Lactic Acid Production from Biomass: Prospect for Bioresidue Utilization in Ghana: Technological Review

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Abstract

The production of lactic acid from fossil fuel is now widely accepted as unsustainable due to depleting resources and the accumulation of environmentally hazardous chemicals. Cheap raw material is one of the key inputs to cost effective production of Lactic acid. This paper reviews current research in lactic acid fermentation processes, bio-residue availability in Ghana and potential utilization for lactic acid production. Bio-renewable residue has been widely studied and employed due to its abundance and cost. Various fermentation technologies have been employed using fungi and lactic acid bacteria to generate different yields of lactic acid. Both starchy and lignocellulosic biomass have been extensively used, however lignocellulosic biomass in Ghana is generated in large volumes as crop residues and mostly considered waste although some amount is used as animal feed. These crop residues are readily available as cheap raw materials for lactic acid production. Cereal crop residues offer the highest potential for lactic acid production in Ghana. By employing appropriate fermentation processes about 199,856 tonnes, 244,305 tonnes, 127,715 tonnes and 362,003 tonnes of lactic acid at 50 % utilization can be generated from maize cobs, millet stalk, sorghum stalk and rice straw respectively for the international market.

Keywords: Lactic acid; Batch; Fermentation; Fed-batch; Biomass; Amylolytic

1.0 Introduction

Lactic acid (2-hydroxypropanoic acid), $CH_3CHOHCOOH$ is the most widely occurring hydroxycarboxylic acid. It was first discovered in 1780 by the Swedish chemist Scheele (Rathin Datta & Henry, 2006). Lactic acid occurred naturally as organic acid and can be produced by fermentation or chemical synthesis. It is present in many foods both naturally or as a product of *in situ* microbial fermentation, as in sauerkraut, yogurt, buttermilk, sourdough breads and many other fermented foods. Lactic acid is also a major metabolic intermediate in most living organisms, from anaerobic prokaryotes to humans (Datta & Henry, 2006).

Lactic acid exists naturally in two optical isomers: d(−)- lactic acid and l(+)-lactic acid. Since elevated levels of the d-isomer are harmful to humans, l(+)-lactic acid is the preferred isomer for food-related and pharmaceutical industries (Datta, 1995).

By 1990, global annual production of lacticacid had increased to approximately 40,000 t with two significant producers, CCA Biochem in The Netherlands, with subsidiaries in Brazil and Spain, and Sterling Chemicals in Texas City, TX, USA, as the primary manufacturers. Different technologies and feedstocks are employed. CCA used carbohydrate feedstocks and fermentation technology whiles Sterling used a chemical technology (Datta & Henry, 2006).

Lactic acid as a chemical is also considered a commodity with a growing market. Chemical synthesis of lactic acid results in a racemic mixture of the two isomers, while the fermentation process can yield an optically pure form of lactic acid or racemate, depending on microorganisms, substrates and fermentation conditions employed in the production process (Yin et al., 1997). It is usually used in food industry as mild acid flavour, pH regulator or as a preservative. Poly lactic acid (PLA), an emerging product from lactic acid is used in the manufacture of biodegradable plastics.

Fermentation of glucose from starch hydrolysate is the new production process for lactic acid. This state-of-the-art production process has replaced the older chemical synthesis, e.g. the addition of hydrogen cyanide to acetaldehyde and the subsequent hydrolysis of the resulting lactonitrile.

The biotechnological process, however, has some disadvantages such as small space-time-yields and the production of stoichiometric amounts of salt due to pH-regulation during fermentation (Arai et al., 2002).

The world today is faced with numerous challenges in supply of energy, feed, food, and other essential products in a sustainable way. One of the important means of abating the negative effects of making these local eco-services available is to convert biomass instead of petroleum or natural gas into a variety of food, feed, biomaterials, energy and fertilizer, optimizing the value of the biomass and reducing the waste (Kamm & Kamm, 2004).

