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Models for the Biological Production of Glycerol and Biosurfactants from Potato-Processing Industry Residuals

Scientific Note

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INTRODUCTION

The fermentative production of valuable chemicals from biomass-derived substrates (e.g., glucose) represents the historical essence of industrial biotechnology (*1*). This is illustrated by the array of chemical products that have been biologically produced and marketed, including numerous antibiotics (such as penicillin), organic acids (such as lactic, citric, and acetic acids), and alcohols (such as ethanol) (*1–4*). In the past, the capabilities of microorganisms to produce useful chemicals have been, at best, sporadically utilized. The primary products produced biotechnologically today are antibiotics and ethanol (for fuel and beverage uses). Many years ago, glycerol (also known as glycerin or glycerine) was produced at an industrial scale by fermentative means (*1,5,6*). Such production was stimulated by increased demand for glycerol and diversion of petroleum resources during wartime. Biotechnological production of glycerol ceased during peacetime, because the undeveloped and inefficient

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biotechnological processes that were used could not compete with inexpensive petroleum and natural feedstocks and the efficient and well-developed methods by which to convert them to commodity chemicals. Industrial glycerol production by biological conversion of sugar has not occurred since that time (*1,7*). However, several factors, including the historical uncertainty of petroleum price and supply, the demand for environmentally safe industrial processes, and the vast development and improvement of bioprocess technology, suggest that the time for taking advantage of bioprocesses that produce marketable chemicals is near (*3,8–13*). Glycerol is a good candidate for such a chemical, because it is biologically produced from glucose in good yield (0.5 g glycerol/g glucose), the market is very large (> 140 million kg consumed/yr in the US), and future market growth is predicted to be good because of the widespread usage of glycerol and its historically strong market (*3,8,14*). Based on this, recent research has involved developing patentable technologies for the conversion of corn starch to glycerol; these efforts have progressed to the pilot plant scale (*15*).

Biosurfactants also represent chemicals that might be profitably produced from biomass. Biosurfactants are produced from glucose and other fermentable sugars by many different microorganisms (*16*). The US has a vast surfactant market whose growth is stable and predictable (*17*). Surfactants currently marketed are derived from petrochemicals and from natural sources of fatty acids; biosurfactants (such as those produced by *Bacillus subtilis, Bacillus licheniformis,* and *Candida bombicola*) are not currently commodities (*18–20*). Several potential uses for biosurfactants have been proposed, including microbial enhanced oil recovery, and research directed at defining potential is in progress (*17,18,21*). Biosurfactants have unique characteristics that differentiate them from chemically synthesized surfactants. One of these is the ease with which biosurfactants are biologically degraded; this property may be important with respect to applications where environmental release of surfactant material is a consideration. The introductory markets for biosurfactants are likely to be in the area of specialty chemicals, rather than high-volume commodity chemicals, because of the high predicted cost of production (*20*). Process development has the potential for considerably lowering production costs of biosurfactants; this could open up commodity markets.

Sources of biomass-derived fermentable sugar (e.g., glucose) that have been used for industrial fermentations have varied, including waste products (e.g., molasses) and starch crops (e.g., corn) (*1–3,8*). In the US, corn and molasses represent the two biomass sources that have been most widely used and researched with respect to industrial fermentative production of chemicals (*2,8*). However, the US has a vast capacity for supplying many other comparable sources of biomass that might be profitably utilized for a similar purpose (22–25). One of these sources is potato-processing waste, composed of starch-containing pieces of potato material that are rejected in the process of making commercial potato products, such as french fries, hash browns, and dehydrated potatoes (*26*). This waste, or residual material, can be quite voluminous, and its disposal is frequently an economic liability to the processing industry. Methods of handling solid potato waste have included sale as animal feed (the most common mechanism), fermentation to ethanol (only small scale, to date), and landfilling (for a disposal fee) (*3,26*). Because of the intrinsically low price of waste and the high starch content, potato-processing residuals could be an ideal feedstock for the fermentative production of marketable chemicals, such as glycerol and biosurfactants. This study demonstrates the feasibility of such an endeavor in terms of potential chemical production levels and also suggests areas where successful research would improve chances for eventual economic success.

