical waste. Furthermore, the thermogravimetric method affords the most accurate results, which is why it is often applied as a reference to validate new indirect techniques (Kaatze and Hübner, 2010). Also, in order to accelerate the thermogravimetric analysis, the sample drying can be done in a microwave oven. Bouraoui et al. (1993) presented successful approaches for a variety of food products when using the microwave drying method.

Electromagnetic techniques can also be used to determine the moisture. They have rapidly developed because of their potential to provide a continuous, fast and stable moisture monitoring in real time. Some of them also have the advantage of being non-invasive. More details can be found in Kaatze and Hübner (2010).

Sweet Potato Mash and Ethanol Potential Equation

The following deduction was done for an ideal condition, where it is assumed that the starch is completely hydrolyzed, and all sugars are converted into ethanol.

We define the variable x_{SWP}, which represents the ratio of sweet potato mass (in kg) to the volume of added dilution water (in L). So, the amount of available sugars in the medium can be calculated as (TRS/100) × x_{SWP}. Considering that 92 g of ethanol is produced by 180 g of glucose/fructose (Figure 3) and that the ethanol density is 0.789 kg/L, it is possible to calculate the ethanol total volume (v_{ETH}):

$$v_{ETH}(L) = \left(\frac{1}{0.789}\right)\left(\frac{92}{180}\right)\left(\frac{TRS}{100}\right)x_{SWP} \qquad (4)$$

$$v_{ETH}(L) = \left(\frac{92}{142.02}\right)(0.01TRS)x_{SWP} \qquad (5)$$

The total volume (v_T) is calculated considering the dilution water (H_2O_{dil}), the sweet potato moisture (x_{MST}, in %), the ethanol volume (v_{ETH}), and the water consumed in the hydrolysis reaction ($H_2O_{cons\,hyd}$):

$$v_T(L) = H_2O_{dil} + \left(\frac{x_{MST}}{100}\right)x_{SWP} + v_{ETH} - H_2O_{cons\,hyd} \qquad (6)$$

H_2O_{dil} is equal to 1, since x_{SWP} is the mass (kg) in relation to 1 L of dilution water. In addition, the water consumed in the hydrolysis was assumed as (18/180) (0.01TRS)x_{SWP} (Figure 1). Considering Eq. (5), Eq. (6) becomes:

$$v_T(L) = 1 + \left(\frac{x_{MST}}{100}\right)x_{SWP} + \left(\frac{92}{142.02}\right)(0.01TRS)x_{SWP} - \\ - \left(\frac{18}{180}\right)(0.01TRS)x_{SWP} \quad (7)$$

$$v_T(L) = 1 + \left(\frac{x_{MST}}{100}\right)x_{SWP} + \left(\frac{77.8}{142.02}\right)(0.01TRS)x_{SWP} \quad (8)$$

It is possible to estimate the ethanol content of a given fermentation (x_{ETH}) with Eq. (5) and (8) through v_{ETH}/v_T. Taking this relation and multiplying by 100 to transform into %, the result is:

$$x_{ETH}(\%, v/v) = 100\frac{\left(\frac{92}{142.02}\right)(0.01TRS)x_{SWP}}{1 + \left(\frac{X_{MST}}{100}\right)x_{SWP} + \left(\frac{77.8}{142.02}\right)(0.01TRS)x_{SWP}} \quad (9)$$

If the numerator and denominator are multiplied by 142.02:

$$x_{ETH}(\%, v/v) = \frac{9200(0.01TRS)x_{SWP}}{142.02 + 1.4202x_{MST}x_{SWP} + 77.8(0.01TRS)x_{SWP}} \quad (10)$$

Replacing TRS by Eq. (3) the result is:

$$x_{ETH}(\%, v/v) = \frac{9200(-0.01121x_{MST} + 1.054)x_{SWP}}{142.02 + 1.4202x_{MST}x_{SWP} + 77.8(-0.01121x_{MST} + 1.054)x_{SWP}} \quad (11)$$

Effect of Sweet Potato Moisture and Concentration on the Ethanol Potential Yield

As the ethanol potential depends on the sweet potato concentration (x_{SWP}) and on the moisture (x_{MST}) (Eq. (11)), it is interesting to evaluate the influence of these variables.

