Perlatti et al. Chemical and Biological Technologies in Agriculture 2014, 1:5
http://www.chembioagro.com/content/1/1/5

Chemical and Biological Technologies in Agriculture
a SpringerOpen Journal

REVIEW Open Access

Green chemistry, sustainable agriculture and processing systems: a Brazilian overview

Bruno Perlatti[1], Moacir R Forim[1,2] and Vânia G Zuin[1,3*]

Abstract

There is a pressing need for renewable and optimal use of resources towards sustainable primary production and processing systems worldwide. Current technologies for food and feedstock production are held accountable for several environmental problems, such as for instance soil and water contamination due to the use of hazardous substances, generation of toxic products and even excess of biomass that is considered waste. To minimize or solve these questions in order to produce an adequate quantity of reliable and healthy food, fibers and other products and energy, new paradigms focusing on sustainable agriculture, bio-based industries or biorefineries have emerged over the last decades. Biorefineries integrate sustainable and environmentally friendly concepts of Green Chemistry with intelligent and integrated farming processes, optimizing the agricultural production. Thermochemical and biochemical processes are excellent alternatives for the production of new classes of renewable biofuels and feedstock, showing relatively small impact on greenhouse gas emissions and important pathways to obtain platform chemicals. This review discusses the current and incipient technological developments for using biomass to generate bio-based chemicals over the last decade, focusing on Green Chemistry concepts towards sustainable agriculture and processing models in Brazil.

Keywords: Green chemistry; Sustainable agriculture; Environmental sustainability; Biorefinery; Biofuel; Platform chemical; Brazilian context

Intoduction

Green chemistry, primary production, and processing systems in Brazil

In the face of an ever-increasing economy with competitive market policies, the demand for food, feed, fuel, and products can lead to serious problems in chemical processes due to excessive amounts of hazardous chemicals and the residues generated. To overcome these obstacles and impel the economy toward a more sustainable panorama, in 1998, Anastas and Warner [1] coined the term 'Green Chemistry' and formulated the twelve principles. These guidelines are approaches to be explored in order to promote a cleaner and more environmentally friendly way of doing chemistry, which includes using less hazardous substances and solvents and renewable feedstock, encouraging the concept of atom and energy economy by reducing unnecessary synthesis steps or designing alternative routes, and also prevent or avoid the generation of residues and/or toxic substances [2,3]. Corrêa et al. [4] explored the evolution of Green Chemistry in Brazil, showing that there was a great deal of effort applied to a greener development in several different areas of chemistry, namely organic and inorganic synthesis and analytical chemistry. The authors stressed that the country has very favorable conditions to develop new trends in biomass conversion technologies for biofuels and bio-based products. Nevertheless, some recent studies [5] have shown that the understanding of Brazilian chemical researchers towards environmental sustainability, sustainable development, and the role of Green Chemistry has been further elaborated to improve the researchers' conceptual reasoning and more uniform understanding about the role of Green Chemistry in a new agribusiness paradigm. More recently, a transition has been observed towards an optimal and renewable use of biomass based on sustainable production systems to generate food and other bio-based products with adequate social value, low inputs, enhanced ecosystem services, zero waste, as well as minimum environmental impact and greenhouse gas emissions [6-10].

* Correspondence: vaniaz@ufscar.br
[1]Laboratory of Natural Products, Department of Chemistry, Federal University of São Carlos, Rodovia Washington Luís, km 235, 13565-905, São Carlos, Brazil
[3]Green Chemistry Centre of Excellence, Department of Chemistry, The University of York, Heslington, YO10 5DD, York, UK
Full list of author information is available at the end of the article

It is estimated that globally, 140 billion tons of agricultural biomass is generated every year, and the use of green strategies to produce high value-added products could represent a reduction of roughly 50 billion tons of fossil fuels needed, enough to greatly reduce greenhouse gas (GHG) emissions and our dependence on non-renewable materials [11]. By employing adequate strategies and high-density and fast-growing crops such as sugarcane, a negative carbon footprint is also possible [12,13]. For instance, the cultivation of palm oil in northern Brazil for biodiesel production generates a GHG emission balance of approximately −208 kg CO_2 equiv./1,000 kg crude palm oil per year [14].

Brazil is a world leader in terms of Green Chemistry in agriculture, and it was the first country to have, at a large scale, biofuels as part of its energy matrix. Due to early investments in the area with policies such as PROALCOOL in 1975, a federal program to prioritize domestic sugarcane-based ethanol distilleries in response to the 1970s oil crisis and which prevented the emission of 675 million tons of CO_2 from fossil fuel burning, have saved almost 50 billion US dollars in expenditures with oil and other non-renewable resources [15,16]. Similar early twenty first-century initiatives focusing on biodiesel production such as the PROBIODIESEL and PNPB (Brazilian Biodiesel Production Program) have placed Brazil on one of the main biodiesel production spots, with estimates that show the country is responsible for more than 11% of global biodiesel production, the second biggest producer after the USA [17]. Nevertheless, as assessed by Rathmann et al. [18], the main goals outlined by those programs were not fully achieved in its initial stage, this was mainly due to the use of the traditional production cost methods using soybean oil and methanol because of the competitive markets for soybean and high import prices for methanol, but there is considerable space for social, economic, and technological growth by developing commercially feasible biodiesel plants based on alternative triglycerides feedstock (palm, sunflower, castor bean, etc.), ethyl transesterification routes, and more economical processes which could overcome the actual problems [19-25]. The country is also a world reference in production and export of several commodities such as orange juice, sugar, and soybean products, and it is estimated that at least one fourth of all agricultural products commercialized worldwide are from Brazil [11]. Given this condition, it is crucial for Brazil to focus its development on innovative strategies and integrated management primarily based on green solutions for crops and industrial processes in order to keep the country as one of the key players in the agribusiness scenario.

This review focuses on the main green techniques and processes already in use and on those already under development to use biomass for generating bio-based chemicals (fuels and platform molecules) described in the literature over the last decade. The focus is on the Green Chemistry principles for the primary biomass production and transformation processes, taking into account the Brazilian context.

Review

Use of available biomass

Even with the increase in the share of renewable sources in the world energy matrix, Brazil has a unique perspective regarding this scenario, as can be seen in the forecast data in Figure 1. Brazil's historic background shows its environmentally friendly technology practices for electric energy production, which generates over 80% of the country's energy requirements through such green routes, at least three times more than in any other region. While hydropower is the main driving force, and which is already responsible for 5% of the country's energy matrix, by applying new technologies and expanding to other biomass resources, it is estimated that this share can increase to almost 30% [26].