By definition, biomass is organic and biodegradable with the added advantage of being renewable. The two most well-known types of biomass are wood and crops including cassava, wheat, maize and rice (Deswarte, 2008). Food crops can indeed be used to produce materials (e.g. polylactic acid from corn) and chemicals (e.g. polyols from wheat). However, it is now becoming widely recognised by governments and scientists that waste and lignocellulosic materials (e.g. wood, straw, energy crops) offer a much better opportunity, since competition from the food sector is avoided, and most often, large track of land and fertilizer is not needed for their growth (Sanders et al., 2005).

In Ghana biomass from agricultural crop residues is mainly from cereal crop, roots and tubers. Major cereal crops grown in the country are sorghum, rice, millet and maize with cassava, yam and cocoyam constituting roots and tubers. Energy crop residues in the country are obtained from sugar cane, coconut, oil palm fruit, coffee, and cocoa. The residues of these energy crops are also useful biowaste resource for energy production. Availability of biomass re-sources in Ghana depends on agricultural production input and the various agro-ecological farming zones, namely rainforest, deciduous forest, transitional, Guinea savannah, Sudan savannah and coastal savannah.

This paper reviews current research in lactic acid fermentation processes, biomass materials and their availability in Ghana as well as the potential of bio-residue utilization for lactic acid production.

2.0 Biomass for Lactic Acid Production

Industrial scale production of lactic acid demands availability of sustainable cheap raw materials with minimum level of contamination. Biomass as raw material in the form of starch (corn, wheat, potato, cassava, rice, sweet sorghum) and lignocelluloses (corn cobs, waste paper and woody materials) can be used as a substrate for fermentation of lactic acid (Oh et al., 2005; Richter & Berthold, 1998).

Biomass from agricultural crop residues can be put into two major categories. The primary category is obtained as a by-product of agricultural post-harvesting activities, normally from the harvesting and processing of staple crops for domestic use. The secondary category is generated from industrial processing of agricultural crops. Cereal crop mills and food processing industries are directly involved in biowaste generation from agricultural residues. (Mohammed et al., 2013).

Availability of primary category of residues for value added application is usually low since collection is difficult and they have other uses as fertilizer, animal feed, etc. However, secondary residues are usually found in relatively large quantities at the processing site and may be used as captive energy source for the same processing plant involving no or little transportation and handling cost (Singh & Gu, 2010). In order to assess the potential of primary residues, the available data has been listed in (Table 1).

Lactic acid can be produced by solid state fermentation using fungal as well as bacterial cultures. Strains of *Rhizopus* sp. have been identified (Koutinas et al., 2007) as one of the common fungal cultures used and *Lactobacillus* sp. among the bacterial cultures (John et al., 2006). Studies conducted by Bulut et al., (2004) and Yin et al., (1997) on carbohydrates revelled the importance of glucose as a major substrate for lactic acid production. However it has been recognised that starch and lignocelluloses materials which are cheap can be used as cost effective carbon source for lactic acid production (Åkerberg & Zacchi, 2000).

2.1 Starch

Starch is a polysaccharide and mainly found in tubers (cassava, potatoes, and yam) as well as grains such as rice, corn, millet, sweet sorghum and wheat. The starchy materials from corn, cassava, potato and rice are mostly hydrolysed into simple sugars before fermentation (Oh et al., 2005).

Simultaneous hydrolysis and fermentation (SHF) can be used and in most cases with amylase-producing *L. amylophilus* and *L. amylovorus* for direct fermentation of starchy materials into lactic acid (Linko & Javanainen, 1996).

Waste starch and pulp from potato have been used as substrates for lactic acid production by *R. oryzae* and *R. arrhizus* (Jin, et al., 2003; Oda et al., 2002). However it was reported that commercial pectinase when added to potato pulp in fermentation by *R oryzae* could increase the bio-accessibility of starch thereby improving formation of lactic acid as metabolites (Saito et al., 2003).