There are studies on ethanol production with high concentrations of the feedstock. Thus, the evaluation of the x_{SWP} influence is important for this subject. The particular condition of high feedstock concentration is called Very High Gravity (VHG) fermentation. Working with VHG is interesting because of the following advantages: lower water consumption for dilution, higher ethanol concentration in the wine, reduction of effluent, lower power consumption (since it works with less mass) and the need for smaller vessels (since it works with lower volumes).

An ethanol content of 10 – 12% (v/v) is the range usually observed in the wine of most ethanol distilleries over the world, whereas the VHG fermentation results for different starchy raw materials are between 15 – 17% (v/v) (Puligundla et al., 2011). Additionally, it is interesting to mention that Thomas and Ingledew (1992) achieved an ethanol level of 21% (v/v) using wheat mash.

Therefore, to evaluate how increasing the sweet potato concentration in the mash and the sweet potato moisture affect the ethanol potential results of Eq. (11) were plotted and presented in Figure 6.

As seen in Figure 6, the behavior is nonlinear for x_{SWP} and linear for x_{MST}. There is a maximum point in the non-linear part, which happens when the x_{SWP} tends to infinity or when no dilution water is added (the ethanol production is direct from sweet potatoes). Considering this condition, in Eq. (11) the maximum is found by removing "142.02" from the denominator (which corresponds to the dilution water contribution). In fact, 1 L of dilution water was multiplied by the factor of 142.02, as seen in the deduction of Eq. (6) to Eq. (11). So, when the "142.02" is removed, the variable x_{SWP} can be eliminated and the resulting equation depends only on the moisture (Eq. (12)).

$$x_{ETH}(\%, v/v) = 100\frac{-1.031x_{MST} + 96.98}{0.548x_{MST} + 82.01} \quad (12)$$

It is important to know that the maximum given by Eq. (12) is an ideal condition informing that a given fermentation cannot exceed that value. In practice, the major limitation is the high viscosity of the medium, which is typical when using root and tuber mashes (Cao et al., 2011). The high viscosity causes handling difficulties during the process and may lead to some negative effects, such as incomplete hydrolysis of the starch, low fermentation efficiency, and problems in the solid-liquid separation.

When the mash is prepared, beyond the starch, other sweet potato components are also present. The cell wall constituents are responsible for the high viscosity of the fermented mash. They are cellulose, hemicellulose and pectic substances. Nevertheless,
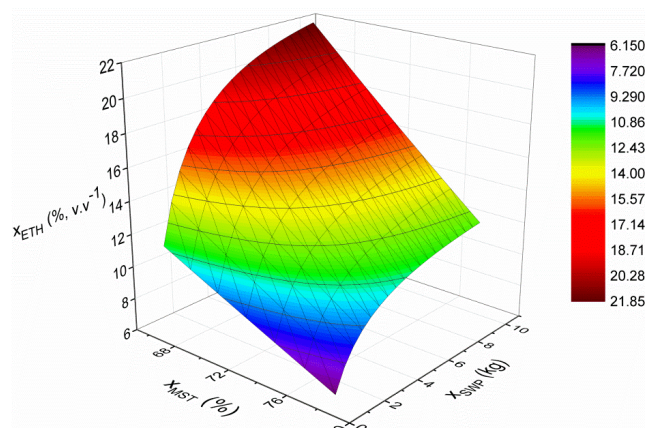

Figure 6. Ethanol potential as a function of the sweet potato moisture (x_{MST}) and the concentration (x_{SWP} (kg): 1 L of dilution water).

some studies have reported good fermentative results when those components were degraded with an enzymatic treatment.

Regarding works that used sweet potatoes, Zhang et al. (2011) reached the ethanol content of 16% (v/v) by using a xylanase (an hemicellulose disintegrating enzyme), Cao et al. (2011) 15.5% (v/v) by using a cellulase, and Srichuwong et al. (2012) 15.1 – 15.4% (v/v) by working with a mixture of enzymes active upon pectic substances, hemicellulose, and cellulose.

