



HAL
open science

Progress of fermentation methods for bio-succinic acid production using agro-industrial waste by *Actinobacillus succinogenes*

Dwini Normayulisa Putri, Muhamad Sahlan, Ludovic Montastruc, Michel Meyer, Stéphane Negny, Heri Hermansyah

► To cite this version:

Dwini Normayulisa Putri, Muhamad Sahlan, Ludovic Montastruc, Michel Meyer, Stéphane Negny, et al.. Progress of fermentation methods for bio-succinic acid production using agro-industrial waste by *Actinobacillus succinogenes*. 6th International Conference on Energy and Environment Research, Jul 2019, Aveiro, Portugal. pp.234-239, 10.1016/j.egy.2019.08.050 . hal-03631082

HAL Id: hal-03631082

<https://hal.science/hal-03631082>

Submitted on 5 Apr 2022

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



6th International Conference on Energy and Environment Research, ICEER 2019, 22–25 July,
University of Aveiro, Portugal

Progress of fermentation methods for bio-succinic acid production using agro-industrial waste by *Actinobacillus succinogenes*

Dwini Normayulisa Putri^a, Muhamad Sahlan^a, Ludovic Montastruc^b, Michel Meyer^b,
Stéphane Negny^b, Heri Hermansyah^{a,*}

^a Department of Chemical Engineering, Faculty of Engineering, Universitas Indonesia, Depok, West Java, 16424, Indonesia

^b Laboratoire de Génie Chimique, UMR CNRS/INPT/UPS, Université de Toulouse, 31432, France

Received 4 August 2019; accepted 25 August 2019

Abstract

Production of bio-succinic acid through microbial fermentation using agro-industrial waste has been observed extensively. Large scale production is now being considered since bio-succinic acid has broad range application in several industries including agricultural, food, chemical, metal, and pharmaceutical industry as a precursor, ion chelator, and or additive agent. One of promising microbes able to produce bio-succinic acid in large amount and recognized for industrial production is *Actinobacillus succinogenes*. However, several factors still need to be considered in order to optimize the fermentation performance. Therefore, this paper aims to review the progress of fermentation methods and discuss the fermentation strategy focused on the influences of different carbon sources, nitrogen sources, pH regulator, and fermentation configuration to the fermentation parameters including concentration, productivity and yield of bio-succinic acid. As a result, combinations of several fermentation strategies are needed to be performed to realize an efficient and effective bio-succinic acid industry.

© 2019 Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Peer-review under responsibility of the scientific committee of the 6th International Conference on Energy and Environment Research, ICEER 2019.

Keywords: *Actinobacillus succinogenes*; Agro-industrial waste; Bio-succinic acid; Fermentation strategies

1. Introduction

Bio-succinic acid – a term of succinic acid (C₄H₆O₄) produced from renewable resources – is one of top twelve value added chemicals from biomass based on report released by US Department of Energy [1]. As the most important C4 building-block, bio-succinic acid is widely used in several industries including agricultural, food, chemical, metal, and pharmaceutical industry as a precursor, ion chelator, and or additive agent [2–6].

Naturally, bio-succinic acid is formed by plants, animals, and microorganism as a fermentation product. However, highest production of bio-succinic acid is achieved by anaerobic microbial fermentation [7]. Various microbes can

* Corresponding author.

E-mail address: heri@che.ui.ac.id (H. Hermansyah).

be utilized as bio-succinic producer including bacteria isolated from rumen, such as *Actinobacillus succinogenes*, *Anaerobiospirillum succiniciproducens*, *Mannheimia succiniciproducens*, *Basfia succiniciproducens* and *Bacillus fragilis* and certain fungi such as *Fusarium*, *Aspergillus* and *Penicillium* species [8–12].

Fortunately, *A. succinogenes* is recognized as one of the most promising microorganisms for industrial production, due to it produces relatively large amount of bio-succinic acid [13,14] and its able to use a broad range of carbon sources [15] including lactose, xylose, arabinose, cellobiose, and other reduced sugars, to produce succinic acid as a major end product [9,16,17]. Besides, various renewable and inexpensive resources have been utilized by *A. succinogenes* to produce bio-succinic acid, including empty fruit bunch (EFB), sugarcane bagasse, corn stover, carob pods, corn fiber, sake lees, rapeseed meal, wheat bran, waste bread, corn stalk, cotton stalk, cane molasses, duckweed, fresh cassava root, cheese whey, corn cob, and corn straw.

