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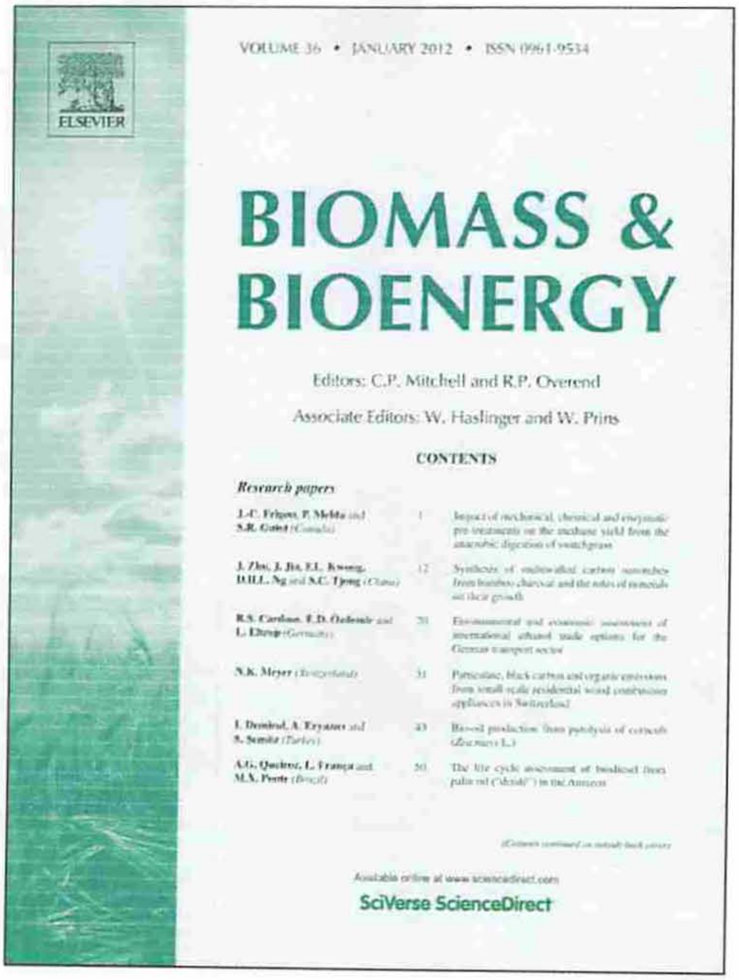

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BIOMASS & BIOENERGY

Editors: C.P. Mitchell and R.P. Overend

Associate Editors: W. Haslinger and W. Prins

CONTENTS

(Contents continued on outside back cover)

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BIOMASS AND BIOENERGY

AIMS AND SCOPE

Biomass and Bioenergy is an international journal publishing original research papers and short communications, review articles and case studies on biological resources, chemical and biological processes, and biomass products for new renewable sources of energy, food and materials.

Key areas covered by the journal:

Biomass:	sources, energy crop production processes, genetic improvements, composition.
Biological Residues:	wastes from agricultural production and forestry, processing industries, and municipal sources (MSW).
Bioenergy Processes:	fermentations, thermochemical conversions, liquid and gaseous fuels, and petrochemical substitutes.
Bioenergy Utilization:	direct combustion, gasification, electricity production, chemical processes, and by-product remediation.
Biomass and the Environment:	carbon cycle, the net energy efficiency of bioenergy systems, assessment of sustainability, and biodiversity issues.

The scope of the journal extends to the **environmental, management** and **economic** aspects of biomass and bioenergy.

The journal also features book reviews, reports on conferences, details of forthcoming meetings, letters to the editor and special interest topics.

Cover image: Biomass resources include tree and shrub species as well as grasses and straw associated with agricultural production of grains as in the photograph.

Biomass and Bioenergy

Volume 36, Pages 1-446 (January 2012)

articles 1 - 51

= Full-text available
= Abstract only

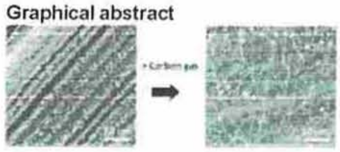
E-mail articles | Export citations | PDF downloader | Open all previews

Research papers

Highlights

► Switchgrass is a model energy crops for biofuels production. ► This study evaluated different pre-treatments to enhance methane production. ► Pre-treatments increase significantly the methane produced from switchgrass. ► Enzymatic pre-treatments were superior to physical and chemical pre-treatments.

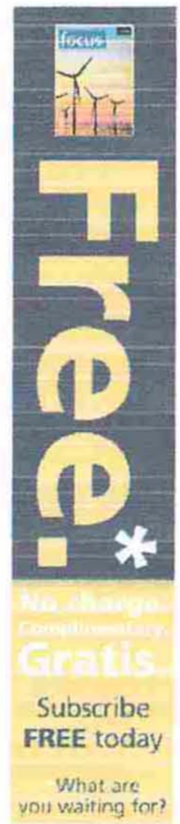
Graphical abstract



Highlights

► The evolution of minerals in bamboo charcoal under heat treatment is found. ► The roles of minerals in bamboo charcoal in the growth of CNTs are proposed. ► The upload of CNTs increases the specific surface area and the adsorption capacity.

Highlights



► We investigate the energy balance, GHG emissions and costs of production and transport of ethanol fuel to Germany. ► Ethanol transport has a minor impact compared to production in terms of fossil energy consumption and costs. ► Ethanol energy ratio in Germany is 7.3 for Brazilian, 1.24 for American and 1.99 for French ethanol. ► Brazilian ethanol has a more competitive price in Germany including transport and taxes, due to lower production costs.

Highlights

► Small-Scale residential wood combustion emissions in Switzerland are dominated by 4 appliance classes. ► PM emissions are dependant upon hardwood:softwood fuel mix. ► TOC, POM and BC emissions are relatively independent of hardwood:softwood fuel mix. ► Current total particulate emissions from Swiss residential wood combustion estimated to be 4.35 kt y^{-1}. ► Black carbon and particle bound organic matter (POM) are estimated to contribute 39% and 42% respectively.

Highlights

► Pyrolysis of corncob was performed in a fixed-bed reactor under different conditions. ► The yield of 26.44% was obtained at a temperature of 500 °C, a heating rate of 40 °C/min and gas flow rate of 100 cm^3/min. ► The oil is a mixture of aliphatic and aromatic hydrocarbons having an empirical formula of $CH_{1.34}O_{0.28}N_{0.01}$. ► The higher calorific value of the oil is 26.22 MJ/kg, which is very close to those of petroleum fractions. ► FTIR analysis showed that the oil composition was dominated by oxygenated species.

Highlights

► Palm oil is a promising primary source of biodiesel in the Amazon. ► We have developed a life cycle assessment of two factories to palm oil in this region. ► The data shows the energetic and materials costs at each stage of production. ► That is important to develop decision criteria for choosing the most efficient source.

Highlights

► We investigated economic feasibility of producing green gas from dairy manure. ► Data from 23 operating biogas plants was used. ► We developed a simulation model of producing green gas from 2 business models. ► The probability of profitability is high for both models. ► Biogas yield and investment cost have significant effect in determining profitability.

Highlights

► In this study, we investigated the potential of biofuels in Turkey. ► Our country has great potential for biodiesel and bioethanol. ► Bioethanol production capacity is very good. ► Turkey has considerable potential for agricultural waste.

Highlights

► A rapid and simple model was developed to predict the leaf area for the purging nut. ► The models are simple and able to produce accurate results without expensive equipment. ► Researchers can accurately estimate large quantities leaf areas of purging nut plants. ► The current model to estimate leaf area of the jatropha underestimate LA.

11 The potential of willow and poplar plantations as carbon sinks in Sweden Original Research Article
Pages 86-95
Rose-Marie Rytter
Show preview | PDF (377 K) | Related articles | Related reference work articles

Highlights

► Poplars and willows as producers of biomass for fuel and as C sinks. ► Calculation of C sequestration rates in biomass and soil in willow and poplar plantations. ► Increasing forested areas has positive impact on high CO_2 levels. ► Willow and poplar plantations on arable land mitigate anthropogenic CO_2 emissions.