Wang et al., (2010) reported that using glucose concentrations of 100 g/l and 150 g/l, there were no change in the yields of L- lactic acid (0.86 g/g). However, when glucose concentration was increased to 200 g/l lower L-lactic acid yield (0.67 g/g) was realised. They further confirmed that with cassava powder as carbon source, the yield (0.85 g/g) was obtained at the cassava powder concentration of 100 g/L. The same phenomenon was realised for higher cassava powder concentration as in glucose resulting in low L-lactic acid yield. The average yield of L-lactic acid from corn powder was around 0.96 g/g, which was higher than those of glucose and cassava powder. The maximum concentration of L-lactic acid obtained in the fermentation experiment with cassava powder and corn powder was 158.2 g/l and 177.7 g/l, respectively.

2.2 Lignocellulose

Lignocellulose is another form of carbohydrate which is made up of lignin, cellulose and hemicellulose. Cellulose materials consist mainly of glucan and the hydrolysate contain xylan, arabinan, galactan and lignin (Hofvendahl & Hahn–Hägerdal, 2000). Hemicellulose is a heteropolysaccharide which has xylose, glucose, arabinose, mannose and galactose as hydrolysate and some traces of other sugars, depending on the source of lignocellulose (Mishra & Singh, 1993).

The major component of hemicellulose after hydrolysis is xylose and this needs an effective conversion to enhance lactic acid production from lignocellulosic materials. Attempts have been made to produce lactic acid from cellulose by simultaneous saccharification and fermentation (Venkatesh, 1997). Woiciechowski et al. (1999) in his work dosed wood with 0.5% (w/v) sulphuric acid followed by steam explosion after which the hydrolysate was fermented by *R. oryzae* NRRL 395. There have been reported cases of corncob and waste paper been used for lactic acid production (Miura et al., 2004; Ruengruglikit & Hang, 2003; Yáñez, Alonso, & Parajó, 2005). Sreenath et al. (2001) carried out research work on lactic acid production from agricultural residues (wheat bran, corn stover, alfalfa fibre and wheat straw). They revealed that addition of pectinase and cellulase to the SSF of alfalfa fibre improved lactic acid formation.

3.0 Lactic Acid Fermentation Processes

Lactic acid production can be done either by fermenting sugars or hydrolysates containing sugars. It can also be produced by converting starchy or cellulosic materials using lactic acid producing microorganisms. Simultaneous hydrolysis and fermentation with saccharifying enzymes is widely deployed. The use of hydrolysate is preferred to refined sugars for solid state or submerged fermentation of lactic acid (John et al., 2006).

The most common fermentation processes used in lactic acid production are batch, repeated batch, fed-batch and continuous. Batch and fed-batch cultures are noted for producing higher lactic acid concentration than continuous culture, although continuous cultures have higher productivity (Hofvendahl & Hahn–Hägerdal, 2000). In addition to higher productivity the process can also be continued for a longer period.

The hydrolysis of starch or cellulose to sugar is a high energy utilization process which can increase the cost of production. Woiciechowski et al., (1999) studied the hydrolysis of cassava bagasse starch by acid and enzymatic hydrolysis. They reported that both methods were quite efficient when considering one or the other parameter like the percentage of hydrolysis, time and cost of the chemicals and energy consumption. Although acid hydrolysis is time saving and cost effective, there will be a neutralizing step after acid hydrolysis and which will create the unnecessary increase of salts in the medium and it will affect the microbial growth and production of lactic acid.

4.0 Direct Lactic Acid Fermentation

The direct conversion of complex substrate to lactic acid can be put into three groups. The first group involves the use of lactic acid producing fungi like *Rhizopus oryzae* which can directly convert starch to lactic acid with the assistance of enzymes.

The second group comprises of amylolytic lactobacilli like *Lactobacillus manihotivorans, Lactobacillus amylovorous, Lactobacillus amylophilus* etc. Whiles the third group utilises substrates when degrading enzymes are simultaneously used with lactic acid bacteria (John et al., 2009).