This paper aims to review the progress of bio-succinic acid production by *A. succinogenes* as the most promising microorganisms using agro-industrial wastes. Fermentation strategy as the key success of microbial production of bio-succinic acid will be discussed.

2. Bio-succinic acid production by microbial fermentation

Microbial fermentation of bio-succinic acid was conducted for the first time by Georgius Agricola in 1546 [5,7]. Currently, large scale microbial fermentation in order to produce bio-succinic acid is expected, since bio-succinic acid has wide application in several industries. In order to meet the needs, different fermentation strategy of bio-succinic acid production has been observed by many researchers considering several factors affect to the fermentation performance, including carbon sources, nitrogen sources, pH regulator, and fermentation configuration. As the promising microorganism, the summary will be focused on the use of *A. succinogenes* as the producer of bio-succinic acid, as shown in Table 1.

3. Production of bio-succinic acid using different carbon sources

Various carbon sources have been employed by researchers to produce bio-succinic acid using *A. succinogenes*. In order to meet industrial needs by reducing production cost, carbon sources were originated from several agro-industrial wastes as the renewable and inexpensive resources which abundantly available. Empty fruit bunch (EFB) of palm oil has been utilized to produce bio-succinic acid. By using autoclave-alkali pretreatment, reducing sugar of EFB was used as the fermentation substrate obtaining 33.4 g/L bio-succinic acid concentration with the productivity of 1.69 g/L/h and yield of 0.47 g/g substrate [36]. In the other side, sugarcane bagasse has been observed as the carbon sources of bio-succinic acid fermentation. By using batch fermentation mode, concentration of bio-succinic acid obtained was 22.5 g/L, with productivity of 1.014 g/L/h and yield of 0.43 g/g substrate [18]. Meanwhile, 70.81 g/L of bio-succinic acid concentration by using fed-batch fermentation mode, with productivity of 1.42 g/L/h and yield of 0.815 g/g sugar [23].

Corn stover has also been utilized as the carbon sources by several researchers. Bio-succinic acid concentration obtained was 42.8 g/L, productivity of 1.27 g/L/h, and yield of 0.74 g/g sugar by using yeast extract and corn steep liquor as the nitrogen sources [29]. Moreover, other study has been attempted to improve the production of bio-succinic acid by supplementing yeast extract and yeast cell hydrolysate as the nitrogen sources, obtaining 56.4 g/L of bio-succinic acid concentration with the yield of 0.73 g/g glucose [27]. Another strategy has been conducted by performing simultaneous saccharification and fermentation and obtaining 47.4 g/L of bio-succinic acid concentration, 0.99 g/L/h of productivity and yield of 0.72 g/g substrate [35].

Other types of corn waste has also been observed as the carbon source to produce bio-succinic acid via fermentation route, including corn fiber, corn stalk, corn cob, and corn straw. Corn fiber has been used in two different studies. Using different types of nitrogen sources, there is slight difference against the value of bio-succinic acid concentration. 35.4 g/L of bio-succinic acid concentration was obtained by using yeast extract and corn steep liquor as the nitrogen source with the productivity of 0.98 g/L/h and yield of 0.725 g/g total sugar [19], while 35.5 g/L of bio-succinic acid concentration was obtained using yeast extract and yeast cell hydrolysate as the nitrogen sources, with 0.63 g/L/h of productivity and 0.677 g/g glucose [22]. Corn cob has also been used obtaining 23.64 g/L of bio-succinic acid concentration, 0.49 g/L/h of productivity, and 0.58 g/g sugar of yield [33]. In the other study, corn straw has been utilized as the carbon sources by conducting different mode of fermentation, obtaining higher value of bio-succinic acid concentration, productivity, and yield at 53.2 g/L, 1.21 g/L/h, and 0.825 g/g sugar respectively, by using fed-batch mode than by using batch mode [34].

Table 1. Production of bio-succinic acid by *A. succinogenes* in different strategy.

