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Optimization of bioethanol production from sorghum grains using artificial neural networks integrated with ant colony

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ABSTRACT

In this study, an artificial neural networks (ANN) model is developed to investigate the relationship between bioethanol production and the operating parameters of enzymatic hydrolysis and fermentation processes. The operating parameters of the hydrolysis process which influence the reducing sugar concentration are the substrate loading, α-amylase concentration, amyloglucosidase concentration and strokes speed. The operating parameters of the fermentation process which influence the ethanol concentration are the yeast concentration, reaction temperature and agitation speed. The desirability function of the model is integrated with ant colony optimization (ACO) in order to determine the optimum operating parameters which will maximize reducing sugar and ethanol concentrations. The optimum substrate loading, α-amylase concentration, amyloglucosidase concentration and strokes speed is determined to be 20% (w/v), 109.5 U/g, 36 U/mL and 50 spm, respectively. The reducing sugar obtained at these optimum conditions is 175.94 g/L, which is close to the average value from experiments (174.29 g/L). The optimum yeast concentration, reaction temperature and agitation speed is found to be 1.3 g/L, 35.6 °C and 181 rpm, respectively. The ethanol concentration obtained from the fermentation of sorghum starch by *Saccharomyces cerevisiae* yeast at these optimum conditions is 82.11 g/L, which is in good agreement with the average value from experiments (81.52 g/L). Based on the results, it can be concluded that the model developed in this study model is an effective method to optimize bioethanol production, and it reduces the cost, time and effort associated with experimental techniques.

1. Introduction

One of the predominant issues nowadays which need to be addressed is humans' heavy dependence on fossil fuel energy, which leads to an increase in greenhouse gas emissions (Dharma et al., 2016; Wang et al., 2014). Hence, it is necessary to search for alternative renewable energy sources that are needed to replace fossil are required to solve the existing energy problems. Many studies have been carried out on the production of fuels from biomass such as bioethanol in order to substitute fossil fuels (Guigou et al., 2011). Environmental friendly bioethanol is produce from agricultural biomass (Deesuth et al., 2015; Tabah et al., 2016). Both Brazil and the USA are the major bioethanol producers in the world and these countries are still dependent on edible feedstocks such as sugar cane and corn (Gupta and Verma, 2015). Meanwhile, Thailand and China produce bioethanol from cassava (*Manihot esculenta*), which is also an edible feedstock (Deesuth et al., 2015).

According to Sebayang et al. (2016) bioethanol can be produced from different kinds of raw materials, which are classified into three categories according to their chemical composition: sucrose-containing feedstocks, starch materials and lignocellulosic materials. An alga is a feedstock considered for the sugars and carbohydrates they contain, which can be fermented to produce ethanol based fuels. However, the use of edible feedstocks for fuel production raises concern on global food security, which hampers the worldwide acceptance of using bioethanol as a fuel. For this reason, much effort is being made to produce bioethanol from non-edible feedstocks such as lignocellulosic and starchy agricultural feedstocks to reduce humans' dependence on fossil fuels (Aditiya et al., 2016).

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Lignocellulosic materials are biomass derived from plants with the main components of lignin, cellulose and hemicellulose. Cellulose and hemicellulose are usually composed of up to two-thirds of lignocellulose and are substrates for second generation ethanol production (Gírio et al., 2010). In bioethanol production, lignocellulosic biomass has complex chemical compounds such as cellulose, hemicellulose and lignin which are required to separate linkages of different polymers into oligomeric subunits by pre-treatment (Alvira et al., 2010). The purposes of pre-treatment are: to remove structural and compositional impediments into (enzymatic) hydrolysis, increase enzymatic accessibility, to remove lignin in lignocellulosic biomass and to improve the digestibility of cellulose (Anjali and Satyendra, 2014). The bioethanol production from lignocellulosic biomass has been given attention to improve bio-oil quality before further process which related to storage, transport, and final processing characteristics of the oil. Briefly, pre-treatment has been conducted by some researchers. Westerhof et al. (2011) conducted pre-treatment with stepwise pyrolysis of pine wood in a fluidized bed reactor. It was found that stepwise pyrolysis has faster reaction rate compare to the conventional reaction and release compounds from the biomass particle. Moreover, Mourant et al. (2011) investigate the effects of inorganic species in biomass such as K, Na, Mg and Ca on the yield and properties of bio-oil from the pyrolysis of biomass. The result was found that components affected in acid-soluble for bio-oil composition and properties.

1.1. Sweet sorghum feedstock

Sorghum (*Sorghum bicolor* (L.) Moench) is one of the non-edible feedstocks used to produce bioethanol (Fedenko et al., 2015). It is one of the plants that originated from Africa, but it is now cultivated in Asia (Elhassan et al., 2015; Mehboob et al., 2015). Sorghum (*Sorghum bicolor* (L.) Moench) is a highly adaptable plant because it can be grown on lowlands and highlands, as well as dry and humid climatic regions (Deesuth et al., 2015). Sorghum can also be grown on marginal lands (mainly arid lands) where other plants are unable to thrive (Elhassan et al., 2015; Wang et al., 2016). For this reason, marginal lands can be utilized for the cultivation of sorghum, which is an advantage since this eliminates competition with lands used for food production (Matsakas and Christakopoulos, 2013).