Biomass used for electricity generation is a growing industry. It started in a robust way with the installation of cogeneration heat and electric power systems by burning sugarcane bagasse to produce all energy needed in the process and sell the surplus for profit, thus presenting another green alternative to lower the dependence on hydropower. From approximately 8GW of electrical energy produced from biomass cogeneration, 80% comes from sugarcane, with the rest produced mainly by black liquor, wood chips, biogas, and rice husks [27]. Though not commercially available, several other agricultural wastes might be explored as fuel source depending on regional characteristics such as corn stalk, soybean stems, wheat straws, cotton branches, coconut shells and coffee husks, among others [28,29].

Although the burning of biomass or related products seems to be a promising alternative which is less polluting because of its nearly neutral carbon footprint, it is considered an inefficient process due to the underutilization of several complex chemical structures found as a major component of biomass, the lignocellulosic matrix, which could be transformed into commercially important feedstock in modern factories called biorefineries, which are able to combine, substitute, and even surpass conventional petrochemicals.

The concept of biorefineries

There is a global trend impelling the transformation of energetic matrix from fossil to renewable feedstock. They generate less hazardous substance such as fine particulates, lead, and sulfur by-products, as well as noxious greenhouse gases such as CH_4, CO, and CO_2, among others [30]. Wyman and Goodman [31] have proposed

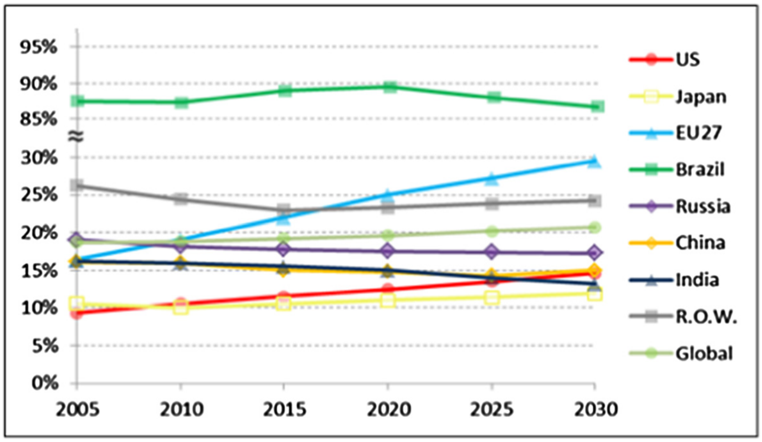

Figure 1 Future renewable energy sources utilization in relative terms of total energy consumed by country/region. Adapted from [26].

an alternative way of dealing with lignocellulosic material, which would use refinery-like processing to transform them into a new set of molecules that could be used in well-established processes, as well as new building blocks to supply the production needs. They coined the term biorefinery, which can be defined as 'the sustainable processing of biomass into a spectrum of marketable products and energy' [32,33]. This concept is linked to two different objectives, the creation of a strong and economic viable bio-based niche connected to a high-ranking approach for obtaining new and renewable raw materials to outdo petroleum derivatives [34]. It is supposed that a biorefinery would be able to create, in the same physical space, environmentally friendly processes for obtaining biofuels, chemical products, electrical power, and heat [35]. There are some examples of readily available material that can be obtained by direct extraction from biomass but, in general, the matrix needs to be transformed into the desired products [36]. For example, Mariano et al. [37] evaluated the utilization of pentoses from sugarcane biomass for the production of biogas, *n*-butanol, and acetone in a simulation of an integrated first and second generation sugarcane biorefinery, with exciting results showing that the production would be profitable even without the optimization of processing technologies.

Second generation fuel: bioethanol

Over the last 10 years, several different groups have studied the most suitable routes for biomass biotransformation, with most of the efforts focused on the production of bioethanol from the lignocellulosic matrix [38-43]. While cellulolytic enzymes for efficient transformation of cellulose have been thoroughly described over the last decade in several different examples, the use of hemicellulose and lignin as substrate is a more incipient technology [44]. Several papers discuss the feasibility of integrating 2G ethanol into conventional ethanol producing units [45-49], but as of yet, there are no commercial plants available. Among the reasons, the complexity of processes such as low yield, lack of effective complete hydrolysis, pentose, and phenolic acid biotransformation technologies, and also financial drawbacks result in lower capital returns [50,51].

Other alternative biofuels

Although ethanol is by far the most explored biofuel in Brazil, several other alternatives have been studied in order to improve the possibility of biomass reuse. Following global tendencies, studies on thermochemical and biological processes of biomass conversion have increased considerably over the past years [28]. The main techniques applied for biomass conversion to biofuels are described in Figure 2.

Gasification of biomass involves the conversion of organic matter in the presence of oxygen in the form of air, steam or pure O_2 with air/fuel ratios below the stoichiometric quantity. This low supply of oxidative agents hinders complete combustion of carbon and hydrogen into CO_2 and H_2O, thus releasing a synthetic fuel gas (syngas) made primarily of CO and H_2 with smaller amounts of CH_4, CO_2, N_2, O_2, and H_2O [52,53]. Centeno et al. [54] used a mathematical model to predict the performance of a feasible biomass-to-energy conversion process, which was optimized by Brazilian researchers [55-57].

Syngas produced from biomass pyrolysis and gasification is an important intermediate for the synthesis of large numbers of industrial products [58]. For instance, Fischer-Tropsch synthesis (FTS) involves diverse complex reactions to produce low-molecular-weight hydrocarbons from syngas [59].

Hotza and Costa [60] reviewed Brazil's current developments on hydrogen production from renewable resources. The authors have identified bottlenecks in the country's development, where although several different research

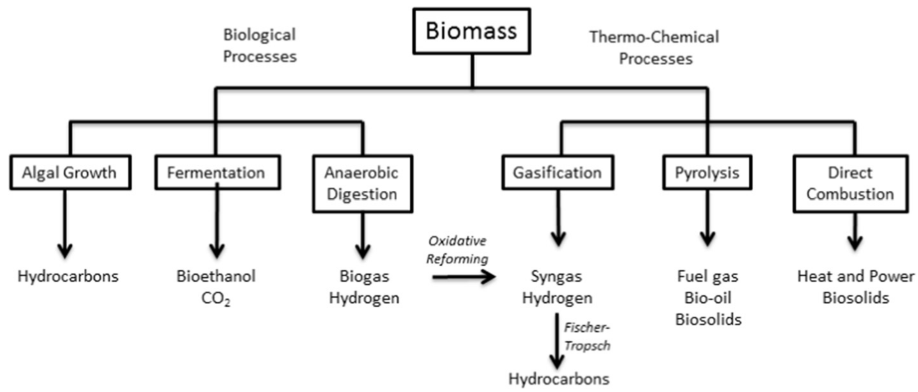

Figure 2 Main biomass conversion routes for production of biofuel.

groups have interesting approaches for hydrogen fuel cell development, little research was carried out on the reuse of biomass for the generation of hydrogen. Also, some studies are already evaluating the production of third-generation biofuels, but the application of such processes are still hindered by their capital-intensive nature [61,62].