Fermentation operating factors				Conc.	Prod.	Yield	Ref.
Carbon sources	Nitrogen sources	pH regulator	Configuration	(g/L)	(g/L/h)	(g/g)	
EFB	Yeast extract and corn steep liquor	MgCO ₃	SSF	33.4	0.69	0.47	[5,7]
Sugarcane bagasse	Yeast extract	NaOH	SHF	22.5	1.014	0.43	[18]
Carob pods	Yeast extract	NaOH	SHF	9.04 18.97	1.67 1.43	0.39 0.94	[13]
Corn fiber	Yeast extract and corn steep liquor	MgCO ₃	SHF	35.4	0.98	0.725	[19]
Sake lees	Yeast extract and corn steep liquor	MgCO ₃	SHF	48	0.94	0.75	[20]
Rapeseed meal	Yeast extract	Na ₂ CO ₃	SSF	15.5 23.4	0.22 0.33	0.12 0.12	[21]
Corn fiber	Yeast extract and yeast cell hydrolysate	MgCO ₃	SHF	35.5	0.63	0.677	[22]
Sugarcane bagasse	Corn steep powder	MgCO ₃	SHF	39.9 70.81	1.37 1.42	0.82 0.815	[23]
Wheat bran	Yeast extract	MgCO ₃	SHF	50.6	1.04	0.73	[24]
Waste bread	Yeast extract	NaOH and H ₂ SO ₄	SHF	47.3	1.12	0.55	[25]
Corn stalk	Yeast extract and urea	NaOH	SHF	17.8	0.56	0.66	[26]
Cotton stalk				15.8	0.62	1.23	
Corn stover	Yeast extract and yeast cell hydrolysate	Mg(OH) ₂ and NaOH	SHF	56.4	N/A	0.73	[27]
Cane molasses	Yeast extract	Na ₂ CO ₃	SHF	46.4 55.2	0.97 1.15	0.79 N/A	[28]
Corn stover	Yeast extract and corn steep liquor	Na ₂ CO ₃	SHF	42.8	1.27	0.74	[29]
Duckweed	Corn steep liquor powder	MgCO ₃	SHF SSF SSSF	62.12 52.41 65.31	1.04 0.87 N/A	0.81 N/A 0.85	[30]
Fresh cassava root	Yeast extract	MgCO ₃	SHF	93.34 151.44	1.87 3.22	0.77 1.51	[31]
Cheese whey	Yeast extract and peptone	NaOH	N/A	21.2	0.44	0.57	[32]
Corn cob	Yeast extract	MgCO ₃	SHF	23.64	0.49	0.58	[33]
Corn straw	Yeast extract	MgCO ₃	SHF	45.5 53.2	0.95 1.21	0.81 0.825	[34]
Corn stover	Corn steep liquor	MgCO ₃	SSF	47.4	0.99	0.72	[35]

SHF: Separate Hydrolysis and Fermentation; SSF: Simultaneous Saccharification and Fermentation; SSSF: Semi-Simultaneous Saccharification and Fermentation; Conc.: concentration of bio-succinic acid; Prod.: productivity of bio-succinic acid.

Carob pods have also been used as the carbon sources for fermentation. A study showed 9.07 g/L and 18.97 g/L of bio-succinic acid concentration has been obtained by employing batch and fed-batch fermentation mode, respectively [13]. Sake lees have also been utilized as carbon sources and obtaining 48 g/L of bio-succinic acid concentration [20]. Rapeseed meal as the carbon source, indicates concentration of bio-succinic acid at 23.4 g/L by employing fed-batch fermentation mode [21], while wheat bran as the carbon sources, shows the concentration of bio-succinic acid at 50.6 g/L by employing batch fermentation mode [24]. Waste bread [25] and cotton stalk [26] has also been studied as the carbon sources for the production of bio-succinic acid, resulting the concentration of bio-succinic acid at 47.3 g/L and 15.8 g/L, respectively. Cane molasses [28] and cheese whey [32] has also been investigated, obtaining concentration of bio-succinic acid of 55.2 g/L and 50 g/L, respectively. Moreover, duckweed [30] as the carbon sources has been investigated by employing different configuration of fermentation and obtaining the highest bio-succinic acid concentration at 65.31 g/L by applying semi-simultaneous saccharification and fermentation (SSSF). From all the carbon sources, fresh cassava root [31] exhibits the highest value of bio-succinic acid concentration at 151.3 g/L by applying fed-batch fermentation mode. Thus, the use of agro-industrial waste has to be considered as the carbon sources of microbial fermentation to produce bio-succinic acid in large

scale since agro-industrial waste abundantly available throughout the year, renewable, inexpensive, environmentally friendly, and does not compete with food needs.

