Supplementary Material I

Yield of Ethanol per Unit Area of Cultivation

Starch and sugar are the first generation (1G) feedstocks and the most abundant renewable carbon sources and are more readily digestible for conversions to biofuels than cellulosic feedstocks which are the second generation (2G) raw material. Cultivations of different crops gain different quantities of yields per unit area. Bioethanol can be produced from various kinds of crops.

However, when ethanol yields per unit area of cultivations are compared, cassava is the highest potential crop to gain the highest yield. Average yields of cassava, sugar beet, sweet potato, wheat, sugar cane, rice, sorghum, and starchy corn are about 31.25, 56.00, 30.00, 9.00, 62.50, 7.31, 6.25, and 6.00 MT/ha/year (metric ton/ha/year), respectively. Carbohydrate contents (as starch or sugar) of those crops are approximately 28.0, 14.0, 24.5, 70.0, 10.5, 80.0, 70.0, and 70.0 (% w/w), respectively. Theoretical yields of bioethanol per unit area of cultivation per annum of those crops could be 4.95, 4.44, 4.16, 3.57, 3.53, 3.31, 2.48, and 2.38 MT/ha/year (tons of ethanol/ha/year), respectively. They were calculated from a ton of starch produces 566 kg of ethanol, and a ton of sucrose sugar produces 538 kg of ethanol.

Table I shows yields of different crops per unit area per year, starch or sugar content in each crop, theoretical yield coefficients, $Y'_{p/s}$ (mass of ethanol/mass of starch or sugar) produced stoichiometrically, and calculated yields of ethanol per unit area per annum.

Feedstocks (Crops)	Yield/rai (kg/rai)	Yield/ha (kg/ha)	No of crops (per year)	Yield/ha (MT/ha)	Yield/ha (MT/ha/year)	Starch or sugar content (%)	Starch or sugar (MT/ha/year)	Yield coefficient (Y'p/s)	EtOH/ha/year (MT/ha/year)	Grading
Cassava	5,000	31,250	1	31.25	31.25	28.0	8.75	0.566	4.95	a
Beet root	n/a	28,000	2	28.00	56.00	14.0	7.84	0.566	4.44	b
Sweet potato	n/a	15,000	2	15.00	30.00	24.5	7.35	0.566	4.16	bc
Wheat	n/a	4,500	2	4.50	9.00	70.0	6.30	0.566	3.57	c
Sugar cane	10,000	62,500	1	62.50	62.50	10.5	6.56	0.538	3.53	c
Rice	585	3,656	2	3.66	7.31	80.0	5.85	0.566	3.31	cd
Sorghum	500	3,125	2	3.13	6.25	70.0	4.38	0.566	2.48	e
Starchy corn	n/a	3,000	2	3.00	6.00	70.0	4.20	0.566	2.38	e

Notes:

− “Rai” is the Thai’s unit area.; ha is hectare.; MT is metric ton.; EtOH means ethanol.; $Y'_{p/s}$ is theoretical yield coefficients of ethanol; where 0.566 and 0.358 g/g are from starch and sugar raw material, respectively.

− Yields per unit area of each crop in column 2 and 3 are the world’s average yields from on-line searches (details not specified or shown herein).

− Percentages of starch or sugar content are in fresh feedstock for cassava, sugar beet, sweet potato, and sugar cane, and in dry feedstock for wheat, rice, sorghum, and starchy corn.

− Grading just differentiates the difference in their ethanol yields per unit area per year.

Supplementary Material II

Degree of Starch Conversion, Hydrolysis of Starch to Release Glucose (molecules) and Its Yield Coefficient

The degree of conversion of raw starch to glucose was calculated as the percentage of glucose released from the raw cassava starch hydrolysis using the equation:

$$Degree\ of\ \ conversion\ (\%) = \frac{Glucose\ released\ (g/L)}{Raw\ cassava\ starch\ used\ (g/L) \times 1.11 (g/g)} \times 100 \qquad (1)$$

where 1.11 (g/g) is the 1.11 g theoretical (stoichiometric) yield of glucose from 1.00 g of starch, calculated from $\frac{n(C_6H_{12}O_6)}{(C_6H_{12}O_6)_n - ((n-1) \times H_2O)}$, where $C_6H_{12}O_6$ is the glucose with a molecular weight (MW) of 180.156 g/mol; H_2O is the water with a MW of 18.015 g/mol, and n is the number of glucose molecules of glucose and of starch or degree of polymerization (Dp). For example* (column 4, highlighted), if a starch chain polymer of 1,000 glucose molecules was completely hydrolyzed, where n = 1,000 molecules, then substitute into the above term to obtain $\frac{1{,}000(180.156)}{((180.156)_{1{,}000}) - ((1{,}000-1) \times 18.015)} = 1.11$ g/g. Although the n or Dp values vary (see low 2), the number of 1.11 g/g values is still obtained as a constant (see Table below).

Table I shows different starch polymers depending on their degree of polymerization (DP) or number of glucose molecules (n) and their molecular weights; glucose yields and their molecular weights; and theoretical yield coefficients, $Y'_{p/s}$ of glucose from each starch polymer hydrolysis.

Starch Polymers	Starch	Starch	Starch*	Starch	Starch	Starch
Degree of Polymerization, Dp or n/	Dp 10,000	Dp 5,000	Dp 1,000	Dp 500	Dp 100	Dp 50
Degree of Polymerization	10,000	5,000	1,000	500	100	50
MW (g/mol) of starch[S]	1,621,578	810,798	162,174	81,258	16,234	8,126
Hydrolysis to release glucose (molecules)	10,000	5,000	1,000	500	100	50
(MWof glucose of 180.156 x no. of glucose molecule)[P]	1,801,560	900,780	180,156	90,078	18,016	9,008
MW fraction = MW of glucose /MW of starch, (P/S)						
or the yield coefficient, $Y'_{p/s}$ (g/g)	1.11	1.11	1.11	1.11	1.11	1.11
One gram of starchs or their polymers relase						
glucose (per g)	1.11	1.11	1.11	1.11	1.11	1.11
On molar concentration basis						
Conclusions	One gram of starch produces 1.11 g of glucose.					

Note: Theoretical yield coefficient, $Y'_{p/s}$ is the stoichiometric yield of glucose produced per unit of starch hydrolyzed. The $Y'_{p/s}$ is calculated from P/S, where P is the (MWof glucose of 180.156 × number of glucose molecule) in row 6, and S is the MW of starch in row 4.