Platform chemicals and green chemistry

Considering the need to achieve optimization both on the use of agricultural by-products and generation of high value-added products, there is a growing interest on the concept of platform chemicals, closely associated with the main pillars of Green Chemistry [63,64]. Platform molecules derived from biomass processing are not exactly the same as those obtained by crude oil. A remarkable characteristic of shifting from petroleum-derived hydrocarbon products to bio-based feedstock is that the latter presents a high oxygen content such as alcohol, ketones, aldehydes, ester, acids, phenols, furans, and others. Those molecules are responsible for the different properties of the liquid obtained from biomass, such as immiscibility with hydrocarbons, thermal, and chemical corrosiveness, low heating value and high density, such as low thermal stability [65]. Nevertheless, properties like high solubility in water and reactivity can be used as an advantage because it allows their manipulation in aqueous phase catalytic reactions under mild temperatures [66]. An initial evaluation conducted by the USDOE [67] and later improved by Bozell and Petersen [68] shows a wide range of molecules which can be listed as an important platform chemical due to their synthesis possibility and potential applications, and this includes organic acids, sugars, hydrocarbons, furans, and other aromatic molecules (Table 1).

Ethanol can also be considered a platform molecule due to its versatility as a building block. Several bio-based products can be tailored through the ethanol chemistry route, with ethylene as the only one that has been explored at a commercial scale. Companies such as Dow, Braskem, and Solvay-Indupa are already producing green plastics in Brazil, with polyethylene (PE) plants for the former two and polyvinylchloride (PVC) for the latter [69]. Several other products can be obtained from ethanol, such as synthetic rubber made from butadiene, acetaldehyde, which is a key intermediate in several different processes, and diethyl ether, a solvent for producing cellulose plastics. Rossi et al. [70] theoretically assessed the thermodynamics of steam reforming ethanol and glycerol for hydrogen production, showing the feasibility of the process and encouraging further research in the area.

Glycerol is a by-product of biodiesel generated in quantities of up to 10% of total weight. However, glycerol obtained directly from this process has low purity, which is an undesired product for chemical and pharmaceutical applications without pretreatment [71]. As pointed out by Coronado et al. [72], molecular properties as well as impurities in crude glycerol hinder its use as fuel for generating heat and power for the biodiesel production process, as it uses by-products of other biofuels such as ethanol. Glycerol is also a very suitable substrate for bacterial growth, with several different organisms being able to use it as sole carbon source to produce several different commodities. Similarly, several microorganisms can also build a wide range of building blocks by biomass and glycerol biotransformation [73-78] (Figure 3).

Also, bio-oil can be produced by heating biomass under controlled conditions using specific equipment, obtaining a mixture of several different molecules of high-added value [80,81]. Crude bio-oil is dark brown, with a composition that varies according to the biomass used. Although coined as oil, the pyrolysis liquid does not mix with other liquid hydrocarbons due to its high oxygen content. In order to upgrade bio-oil to usual fuel such as gasoline and diesel, the samples need to be deoxygenated [51,65]. Several different biomasses have been tested for bio-oil production. There is an uncomplicated commercial process for bio-oil

Table 1 Platform molecules

Original platform molecules		**Revised platform molecules**	
[67]		[68]	
Succinic, fumaric and malic acids	Glycerol	Ethanol	Furans (furfural, HMF and 2,5-furandicarboxylic acid
3-Hydroxypropanoic acid	Aspartic acid	Glycerol	Bio-hydrocarbons
Glucaric acid	Glutamic acid	Lactic acid	Succinic acid
Itaconic acid	Levulinic acid	3-Hydroxypropanoic acid	
3-Hydroxybutyrolactone	2,5-Furandicarboxylic acid	Levulinic acid	
Sugars (sorbitol, xylitol, arabinitol)		Sugars (sorbitol, xylitol)	

Adapted from [66].

production through fast pyrolysis operating in Brazil, named Bioware, and which has the support of the University of Campinas. The operating pilot facility has a nominal capacity of 300 kg h^{-1}, and was built to produce bio-oil from elephant grass and sugarcane for industrial applications [51].

Agriculture as an alternative for reutilization of by-products

Though it has been applied worldwide for a long time, the reutilization of residues originating from other sources, such as industries and cities, is somewhat incipient in Brazil. Recently, public institutions and universities have shown interest in using one of the most efficient means of by-product disposals [82].

Herpin et al. [83] utilized secondary treated wastewater (STW) from an anaerobic/facultative pond system to irrigate coffee plantation for 43 months. They observed that although the use of STW did not negatively affect the soil-plant system, its use alone would not be able to supply the plant with all the necessary elements and would cause some unbalance to soil composition, suggesting that new methodologies for the integrated use of fertilizers and wastewater are needed to enable the full potential of water recycling. Barros et al. [84] evaluated several treatments for the correct application of bio-solids from sewage sludge, obtaining interesting results when applied to maize crops. With the same objective, Lúcio et al. [85] studied the application of a product known as potato bio-product, a by-product from alcoholic potato fermentation, with organomineral composition similar to sugarcane vinasse.

More examples of using green chemistry in agriculture

Additionally, (Additional file 1: Table S1) summarizes most of the studies that have been carried out over the last decade to improve the research of green techniques for biomass transformation into fuels and platform chemicals,

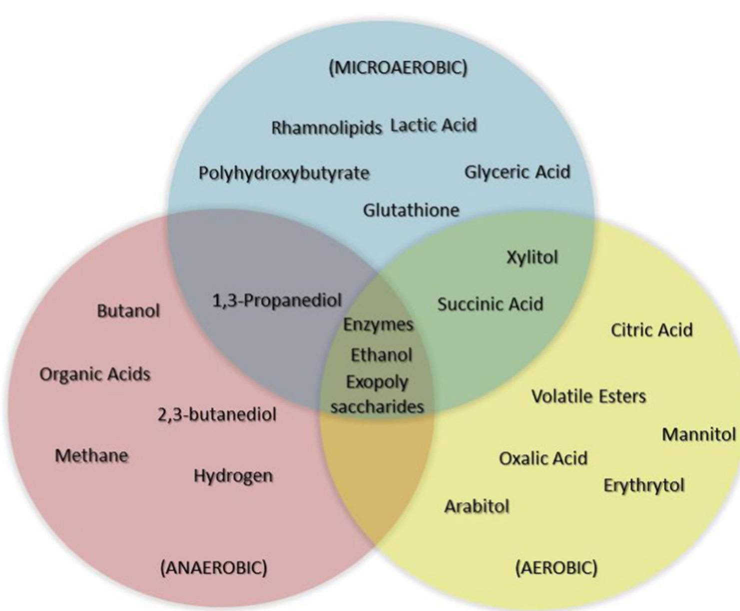

Figure 3 Example of chemicals produced by biotransformation of biomass and platform chemicals. Adapted from [79].

as well as establishing and using alternatives towards sustainable agriculture in Brazil. As can be noted, the majority of the papers focus on biofuels and platform chemicals (82%), but the development and application of biopesticides have also gained momentum in Brazil over the last years. Among the current trends in the development of biopesticides is the control of release rate and targeting of compounds by nanoencapsulation, as this technique can increase the stability and solubility of natural products and, consequently, increase their efficacy. These proposals, taking into account the plagues and crops found in Brazil, could change the manner in which natural products are used for controlling agricultural pest and insects considering an optimal and renewable use of biological resources [86-135].