4. Production of bio-succinic acid using different nitrogen sources

One of the significant factors affecting the fermentation performance and bio-succinic acid production is the presence of proper nitrogen sources. There are two types of nitrogen sources, including organic and inorganic sources. However, in the production of bio-succinic acid by *A. succinogenes*, organic nitrogen sources are extensively used by researchers due to inorganic nitrogen sources are not proper for *A. succinogenes* growth [28]. The organic nitrogen sources commonly used are yeast extract, meat extract, peptone, tryptone, corn steep liquor, and nutrient broth.

Different types of nitrogen sources has been employed including wheat bran, beef extract, soy peptone, soy bean powder, yeast extract, and corn steep liquor. Among them, yeast extract exhibits the highest result for bio-succinic acid production with 22.09 g/L of bio-succinic acid concentration. Besides, by applying yeast extract as the nitrogen sources, ratio of bio-succinic acid is also high comparing with other by products [33]. Yeast extract as the nitrogen source has also been extensively used by researchers in order to produce bio-succinic acid by microbial fermentation. In the other hand, a mixture of yeast extract and corn steep liquor has also been employed obtaining various concentration of bio-succinic acid.

The effect of supplementing yeast cell hydrolysate to the production of bio-succinic acid has also been observed considering yeast cell containing high amounts of protein, lipid, RNA, vitamin and mineral [37]. Based on the result, by supplementing yeast cell hydrolysate, cell growth and glucose consumption is increase 32.5% and 49%, respectively, obtaining 53.24 g/L of bio-succinic acid concentration and total sugar utilization of 97.5%.

5. Production of bio-succinic acid using different pH regulator

pH level is one of key parameter in the microbial fermentation since the maintenance and regulation of cell activities is highly dependent to the pH [38]. Most bacterial fermentation require near neutral pH level to optimize the performance. However, in the production of bio-succinic acid through fermentation route, acidification of medium will be absolutely occurred. Therefore, pH regulator should be provided to neutralize the pH condition of fermentation cultures.

Study about the effect of pH regulator to the fermentation performance in order to produce bio-succinic acid has been conducted. $MgCO_3$, $NaHCO_3$, and Na_2CO_3 have been tested as the pH regulator of the fermentation culture. From the result, $MgCO_3$ exhibited higher bio-succinic acid production and less by-product comparing with the use of $NaHCO_3$ and Na_2CO_3 [33]. This is due to Mg^{2+} has several effects on the cellular metabolism including controlling pH, providing CO_2 which is required to form succinic acid, and acts as the cofactor of PEP carboxykinase as the key enzyme used to synthesize succinate [39].

Other study also revealed that glucose consumption in the fermentation using Na_2CO_3 , $NaHCO_3$, $Mg(OH)_2$, and $MgCO_3$ as the pH regulator were much higher compared with $Ca(OH)_2$, $CaCO_3$, $NaOH$, and $NH_3 \cdot H_2O$ [27]. However, when $Ca(OH)_2$ and $CaCO_3$ were used as pH regulator, the cell growth was severely suppressed obtaining low amount of bio-succinic acid. Meanwhile, among the three Na^+ pH regulator, $NaOH$ obtained higher concentration of bio-succinic acid than Na_2CO_3 and $NaHCO_3$. Based on the study, the use of $MgCO_3$ as pH regulator also resulted the best cell growth, glucose utilization, and succinic acid production parameters [27]. Due to its good performance as pH regulator, $MgCO_3$ has been widely used by researchers to produce bio-succinic acid using *A. succinogenes* obtaining various concentration, productivity, and yield of bio-succinic acid as shown in the Table 1. Besides, $NaOH$ has also been used by researchers considering relatively cheap cost.