Also, it is important to comment that the x_{SWP} has a major influence on the initial concentrations. After that there is a stabilization, and then increasing the sweet potato concentration no longer implies in significant gains in the ethanol potential (as shown in Figure 6). This finding should be taken into account when someone decides to work with very high sweet potato concentrations to check if the concentration increase would be an advantage. On the other hand, by evaluating the influence of the variable x_{MST}, it is noted that it is always desirable to work with drier sweet potatoes, since they lead to higher ethanol potential contents.

Considerations on the Proposal Application to Other Feedstocks

In the present study, the sweet potato was selected for the reasons explained in the introduction section. However, it is worth a brief mention of other starchy materials. Additionally, beyond corn, wheat and cassava are also used in the industrial production of ethanol in some countries (Wheat: Canada and France; Cassava: China and Thailand) (Gupta and Verma, 2015).

It is supposed that the principle presented in this study is also applicable to other starchy feedstocks since their dry matter consists predominantly of carbohydrates (mostly starch). Estimates of the compositions are given in Table 2.

Also, regarding other feedstocks, we found some studies using the hydrostatic balance method applied to cassava (as in Carvalho et al. (2007) and Tinini et al. (2009)) where fresh cassava is weighed dry (DW) and weighed immersed in water (WW). The relation of these two measurements provides the relative density [DW/(DW – WW)], which is then correlated with the dry matter and the starch content. Thus, this is another

method to relate the starch and the dry matter (in this case for cassava and based on the relative density). It is also an interesting and straightforward method. However, it presented a lack of accuracy and precision when estimating the dry matter, as shown in the study of Carvalho et al. (2007).

Finally, although our method is promising for other starchy feedstocks, it is noteworthy the need for further research to obtain more data (considering quality and sufficient quantity), to construct the TRS and ethanol curves to validate the hypothesis.

CONCLUSIONS

The starch content is one of the main factors that determine the final ethanol production, since the sweet potato is mainly composed of starch and moisture. Thus, assuming a certain error, other constituents can be considered constant, leading to a simple function where the TRS value depends only on the moisture.

Considering the relation TRS x moisture, the ethanol potential of a fermentation could be estimated. It was shown that the ethanol potential increases nonlinearly with the sweet potato concentration. So, the higher viscosity and the ethanol gain should be taken into account when increasing the sweet potato concentration. Also, the sweet potato moisture is essential because drier sweet potatoes result in higher ethanol potentials, i.e., it is more desirable to work with drier sweet potatoes than increasing their concentration in the mash.

The equations presented in this paper are a proposal. When greater precision is desired, one can apply the central idea to construct new equations for more specific cases. The suggested method has the advantages that the moisture measurement is simple, involves cheaper apparatus and does not generate chemical waste.

Finally, this work uses a different approach, showing that simple data can be explored to provide more information than we usually expect. It begins from the simple relationship TRS x moisture until obtaining a 3D graph that shows the ethanol potential. So far, we have not found another study presenting the behavior of the ethanol potential in relation to the feedstock moisture and the concentration in the mash. Once the equation is available, it is possible to use it in different practical cases. Schweinberger et al. (2016) used the equation presented here to simulate an ethanol micro plant. Then, several scenarios were evaluated varying the sweet potato moisture.

ACKNOWLEDGMENTS

Table 2. Carbohydrate and moisture contents in different starchy feedstocks (data on wet basis).

Feedstock	Carbohydrates	Moisture
	(%)	
Cassava	36[a]	62[a]
Yam	23[a]	73[a]
Corn	66[b]	20 – 23[c]
Wheat	65[b]	15 – 17[c]

[a]Source: Lima et al. (2006).
[b]Source: Machado and Abreu (2006).
[c]Source: Silva et al. (2005).

Education Personnel (CAPES), and the Federal University of Rio Grande do Sul (UFRGS).