Lactic acid bacteria with amylase activity have been known to be isolated from different plant and animal sources. *Lactobacillus plantarum* A6 (LMG 18053) was isolated from retted cassava in the Congo, whiles *L. manihotivorans* LMG 18010T and *L. plantarum* R10101/2, from cassava starch fermentations in Colombia, and *Pediococcus sp*. VA403 from cow rumen (Pintado, Guyot, & Raimbault, 1999). Sanni et al. (2002) in their work on traditional fermented foods in Nigeria isolated nine amylolytic gram-positive anaerobic bacteria capable of hydrolysing soluble starch. They further identify the strains of *L. plantarum* and *L. fermentum* as most effective.

4.1. Direct Fermentation with Amylolytic Lactic Acid Bacteria

Only small group of lactic acid bacterial species have the ability to produce hydrolysing enzymes. Attempts were made to isolate and use amylolytic lactic acid bacteria for the direct fermentation of complex substrates like starchy waste (John et al., 2009).

An amylolytic strain, *L. amylophilus* GV6 was used for production of l(+) lactic acid in SSF using wheat bran as solid support and substrate having a particle size ranging 1.5–3mm. 36 g of l(+) lactic acid was produced from 54 g of starch present in 100 g of wheat bran (Naveena, Altaf, Bhadrayya, Madhavendra, & Reddy, 2005) A novel strain *Streptococcus bovis* 148 was used to produce 14.2 g/l lactic acid directly from starch (Narita, Nakahara, & Fukuda, 2004). Direct lactic acid production by *Lactobacillus manihotivorans* LMG18011 using soluble starch and food wastes as substrates resulted in 19.5 g L(+)-lactic acid from 200 g food wastes (Ohkouchi & Inoue, 2006). Shibata et al. (2007) in their work produced (0.93 gg^{-1}, 0.68 gg^{-1} and 0.76 gg^{-1}) of lactic acid from sago starch, wheat starch and corn starch respectively using *E. faecium. L. plantarum* produced lactate yield of 0.81 g/g substrate (Giraud, Champailler, Raimbault, Biotechnologie, & Cedex, 1994). *L. plantarum* SW14 was used directly to produce an increasing concentration of lactic acid from cassava starch up to 20 g/l and 8.0 $gl^{-1}h^{-1}$ (Univers, 2012). *S. bovis* 148 was found to directly produce lactic acid from raw starch. The maximum lactic acid concentrations at varying temperatures of 30°C, 37°C, and 45°C were 10.60, 14.73, and 10.77 g/l, respectively (Narita et al., 2004).

Narita et al. (2006) constructed a starch-degrading *L. caseistrain* with active AmyAF display by using the PgsA anchor protein. In their fermentation experiment, they demonstrated that *L. caseistrain* utilises 50 g/l of soluble starch to produce 13.7 g/l, and 21.8 g/l of lactic acid within 24 h yielding 0.6 g lactic acid.

4.2. Direct Lactic Acid Fermentation of Complex Substrates by Fungal Species

Besides lactic acid bacteria certain fungi like *Rhizopus* can produce lactic acid. The best-known fungal source of lactic acid is *R. oryzae* (Yu & Hang, 1989). The first report of an efficient submerged fermentation for the fungal production of L-lactic acid came in 1936 (Lockwood et al., 1936). In an experiment conducted by Ward et al. (1938) using *Rhizopus* and *Actinomucor* in fermentation yielded 63– 69% of L-lactic acid from chemically defined media containing 15% glucose. Bai et al. (2003) carried out repeated batch culture of *Rhizopus oryzae* R1021, and the L(+) lactic acid concentration after 7th cycle, was 64.5 g^{-1}.

In solid state fermentation for lactic acid production, filamentous fungus *R. oryzae* is normally used (Giraud et al., 1994). Saito et al. (2012) conducted experiment with 56 strains of *R. oryzae* to produce lactic acid from xylose. Among them, *R. oryzae* NBRC 5378 produced the largest amounts of lactic acid from xylose (8.9 g/l), followed by *R. oryzae* NBRC 4766 (8.3 g/l), NBRC 4780 (7.1 g/l), and NBRC 5440 (6.7 g/l) respectively. The yield of lactic acid from xylose by *R. oryzae* NBRC 5378 was 0.45 g/g, and the value was higher than that from glucose under the same conditions (0.27 g/g).