12 Effects of biodiesel blend fuel on volatile organic compound (VOC) emissions from diesel engine exhaust Original Research Article
Pages 96-106
Chiung-Yu Peng, Cheng-Hang Lan, Chun-Yuh Yang
Show preview | PDF (259 K) | Related articles | Related reference work articles

Highlights

► VOC emissions from diesel engines fueled with biodiesel blend and diesel fuels are characterized and compared. ► Biodiesel blend fuel has much lower total VOC emissions, and total ozone potentials. ► Reduction in health risks also found in biodiesel blend fuel, especially for the developmental, nervous and respiratory systems. ► Use of biodiesel in diesel engines has beneficial effects in terms of VOC emissions.

13 Wood biomass supply costs and potential for biomass energy plants in Japan Original Research Article
Pages 107-115
Kana Kamimura, Hirofumi Kuboyama, Koichi Yamamoto
Show preview | PDF (684 K) | Related articles | Related reference work articles

Highlights

► 10–32% of the wood biomass supply cost was reduced due to improved supply system. ► Regions having large sawmills could provide certain amount of biomass with low cost. ► At 14,000 yen t^{-1} of MC and AC, Regions 7 and 9 could supply by 0.1 Mt using CC. ► IC increased the wood biomass supply potential, in particular Regions 2, 7, and 9.

14 Enhanced biogas production from rice straw, triticale straw and softwood spruce by NMMO pretreatment Original Research Article
Pages 116-120
Anna Teghammar, Keikhosro Karimi, Ilona Sárvári Horváth, Mohammad J. Taherzadeh
Show preview | PDF (237 K) | Related articles | Related reference work articles

Highlights

► Spruce, rice and triticale straw were treated with NMMO prior to anaerobic digestion. ► The pretreatments were performed at 130 °C for 1–15 h. ► The pretreatments have improved the methane yields by 400–1200%. ► This is due to the breakdown of the crystalline structure of the lignocelluloses.

15 Effectiveness of weed management methods in establishment of switchgrass and a native species mixture for biofuels in Wisconsin Original Research Article
Pages 121-131
Jessica R. Miesel, Mark J. Renz, Julie E. Doll, Randall D. Jackson
Show preview | PDF (733 K) | Related articles | Related reference work articles

Highlights

►Regional assessment of perennial bioenergy crop establishment in southwestern WI. ►Comparative effects of weed management treatments on biomass yield. ►Biomass yield from switchgrass monocultures and a diverse species mixture. ►Economic assessment of alternative establishment methods.

16 A mutant strain of microalga *Chlorella* sp. for the carbon dioxide capture from biogas Original Research Article
Pages 132-140
Chien-Ya Kao, Sheng-Yi Chiu, Tzu-Ting Huang, Le Dai, Guan-Hua Wang, Ching-Ping Tseng, Chiun-Hsun Chen, Chih-Sheng Lin
Show preview | PDF (475 K) | Related articles | Related reference work articles

► We evaluate the impacts of biofuel production on water quantity and quality. ► Biomass production can be sustained under higher removal rates with fertilization. ► Sediment yield increased and N load decreased when more corn stover was removed. ► Conversion from grass to bioenergy crops could decrease water and raise N load. ► Miscanthus is more productive but it consumes more water and N than switchgrass.

Highlights

► Allometry of coppice-shoots in managed oaks differ from non-managed trees. ► Current harvest cycles are non-optimal for maximizing charcoal productivity. ► Oaks could be potentially used as a mid-term rotation coppice species for energy.

Highlights

► Comprehensive cost model produces using data from a number of sources. ► Costs include pre-processing plant for woodchip and baled miscanthus. ► Cost include electricity consumed and sales of surplus bio-char. ► Product yields predicted for energy crops from published experimental data. ► Thermal model produced to estimate surplus bio-char production.

Highlights

► Fermentation of biowaste into hydrogen (H_2) and polyhydroxybutyrate (PHB) using defined bacterial cultures for each stage. ► Combination of bacterial cultures for hydrolysis of biowaste along with H_2 producers increased H_2 production by 1.89 fold. ► A 2.87 fold enhancement in PHB production by *Bacillus* strains from peashells as sole feed. ► Pea-shells as feed produced 65 L H_2 kg^{-1} and 62.5 g PHB kg^{-1} TS fed.

Highlights

► We study the moisture sorption behaviour of jatropha seed allowing the development of a model correlating the equilibrium moisture content (EMC) and the free fatty acids (FFA) content as a function of water activity and EMC, respectively. ► We examine the influences of temperature and water activity on the EMC of jatropha seed. ► Increasing water activity will increase the EMC of jatropha seed. ► We recommend the BET, GAB, Harkins-Jura, Halsey and Henderson models as adequate models in predicting the amount of moisture adsorbed or desorbed at known humidity. ► The polynomial equation is the best fitting for the relationship between EMC and FFA content of jatropha seed.

Highlights

► We compared the completely unknown perennials' *Sida hermaphrodita* with willow. Virginia fanpetals (*Sida*) yielded better than two willow clones (*Salix ssp.*). Seed dressing increased biomass dry matter yields of Virginia fanpetals.

Highlights

► We optimized two-stage hydrogen production by investigating the effects of light and carbon sources. ► Among various patterns of light, fully light condition proved to be most effective. ► The use of optical fiber slowed down the rate of hydrogen production. ► Malt extract resulted in maximum hydrogen production.

29 Statistical optimization of dilute sulfuric acid pretreatment of corncob for xylose recovery and ethanol production Original Research Article
Pages 250-257
Bai-Yan Cai, Jing-Ping Ge, Hong-Zhi Ling, Ke-Ke Cheng, Wen-Xiang Ping
Show preview | PDF (428 K) | Related articles | Related reference work articles

Highlights

► Optimize H_2SO_4 pretreatment of corncob for xylose yield using response surface method. ► Condition for the highest xylose yield didn't give the best glucose yield. ► Pretreatment conditions for best sugar yields depended on products wanted.

30 Experimental investigation on hydrogen production from biomass gasification in interconnected fluidized beds Original Research Article
Pages 258-267
Tao Song, Jiahua Wu, Laihong Shen, Jun Xiao
Show preview | PDF (572 K) | Related articles | Related reference work articles

Highlights

► Biomass gasification in interconnected fluidized beds. ► Hydrogen production performance with steam/biomass ratio and temperature. ► Tar measurement in syngas. ► Hydrogen yield and carbon gasification of biomass reach its maximum values of 0.553 $Nm^3\ kg^{-1}$ biomass and 50.02%.

31 Life cycle assessment of hemp hurds use in second generation ethanol production Original Research Article
Pages 268-279
Sara González-García, Lin Luo, Mª Teresa Moreira, Gumersindo Feijoo, Gjalt Huppes
Show preview | PDF (1402 K) | Related articles | Related reference work articles

Highlights

► Hemp hurds are a by-product from dedicated fibre crops. ► The environmental performance of two ethanol fuel blends, E10 and E85, was analyzed and compared with the conventional gasoline. ► The influence on the results of the allocation procedure assumed in the study was also evaluated. ► The results show that ethanol-based fuels can offer improved environmental performance in some impact categories. ► The choice of allocation approach significantly affects the environmental performance.

32 Effect of steam pretreatment on oil palm empty fruit bunch for the production of sugars Original Research Article
Pages 280-288
Saleha Shamsudin, Umi Kalsom Md Shah, Huzairi Zainudin, Suraini Abd-Aziz, Siti Mazlina Mustapa Kamal, Yoshihito Shirai, Mohd Ali Hassan
Show preview | PDF (1268 K) | Related articles | Related reference work articles

Highlights

► We investigate the feasibility of steam pretreatment to enhance digestibility of EFB. ► Steam pretreatment increased sugars to 3.4 fold and caused major alteration in EFB morphology under SEM. ► Autohydrolysis which does not require the addition of chemicals is an attractive pretreatment approach to EFB.