ABBREVIATIONS

AOAC	Association of Official Analytical Chemists
DMSO	dimethyl sulfoxide
DNS	3,5-dinitro salicylic acid
Embrapa	Brazilian Agricultural Research Corporation
GIMSCOP	Group of Intensification, Modelling, Simulation, Control, and Optimization of Processes
HPLC	High-Performance Liquid Chromatography
RS	Rio Grande do Sul (Brazilian State)
v/v	volume/volume
w/v	weight/volume
w/w	weight/weight

REFERENCES

Betemps, C., Pinto, E., Fepagro e Embrapa lançam nova cultivar de batata-doce na Expoagro. Embrapa (2016). Avaliable at: https://www.embrapa.br/busca-de-noticias/-/noticia/10803441/fepagro-e-embrapa-lancam-nova-cultivar--de-batata-doce-na-expoagro.

Bouraoui, M., Richard, P. and Fichtali, J., A review of moisture content determination in foods using microwave oven drying. Food Research International, 26, 49-57 (1993). https://doi.org/10.1016/0963-9969(93)90105-r

Bradbury, J. H. and Holloway, W. D., Chemistry or Tropical Root Crops: significance for nutrition and agriculture in the Pacific. ACIAR Monograph, No. 6 (1988).

Cao, Y., Tian, H., Yao, K. and Yuan, Y., Simultaneous saccharification and fermentation of sweet potato powder for the production of ethanol under conditions of very high gravity. Front Chem Sci Eng, 5, 318-324 (2011). https://doi.org/10.1007/s11705-010-1026-3

Carvalho, P. R. N., Mezette, T. F., Valle, T. L., Carvalho, C. R. L., Feltran, J. C., Avaliação da Exatidão, Precisão e Robustez do Método de Análise do Teor de Matéria Seca de Mandioca (*Manihot esculenta, Crantz*) por Meio da Determinação do Peso Específico (Balança Hidrostática). Revista Raízes e Amidos Tropicais, 3, 1-4, (2007).

Castro, L. A. S. de and Becker, A., Batata-doce BRS Amélia. Embrapa, Pelotas (2011a).

Castro, L. A. S. de and Becker, A., Batata-doce BRS Cuia. Embrapa, Pelotas (2011b).

Castro, L. A. S. de and Becker, A., Batata-doce BRS Rubissol. Embrapa, Pelotas (2011c).

Cui, S. W., Food Carbohydrates: Chemistry, Physical Properties, and Applications. Taylor & Francis Group (2005).

Dewan, A., Li, Z., Han, B. and Karim, M. N., Saccharification and Fermentation of Waste Sweet Potato for Bioethanol Production. Journal of Food Process Engineering, 36, 739-747 (2013). https://doi.org/10.1111/jfpe.12042

Duvernay, W. H., Chinn, M. S. and Yencho, G. C., Hydrolysis and fermentation of sweetpotatoes for production of fermentable sugars and ethanol. Industrial Crops and Products, 42, 527-537 (2013). https://doi.org/10.1016/j.indcrop.2012.06.028

EIA, International Energy Outlook 2016. U.S. Energy Information Administration (EIA) (2016). Available at: https://www.eia.gov/forecasts/ieo/pdf/0484(2016).pdf.

Gupta, A. and Verma, J. P., Sustainable bio-ethanol production from agro-residues: A review. Renewable and Sustainable Energy Reviews, 41, 550-567 (2015). https://doi.org/10.1016/j.rser.2014.08.032

Huang, Y., Jin, Y., Shen, W., Fang, Y., Zhang, G., Zhao, H., The use of plant cell wall–degrading enzymes from newly isolated *Penicillium ochrochloron* Biourge for viscosity reduction in ethanol production with fresh sweet potato tubers as feedstock. Biotechnology and Applied Biochemistry, 61, 480-491 (2014). https://doi.org/10.1002/bab.1190

IBGE, Produção Agrícola Municipal. Instituto Brasileiro de Geografia e Estatística (IBGE) (2016). Available at: http://www.sidra.ibge.gov.br/bda/pesquisas/pam/.

Kaatze, U. and Hübner, C., Electromagnetic techniques for moisture content determination of materials. Measurement Science and Technology, 21 (2010).