Conclusions

Simultaneously raising the awareness in government and the general population about environmental issues, the pressure by the public and non-government organizations for the production of an adequate quantity and quality of food and other primary materials, the reduction of waste emissions and the increase in prices of non-renewable fuel and feedstock have led to a significant increase in the research and development of sustainable processes for biomass generation and conversion in Brazil. These processes are strictly aligned with concepts of Green Chemistry already in use for chemical processes.

First-generation biofuels such as ethanol and biodiesel have already achieved a significant role in agribusiness through accepted and widely applied technologies. As for second generation, intense research is still needed for a fully functional industry at a suitable time. Concerning bio-based products derived from platform chemicals, the absence of well-established processes and the lack of a specific market hinder a more ostensive application of such compounds. With the development and application of reliable biomass transformation technologies, both in the academic environment as well as in the industrial sector, there will surely be a tendency to focus on the use of available biomass sources in scenarios with more value-added products. Nevertheless, the costs of such processes will continue to be the driving force for the consolidation of biomass-derived feedstock, in spite of its attractiveness from the environmental, social, and sustainable point of view.

There is a bright future for Brazil with regards to the development and application of biorefineries. The large amount of feedstock readily available and presumably close to the production sites can propel the country to a prominent position for producing renewable biofuels and high value-added products, as long as regulation policies and an effective distribution of goods through efficient production flow also follows the steps of technological expansion.

Additional file

Additional file 1: Table S1. The following additional data are available with the online version of this paper. Additional data file 1 is a table listing the research related to the transformation of biomass-derived feedstock into high value-added products.

Competing interests
The author declares they have no competing interests.

Author details
[1]Laboratory of Natural Products, Department of Chemistry, Federal University of São Carlos, Rodovia Washington Luís, km 235, 13565-905, São Carlos, Brazil. [2]Department of Chemistry, University of Waterloo, 200 University Ave. W, N2L 3G1, Waterloo, Canada. [3]Green Chemistry Centre of Excellence, Department of Chemistry, The University of York, Heslington, YO10 5DD, York, UK.

Received: 31 March 2014 Accepted: 30 June 2014
Published online: 13 August 2014

References

1. Anastas PT, Warner JC (1998) Green chemistry: theory and practice. Oxford University Press, New York
2. Corrêa AG, Zuin VG (2009) Química Verde: Fundamentos e Aplicações, 1st edition. EDUFSCar, São Carlos
3. Marques CA, Santiago FPG, Yunes F, Machado AASC (2013) Environmental sustainability: a study involving chemical researchers in Brazil. Quim Nova 36(6):914–920
4. Corrêa AG, Zuin VG, Ferreira VF, Vazquez PG (2013) Green chemistry in Brazil. Pure Appl Chem 85(8):1643–1653
5. Zuin VG (2013) A inserção da Química Verde nos Programas de Pós-Graduação em Química do Brasil: tendências e perspectivas. RBPG-Rev Bras Pós-Graduação 10(21):557–573
6. Krausmann F, Gingrich S, Eisenmenger N, Erb KH, Haberl H, Kowalski-Fischer M (2009) Growth in global materials use, GDP and population during the 20th century. Ecol Econ 68(10):2696–2705
7. Caldeira-Pires A, Luz SM, Palma-Rojas S, Rodrigues TO, Silverio VC, Vilela F, Barbosa PC, Alves AM (2013) Sustainability of the biorefinery industry for fuel production. Energies 6:329–350
8. Claudino ES, Talamini E (2013) Life Cycle Assessment (LCA) applied to agribusiness - a review. Rev Bras Eng Agr Amb 17(1):77–85
9. Clark J (2011) Química Verde com potencial econômico. In: Vaz Junior S (ed) Biorrefinarias: Cenários e perspectivas. Embrapa Agroenergia, Brasília, DF, pp 131–138
10. Centro de Gestão e Estudos Estratégicos (CGEE) (2010) Química Verde no Brasil: 2010 -2030. CGEE, Brasília, DF http://www.cgee.org.br/atividades/redirect.php?idProduto=6528. ISBN 978-85-60755-31-8
11. Forster-Carneiro T, Berni MD, Dorileo IL, Rostagno MA (2013) Biorefinery study of availability of agriculture residues and wastes for integrated biorefineries in Brazil. Resour Conserv Recy 77:78–88
12. Moreira JR (2006) Global biomass energy potential. Mitig Adapt Strat Gl 11:313–342
13. Freitas LC, Kaneko S (2011) Decomposition of CO_2 emissions change from energy consumption in Brazil: challenges and policy implications. Energ Policy 39:1495–1504
14. Rodrigues TO, Caldeira-Pires A, Luz S, Frate CA (2014) GHG balance of crude palm oil for biodiesel production in the northern region of Brazil. Renew Energ 62:516–521
15. Costa ACA, Pereira Junior N, Aranda DAG (2010) The situation of biofuels in Brazil: new generation technologies. Renew Sust Energ Rev 14:3041–3049
16. Höfer R, Bigorra J (2008) Biomass-based green chemistry: sustainable solutions for modern economies. Green Chem Lett Rev 1(2):79–97
17. Merchant Research and Consulting Ltd (2014) Biodiesel: 2014 World Market Outlook and Forecast up to 2018. In: Merchant Research and Consulting Ltd, Burmingham. http://mcgroup.co.uk/researches/biodiesel. Accessed 29 July 2014
18. Rathmann R, Szklo A, Schaeffer R (2012) Targets and results of the Brazilian biodiesel incentive program – has it reached the promised land? App Energ 97:91–100