Jin et al. (2005) utilised biomass from potato, corn, wheat and pineapple waste streams to produce lactic acid from *Rhizopus arrhizus* 36017 and *R. oryzae* 2062. The lactic acid and fungal biomass were produced in a single-stage simultaneous saccharification and fermentation. *R. arrhizus* 36017 produced a high lactic acid concentration of 0.94-0.97 g/g of starch or sugars, while a lactic acid concentration of 0.65-0.76 g/g was produced by the *R. oryzae* 2062 in 36-48 h fermentation. Supplementation of 2 g/l of ammonium sulphate, yeast extract and peptone stimulated an increase of 8-15% lactic acid.

4.3. Direct Lactic Acid Production by Simultaneous Saccharification and Fermentation

Conventional fermentative production of lactic acid from starch materials requires a pre-treatment process that involves gelatinization and liquefaction, which is carried out at a temperature between 90 and 130 °C for 15 min followed by long time enzymatic saccharification to glucose at a higher temperature, and subsequent conversion of glucose to lactic acid by fermentation.

Anuradha et al. (1999) conducted batch experiments to establish optimum operating conditions for the simultaneous saccharification and fermentation (SSF) of starch to lactic acid using *Lactobacillus delbrueckii*. They developed a predictive model for SSF by combining the kinetics of saccharification and fermentation. Their results showed that saccharification rate was always higher for SSF than in simple saccharification (SS) at all substrate concentrations. Lactate productivity was 1.21 g/l h for SSF conducted under optimum conditions with 250 g/l potato starch, higher than that of lactic acid productivity by fermentation after saccharification. They further stated that potato tuber and pearl tapioca are good raw materials for the production of lactic acid using SSF with yields up to 70%.

It has been demonstrated that a l(+)-lactic acid concentration as high as 162 g l^{-1} can be generated from barley starch in less than 48 h of processing time with a balanced SSF. Yields of 98 and 87% were obtained from 130 and 170 g l^{-1} starch, respectively (Linko & Javanainen, 1996).

(Marques, Santos, Gírio, & Roseiro, 2008) used recycled paper sludge (RPS) as feedstock to produce lactic acid (LA) with *Lactobacillus rhamnosus* ATCC 7469. Maximum lactic acid was produced when the hydrolysis and fermentation steps were simultaneously carried out on medium supplemented with Man Rogosa and Sharpe components and calcium carbonate. *L. rhamnosus* produced 73 gL^{-1} of lactic acid, corresponding to a maximum productivity of 2.9 gL^{-1} h^{-1}, with 0.97 g lactic acid produced per gram of carbohydrates on initial substrate.

5.0 Batch and Fed Batch Fermentation

Fermentations can be done in batch, fed-batch or continuous reactors. In batch reactor all components are put in the reactor in the beginning of the fermentation, except gaseous substrates such as oxygen, pH-controlling substances and antifoaming agents. When the process starts there is no input output flows. In fed-batch process, nothing is removed from the reactor during the process, but one substrate component is added in order to control the reaction rate by its concentration (Saarela et al., 2003).

5.1 Fed Batch Fermentation

Fed-batch reactors are widely used in industrial applications because they combine the advantages from both batch and continuous processes. The process is at first initiated as a batch process, but it is prevented from reaching the steady state by adding new substrate once the initial glucose is consumed. The growth rate of the fermentation is maintained until some practical limitation inhibits cell growth. The main advantages of the fed-batch operation are the possibilities to control both reaction rate and metabolic reactions by substrate feeding rate. (Saarela et al., 2003).