In addition, sorghum has other advantages such as high grains production and high biomass. Moreover, it is resistant to droughts (Marx et al., 2014; Mehboob et al., 2015; Zhang et al., 2010), it has short regeneration time (3–5 months), it has low fertilization needs and it has higher photosynthetic rate compared to sugar cane and corn (Deesuth et al., 2015; Houx Iii and Fritschi, 2015; Sjöblom et al., 2015). The starch content of sorghum grains is high (65–71%) and therefore, this starch can be hydrolysed into simple sugars (Dyartanti et al., 2015). Moreover, Sweet sorghum juice is better suited for bioethanol production due to higher reducing sugar content as compared to other sources such as sugarcane juice (Khalil et al., 2015). The important parameters of sweet sorghum such as seed propagation, mechanized crop production, non-invasiveness, biological nitrification inhibition have attracted much attention as a potential non-edible feedstock for bioethanol production. The cost of bioethanol production from sweet sorghum is cheaper as compared to sugarcane molasses at prevailing prices (Ibeto et al., 2011).

As a substitute for gasoline, sorghum bioethanol is widely valued. Few studies have examined on the bioethanol production from sweet sorghum. Guo et al. (2010) investigated optimization and analysis of a bioethanol agro-industrial system from sweet sorghum. Balat and Balat (2009) summarized life cycle analysis of the sweet sorghum ethanol process to evaluate energy efficiency and environmental for different production and use scenarios. There has been a major research effort to investigate storage and continuous supply of sweet sorghum for the bio refinery has been presented in Table 1 (Rao et al., 2009). Therefore, the assessments of environmental sustainability must be addressed to energy and environmental impacts such as land use can be intensive, air, water and soil pollution from the use of fertilizers and plant protection (Guptaand Verma, 2015).

As one of the renewable energy sources derived from non-edible plants, bioethanol is an alternative fuel which can be used to substitute fossil fuels (Costagliola et al., 2013). Therefore, studies on bioethanol production have been carried out in pre-treatment, hydrolysis, fermentation and distillation process. Currently, conversion technologies for producing bioethanol from biomass feedstock focuses on the development of cellulose-derived glucose due to enzyme cellulosic and fermentation of sugars derived from starch and sugar. Marx et al. (2014) conducted bioethanol production from sweet sorghum bagasse. Pre-treatment and hydrolysed were performed in a single step using catalyst acid (H_2SO_4) with microwave irradiation assistance. The obtained of ethanol yield was 94% based on the total sugar 480 g/kg during fermentation after 24 h using a mixed S. *cerevisiae* and Z. *Mobilis* organisms. On the other hand, Wang et al. (2013) has focused on optimization simultaneous saccharification and fermentation from sweet sorghum using response surface methodlogy (RSM). They found that the optimum concentration of solid bagasse to be 7% and it can be increased as well as high concentration of solid bagasse. Goshadrou et al. (2011) investigated bioethanol production from sweet sorghum bagasse using zygomycetes fungus *Mucor hiemalis*. It was treated with H_2SO_4 and KOH which improve the subsequent enzymatic hydrolysis to be 79–92% of the theoretical yield of 81%. Moreover, Khawla et al. (2014) compared acidic hydrolysis and enzymatic hydrolysis at a temperature of 60 °C and pH of 4.5 in which potato peel wastes were used as the feedstock. S. *cerevisiae* yeast was used during the fermentation process and the pH, reaction temperature and agitation speed was 5.0, 30 °C and 100 rpm, respectively. The fermentation process was carried out over a period of 48 h. The reducing sugar concentration and ethanol concentration was found to be 69 and 21 g/L, respectively. Based on the discussion above, it can be deduced that the production of bioethanol by hydrolysis and fermentation gives satisfactory results. However, the production of bioethanol via experiments is both costly and time-consuming since it requires raw materials, time and effort to prepare samples, run the experiments and determine the optimum operating conditions which will maximize the bioethanol yield. Hence, there is a need to determine the optimum conditions for bioethanol production in a simpler, more efficient manner.

1.2. Artificial neural networks (ANN) modelling

Artificial neural networks (ANN) are an artificial intelligence technique inspired by the human nervous system and it is commonly used for modelling and optimizing complex phenomena involving a large number of process variables (Kamairudin et al., 2015; Siswantoro et al., 2016; Vani et al., 2015). Trained ANN can be used as prediction and optimization models for a variety of applications. The prediction capability of the ANN is determined based on experimental data and then validated by independent data (Deh Kiani et al., 2010). ANN can be used to solve non-linear problems by evaluating the relationship between the input and output parameters even when the data are complex and incomplete (Mohamed Ismail et al., 2012). ANN has the ability to relearn in order to increase production when new data are available (Najafi et al., 2009). Therefore, ANN is a good alternative to model and optimize the operating parameters of bioethanol production because of its high reliability and efficiency.