33 Ethanol production from *Ferula communis* Original Research Article
Pages 289-292
Polycarpos Polycarpou
Show preview | PDF (531 K) | Related articles | Related reference work articles

Highlights

► The use of *Ferula communis* as an energy plant for ethanol production is examined. ► Its flower stalks contain 0.5 – 0.55 $kg\ kg^{-1}$ sugars and starch. ► Ethanol is produced by fermentation of the juice extracted from the flower stalks. ► The alcohol yield per kilogram dry stalks was 55.8 $cm^3\ kg^{-1}$. ► The plant seems to be a potential energy plant for ethanol production.

34 Quantitative analysis of media dilution rate effects on *Methanothermobacter marburgensis* grown in continuous culture on H_2 and CO_2 Original Research Article
Pages 293-301
S. Rittmann, A. Seifert, C. Herwig
Show preview | PDF (353 K) | Related articles | Related reference work articles

Highlights

► We precisely correlated results of volumetric hydrogen and carbon dioxide uptake rates to methane and water production rates. ► Specific methane and water productivity is presented for *Methanothermobacter marburgensis* grown on H_2/CO_2. ► Water production from biological methanogenesis was gravimetrically determined by using a comprehensive bioreactor set-up. ► A dynamic medium dilution rate experiment substantiated chemostat culture steady state results.

35 Comparative life cycle assessment of improved and conventional cultivation practices for energy crops in Japan Original Research Article
Pages 302-315
Susumu Uchida, Kiyotada Hayashi
Show preview | PDF (1059 K) | Supplementary content | Related articles | Related reference work articles

Highlights

► Improvements in energy crop cultivation reduce environmental impacts. ► Breeding of high-yield varieties is effective for reducing environmental impacts. ► Introduction of simplified operations and disease resistance are also effective. ► Reducing nitrogen use through adequate fertilising and crop residue input is needed. ► The results are different by categories, and a comprehensive assessment is important.

36 Carbon isotope variation in shrub willow (*Salix* spp.) ring-wood as an indicator of long-term water status, growth and survival Original Research Article
Pages 316-326
Laura A. Schifman, John C. Stella, Timothy A. Volk, Mark A. Teece
Show preview | PDF (710 K) | Related articles | Related reference work articles

Highlights

► A 0.26‰ ^{13}C depletion in wood tissue occurred per 100 mm increase in precipitation. ► There was an average ^{13}C enrichment with plant age and size for all varieties. ► Greater ^{13}C enrichment often lead to lower survival rates in plants. ► Shorter growth rotations maximize biomass yield and phytoremediation applications.

37 Continuous production of bio-oil by catalytic liquefaction from wet distiller's grain with solubles (WDGS) from bio-ethanol production Original Research Article
Pages 327-332
Saqib Sohail Toor, Lasse Rosendahl, Mads Pagh Nielsen, Marianne Glasius, Andreas Rudolf, Steen Brummerstedt Iversen
Show preview | PDF (307 K) | Related articles | Related reference work articles

Highlights

► Hydrothermal liquefaction of wet biomass. ► Product phase analysis: oil, acqeous, gas and mineral phase. ► Energy and mass balance evaluation.

38 Concentration dependent glycine effect on the photosynthetic growth and bio-hydrogen production by *Rhodobacter sphaeroides* from mineral springs Original Research Article
Pages 333-338
Lilit Gabrielyan, Armen Trchounian
Show preview | PDF (384 K) | Related articles | Related reference work articles

Highlights

► The results point out concentration dependent glycine effects on *Rhodobacter sphaeroides*. ► 5 mol m^{-3} glycine can serve as nitrogen source for growth and H_2 production. ► 10 mol m^{-3} glycine suppressed growth and H_2 production by *R. sphaeroides*.

39 A supply chain evaluation of slash bundling under the conditions of mountain forestry Original Research Article
Pages 339-345
Raffaele Spinelli, Natascia Magagnotti, Gianni Picchi
Show preview | PDF (209 K) | Related articles | Related reference work articles

Highlights

► Bundling represents an additional step in the forest biomass supply chain. ► Bundling cost varies around 30 € per oven-dry tonne. ► Bundling accrues savings on transportation, storage and comminution. ► These savings offset bundling cost only under special conditions. ► Technology improvement may reduce bundling cost and make bundling more attractive.

40 Acid hydrolysis of wheat straw: A kinetic study Original Research Article
Pages 346-355
Esther Guerra-Rodríguez, Oscar M. Portilla-Rivera, Lorenzo Jarquín-Enríquez, Jose A. Ramírez, Manuel Vázquez
Show preview | PDF (321 K) | Related articles | Related reference work articles

Highlights

► The acid hydrolysis of wheat straw eliminates a waste. ► The acid hydrolysis also generates a value-added products. ► The objective was to study the sugar production from wheat straw as a pretreatment for ethanol or xylose fermentation. ► Kinetic models were developed to explain the variation with time of sugars and growth inhibitors. ► Optimal conditions found were 2% H_2SO_4 at 130 °C for 29 min.

41 Estimating potential logging residues in a boreal forest by airborne laser scanning Original Research Article
Pages 356-365
Marius Hauglin, Terje Gobakken, Vegard Lien, Ole Martin Bollandsås, Erik Næsset
Show preview | PDF (335 K) | Related articles | Related reference work articles

Highlights

► Area-based estimates of potential logging residues were obtained using airborne laser scanning. ► The accuracy of the estimates was comparable to those obtained for e.g. timber volume. ► Stratification according to site quality did not significantly improve the accuracy of the estimates.

42 Fermentation and purification of cellulase from a novel strain *Rhizopus stolonifer* var. *reflexus* TP-02 Original Research Article
Pages 366-372
Bin Tang, Haibo Pan, Wenjing Tang, Qingqing Zhang, Lixia Ding, Fengqin Zhang
Show preview | PDF (690 K) | Related articles | Related reference work articles

Highlights

► A novel strain *Rhizopus stolonifer* var. *reflexus* was well identified and characterized. ► The *stain* is very active to produce the cellulase during fermentation characteristics. ► The enzyme characteristics of the cellulose were also carried out.

43 Immobilized lipase on magnetic chitosan microspheres for transesterification of soybean oil Original Research Article
Pages 373-380
Wenlei Xie, Jianlong Wang
Show preview | PDF (649 K) | Related articles | Related reference work articles

Highlights

► The lipase bound on magnetic chitosan microsphere can give 87% biodiesel conversion. ► The immobilization had no significant change in the property of magnetic microsphere. ► The immobilized lipase had a better reusability.

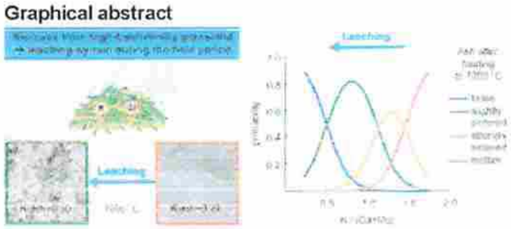
44 Nutrient enrichment reduces complementarity and increases priority effects in prairies managed for bioenergy Original Research Article
Pages 381-389
Meghann E. Jarchow, Matt Liebman
Show preview | PDF (549 K) | Related articles | Related reference work articles

Highlights

► Prairies provide biomass for bioenergy and ecosystem services. ► Both diversity and nitrogen fertilization increase prairie productivity. ► Fertilization stimulated C_3 grasses always and C_4 grasses later in growing season. ► Unfertilized, diverse prairies had phenological complementarity of resource use. ► Fertilized, diverse prairies had priority effects due to C_3 grass dominance.

45 Leaching of biomass from semi-natural grasslands – Effects on chemical composition and ash high-temperature behaviour Original Research Article
Pages 390-403
Bettina Tonn, Ulrich Thumm, Iris Lewandowski, Wilhelm Claupein
Show preview | PDF (1012 K) | Supplementary content | Related articles | Related reference work articles

Graphical abstract



Highlights

► Combustion of biomass from biodiversity-rich nature conservation grassland. ► Leaching by rain during the field period reduces K and Cl concentrations. ► Increasing K/(Ca + Mg) and decreasing (K + Ca + Mg)/ash ratios increase ash melting. ► Leaching reduces ash melting and elemental release during combustion.