19. Bergmann JC, Tupinambá DD, Costa OYA, Almeida JRM, Barreto CC, Quirino BF (2013) Biodiesel production in Brazil and alternative biomass feedstocks. Renew Sust Energ Rev 21:411–420
20. Castanheira ÉG, Grisoli R, Freire F, Pecora V, Coelho ST (2014) Environmental sustainability of biodiesel in Brazil. Energ Policy 65:680–691
21. César AS, Batalha MO, Zopelari ALMS (2013) Oil palm biodiesel: Brazil's main challenges. Energ 60:485–491
22. Costa AO, Oliveira LB, Lins MPE, Silva ACM, Araujo MSM, Pereira AO, Jr, Rosa LP (2013) Sustainability analysis of biodiesel production: a review on different resources in Brazil. Renew Sust Energ Rev 27:407–412
23. Rodríguez-Guerrero LK, Rubens MC, Rosa PTV (2013) Production of biodiesel from castor oil using sub and supercritical ethanol: effect of sodium hydroxide on the ethyl ester production. J Supercrit Fluid 83:124–132
24. Souza TPC, Stragevitch L, Knoechelmann A, Pacheco JGA, Silva JMF (2014) Simulation and preliminary economic assessment of a biodiesel plant and comparison with reactive distillation. Fuel Process Technol 123:75–81
25. Zonin VJ, Antunes JAV, Jr, Leis RP (2014) Multicriteria analysis of agricultural raw materials: a case study of BSBIOS and PETROBRAS BIOFUELS in Brazil. Energ Policy 67:255–263
26. Resch G, Held A, Faber T, Panzer C, Toro F, Haas R (2008) Potentials and prospects for renewable energies at global scale. Energ Policy 36(11):4048–4056
27. Pottmaier D, Melo C, Sartor MN, Kuester S, Amadio TM, Fernandes CAH, Marinha D, Alarcon OE (2013) The Brazilian energy matrix: from a materials science and engineering perspective. Renew Sust Energ Rev 19:678–691
28. Lora ES, Andrade RV (2009) Biomass as energy source in Brazil. Renew Sust Energ Rev 13:777–788
29. Ferreira-Leitão V, Gottschalk LMF, Ferrara MA, Nepomuceno AL, Molinari HBC, Bon EPS (2010) Biomass residues in Brazil: availability and potential uses. Waste Biomass Valor 1:65–76
30. Goldemberg J (2007) Ethanol for a sustainable energy future. Science 315:808–810
31. Wyman CE, Goodman BJ (1993) Biotechnology for production of fuels, chemicals, and materials from biomass. Appl Biochem Biotechnol 39/40:41–59
32. de Jong E, Langeveld H, van Ree R (2009) IEA Bioenergy Task 42 Biorefinery. http://www.biorefinery.nl/fileadmin/biorefinery/docs/Brochure_Totaal_definitief_HR_opt.pdf Accessed 29 July 2014
33. Cherubini F (2010) The biorefinery concept: using biomass instead of oil for producing energy and chemicals. Energ Convers Manage 51:1412–1421
34. Budarin VL, Shuttleworth PS, Dodson JR, Hunt AJ, Lanigan B, Marriott R, Milkowski KJ, Wilson AJ, Breeden SW, Fan J, Sin EHK, Clark JH (2011) Use of green chemical technologies in an integrated biorefinery. Energ Environ Sci 4(2):471–479
35. Vaz S, Jr (2011) Biorrefinarias: cenários e perspectivas. In: Embrapa Agroenergia, p 176
36. Ragauskas AJ, Williams CK, Davison BH, Britovsek G, Cairney J, Eckert CA, Frederick WJ, Jr, Hallett JP, Leak DJ, Liotta CL, Mielenz JR, Murphy R, Templer R, Tschaplinski T (2006) The path forward for biofuels and biomaterials. Science 311:484–489
37. Mariano AP, Dias MOS, Junqueira TL, Cunha MP, Bonomi A, Maciel Filho R (2013) Utilization of pentoses from sugarcane biomass: techno-economics of biogas vs. butanol production. Bioresource Technol 142:390–399
38. Almeida MN, Guimarães VM, Falkoski DL, Visser EM, Siqueira GA, Milagres AMF, Rezende ST (2013) Direct ethanol production from glucose, xylose and sugarcane bagasse by the corn endophytic fungi *Fusarium verticillioides* and *Acremonium zeae*. J Biotechnol 168:71–77
39. Chandel AK, Antunes FAF, Silva MB, Silva SS (2013) Unraveling the structure of sugarcane bagasse after soaking in concentrated aqueous ammonia (SCAA) and ethanol production by *Scheffersomyces* (*Pichia*) *stipites*. Biotechnol Biofuel 6:102
40. Correia JAC, Marques Júnior JE, Gonçalves LRB, Rocha MVP (2013) Alkaline hydrogen peroxide pretreatment of cashew apple bagasse for ethanol production: study of parameters. Bioresource Technol 139:249–256
41. Groposo C, Castro AM, Pereira N, Jr (2013) Effects of agitation and exogenous H2 on bioconversion of sugarcane bagasse into ethanol by Clostridium thermocellum ATCC 27405. Electron J Biotechnol 16(6):7
42. Mussatto SI, Machado EMS, Carneiro LM, Teixeira JA (2012) Sugars metabolism and ethanol production by different yeast strains from coffee industry wastes hydrolysates. Appl Energ 92:763–768
43. Rocha NRAF, Barros MA, Fischer J, Coutinho Filho U, Cardoso VL (2013) Ethanol production from agroindustrial biomass using a crude enzyme complex produced by Aspergillus niger. Renew Energy 57:432–435
44. Silva CR, Zangirolami TC, Rodrigues JP, Matugi K, Giordano RC, Giordano RLC (2012) An innovative biocatalyst for production of ethanol from xylose in a continuous bioreactor. Enzyme Microb Tech 50:35–42
45. Agostinho F, Ortega E (2013) Energetic-environmental assessment of a scenario for Brazilian cellulosic ethanol. J Clean Prod 47:474–489
46. Dias MOS, Ensinas AV, Nebra SA, Maciel Filho R, Rossell CEV, Maciel MRW (2009) Production of bioethanol and other bio-based materials from sugarcane bagasse: integration to conventional bioethanol production process. Chem Eng Res Design 87:1206–1216
47. Dias MOS, Junqueira TL, Cavalett O, Cunha MP, Jesus CDF, Rossell CEV, Maciel Filho R, Bonomi A (2012) Integrated versus stand-alone second generation ethanol production from sugarcane bagasse and trash. Bioresource Technol 103:152–161
48. Dias MOS, Junqueira TL, Cavalett O, Pavanello LG, Cunha MP, Jesus CDF, Maciel Filho R, Bonomi A (2013) Biorefineries for the production of first and second generation ethanol and electricity from sugarcane. App Energ 109:72–78
49. Dias MOS, Junqueira TL, Cavalett O, Cunha MP, Jesus CDF, Mantelatto PE, Rossella CEV, Maciel Filho R, Bonomi A (2013) Cogeneration in integrated first and second generation ethanol from sugarcane. Chem Eng Res Design 91:1411–1417
50. Furlan FF, Tonon Filho R, Pinto FHPB, Costa CBB, Cruz AJG, Gioradno RLC, Giordano RC (2013) Bioelectricity versus bioethanol from sugarcane bagasse: is it worth being flexible? Biotechnol Biofuel 6:142
51. Virmond E, Rocha JD, Moreira RFPM, José HJ (2013) Valorization of agroindustrial solid residues and residues from biofuel production chains by thermochemical conversion: a review, citing Brazil as a case study. Braz J Chem Eng 30(2):197–230
52. Martínez JD, Mahkamov K, Andrade RV, Lora EES (2012) Syngas production in downdraft biomass gasifiers and its application using internal combustion engines. Renew Energ 38:1–9
53. Pereira EG, Silva JN, Oliveira JL, Machado CS (2012) Sustainable energy: a review of gasification technologies. Renew Sust Energ Rev 16:4753–4762
54. Centeno F, Mahkamov K, Lora EES, Andrade RV (2012) Theoretical and experimental investigations of a downdraft biomass gasifier-spark ignition engine power system. Renew Energ 37:97–108
55. Asencios YJO, Rodella CB, Assaf EM (2013) Oxidative reforming of model biogas over $NiO–Y_2O_3–ZrO_2$ catalysts. Appl Catal B: Environ 132–133:1–12
56. Eliott RM, Nogueira MFM, Sobrinho ASS, Couto BAP, Maciel HS, Lacava PT (2013) Tar reforming under a microwave plasma torch. Energ Fuel 27:1174–1181
57. Freitas ACD, Guirardello R (2012) Supercritical water gasification of glucose and cellulose for hydrogen and syngas production. Chem Eng Trans 27:361–366
58. Peres APG, Lunellia BH, Maciel Filho R (2013) Application of biomass to hydrogen and syngas production. Chem Eng Trans 32:589–594
59. Sousa-Aguiar EF, Noronha FB, Faro A (2011) The main catalytic challenges in GTL (gas-to-liquids) processes. Catal Sci Technol 1:698–713
60. Hotza D, Costa JCD (2008) Fuel cells development and hydrogen production from renewable resources in Brazil. Int J Hydrogen Energ 33:4915–4935
61. Marques SSI, Nascimento IA, Almeida PF, Chinalia FA (2013) Growth of chlorella vulgaris on sugarcane vinasse: the effect of anaerobic digestion pretreatment. Appl Biochem Biotechnol 171:1933–1943
62. Bezerra RP, Matsudo MC, Sato S, Converti A, Carvalho JCM (2013) Fed-batch cultivation of arthrospira platensis using carbon dioxide from alcoholic fermentation and urea as carbon and nitrogen sources. Bioenerg Res 6:1118–1125
63. Rocha JD (2013) Chemistry without borders: the energy challenges. Quim Nova 36(10):1540–1551
64. Coutinho P, Bomtempo JV (2011) A technology roadmap in renewable raw materials: a basis for public policy and strategies in Brazil. Quim Nova 34(5):910–916
65. Graça I, Lopes JM, Cerqueira HS, Ribeiro MF (2013) Bio-oils upgrading for second generation biofuels. Ind Eng Chem Res 52:275–287
66. Serrano-Ruiz JC, Luque R, Sepúlveda-Escribano A (2011) Transformations of biomass-derived platform molecules: from high added-value chemicals to fuels via aqueous-phase processing. Chem Soc Rev 40:5266–5281