RESULTS AND DISCUSSION

Glycerol Production from Total US Potato Waste

If all of the solid potato-processing waste produced in the US today were to be biologically converted to glycerol, a vast amount would be produced that could rival current production levels (Table 1). Values in Table 1 represent worst-, average-, and best-case scenarios. The worst-case scenario would be a glycerol level of 15 million kg/yr with a potential 6.8% displacement of current glycerol production. The best-case scenario, which assumes that research would result in increasing the experimental yield up to the theoretical potential, would be a production level of 655 million kg/yr, which would completely saturate the current and projected needs for glycerol. The most realistic expectation for an endeavor in the near future is probably represented by glycerol produced at 67.9 million kg/yr (30.6% displacement), based on (1) average production levels of reducing sugars from potato waste and (2) glycerol production at the currently observed experimental yield (Table 1).

Biosurfactant Production from Total US Potato Waste

Projected production of the biosurfactants surfactin and lichenysin from total waste is low, ranging from 301,000 to 11.9 million kg/yr. These values represent 0.03–1.2% of current industrial surfactant demand. Low production levels are primarily the result of the very low experimental yields observed for these surfactants. Increase of these yields by at least 10-fold should be attainable using microbial strain development and improvements in surfactant purification processes; these areas have not undergone significant research in the field of biosurfactant science.

Table 1
Projected Production of Total Reducing Sugars (TRS), Glycerol, and Biosurfactants from Total US Potato-Processing Residuals (Values in kg/yr)

	Minimum	Average	Maximum
US production of potatoes[1]	1.38×10^{10}	1.62×10^{10}	1.84×10^{10}
Potatoes used in food processing[2]	6.89×10^{9}	8.10×10^{9}	9.22×10^{9}
Processing residuals[3]	3.45×10^{8}	8.10×10^{8}	2.21×10^{9}
Dry matter in residuals[4]	4.48×10^{7}	1.70×10^{8}	7.97×10^{8}
Starch in dry matter[5]	2.69×10^{7}	1.19×10^{8}	6.37×10^{8}
Sucrose in dry matter[6]	1.12×10^{5}	1.28×10^{6}	1.20×10^{7}
Free reducing sugars in dry matter[7]	1.12×10^{5}	2.13×10^{6}	2.39×10^{7}
Reducing sugars from sucrose in dry matter[8]	1.18×10^{5}	1.35×10^{6}	1.26×10^{7}
Glucose from starch[9]	2.99×10^{7}	1.32×10^{8}	7.08×10^{8}
TRS from residuals[10]	3.01×10^{7}	1.36×10^{8}	7.45×10^{8}
Glycerol from TRS, experimental yield[11]	1.50×10^{7}	6.79×10^{7}	3.72×10^{8}
Glycerol from TRS, theoretical yield[12]	2.65×10^{7}	1.20×10^{8}	6.55×10^{8}
Percentage of current industrial glycerol production (experimental yield)[13]	6.8%	30.6%	167.9%
Percentage of current industrial glycerol production (theoretical yield)[13]	11.9%	53.9%	295.4%
Surfactin from TRS[14]	4.82×10^{5}	2.17×10^{6}	1.19×10^{7}
Lichenysin from TRS[15]	3.01×10^{5}	1.36×10^{6}	7.45×10^{6}
Percentage of current industrial surfactant consumption (surfactin)[16]	0.05%	0.2%	1.2%
Percentage of current industrial surfactant consumption (lichenysin)[16]	0.03%	0.1%	0.7%

[1]Min, 1980; avg, 1976–1989; max, 1985 (*28*).
[2]Factor = 0.5 (*26*).
[3]Solid residuals, excluding culled potatoes. Factors = 0.05 (min), 0.1 (avg), 0.24 (max) (*26*).
[4]Factors = 0.13 (min), 0.21 (avg), 0.36 (max) (*26,29–31*).
[5]Factors = 0.6 (min), 0.7 (avg), 0.8 (max) (*26,32*).
[6]Factors = 0.0025 (min), 0.0075 (avg), 0.015 (max) (*26,32*).
[7]Sugars (e.g., glucose) in monomeric form. Factors = 0.0025 (min), 0.0125 (avg), 0.03 (max) (*26,32*).
[8]Factor = 1.0555 (*8*).
[9]Factor = 1.111 (*8*).
[10]Sum of free reducing sugars and those derived from sucrose and starch.
[11]Fermentative production of glycerol based on highest reported experimental yield. Factor = 0.5 (*8*).
[12]Fermentative production of glycerol based on theoretical yield. Factor = 0.88 (*8*).
[13]Factor = 4.5084×10^{-7}. Based on 2.21×10^{8} kg/yr glycerol production capacity in US (*14*).
[14]Factor = 0.016 (*19*).
[15]Factor = 0.01 (*18*).
[16]Factor = 9.9084×10^{-8}. Based on 1.009×10^{9} kg/yr industrial surfactant consumption (*17*).