46 Biomass, grain and energy yield in *Cynara cardunculus* L. as affected by fertilization, genotype and harvest time Original Research Article
Pages 404-410
Anita Ierna, Rosario P. Mauro, Giovanni Mauromicale
Show preview | PDF (289 K) | Related articles | Related reference work articles

Highlights

► Some cardoons maximized biomass and energy yield at medium level of fertilization. ► Cardoons improved their performances along the three-year experiment. ► Harvest at flowering or at achenes ripening did not affect energy yield.

47 Lignite clean up of magnesium bisulphite pulp mill effluent as a proxy for aqueous discharge from a ligno-cellulosic biorefinery Original Research Article
Pages 411-418
Galuh Yuliani, Ying Qi, Andrew F.A. Hoadley, Alan L. Chaffee, Gil Garnier
Show preview | PDF (606 K) | Related articles | Related reference work articles

Highlights

► The process water of a bisulfite pulp mill was selected to model the effluent of an industrial biorefinery. ► We report the use of lignite as a low cost adsorbent and quantify its selectivity for colour, organics and phosphorus removal. ► The lignite has a higher capacity for phosphorus than activated carbon.

48 Processing of *Siraitia grosvenori'* leaves: Extraction of antioxidant substances Original Research Article
Pages 419-426
Yingming Pan, Liuxin Wei, Zhiren Zhu, Ying Liang, Chusheng Huang, Hengshan Wang, Kai Wang
Show preview | PDF (491 K) | Related articles | Related reference work articles

Highlights

► The leaves of *Siraitia grosvenori'* are rich in total flavonoids. ► The antioxidant activity of alcoholic extract of *Siraitia grosvenori'* leaves was found to be comparable to BHT. ► Three flavonoid compounds were first successfully separated from *Siraitia grosvenori'* leaves. ► These flavonoid compounds expressed high free radical scavenging activities.

Short Communications

49 Exploring a promising feedstock for biodiesel production in Mediterranean countries: A study on free fatty acid esterification of olive pomace oil
Pages 427-431
Franklin Che, Ioannis Sarantopoulos, Theocharis Tsoutsos, Vasileios Gekas
Show preview | PDF (504 K) | Related articles | Related reference work articles

Highlights

► We carried out experiments to optimize the pretreatment process to convert FFAs to methyl esters. ► The olive kernel oil can be efficiently processed to decrease the FFAs' concentration. ► The olive pomace oil could be sustainably used as a complementary feedstock to biodiesel.

50 Satellite retrieval of woody biomass for energetic reuse of riparian vegetation
Pages 432-438
Giovanni Forzieri
Show preview | PDF (1111 K) | Related articles | Related reference work articles

Highlights

► Strong correlations between satellite spectral signatures and tree high/stem diameter. ► Tri-parametric power laws for satellite retrieval of biomass-related vegetation parameters. ► Satellite-derived products as suitable inputs into decision making tools for a sustainable management of riparian corridors.

51 Monitoring of the startup phase of one continuous anaerobic digester at pilot scale level
Pages 439-446
Massimo Brambilla, Fabio Araldi, Mario Marchesi, Barbara Bertazzoni, Matteo Zagni, Pierluigi Navarotto
Show preview | PDF (684 K) | Related articles | Related reference work articles

Highlights

► In this study we monitored the startup phase of one pilot scale anaerobic digester. ► All process parameters were recorded as well as biogas productions. ► PCA and LDA analysis showed that three groups of cases were enlightable. ► FOS/TAC value is the parameter better accounting for AD establishment.

articles 1 - 51

< Previous vol/iss | Next vol/iss >

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BIOMASS AND BIOENERGY 36 (2012) 226–233

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Moisture sorption behaviour of jatropha seed (*Jatropha curcas*) as a source of vegetable oil for biodiesel production

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ABSTRACT

This research studied the moisture sorption behaviour of jatropha seed allowing the development of a model correlating the equilibrium moisture content (EMC) and the free fatty acids (FFA) content as a function of water activity and EMC, respectively. Two sets of sorption-isotherm experiment were performed to describe the relationship between EMC and FFA content with water activity, for both fresh and dried seeds. The seeds were conditioned in series of saturated salts having certain water activity and stored at different temperatures (20, 30, 40 °C). The nested experimental design and ANOVA (F-test at $p = 0.05$) were applied to study the effects of temperature and water activity on the EMC of jatropha seed.

EMC increased generally with the increase in water activity and with the decrease in temperature at either desorption or adsorption. The EMC was significantly affected by water activity, but the temperature did not significantly affect the EMC. The hysteresis effect was more pronounced at lower temperatures. The FFA content of seed was relatively constant at low water activity ($a_w < 0.8$), but it was high at higher water activity.

The moisture sorption behaviour of jatropha seed revealed that like most product, it exhibited the sigmoid pattern. The BET, GAB, Harkins-Jura, Halsey and Henderson models were recommended as adequate models in predicting the amount of moisture adsorbed or desorbed at known humidity. The relationship between EMC and FFA content of jatropha seed showed that the polynomial equation was the best fitting for either fresh or dried seed.

1. Introduction

Jatropha curcas is a drought-resistant shrub or tree belonging to the family Euphorbiaceae, which is cultivated in Central and South America, South-East Asia, India and Africa [1]. The plant can be used to prevent and/or control erosion, to reclaim land, grown as a hedge to protect fields, and be planted as a commercial crop [2–4].

The seeds, a part of jatropha plant with the highest potential for utilization, contain 40–60% oils and 20–30% proteins. The jatropha seed is generally toxic to humans and animals due to phorbol ester and curcin contents [1,5].

The oil of *Jatropha curcas* is regarded as a potential diesel substitute [1–5]. The fact that the jatropha oil cannot be used for nutritional purposes without detoxification makes its use as an energy source for fuel production very attractive.

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Most of biodiesel is produced using methanol and an alkaline catalyst through a transesterification reaction [6,7]. The problem with an alkaline-transesterification of the vegetable oils is that they often contain large amount of free fatty acids (FFA) which quickly react with the catalyst to produce soaps that are difficult to separate [8,9]. This may reduce the quantity of catalyst available for transesterification, lowering the ester production yield. Low free fatty acids content in the oil (less than 3%) is therefore required for alkali-catalyzed transesterification [8].

Attractive approach to control the FFA in the seed level is by controlling water activity (a_w) of the seed to a level that disables any undesirable reactions or enzyme activities. A fundamental approach for controlling the water activity of the seed is by understanding of seed characteristics and its behaviour in responding the changes in environmental conditions, particularly the relative humidity (RH, where a_w = %RH/100 at saturation condition). This approach has been successfully applied to several oilseeds such as canola, macadamia nuts [10], wheat [11], soybean, hazelnut [12], peanut [13], amaranth [14], sunflower [15] and corn [16]. Controlling the FFA in the seed level can thus be achieved by proper handling and storage of the seed before oil extraction.

The main purpose of this research is to achieve a fundamental understanding of the hygroscopic properties of jatropha seed allowing the development of models correlating the equilibrium moisture content (EMC) and the FFA content as a function of water activity and EMC, respectively.

2. Materials and methods

Jatropha fruit used in this research was originated from two different locations in Indonesia, i.e. Lampung and Banten, and supplied by Indonesian Center for Estate Crops Research and Development. All chemicals and solvent were of analytical grades (Sigma–Aldrich, AppliChem and J.T. Baker, Indonesia).

The seed was first characterized for their chemical composition. The sorption isotherm properties of the seed from each location were determined for both fresh and dried seeds at 20, 30 and 40 °C. The moisture and FFA contents of the seed were quantified at equilibrium condition of given relative humidity using $ZnCl_2$, NaOH, CH_3COOK, $MgCl_2$, K_2CO_3, NaBr, NaCl, $(NH_4)_2SO_4$, KNO_3 and K_2SO_4 to determine sorption behaviour of the seed and its correlation with FFA content.

