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MACROFUELS

Production of fuels and chemicals from seaweeds

Truus de Vrije[1], Miriam A.W. Budde[1], Xiaoru Hou[2], Anne-Belinda Bjerre[2] and Ana M. López-Contreras[1]

Background

Seaweed biomasses are highly suited as raw material for production of renewable chemicals and fuels because of their special chemical composition (carbohydrates, proteins and minerals) and the possibility of cultivating them at large scale [1]. In the MACROFUELS project, year-round cultivation strategies for seaweeds are being developed. *Laminaria digitata* (Fig. 1) is one of the most well-studied brown seaweed species, and it has the potential to be cultivated in the North Sea. Brown seaweeds are rich in glucans and mannitol that can be converted to a biofuel such as butanol by fermentation by solvent-producing Clostridia [2]. These organisms ferment mannitol and other sugars including glucose and xylose and produce a mix of acetone / isopropanol, butanol and ethanol (ABE/IBE) as end products.

Objectives

- Butanol production from *L. digitata* hydrolysates by Clostridial fermentation at high titers
- Efficient fermentation in seaweed-based medium without addition of external enzymes or nutrients

Results

Solvent production from L. digitata *hydrolysate*

Butanol was produced from sugars in *Laminaria digitata* hydrolysate (Table 1) by 3 *Clostridium* spp. up to 6.7 g/l (Table 2). All main sugars including oligomeric glucan, were metabolized up to 91% of the initial amount. A high conversion efficiency of 0.36 g of IBE/ABE per g of consumed sugars was achieved (approx. 90% of theoretical).

Figure 1. *Laminaria digitata* – photo courtesy and copyright of Prof M. Guiry (AlgaeBase, Ryan Institute, National University of Ireland, Galway, Ireland).

Table 1. Fermentable sugars in *L. digitata* hydrolysate. Hydrolysate was produced by enzymatic hydrolysis of dried *L. digitata* biomass (Teknologisk Institut, [2]).

Component	Content, g/l
Glucose	10.0
Glucan (soluble)	9.9
Mannitol	3.3

Table 2. Solvent production from *L. digitata* hydrolysate. Hydrolysate was supplemented with salts (micro- and macro-elements) and nutrients (yeast extract and *p*-ABA). Yield: g of solvents per g of consumed sugars.

		***C. beijerinckii* NRRL B593**	***C. beijerinckii* NCIMB 8052**	***C. acetobutylicum* ATCC 824**
Substrate consumption	%	78	85	91
Butanol	g/l	5.4	6.7	4.6
Acetone	g/l	-	0.6	0.8
Iso-propanol	g/l	0.6	-	-
Ethanol	g/l	0.1	0.2	0.4
ABE or IBE yield	g/g*	0.31	0.36	0.24

Glucose was preferred over mannitol as carbon source by all 3 strains (Fig. 2). *C. acetobutylicum* consumed glucose very rapidly and degraded more than 95% of the soluble glucan (result not shown). Mannitol consumption was highest by *C. beijerinckii* NCIMB 8052. The rate and final level of solvent production from *L. digitata* hydrolysate was highest by *C. beijerinckii* NCIMB 8052 (Fig. 2, Table 2).