67. Werpy T, Petersen G (2004) Top Value Added Products from Biomass Volume I: Results of Screening for Potential Candidates from Sugars and Synthesis Gas., http://www.nrel.gov/docs/fy04osti/35523.pdf. Accessed 29 July 2014
68. Bozell JJ, Petersen GR (2010) Technology development for the production of biobased products from biorefinery carbohydrates: the US Department of Energy's "Top 10" revisited. Green Chem 12:539–554
69. Villela Filho M, Araujo C, Bonfá A, Porto W (2011) Chemistry based on renewable raw materials: perspectives for a sugar cane- based biorefinery. Enzyme Res 654596:8
70. Rossi CCRS, Alonso CG, Antunes OAC, Guirardello R, Cardozo-Filho L (2009) Thermodynamic analysis of steam reforming of ethanol and glycerine for hydrogen production. Int J Hydrogen Energ 34:323–332
71. Amaral PFF, Ferreira TF, Fontes GC, Coelho MAZ (2009) Glycerol valorization: new biotechnological routes. Food Bioprod Process 87:179–186
72. Coronado CR, Carvalho JA, Jr, Quispe CA, Sotomonte CR (2014) Ecological efficiency in glycerol combustion. App Therm Eng 63:97–104
73. Quispe CAG, Coronado CJR, Carvalho JA, Jr (2013) Glycerol: production, consumption, prices, characterization and new trends in combustion. Renew Sust Energ Rev 27:475–493
74. Branco RF, Santos JC, Silva SS (2011) A novel use for sugarcane bagasse hemicellulosic fraction: xylitol enzymatic production. Biomass Bioenerg 35:3241–3246
75. Godoy MG, Gutarra MLE, Maciel FM, Felix SP, Bevilaqua JV, Machado OLT, Freire DMG (2009) Use of a low-cost methodology for biodetoxification of castor bean waste and lipase production. Enzyme Microb Technol 44:317–322
76. Godoy MG, Gutarra MLE, Castro AM, Machado OLT, Freire DMG (2011) Adding value to a toxic residue from the biodiesel industry: production of two distinct pool of lipases from Penicillium simplicissimum in castor bean waste. J Ind Microbiol Biotechnol 38:945–953
77. López JA, Lázaro CC, Castilho LR, Freire DMG, Castro AM (2013) Characterization of multienzyme solutions produced by solid-state fermentation of babassu cake, for use in cold hydrolysis of raw biomass. Biochem Eng J 77:231–239
78. Oliveira LA, Porto ALF, Tambourgi EB (2006) Production of xylanase and protease by *Penicillium janthinellum* CRC 87M-115 from different agricultural wastes. Bioresource Technol 97:862–867
79. Almeida JRM, Fávaro LCL, Quirino BF (2012) Biodiesel biorefinery: opportunities and challenges for microbial production of fuels and chemicals from glycerol waste. Biotechnol Biofuel 5:48
80. Mesa-Pérez JM, Rocha JD, Barbosa-Cortez LA, Penedo-Medina M, Luengo CA, Cascarosa E (2013) Fast oxidative pyrolysis of sugar cane straw in a fluidized bed reactor. Appl Therm Eng 56:167–175
81. Venderbosch RH, Prins W (2010) Review: fast pyrolysis technology development. Biofuel Bioprod Bior 4:178–208
82. Pires AMM, Mattiazzo ME (2008) Avaliação da Viabilidade de Uso de Resíduos na Agricultura., http://www.infoteca.cnptia.embrapa.br/bitstream/doc/15550/1/circular19.pdf. Accessed 29 July 2014
83. Herpin U, Gloaguen TV, Fonseca AF, Montes CR, Mendonça FC, Piveli RP, Breulmann G, Forti MC, Melfi AJ (2007) Chemical effects on the soil–plant system in a secondary treated wastewater irrigated coffee plantation—a pilot field study in Brazil. Agr Water Manage 89:105–115
84. Barros IT, Andreoli CV, Souza Junior IG, Costa ACS (2011) Agronomic evaluation of biosolids treated by different chemical methods for cultivation of maize. Rev Bras Eng Agríc Ambient 15(6):630–638
85. Lúcio AD, Schwertner DV, Santos D, Haesbaert FM, Brunes RR, Brackmann A (2013) Productive and morphological characteristics of tomato fruits cultivated with potato bioproduct. Hortic Bras 31(3):369–374
86. Rabelo SC, Carrere H, Maciel Filho R, Costa AC (2011) Production of bioethanol, methane and heat from sugarcane bagasse in a biorefinery concept. Bioresource Technol 102:7887–7895
87. Moraes BS, Junqueira TL, Pavanello LG, Cavalett O, Mantelatto PE, Bonomi A, Zaiat M (2014) Anaerobic digestion of vinasse from sugarcane biorefineries in Brazil from energy, environmental, and economic perspectives: profit or expense? App Energ 113:825–835
88. Pedroso DT, Machín EB, Silveira JL, Nemoto Y (2013) Experimental study of bottom feed updraft gasifier. Renew Energ 57:311–316
89. Zonetti PC, Gaspar AB, Mendes FMT, Sobrinho EV, Sousa-Aguiar EF, Appel LG (2010) Fischer–Tropsch synthesis and the generation of DME in situ. Fuel Process Technol 91:469–475