A model is fitted to the data to provide an estimate of change of moisture content under different conditions of equilibrium relative humidity. Data of sorption isotherm was applied to eight different isotherm equations, i.e. Halsey, Henderson, Harkins-Jura, Iglesias-Chirife, Oswin, Smith, BET (Brunauer, Emmet and Teller) and GAB (Guggenheim, Anderson and de Boer) (Table 1) in order to determine the best model to predict the sorption behaviour of the jatropha seed. The constants for isotherm equations were calculated using linear regression and differently non-linear regression for GAB model. The goodness of fit of the different models was evaluated with the mean relative deviation modulus [$P = (100/n)\sum(M_i{-}Mp_i)/M_i)$] between the experimental (M_i) and predicted moisture contents (Mp_i).

Table 1 – Models considered in equilibrium isotherm modeling.

Model	Equation
BET	$a_w/(1-a_w).M = 1/Mo.C + a_w.(C-1)/Mo.C$
GAB	$M = A.B.Mo.a_w/(1-B.a_w).(1-B.a_w + A.B.a_w)$
Halsey	$M = (-A/T.\ln(a_w))^{1/B}$
Harkin-Jura	$1/M^2 = (B/A)-(1/A).\log a_w$
Henderson	$M = -(\ln(1-a_w)/A.T)^{1/B}$
Iglesias-Chirife	$\ln(M + ((M^2 + M^{0.5})^{0.5}) = A + B.a_w$
Oswin	$M = A.(a_w/1-a_w)^B$
Smith	$M = A-B.\ln(1-a_w)$

A, B, C are parameters pertinent to each equation; Mo is monolayer moisture content; T is temperature absolute (K).

2.1. *Jatropha fruit collection and preparation*

The ripe fruits were peeled, and the seeds were removed and collected. The seed from each location was separated into two groups; one was directly transferred into series of desiccators containing saturated salts for determination of sorption isotherm, and the other one went into oven drying (50 °C, 48 h) to reduce its moisture content (around 3–5%) then transferred into desiccators for the same saturation treatments.

2.2. *Characterization of jatropha seed*

The chemical compositions of the seed were determined to provide the initial conditions of the seed before conditioning for sorption isotherm determination. Moisture content of both fresh and dried seeds was determined using the constant-temperature-oven method. The seeds were dried at 105 °C for 15 h, after which they were cooled in a desiccator containing silica gels and reweighed to quantify moisture loss in weight upon drying.

Oil content of the seed was determined using solvent extraction method. Ground seed was placed into an extraction thimble, and the oil was extracted using soxhlet extraction apparatus with hexane for 6 h. The solvent was then evaporated using rotary vacuum evaporator, and the remaining oil was weighed. Seed oil content was expressed as percent by mass of the dry matter. The oil was then sent to the Gas Chromatography (Perkin Elmer Autosystem XL) to determine the fatty acid compositions. The GC was equipped with a flame ionization detector and using helium as carrier gas. The sample injected was separated in a VF-5 ms (VARIAN) column (15 m × 0.32 mm). The oven temperature of the GC was programmed from 55 °C to 360 °C at an increasing rate of 45 °C min^{-1} to the temperature of 80 °C, and then 100 °C min^{-1}. The oven temperature was then held at 360 °C for 15 min. The injector temperature was programmed from 55 °C to 340 °C at an increasing rate of 200 °C min^{-1} and was held at 340 °C for 35 min. On the other hand, the detector temperature was fixed at 365 °C.

Initial FFA content of the seed was determined using a method described in section 2.4. Protein, ash and fiber crude contents were determined according to AOAC approved methods (AOAC 991.20, AOAC 923.03 and AOAC 962.09).

2.3. Determination of sorption isotherm

An isopiestic method was employed for the determination of sorption isotherms by exposing the seed to atmospheres of known relative humidity at different temperatures. 200 g seeds were taken randomly from 5 kg of fresh seeds then divided into ten of 20 g for sorption isotherm determination. Each 20 g seeds were placed into a desiccator containing saturated salts with certain relative humidity. Saturated salt solutions comprised $ZnCl_2$, NaOH, CH_3COOK, $MgCl_2$, K_2CO_3, NaBr, NaCl, $(NH_4)_2SO_4$, KNO_3 and K_2SO_4. The seeds were removed every day, reweighed and returned to the desiccators. When seeds reached constant weight, i.e. in equilibrium with the saturated salt solution (2–4 weeks), their moisture content was determined using oven method. The same procedure was repeated for the dried seed. These sorption isotherm experiments were conducted at three different temperatures (20, 30 and 40 °C) in two replications.

The experimental design applied to this study was nested design, and its analysis was carried out using ANOVA (F-test at $p = 0.05$). The level of water activity factor (β) was nested within temperature factor (τ). The model can be written as [17]: $Yijk = \mu + \tau_i + \beta_{j(i)} + \varepsilon_{(ij)k}$ with $1 \le k \le K$; $1 \le i \le I$; $1 \le j \le J$, where K is the number of replicates performed for each level of τ and β factors ($K = 2$), I is the number of temperature levels ($I = 3$), and J is the number of water activity levels ($J = 10$). Yijk is the observed equilibrium moisture content of jatropha seed and $\varepsilon_{(ij)k}$ is the measurement error of the kth experimental unit of the ith temperature at the jth water activity level. The true common mean is denoted by μ, τ_i is the ith temperature effect, and $\beta_{j(i)}$ is the jth water activity effect nested within the ith level of temperature factor. The water activity of salt at different temperatures was measured using a_w-meter (NOVASINA MS 1).

2.4. FFA determination

Two gram seeds were ground, and placed into an erlenmeyer containing 50 mL ethanol 96%. The acid value (FFA content) was determined by titration using KOH (0.1 N) with phenolphthalein as an indicator. The end point of titration was the appearance of permanent pink in the solvent mixture.

3. Results and discussion

The average physicochemical characteristics of the two jatropha varieties used in these experiments are shown in Table 2. The moisture content of jatropha seed was relatively high for fresh seed (Lampung: 44.11–45.77%; Banten: 42.34–44.18%), and 3.65–4.63% (Lampung) and 3.29–4.03% (Banten) for dried seed. The oil content of jatropha seed ranged from 34.77 to 40.25% for Lampung variety and from 34.04 to 37.06% for Banten variety with FFA content of 1.49–2.56% (Lampung, fresh seed), 1.39–2.08% (Lampung, dried seed), 1.80–3.00% (Banten, fresh seed) and 1.40–2.46% (Banten, dried seed). Both varieties are rich in oleic, linoleic and palmitic fatty acids. Protein and ash contents of jatropha seed were respectively 20.14–21.96% (Lampung) and 21.26–22.70% (Banten), and 3.62–3.72% (Lampung) and 4.13–4.21% (Banten). In addition, the jatropha seed contained the crude fiber of 49.13% (Lampung) and 53.31% (Banten) (expressed as percent by mass of the dry and deoiled matter).

Fig. 1A showed typical adsorption and desorption isotherm for Lampung and Banten varieties of jatropha seed at the temperature of 20 °C. The EMC increased with the increase in water activity. The adsorption and desorption curves for jatropha seed followed the characteristics of sigmoidal shape commonly found in many hygroscopic products, as observed for macadamia nuts [10], hazelnut [12] and corn [16]. A significant hysteresis phenomenon between adsorption and desorption was also observed (Table 3). The FFA content of fresh seed increased with the increase in water activity, while the FFA content of dried seed was relatively constant (Fig. 2A).

The EMC of Banten variety was not significantly different with Lampung variety at the same water activity for both desorption and adsorption (Table 4). However, the FFA content of seed from Banten was higher than those from Lampung for

Table 2 – Physicochemical characteristics of jatropha seed and fatty acid composition of jatropha oil.