Lareo, C., Ferrari, M., Guigou, M., Fajardo, L., Larnaudie, V., Ramirez, M. and Martinez-Garreiro, J., Evaluation of sweet potato for fuel bioethanol production: hydrolysis and fermentation. SpringerPlus, 2, 1-11 (2013). https://doi.org/10.1186/2193-1801-2-493

Lima, D. M., Colugnati, F. A. B., Padovani, R. M., Rodriguez-Amaya, D. B., Salay, E., Galeazzi, M. A. M, Tabela Brasileira de Composição de Alimentos – TACO. Núcleo de Estudos e Pesquisas em Alimentação – NEPA/UNICAMP, Campinas (2006).

Machado, C. M. M. and Abreu, F. R. E., Produção de Álcool Combustível a Partir de Carboidratos. Revista de Política Agrícola, 3, 64-78 (2006).

Masiero, S. S., Microusinas de etanol de batata-doce: viabilidade econômica e técnica. Master dissertation, Federal University of Rio Grande do Sul (UFRGS) (2012).

Oboh, S., Ologhobo, A. and Tewe, O., Some aspects of the biochemistry and nutritional value of the sweet potato (Ipomea batatas). Food Chemistry, 31, 9-18 (1989). https://doi.org/10.1016/0308-8146(89)90146-5

Puligundla, P., Smogrovicova, D., Obulam, V. S. R. and Ko, S., Very high gravity (VHG) ethanolic brewing and fermentation: A research update. Journal of Industrial Microbiology and Biotechnology, 38, 1133-1144 (2011). https://doi.org/10.1007/s10295-011-0999-3

Schweinberger, C. M., Inovação e Otimização no Processo de Produção de Etanol a partir de Batata-Doce. Ph. D. Thesis, Federal University of Rio Grande do Sul (UFRGS) (2016).

Schweinberger, C. M., Putti, T. R., Susin, G. B., Trierweiler, J. O. and Trierweiler, L. F., Ethanol production from sweet potato: The effect of ripening, comparison of two heating methods, and cost analysis. The Canadian Journal of Chemical Engineering, 94, 716-724 (2016). https://doi.org/10.1002/cjce.22441

Silva, J. de S. e, Nogueira, R. M., Roberto, C. D., Tecnologias de secagem e armazenagem para a agricultura familiar. Suprema Gráfica e Editora, Visconde do Rio Branco, MG (2005).

Sluiter, A. and Sluiter, J., Determination of Starch in Solid Biomass Samples by HPLC. Technical Report NREL/TP-510-42624 (2005).

Srichuwong, S., Orikasa, T., Matsuki, J., Shiina, T., Kobayashi, T. and Tokuyasu, K., Sweet potato having a low temperature-gelatinizing starch as a promising feedstock for bioethanol production. Biomass and Bioenergy, 39, 120-127 (2012). https://doi.org/10.1016/j.biombioe.2011.12.023

Thomas, K. C. and Ingledew, W. M., Production of 21% (v/v) ethanol by fermentation of very high gravity (VHG) wheat mashes. Journal of Industrial Microbiology, 10, 61-68 (1992). https://doi.org/10.1007/bf01583635

Tinini, R. C. dos R., Coelho, S. R. M., Monteiro, V. H., Figueiredo, P. R. A. de, Schoeninger, V., Caracterização do Teor de Amido em Raízes de Mandioca para Agroindústrias de Extração de Fécula. Anais do I Seminário Internacional de Ciência, Tecnologia e Ambiente, Unioeste, Cascavel, PR (2009).

Zhang, L., Zhao, H., Gan, M., Jin, Y., Gao, X., Chen, Q., Guan, J. and Wang, Z., Application of simultaneous saccharification and fermentation (SSF) from viscosity reducing of raw sweet potato for bioethanol production at laboratory, pilot and industrial scales. Bioresource Technology, 102, 4573-4579 (2011). https://doi.org/10.1016/j.biortech.2010.12.115

Zhang, Z., Wheatley, C. C. and Corke, H., Biochemical changes during storage of sweet potato roots differing in dry matter content. Postharvest Biology and Technology, 24, 317-325 (2002). https://doi.org/10.1016/s0925-5214(01)00149-1