90. Fernandes BS, Peixoto G, Albrecht FR, Aguila NKS, Zaiat M (2010) Potential to produce biohydrogen from various wastewaters. Energ Sust Dev 14:143–148
91. Cappelletti BM, Reginatto V, Amante ER, Antônio RV (2011) Fermentative production of hydrogen from cassava processing wastewater by *Clostridium acetobutylicum*. Renew Energ 36:3367–3372
92. Ratti RP, Botta LS, Sakamoto IK, Varesche MBA (2013) Microbial diversity of hydrogen-producing bacteria in batch reactors fed with cellulose using leachate as inoculum. Int J Hydrogen Energ 38:9707–9717
93. Menezes AO, Rodrigues MT, Zimmaro A, Borges LEP, Fraga MA (2011) Production of renewable hydrogen from aqueous-phase reforming of glycerol over Pt catalysts supported on different oxides. Renew Energ 36:595–599
94. Tuza PV, Manfro RL, Ribeiro NFP, Souza MMVM (2013) Production of renewable hydrogen by aqueous-phase reforming of glycerol over Ni-Cu catalysts derived from hydrotalcite precursors. Renew Energ 50:408–414
95. Bueno AV, Oliveira MLM (2013) Glycerol steam reforming in a bench scale continuous flow heat recovery reactor. Int J Hydrogen Energ 38:13991–14001
96. Monteiro SA, Sassaki GL, Souza LM, Meira JA, Araújo JM, Mitchell DA, Ramos LP, Krieger N (2007) Molecular and structural characterization of the biosurfactant produced by Pseudomonas aeruginosa DAUPE 614. Chem Phys Lipids 147:1–13
97. Silva SNRL, Farias CBB, Rufino RD, Luna JM, Sarubbo LA (2010) Glycerol as substrate for the production of biosurfactant by *Pseudomonas aeruginosa* UCP0992. Colloid Surface B 79:174–183
98. Assaf PGM, Nogueira FGE, Assaf EM (2013) Ni and Co catalysts supported on alumina applied to steam reforming of acetic acid: representative compound for the aqueous phase of bio-oil derived from biomass. Catal Today 213:2–8
99. Guedes CLB, Adão DC, Quessada TP, Borsato D, Galão OF, Di Mauro E, Pérez JMM, Rocha GO, Andrade JB, Guarieiro ALN, Guarieiro LLN, Ramos LP (2010) Evaluation of biofuel derived from lignocellulosic biomass fast pyrolysis bio-oil for use as gasoline addictive. Quim Nova 33:781–786
100. Braga RM, Melo DMA, Aquino FM, Freitas JCO, Melo MAF, Barros JMF, Fontes MSB (2014) Characterization and comparative study of pyrolysis kinetics of the rice husk and the elephant grass. J Therm Anal Calorim 115:1915–1920
101. Abdelnur PV, Vaz BG, Rocha JD, Almeida MBB, Teixeira MAG, Pereira RCL (2013) Characterization of bio-oils from different pyrolysis process steps and biomass using high-resolution mass spectrometry. Energ Fuel 27:6646–6654
102. Cunha ME, Schneider JK, Brasil MC, Cardoso CA, Monteiro LR, Mendes FL, Pinho A, Jacques RA, Machado ME, Freitas LS, Caramão EB (2013) Analysis of fractions and bio-oil of sugar cane straw by one-dimensional and two-dimensional gas chromatography with quadrupole mass spectrometry (GC × GC/qMS). Microchem J 110:113–119
103. Almeida TM, Bispo MD, Cardoso ART, Migliorini MV, Schena T, Campos MCV, Machado ME, López JA, Krause LC, Caramão EB (2013) Preliminary studies of bio-oil from fast pyrolysis of coconut fibers. J Agric Food Chem 61:6812–6821
104. Fernandes ERK, Marangoni C, Souza O, Sellin N (2013) Termochemical characterization of banana leaves as a potential energy source. Energ Convers Manage 75:603–608
105. Anschau A, Santos LO, Alegre RM (2013) A cost effective fermentative production of glutathione by *Saccharomyces cerevisiae* with cane molasses and glycerol. Braz Arch Biol Technol 56(5):849–857
106. Barros M, Freitas S, Padilha GS, Alegre RM (2013) Biotechnological production of succinic acid by *Actinobacillus Succinogenes* using different substrate. Chem Eng Trans 32:985–990
107. Volpato G, Rodrigues RC, Heck JX, Ayub MAZ (2008) Production of organic solvent tolerant lipase by Staphylococcus caseolyticus EX17 using raw glycerol as substrate. J Chem Technol Biotechnol 83:821–828
108. Santos EO, Michelon M, Gallas JA, Kalil SJ, Burkert CAV (2013) Raw glycerol as substrate for the production of yeast biomass. Int J Food Eng 9(4):413–420
109. Vargas GDLP, Treichel H, Oliveira D, Beneti S, Freire DMG, Luccio M (2008) Optimization of lipase production by Penicillium simplicissimum in soybean meal. J Chem Technol Biotechnol 83:47–54
110. Visser EM, Falkoski DL, Almeida MN, Maitan-Alfenas GP, Guimarães VM (2013) Production and application of an enzyme blend from *Chrysoporthe cubensis* and *Penicillium pinophilum* with potential for hydrolysis of sugarcane bagasse. Bioresource Technol 144:587–594