Parameter	Variety			
	Lampung		Banten	
	Fresh seed	Dried seed	Fresh seed	Dried seed
Moisture (%)	44.94 ± 0.830	4.14 ± 0.486	43.26 ± 0.915	3.66 ± 0.365
FFA (%)	2.03 ± 0.533	1.74 ± 0.342	2.40 ± 0.598	1.93 ± 0.530
Oil (%)	37.51 ± 2.735		35.55 ± 1.505	
Protein (%)	21.05 ± 0.909		21.98 ± 0.719	
Ash (%)	3.67 ± 0.047		4.17 ± 0.039	
Fatty acid composition (%):				
1. Palmitic (C16:0)	14.70 ± 0.244		14.76 ± 0.128	
2. Palmitoleic (C16:1)	0.86 ± 0.035		0.91 ± 0.032	
3. Stearic (C18:0)	7.37 ± 0.291		7.01 ± 0.205	
4. Oleic (C18:1)	39.44 ± 0.795		39.29 ± 0.657	
5. Linoleic (C18:2)	36.52 ± 0.925		36.84 ± 0.487	
6. Linolenic (C18:3)	0.70 ± 0.034		0.75 ± 0.078	
7. Arachidic (C20:0)	0.25 ± 0.011		0.25 ± 0.018	
8. Gadoleic (C20:1)	0.16 ± 0.018		0.18 ± 0.040	

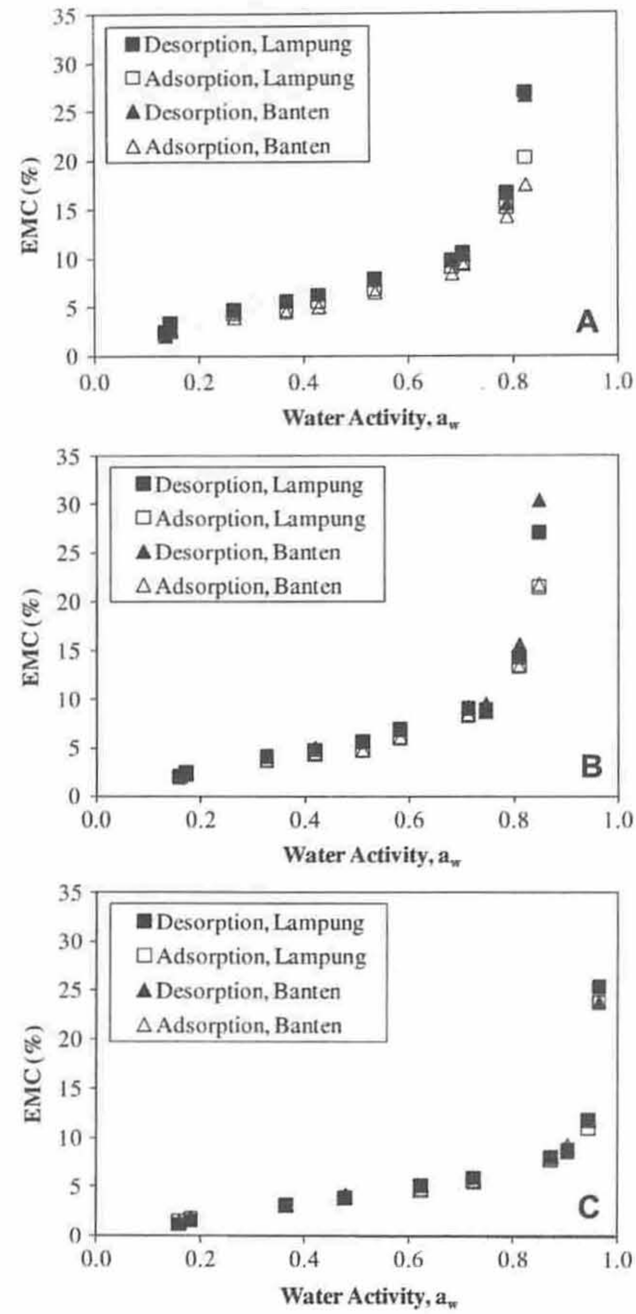

Fig. 1 – Adsorption-desorption isotherm for Lampung and Banten varieties of jatropha seeds at (A) 20 °C, (B) 30 °C and (C) 40 °C.

both fresh and dried seeds. For sorption isotherm of jatropha seed at temperature of 20 °C, the variety of jatropha seed affected thus FFA content of seed, but it did not influence the equilibrium isotherm of seed.

Fig. 1B and C showed the EMC for seed from both locations at the temperature of 30 and 40 °C. Both for adsorption and desorption, the EMC increased with the increase in water activity, and the equilibrium isotherm for both seeds was relatively similar. These indicated that the variety of jatropha seed did not affect the equilibrium isotherm at the temperature of 30 and 40 °C. The same phenomenon was also observed for sorption isotherm of wheat and hazelnut, respectively [11,12].

The EMC decreased with the increase in temperature at constant water activity in either desorption or adsorption. This indicates that the jatropha seed becomes less hygroscopic when temperature increases. The decrease in moisture content with the increase in temperature may be due to a reduction in the total number of active sites for water binding as a result of physical and/or chemical changes in the product induced by temperature [10]. This may also be due to the increased state of excitation of molecules at higher temperature, leading to an increase in distance and corresponding decrease in attractive forces between them [16]. However, the increase in temperature may also lead to activation of water molecules due to an increase in their energy level, causing them to become less stable and to break away from the water-binding sites.

The ANOVA applied to data (Table 5) showed that the temperature did not significantly affect the EMC of jatropha seed for both desorption and adsorption in either Lampung or Banten variety. On the other hand, the water activity affected the EMC of jatropha seed significantly.

More water is held at the same water activity for the desorption curve than the adsorption curve. The hysteresis effect was more pronounced at lower temperatures (20 °C) (Fig. 1A). In the original wet condition the polar sites in the molecular structure of the material are almost entirely satisfied by absorbed water. Upon drying, the molecules and their water holding sites are drawn closely enough together to satisfy each other. This reduces the water holding capacity of the material upon subsequent adsorption [10,16].

Bell and Labuza [18] described that one aspect of moisture sorption leading to hysteresis was how water interacts within pores or capillaries. During moisture adsorption, water moves into the capillaries. However, these capillaries may empty differently upon desorption. Narrow ends of surface pores can trap and hold water internally below the water activity where the water should have been released. In addition, during adsorption the pure water will dissolve solutes present in the dry product. The dissolution of solutes may increase the surface tension such that upon desorption, a lower water activity results at given moisture content. Similarly, the wetting angle is lower for desorption as compared to adsorption, also resulting in a lower water activity at given moisture content for desorption.

The temperature dependences of the EMC have an important practical bearing on chemical and microbiological reactions associated with spoilage. At the same moisture content, higher temperatures entail a higher water activity and consequently faster rates of deterioration [16].

Deteriorative changes in oilseeds may be either oxidative or hydrolytic, resulting in the production of free fatty acids [19,20]. Fats in seeds are readily broken down by lipases into free fatty acids and glycerol during storage, particularly when the temperature and moisture content are high. This type of change is greatly accelerated by mold growth because of high lipolytic activity of the molds. The kinds of molds are influenced by the initial moisture, temperature and oxygen concentration [21–26]. *A. niger*, *A. candidus* and *A. versicolor* are the predominant species present [19].

Table 3 – Tukey's test for desorption and adsorption of Lampung and Banten varieties of jatropha seed at different water activities and temperature of 20 °C.

Variety	Water activity	Difference in averages of EMC of desorption and adsorption	T value at $p = 0.05$
Lampung	1	0.33	0.08
	2	0.43	0.28
	3	0.38 (NS)	0.73
	4	0.80	0.26
	5	0.75	0.24
	6	0.97	0.77
	7	0.64	0.55
	8	1.19	0.31
	9	1.38 (NS)	1.51
	10	6.71	2.73
Banten	1	0.42	0.25
	2	0.15 (NS)	0.42
	3	0.61	0.06
	4	1.20	0.32
	5	1.37	1.08
	6	1.22	0.53
	7	1.37	0.78
	8	0.94	0.59
	9	1.30	1.39
	10	9.04	3.48

NS: Non-Significant.