Table 2
Projected Production of Total Reducing Sugars (TRS), Glycerol, and Biosurfactants from Total Processing Residuals from a Single Potato-Processing Plant (Values in kg/yr)

	Minimum	Average	Maximum
Processing residuals[1]	9.43×10^4	3.86×10^6	2.48×10^7
Dry matter in residuals[2]	1.23×10^4	8.10×10^5	8.92×10^6
Starch in dry matter[2]	7.36×10^3	5.67×10^5	7.14×10^6
Sucrose in dry matter[2]	3.10×10^1	6.07×10^3	1.34×10^5
Free reducing sugars in dry matter[2]	3.10×10^1	1.01×10^4	2.68×10^5
Reducing sugars from sucrose in dry matter[2]	3.20×10^1	6.41×10^3	1.41×10^5
Glucose from starch[2]	8.18×10^3	6.30×10^5	7.93×10^6
TRS from residuals[2]	8.24×10^3	6.46×10^5	8.34×10^6
Glycerol from TRS, experimental yield[2]	4.12×10^3	3.23×10^5	4.17×10^6
Glycerol from TRS, theoretical yield[2]	7.25×10^3	5.69×10^5	7.34×10^6
Percentage of current industrial glycerol production (experimental yield)[2]	0.002%	0.1%	1.9%
Percentage of current industrial glycerol production (theoretical yield)[2]	0.003%	0.2%	3.3%
Surfactin from TRS[2]	1.32×10^2	1.03×10^4	1.33×10^5
Lichenysin from TRS[2]	8.20×10^1	6.46×10^3	8.34×10^4
Percentage of current industrial surfactant consumption (surfactin)[2]	0.00001%	0.001%	0.01%
Percentage of current industrial surfactant consumption (lichenysin)[2]	0.00001%	0.001%	0.01%

[1]Values are actual outputs from three anonymous plants in the northwest US. Minimum value represents sliver waste from a french fry plant. Average value is the sum of filtercake solids, peel waste, and culled potatoes from a general product plant. Maximum value is hopper waste from a general product plant.
[2]*See* relevant footnotes in Table 1.

Glycerol and Biosurfactant Production from Single Plant-Generated Potato Waste

The amount and type of potato waste generated from a single plant vary based on the plant size and on the types of potato products that are generated. Table 2 exhibits worst-, average-, and best-case scenarios based on waste from three different types of plants that vary in waste composition and output. The significance of determining the production levels of glycerol and biosurfactants from the waste stream of a single plant lies in the notion that a proposed chemical production plant might actually be located adjacent to a potato plant, thus minimizing waste transportation costs and therefore reducing product costs. Results indicated that, at the worst, a small plant could generate glycerol at 4120 kg/yr and biosurfactant at 82 kg/yr. At best, a large plant could generate glycerol at 7.34 million kg/yr and biosurfactant at 133,000 kg/yr. Realistic near-term projections for a medium-sized plant would be glycerol at 323,000 kg/yr and biosurfactant at 10,300 kg/yr. These production levels could be boosted if several potato plants, located in close geographic proximity, supplied a centrally located chemical production plant.

CONCLUSIONS

Results clearly show that potato waste is a viable feedstock for the production of glycerol. The case for biosurfactant is less convincing primarily because of low yields; however, microbial strain development and surfactant purification research may alleviate this constraint. Improvement of experimental yields for glycerol (0.5 g glycerol/g glucose) so that they more closely resemble the theoretical yield (0.88 g glycerol/g glucose) would significantly improve the prospects for glycerol bioproduction, as well. With respect to this, an area of endeavor that might prove to be fruitful would be the re-examination of glycerol production by bacteria, such as *Bacillus subtilis*. Research in this area was conducted many years ago and good yields were observed, but efforts were abandoned before anything conclusive was developed (*27*). Our conclusions concerning glycerol are supported by a recent economic analysis of potential bioproduction of glycerol. The study indicated that an efficient industrial bioprocess could be realistically developed and that such a process would compete favorably with the current petrochemical process (*8*).

In conclusion, this study provides a "user-friendly" general model for defining the potential fermentative production of any chemical from any biomass-containing food-processing waste. Pessimistic, realistic, and optimistic production levels can easily be generated, provided biomass composition and product yield data are available. Additionally, the production data can be used to generate approximate primary product revenue yields based on the current market price of the product. For example, using the current market price of glycerol ($1.56/kg) (*14*), revenues derived from single potato plants would range from $6427 to $11.4 million/yr based on worst and best projected production levels presented in this study.

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