6. Production of bio-succinic acid using different fermentation configuration

In order to enhance the production efficiency and reduce the cost, configuration of hydrolysis and fermentation step is able to be adjusted. There are three configurations that have been investigated, including separate hydrolysis and fermentation (SHF), simultaneous saccharification and fermentation (SSF) and semi-simultaneous saccharification and fermentation (SSSF) [30]. SHF occurred by operating enzyme hydrolysis and fermentation in different stage, therefore optimization of each stage can be achieved. However, SHF process produces high glucose concentration and poses high contamination risk [40]. To overcome this problem, different configuration

of fermentation was proposed, called SSF. SSF occurred by operating enzyme hydrolysis and fermentation in the same stage and maintain low sugar concentration, thus decreasing the contamination risk. Several production of bio-succinic acid through SSF has been attempted by several researchers. Unfortunately, optimal condition of enzymatic hydrolysis and microbial fermentation is mismatched. Therefore, another strategy was proposed by combining SHF and SSF, called SSSF. SSSF occurred by operating pre-saccharification in short period with a faster hydrolytic rate before the main SSF process occurred. With the combined advantages of SSF and SHF, SSSF produces higher yields than SHF and SSF [41]. A study has been proven that SSSF produces higher concentration and yield of bio-succinic acid than SHF and SSF. Based on the results, by operating SHF, SSF, and SSSF, bio-succinic concentration obtained is 62.12 g/L, 52.41 g/L, and 65.31 g/L, respectively and yield of bio-succinic acid obtained by SSSF reach 0.85 g/g sugar [30].

7. Conclusion

Bio-succinic acid as the most important C4 building-block has to be industrially produced by microbial fermentation considering the wide application of this compound. As the most promising microbes, *A. succinogenes* has been investigated applying several fermentation strategies to improve the production of bio-succinic acid. Different carbon sources have been attempted utilizing several agro-industrial wastes since it is renewable, inexpensive, abundantly available, and environmentally friendly. Nitrogen sources as one of the significant factors has also been observed to improve cell growth. To maintain the pH condition of the fermentation cultures, pH regulator also play an important role to be chosen. Besides, configuration of fermentation also contribute to improve bio-succinic acid production. However, as the most recent strategy, fermentation configuration seems important to be more considered in order to realize an efficient bio-succinic industry, since the recent configuration improved the yield of bio-succinic acid.

Acknowledgments

The authors would like to thank for the research support provided by Universitas Indonesia and Ministry of Research, Technology and Higher Education Republic of Indonesia through PMDSU Grant.

References

- [1] Werpy T, Petersen G, Aden A, Bozell J, Holladay J, White J, et al. Top value added chemicals from biomass. volume 1-results of screening for potential candidates from sugars and synthesis gas. Department of Energy Washington DC; 2004.
- [2] Ahn JH, Jang YS, Lee SY. Production of succinic acid by metabolically engineered microorganisms. *Curr Opin Biotechnol* 2016;42:54–66.
- [3] Chen X, Zhou L, Tian K, Kumar A, Singh S, Prior BA, et al. Metabolic engineering of escherichia coli: a sustainable industrial platform for bio-based chemical production. *Biotechnol Adv* 2013;31(8):1200–23.
- [4] Hong S, Lee S. Importance of redox balance on the production of succinic acid by metabolically engineered escherichia coli. *Appl Microbiol Biotechnol* 2002;58(3):286–90.
- [5] Song H, Lee SY. Production of succinic acid by bacterial fermentation. *Enzyme Microb Technol* 2006;39(3):352–61.
- [6] Zeikus J, Jain M, Elankovan P. Biotechnology of succinic acid production and markets for derived industrial products. *Appl Microbiol Biotechnol* 1999;51(5):545–52.
- [7] Akhtar J, Idris A, Aziz RAbd. Recent advances in production of succinic acid from lignocellulosic biomass. *Appl Microbiol Biotechnol* 2014;98(3):987–1000.
- [8] Beauprez JJ, Mey MDe, Soetaert WK. Microbial succinic acid production: natural versus metabolic engineered producers. *Process Biochem* 2010;45(7):1103–14.
- [9] Guettler MV, Rumler D, Jain MK. *Actinobacillus succinogenes* sp. nov. a novel succinic-acid-producing strain from the bovine rumen. *Int J Systematic Evol Microbiol* 1999;49(1):207–16.
- [10] Lee P, Lee S, Hong S, Chang H. Isolation and characterization of a new succinic acid-producing bacterium, *mannheimia succiniciproducens* mbel15e, from bovine rumen. *Appl Microbiol Biotechnol* 2002;58(5):663–8.
- [11] Olajuyin AM, Yang M, Liu Y, Mu T, Tian J, Adaramoye OA, et al. Efficient production of succinic acid from palmaria palmata hydrolysate by metabolically engineered escherichia coli. *Bioresour Technol* 2016;214:653–9.
- [12] Samuelov N, Lamed N, Lowe S, Zeikus J. Influence of CO₂-HCO₃⁻ levels and ph on growth, succinate production, and enzyme activities of anaerobiospirillum succiniciproducens. *Appl Environ Microbiol* 1991;57(10):3013–9.
- [13] Carvalho M, Roca C, Reis MA. Improving succinic acid production by actinobacillus succinogenes from raw industrial carob pods. *Bioresour Technol* 2016;218:491–7.
- [14] McKinlay JB, Vieille C, Zeikus JG. Prospects for a bio-based succinate industry. *Appl Microbiol Biotechnol* 2007;76(4):727–40.
- [15] Gunnarsson IB, Karakashev D, Angelidaki I. Succinic acid production by fermentation of jerusalem artichoke tuber hydrolysate with actinobacillus succinogenes 130z. *Ind Crops Prod* 2014;62:125–9.