Fig. 2B and C showed FFA contents of fresh and dried seeds after sorption isotherm at 30 and 40 °C. Both seeds from Lampung and Banten had a relatively constant FFA content at water activity less than 0.8, but very high at higher water activity. In addition, FFA content of seeds after sorption isotherm at 40 °C was higher than those of 20 and 30 °C for both Lampung and Banten varieties. The sorption isotherm is suspected to affect seed properties because water acting as a solvent seems to impart mobility to chemical constituents of seeds by dissolution. This will account for the increased rate of chemical reaction [27], and it is accelerated by temperature, relative humidity and initial seed moisture content.

Free fatty acids are carboxylic acids released from triglycerides through the effect of lipase or oxidation. The risk of oxidation is high in jatropha seeds due to their high unsaturated fatty acids content, especially oleic and linoleic fatty acids (Table 2). Fatty acids containing one or more conjugated pentadiene systems, $-CH{=}CH{-}CH_2{-}CH{=}CH{-}$, are especially sensitive [28]. Bell and Labuza [18] described that lipid oxidation began to increase above a water activity of 0.3. At this water activity, the amount of water adsorbed on surface and in capillaries is enough to affect the overall dielectric properties such that the water can behave as a solvent. Thus, chemical species can dissolve, become increasingly mobile, and react. The higher water activity is the faster the reaction rate because of the greater solubility and increased mobility.

(E-4323-1) The suitability of eight sorption models (Table 6) in describing the sorption data of jatropha seeds was examined. The mean relative deviation modulus (P) of all tested sorption models for adsorption were smaller than those for desorption. Thus, the adsorption data gave more suitable fit for sorption models than desorption data.

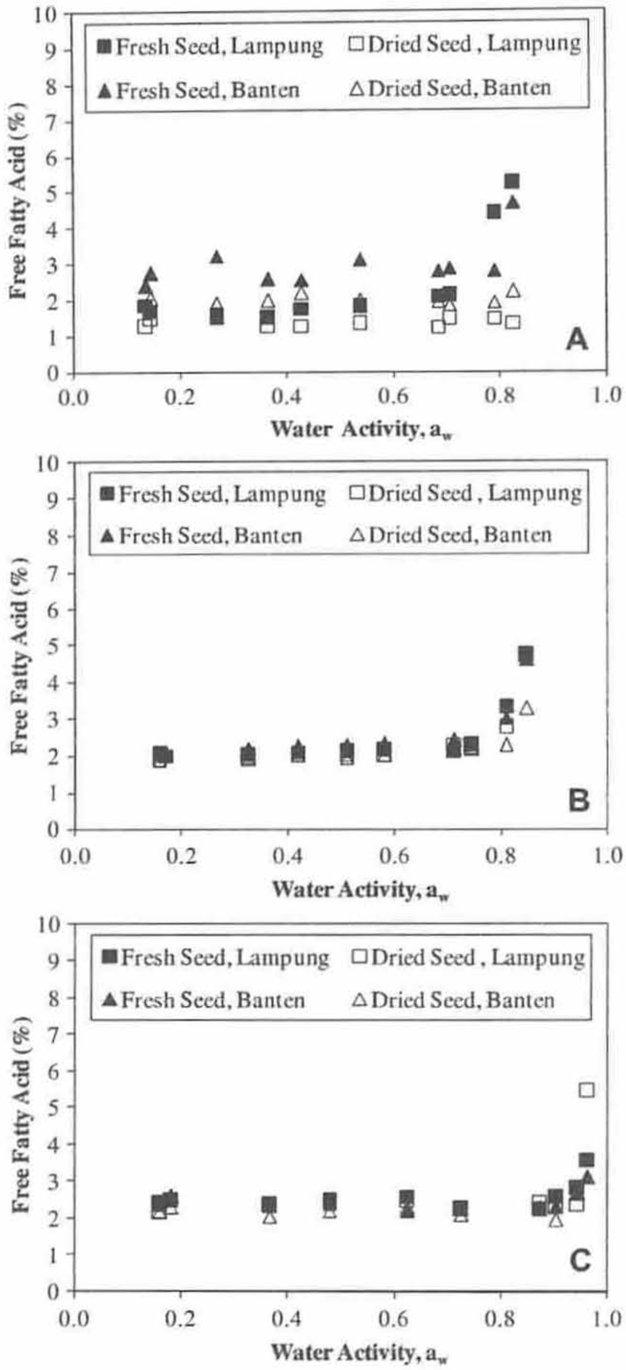

Fig. 2 – FFA content of fresh and dried jatropha seeds for Lampung and Banten varieties after sorption isotherm at (A) 20 °C, (B) 30 °C and (C) 40 °C.

On the basis of P, the Halsey, BET and GAB models were the most efficient and versatile models for adsorption for both Lampung and Banten varieties at the temperature of 20 and 30 °C. For desorption, the BET, GAB and Harkin-Jura models were the most appropriate for Lampung variety at the temperature of 20 °C, while for Banten variety the GAB and Henderson were the most suitable fitting. At the temperature of 30 °C, the GAB model was the most appropriate for both Lampung and Banten varieties. The Henderson, Oswin, Smith

Table 4 – Tukey's test for Lampung and Banten varieties of jatropha seed both for desorption and adsorption at different water activities and temperature of 20 °C.

Variety	Water activity	Difference in averages of EMC of Lampung and Banten	T value at $p = 0.05$
Desorption	1	0.48	0.14
	2	0.53	0.44
	3	0.11 (NS)	0.26
	4	0.26 (NS)	0.35
	5	0.02 (NS)	1.01
	6	0.02 (NS)	0.72
	7	0.16 (NS)	0.73
	8	0.31 (NS)	0.62
	9	0.91 (NS)	1.13
	10	0.43 (NS)	2.18
Adsorption	1	0.27	0.22
	2	0.26	0.25
	3	0.35 (NS)	0.68
	4	0.18 (NS)	0.22
	5	0.60	0.24
	6	0.28 (NS)	0.60
	7	0.57 (NS)	0.62
	8	0.06 (NS)	0.26
	9	0.83 (NS)	1.68
	10	2.77 (NS)	3.86

NS: Non-Significant.

and GAB models were the most fitting models for adsorption for both Lampung and Banten varieties at the temperature of 40 °C. For desorption, the Henderson and GAB models were the most appropriate.

The R^2 of desorption and adsorption curves showed similar features. At temperature of 20 °C, the BET and GAB models gave significantly lower R^2 than other models for both desorption and adsorption curves. At temperatures of 30 and 40 °C, the GAB model had the lowest R^2.

The BET, GAB, Harkins-Jura and Halsey models correspond to multilayer adsorption models. These indicated that water adsorption was likely to be a multilayer adsorption in jatropha-water system. Thus, the surface force distribution may be considered to act by causing the adsorbed film to behave as liquid in a two-dimensional state. Moreover, the sorption data obtained fit the Harkins-Jura model well, which indicated that the isotherm had the characteristics of a type II isotherm (sigmoidal-shaped curve).

An important parameter usually obtained from sorption data is the monolayer moisture content (Mo) (Table 7). In the BET and GAB isotherm equations, the monolayer moisture content is regarded as the sorption capacity of the adsorbent and as the indicator of usefulness of polar sites for water vapor. It also defines the safest moisture content for storage. Below its monolayer value, for most dry product, the rate of quality loss due to chemical reaction is negligible. In this research, in a temperature range of 20–40 °C, the monolayer moisture content for Lampung and Banten varieties was 2.05–4.48% (db) and 1.83–4.74% (db), respectively. The monolayer moisture content for desorption isotherm was higher than that for adsorption isotherm for both BET and GAB models, as also observed by some other researchers [10,15,16,29–31]. In addition, the apparent decrease in the

Table 5 – Analysis of variance (ANOVA) for desorption and adsorption of Lampung and Banten varieties of jatropha seed.