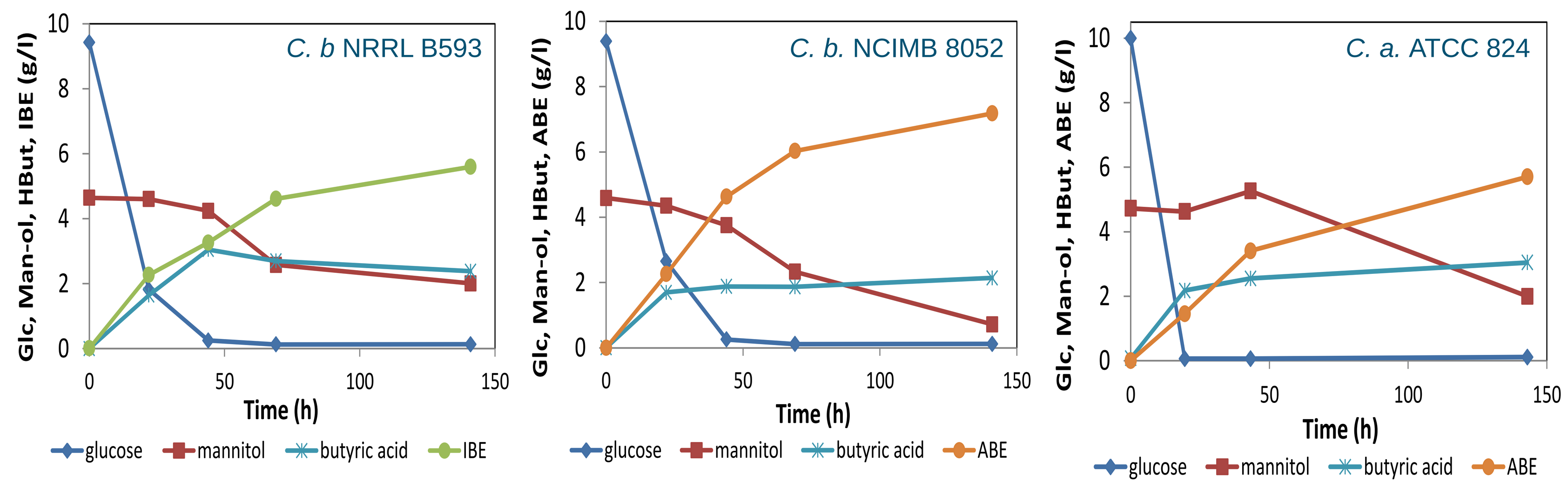

Figure 2. Sugar consumption and solvent production from *L. digitata* hydrolysate by *C. beijerinckii* NRRL B593, *C. beijerinckii* NCIMB 8052 and *C. acetobutylicum* ATCC 824.

No need for hydrolysate enrichment with nutrients

Salts and nutrient additions to the hydrolysate did not affect significantly ABE production by *C. acetobutylicum*. In *C. beijerinckii* cultures extra salts stimulated sugar consumption and ABE production. Extra nutrients did not further enhance ABE production (Table 3).

Table 3. Nutrients and salt requirement of *C. beijerinckii* and *C. acetobutylicum* for production of ABE from substrates in *L. digitata* hydrolysate.

Medium composition		***C. beijerinckii* NCIMB 8052**		***C. acetobutylicum* ATCC 824**	
Hydrolysate	Addition	Substrate consumption %	ABE g/l	Substrate consumption %	ABE g/l
+	-	45	3.6	91	5.5
+	Salts	87	7.2	91	5.7
+	Salts, nutrients	85	7.5	91	5.8

Conclusions

- Butanol was produced from *L. digitata* hydrolysate by all 3 *Clostridium* strains. Hydrolysates with a higher sugar content are necessary to achieve higher butanol concentrations.
- Glucose, glucan and mannitol were utilised up to 91%. Higher rate of mannitol usage is needed to increase the butanol productivity.
- *C. beijerinckii* NCIMB 8052 seems the preferred strain for butanol production from *Laminaria digitata*.

Current research

- ABE fermentation of cultivated *Saccharina latissima* feedstock.
- Adaptation of strains to growth on hydrolysates rich in salts.
- Strategies for the fermentation of seaweed sugars without a separate enzymatic hydrolysis step.

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[1]Wageningen Food and Biobased Research
P.O. Box 123, 6700 AB Wageningen
Contact: ana.lopez-contreras@wur.nl
T + 31 (0)317 48 13 14
www.wur.eu/wfbr

[2]Teknologisk Institut
Gregersensvej, 2630 Taastrup
Contact: xih@teknologisk.dk
T + 45 72 20 20 00
www.teknologisk.dk

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