- [16] Jiang M, Xu R, Xi Y-L, Zhang J-H, Dai W-Y, Wan Y-J, et al. Succinic acid production from cellobiose by *actinobacillus succinogenes*. *Bioresour technol* 2013;135:469–74.
- [17] Van der Werf MJ, Guettler MV, Jain MK, Zeikus JG. Environmental and physiological factors affecting the succinate product ratio during carbohydrate fermentation by *actinobacillus* sp. 130z. *Arch Microbiol* 1997;167(6):332–42.
- [18] Borges ER, Pereira N. Succinic acid production from sugarcane bagasse hemicellulose hydrolysate by *actinobacillus succinogenes*. *J Ind Microbiol Biotechnol* 2011;38(8):1001–11.
- [19] Chen K, Jiang M, Wei P, Yao J, Wu H. Succinic acid production from acid hydrolysate of corn fiber by *actinobacillus succinogenes*. *Appl Biochem Biotechnol* 2010;160(2):477–85.
- [20] Chen K, Zhang H, Miao Y, Jiang M, Chen J. Succinic acid production from enzymatic hydrolysate of sake lees using *actinobacillus succinogenes* 130z. *Enzyme Microb Technol* 2010;47(5):236–40.
- [21] Chen K, Zhang H, Miao Y, Wei P, Chen J. Simultaneous saccharification and fermentation of acid-pretreated rapeseed meal for succinic acid production using *actinobacillus succinogenes*. *Enzyme Microb Technol* 2011;48(4–5):339–44.
- [22] Chen K-Q, Li J, Ma J-F, Jiang M, Wei P, Liu Z-M, et al. Succinic acid production by *actinobacillus succinogenes* using hydrolysates of spent yeast cells and corn fiber. *Bioresour Technol* 2011;102(2):1704–8.
- [23] Chen P, Tao S, Zheng P. Efficient and repeated production of succinic acid by turning sugarcane bagasse into sugar and support. *Bioresour Technol* 2016;211:406–13.
- [24] Dorado MP, Lin SKC, Koutinas A, Du C, Wang R, Webb C. Cereal-based biorefinery development: utilisation of wheat milling by-products for the production of succinic acid. *J Biotechnol* 2009;143(1):51–9.
- [25] Leung CCJ, Cheung ASY, Zhang AY-Z, Lam KF, Lin CSK. Utilisation of waste bread for fermentative succinic acid production. *Biochem Eng J* 2012;65:10–5.
- [26] Li Q, Yang M, Wang D, Li W, Wu Y, Zhang Y, et al. Efficient conversion of crop stalk wastes into succinic acid production by *actinobacillus succinogenes*. *Bioresour Technol* 2010;101(9):3292–4.
- [27] Li J, Zheng X-Y, Fang X-J, Liu S-W, Chen K-Q, Jiang M, et al. A complete industrial system for economical succinic acid production by *actinobacillus succinogenes*. *Bioresour Technol* 2011;102(10):6147–52.
- [28] Liu Y-P, Zheng P, Sun Z-H, Ni Y, Dong J-J, Zhu L-L. Economical succinic acid production from cane molasses by *actinobacillus succinogenes*. *Bioresour Technol* 2008;99(6):1736–42.
- [29] Salvachúa D, Mohagheghi A, Smith H, Bradfield MF, Nicol W, Black BA, et al. Succinic acid production on xylose-enriched biorefinery streams by *actinobacillus succinogenes* in batch fermentation. *Biotechnol Biofuels* 2016;9(1):28.