Source	Degree of Freedom		Sum of Square		Mean of Square		F value		F value at $p = 0.05$	
	Desorption	Adsorption	Desorption	Adsorption	Desorption	Adsorption	Desorption	Adsorption	Desorption	Adsorption
Lampung										
τ_i	2	2	35.16	7.87	17.58	3.93	0.16 (NS)	0.052 (NS)	3.35	3.35
$\beta_{j(i)}$	27	27	2915.62	2037.46	107.99	75.46	47.81	64.42	1.87	1.87
$\varepsilon_{(ij)k}$	30	30	67.76	35.14	2.26	1.17				
Total	59	59	3018.54	2080.47						
Banten										
τ_i	2	2	38.44	0.068	19.22	0.034	0.17 (NS)	0.00045 (NS)	3.35	3.35
$\beta_{j(i)}$	27	27	3044.97	2020.82	112.78	74.85	37.39	201.97	1.87	1.87
$\varepsilon_{(ij)k}$	30	30	90.48	11.12	3.02	0.37				
Total	59	59	3173.89	2032.01						

NS: Non-Significant.

Table 6 – Mean relative deviation modulus (P) and regression coefficient (R^2) of tested models at different temperatures.

Model	Mean relative deviation modulus (P, %)												Regression coefficient (R^2, dec)											
	Lampung variety						Banten variety						Lampung variety						Banten variety					
	Desorption			Adsorption			Desorption			Adsorption			Desorption			Adsorption			Desorption			Adsorption		
	20	30	40	20	30	40	20	30	40	20	30	40	20	30	40	20	30	40	20	30	40	20	30	40
BET	11.6	12.9	64.2	8.8	8.7	56.7	13.7	12.7	53.2	5.1	10.0	43.8	0.77	0.94	0.92	0.90	0.96	0.93	0.75	0.93	0.89	0.96	0.96	0.91
GAB	11.2	11.3	14.6	8.8	7.9	14.9	12.8	12.2	14.2	5.5	8.9	14.9	0.76	0.78	0.70	0.81	0.89	0.70	0.62	0.80	0.68	0.92	0.85	0.71
Halsey	13.4	12.6	26.4	9.7	9.5	18.5	16.2	13.4	25.7	5.9	10.2	18.8	0.95	0.98	0.98	0.97	0.99	1.00	0.95	0.97	0.99	0.99	0.98	1.00
Harkin-Jura	10.9	12.8	26.0	10.6	10.6	18.3	17.8	12.8	24.9	9.5	10.9	18.8	0.99	0.99	0.97	0.99	0.99	0.99	0.98	1.00	0.97	1.00	0.99	0.99
Henderson	13.4	12.9	11.7	13.4	13.6	11.9	12.8	14.6	11.5	11.2	12.8	12.4	0.99	0.99	0.99	0.99	0.99	0.99	1.00	0.99	0.99	1.00	0.99	0.99
Iglesias	14.6	13.8	17.0	13.3	13.1	15.6	15.9	16.1	17.0	9.1	13.2	17.0	0.99	0.97	0.98	0.99	0.97	0.99	0.96	0.96	0.98	0.98	0.97	0.98
Oswin	12.2	12.8	19.4	11.1	10.8	12.9	14.4	13.7	18.9	8.3	11.3	13.8	1.00	0.99	0.99	0.99	0.99	1.00	0.99	1.00	0.99	0.99	0.99	1.00
Smith	14.2	13.6	16.0	12.6	11.6	12.1	17.9	14.9	15.7	9.1	12.2	12.3	0.99	0.99	0.98	1.00	0.99	0.99	0.99	0.99	0.98	0.99	0.99	0.99

monolayer moisture content with increase in temperature had also been observed in this research. This trend can be explained by the variation of excitation states, distance and attraction between molecules as temperature varied. Palipane and Driscoll [10] explained that at higher temperatures some water molecules can break away from their sorption sites, giving rise to lower monolayer moisture content values as temperature increased.

The EMC corresponding to a water activity of 0.7 was calculated as safe storage moisture without any microbial damage (Table 7). The safe storage moisture content of grain was found to decrease with the increase in temperature. This behavior indicates that if the jatropha seeds are to be stored warmer then the seeds must be brought to lower moisture content.

The relationship between EMC and FFA content of jatropha seed after sorption isotherm can be described in polynomial equation, and constant equation for dried seed at storage temperature of 20 °C (Table 8). The rate of quality loss (FFA in this case) due to chemical reaction (hydrolysis in this case) of a product during sorption isotherm was insignificant below its monolayer value (<5%). In the case of dried jatropha seed, its initial moisture content before sorption isotherm was 3.65–4.63% for Lampung variety and 3.29–4.03% for Banten variety (Table 2). This is in accordance with the monolayer moisture content obtained by BET and GAB isotherm models at storage temperature of 20 °C. At storage temperature of 30 and 40 °C, the initial moisture content of jatropha seed has to be lower than 3.3%. Drying jatropha seed to their moisture contents (<5%) is very effective to inactive the enzyme

Table 7 – Monolayer moisture content and moisture levels corresponding to 70% relative humidity of jatropha seed at different temperatures.

Temperature (°C)	Monolayer moisture content (% dry basis)								Moisture content at 70% RH (% dry basis)							
	Lampung variety				Banten variety				Lampung variety				Banten variety			
	EBT		GAB		EBT		GAB		EBT		GAB		EBT		GAB	
	Des.	Ads.	Des.	Ads.	Des.	Ads.	Des.	Ads.	Des.	Ads.	Des.	Ads.	Des.	Ads.	Des.	Ads.
20	4.48	3.78	3.98	3.64	4.45	3.45	4.74	3.32	14.11	12.01	13.54	11.79	13.84	11.07	13.67	10.91
30	3.01	2.77	3.24	2.68	3.19	2.79	3.20	2.87	9.70	8.91	10.50	9.22	10.20	8.99	10.92	9.45
40	2.40	2.05	3.08	2.51	2.04	1.83	3.17	2.57	7.42	6.63	6.45	5.93	6.57	6.05	6.56	6.14

Table 8 – Mean relative deviation modulus (P) for relation between EMC and FFA of fresh and dried jatropha seeds at different temperatures.

Model	Mean relative deviation modulus (P, %)											
	Lampung variety						BantenVariety					
	Fresh seed			Dried seed			Fresh seed			Dried seed		
	20	30	40	20	30	40	20	30	40	20	30	40
FFA = constant	–	–	–	7.41	11.79	9.06	–	–	–	4.5	8.6	9.64
Linear[a]	15.9	7.35	5.3	–	9.62	15	9.87	4.72	5.82	–	4.42	7.73
Polynomial[b]	3.73	5.50	5.14	–	1.86	3.28	5.85	2.41	4.53	–	3.07	5.91

a $y = a.x + b$.
b $y = a.x^3 + b.x^2 + c.x + d$, where y and x are FFA and EMC, while a, b, c and d are constant parameters for each equation.

hydrolyzing triglycerides. The FFA content of jatropha seed during sorption isotherm can be thus remained constant. This moisture content is very important in storage of jatropha seed because of their high oil content which susceptible to hydrolysis reactions.

4. Conclusion

This study of moisture sorption behavior of jatropha seed reveals that like most product, it exhibits the sigmoid pattern irrespective of the environmental temperature. Although empirical, the BET, GAB, Harkins-Jura, Halsey and Henderson models are recommended as adequate in predicting the amount of moisture adsorbed or desorbed at known humidity and consequently estimating the likely changes in moisture content at varying humidity during handling. This will be valuable in planning strategies to minimize post-harvest losses of the jatropha seed, as source of vegetable oil for biodiesel production. The relationship between EMC and FFA content of jatropha seed shows that the polynomial equation is the best fitting for fresh and dried seeds, and constant equation for dried seed at storage temperature of 20 °C. The rate of quality loss of jatropha seed during sorption isotherm is insignificant below its monolayer value. The storage of jatropha seed at the monolayer level (<5%) is therefore sufficient.

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