111. Pereira BMP, Alvarez TM, Delabona PS, Dillon AJP, Squina FM, Pradella JGC (2013) Cellulase on-site production from sugar cane bagasse using penicillium echinulatum. Bioenerg Res 6:1052–1062
112. Guimarães LHS, Somera AF, Terenzi HF, Polizeli MLTM, Jorge JA (2009) Production of β-fructofuranosidases by *Aspergillus niveus* using agroindustrial residues as carbon sources: characterization of an intracellular enzyme accumulated in the presence of glucose. Process Biochem 44:237–241
113. Damásio ARL, Braga CMP, Brenelli LB, Citadini AP, Mandelli F, Cota J, Almeida RF, Salvador VH, Paixao DAA, Segato F, Mercadante AZ, Neto MO, Santos WD, Squina FM (2013) Biomass-to-bio-products application of feruloyl esterase from *Aspergillus clavatus*. Appl Microbiol Biotechnol 97:6759–6767
114. Bragatto J, Segato F, Squina FM (2013) Production of xylooligosaccharides (XOS) from delignified sugarcane bagasse by peroxide-HAc process using recombinant xylanase from Bacillus subtilis. Ind Crop Prod 51:123–129
115. Brienzo M, Carvalho W, Milagres AMF (2010) Xylooligosaccharides production from alkali-pretreated sugarcane bagasse using xylanases from *Thermoascus aurantiacus*. Appl Biochem Biotechnol 162:1195–1205
116. Martins AB, Schein MF, Friedrich JLR, Fernandez-Lafuente R, Ayub MAZ, Rodrigues RC (2013) Ultrasound-assisted butyl acetate synthesis catalyzed by Novozym 435: enhanced activity and operational stability. Ultrason Sonochem 20:1155–1160
117. Santos DT, Albarelli JQ, Joyce K, Oelgemllöer M (2009) Sensitizer immobilization in photochemistry: evaluation of a novel green support. J Chem Technol Biotechnol 84:1026–1030
118. Machado NRCF, Calsavara V, Astrath NGC, Matsuda CK, Paesano Junior A, Baesso ML (2005) Obtaining hydrocarbons from ethanol over iron-modified ZSM-5 zeolites. Fuel 84:2064–2070
119. Nunes AA, Franca AS, Oliveira LS (2009) Activated carbons from waste biomass: an alternative use for biodiesel production solid residues. Bioresource Technol 100:1786–1792
120. Medeiros ABP, Pandey A, Vandenberghe LPS, Pastore GM, Soccol CR (2006) Production and recovery of aroma compounds produced by solid-state fermentation using different adsorbents. Food Technol Biotechnol 44(1):47–51
121. Rossi SC, Vandenberghe LPS, Pereira BMP, Gago FD, Rizzolo JA, Pandey A, Soccol CR, Madeiros ABP (2009) Improving fruity aroma production by fungi in SSF using citric pulp. Food Res Int 42:484–486
122. Zonetti PC, Celnik J, LEtichevsky S, Gaspar AB, Appel LG (2011) Chemicals from ethanol – the dehydrogenative route of the ethyl acetate one-pot synthesis. J Mol Catal A-Chem 334:29–34
123. Guilherme AA, Silveira MS, Fontes CPML, Rodrigues S, Fernandes FAN (2012) Modeling and optimization of lactic acid production using cashew apple juice as substrate. Food Bioprocess Technol 5:3151–3158
124. Leite JAC, Pozzi E, Pelizer LH, Zaiat M, Barboza M (2013) Use of volatile fatty acids salts in the production of xanthan gum. Food Bioprocess Technol 16(2):6
125. Olivério JL, Boscariol FC, Mantelatto PE, César ARP, Ciambelli JRP, Gurgel MNA, Souza RTG (2011) Integrated production of organomineral biofertiliser (BIOFOM) using by-products from the sugar and ethanol agro-industry, associated with the cogeneration of energy. Sugar Tech 13(1):17–22
126. Rodrigues S, Pinto GAS, Fernandes FAN (2008) Optimization of ultrasound extraction of phenolic compound from coconut (*Cocos nucifera*) shell powder by response surface methodology. Ultrason Sonochem 15:95–100
127. Forim MR, Costa ES, da Silva MFGF, Fernandes JB, Mondego JM, Boiça-Junior AL (2013) Development of a new method to prepare nano/micro particles loaded with extracts of *Azadirachta indica*, their characterization, and use in controlling *Plutella xylostella*. J Agr Food Chem 61:9131–9139
128. Da Costa JT, Forim MR, Costa ES, de Souza JR, Mondego JM, Boiça-Jr AL (2013) Effects of different formulations of neem oil-based products on control *Zabrotes subfasciatus* Boheman, 1833) (Coleoptera: Bruchidae) on beans. J Stored Products Research 56:49–53
129. Carvalho SS, Vendramim JD, Pitta TM, Forim MR (2012) Efficiency of neem oil nanoformulations to *Bemisia tabaci* (Genn.) biotype B (Hemiptera: Aleyrodidae). Semina Cienc Agrárias 33:193–202
130. Rampelotti-Ferreira FT, Vendramim JD, Forim MR (2012) Bioatividade de nanoformulações de nim sobre a traça-do-tomateiro. Cienc Rural 42:1347–1353
131. Cazal CM, Batalhão JR, Domingues VC, Bueno OC, Rodrigues-Filho E, Forim MR, da Silva MFGF, Vieira PC, Fernandes JB (2009) High-speed counter-current chromatographic isolation of ricinine, an insecticide from *Ricinus communis*. J Chromatogr A 1216:4290–4294
132. Severino VGP, Cazal CM, Forim MR, da Silva MFGF, Rodrigues-Filho E, Viera PC (2009) Isolation of secondary metabolites from *Hortia oreadica* (Rutaceae) leaves through high-speed counter-current chromatography. J Chromatogr A 1216:4275–4281
133. Cazal CM, Domingues VC, Batalhão JR, Bueno OC, Rodrigues-Filho E, Forim MR, da Silva MFGF, Vieira PC, Fernandes JB (2009) Isolation of xanthyletin, an inhibitor of ants' symbiotic fungus, by high-speed counter-current chromatography. J Chromatogr A 1216:4307–4312
134. Veiga TAM, King-Díaz B, Marques ASF, Sampaio OM, Vieira PC, da Silva MFGF, Lotina-Hennsen B (2013) Furoquinoline alkaloids isolated from Balfourodendron riedelianum as photosynthetic inhibitors in spinach chloroplasts. J Photoch Photob B 120:36–43
135. EU Standing Committee on Agricultural Research (2013) Agricultural knowledge and innovation systems towards 2020 – an orientation paper on linking innovation and research., http://ec.europa.eu/research/bioeconomy/pdf/agricultural-knowledge-innovation-systems-towards-2020_en.pdf. Accessed 29 July 2014

doi:10.1186/s40538-014-0005-1
Cite this article as: Perlatti *et al.*: Green chemistry, sustainable agriculture and processing systems: a Brazilian overview. *Chemical and Biological Technologies in Agriculture* 2014 **1**:5.