- [30] Shen N, Zhang H, Qin Y, Wang Q, Zhu J, Li Y, et al. Efficient production of succinic acid from duckweed (*landoltia punctata*) hydrolysate by *actinobacillus succinogenes* gxas137. *Bioresour Technol* 2018;250:35–42.
- [31] Thuy NTH, Kongkaew A, Flood A, Boontawan A. Fermentation and crystallization of succinic acid from *actinobacillus succinogenes* atcc55618 using fresh cassava root as the main substrate. *Bioresour Technol* 2017;233:342–52.
- [32] Wan C, Li Y, Shahbazi A, Xiu S. Succinic acid production from cheese whey using *actinobacillus succinogenes* 130 z. In: *Biotechnology for fuels and chemicals*. Springer; 2007, p. 111–9.
- [33] Yu J, Li Z, Ye Q, Yang Y, Chen S. Development of succinic acid production from corn cob hydrolysate by *actinobacillus succinogenes*. *J Ind Microbiol Biotechnol* 2010;37(10):1033–40.
- [34] Zheng P, Dong J-J, Sun Z-H, Ni Y, Fang L. Fermentative production of succinic acid from straw hydrolysate by *actinobacillus succinogenes*. *Bioresour Technol* 2009;100(8):2425–9.
- [35] Zheng P, Fang L, Xu Y, Dong J-J, Ni Y, Sun Z-H. Succinic acid production from corn stover by simultaneous saccharification and fermentation using *actinobacillus succinogenes*. *Bioresour Technol* 2010;101(20):7889–94.
- [36] Akhtar J, Idris A. Oil palm empty fruit bunches a promising substrate for succinic acid production via simultaneous saccharification and fermentation. *Renew Energy* 2017;114:917–23.
- [37] Rivas B, Moldes AB, Dominguez JM, Parajó JC. Development of culture media containing spent yeast cells of *debaryomyces hansenii* and corn steep liquor for lactic acid production with *lactobacillus rhamnosus*. *Int J Food Microbiol* 2004;97(1):93–8.
- [38] Pateraki C, Patsalou M, Vlysidis A, Kopsahelis N, Webb C, Koutinas AA, et al. *Actinobacillus succinogenes* : Advances on succinic acid production and prospects for development of integrated biorefineries. *Biochem Eng J* 2016;112:285–303.
- [39] Bazaes S, Toncio M, Laivenieks M, Zeikus JG, Cardemil E. Comparative kinetic effects of mn (II), mg (II) and the ATP/adp ratio on phosphoenolpyruvate carboxykinases from *anaerobiospirillum succiniciproducens* and *saccharomyces cerevisiae*. *Protein J* 2007;26(4):265–9.
- [40] Chng LM, Lee KT, Chan DJC. Synergistic effect of pretreatment and fermentation process on carbohydrate-rich *scenedesmus dimorphus* for bioethanol production. *Energy Convers Manag* 2017;141:410–9.
- [41] Perez-Pimienta JA, Vargas-Tah A, Lopez-Ortega KM, Medina-Lopez YN, Mendoza-Perez JA, Avila S, et al. Sequential enzymatic saccharification and fermentation of ionic liquid and organosolv pretreated agave bagasse for ethanol production. *Bioresour Technol* 2017;225:191–8.