Fed-batch fermentations conducted by Abdel-Rahman et al. (2014) with 2 rounds of substrate feeding which were performed in mMRS media (G25X50) supplemented with 5 g/L yeast extract at 43°C and pH 7.0 using either sodium hydroxide or ammonium hydroxide as the neutralizing agent. Mixtures of 25 g/L glucose and 50 g/L xylose were fed at 27 h and 54 h to maintain the xylose concentration at greater than 10 g/L. 129 g/L lactic acid without by-products was obtained with a maximum lactic acid productivity of 5.60 g/(L.h) in fed-batch fermentation with feeding a glucose/xylose mixture using ammonium hydroxide as the neutralizing agent. Fed-batch fermentation was developed to produce L-lactic acid using *Lactobacillus lactis* in which the residual glucose concentration in the culture was used to control a continuous feeding regime. Up to 210 g L-lactic acid l(-1) (97% yield) was obtained. The maximal dry cell was 2.7 g l(-1) and the average L-lactic acid productivity was 2 g l(-1) h(-1) (Bai, Wei, et al., 2003).

Bacillus coagulans C106 was isolated from environment and used to produce l-lactic acid from xylose at 50°C and pH 6.0 in mineral salts medium containing 1-2% (w/v) of yeast extracts without sterilizing the medium before fermentation. In fed-batch (120+80+60g/L) fermentation, lactic acid production reached 215.7g/L and 4.0g/Lh, respectively (Ye et al., 2013).

5.2 Batch Fermentation

In batch fermentation of whey lactose Hamidreza et al. (2014) reported of lactic acid production of 32.1 g/l at a HRT of 30 hours. Batch fermentation for lactic acid production on distillery stillage was performed by *Lactobacillus rhamnosus* ATCC 7469. The most efficient sugar conversion in batch fermentation was attained with the initial sugar concentration of 55 g/L (Djuki et al., 2013). Ruengruglikit & Hang (2003) used corncobs as a substrate for production of l(+)-lactic acid by *Rhyzopus oryzae* NRRL-395. Under optimal conditions (0.2g/100mL CaCO3, 0.5mL/100mL Rapidase Pomaliq, and 5g/100mL corncobs), 299.4±6.8g per kg dry matter of corncobs was produced after 48h of fermentation at 30°C. *Lactococcus lactis subs lactis* strain isolated from the leaves of sugar cane plants was used in batch fermentation at 32ºC, with 60 gl^{-1} of glucose and a pH of 6.0, concentrations of up to 35 gl^{-1} of lactic acid were obtained (Serna Cock & Rodriguez de Stouvenel, 2006). Lactic acid production using dates syrup as a substrate was investigated in batch fermentation by mixed culture of *Streptococcus thermophilus* and *Lactobacillus bulgaricus*. The enriched culture medium with Tween80 (1 g/l), MgSO4 (1 g/l), MnSO4 (1.5 g/l), yielded 49 g/l of lactic acid (Varghese, 2013). Lactic acid production from sugar molasses by batch fermentation of *Enterococcus faecalis* RKY1 yielded a maximum lactic acid concentration of 134.9 g/l with productivity of 4.3 g/l h when 15 g/l of yeast extract was used, at molasses concentrations of 333 g/l (equivalent to 170 g/l of total sugar) (Wee et al., 2004). Yamane & Tanaka (2013) fermented glucose with *Rhizopus oryzae* NBRC 5384 and 145 g/L lactic acid from glucose concentration of 150 g/L was produced.

6.0 Economic Importance of Bio-Residue Utilisation for Lactic Acid Production in Ghana

Ghana is agricultural producing country and production of food and cash crops are the main occupation of the population. Annual production of food and cash crops often results in the generation of tonnes of residues (Table 1) which are mostly left at the farms. Bio-residues are also generated from industrial processing of agricultural crops. The potential of turning these bio-residues into value added products especially lactic acid is very significant (Table 2).

Currently, global demand for lactic acid as a feedstock for the production of biopolymer poly-lactic acid (PLA) has increased, because of its usage to produce biodegradable, biocompatible, and environmentally friendly plastics alternative to plastics derived from petrochemicals (Abdel-Rahman et al., 2010). PLA is used in surgical sutures, orthopaedic implants, drug delivery systems, and disposable consumer products, this can reduce waste disposal problems (Mohd Adnan & Tan, 2007).

Grand View Research Inc. (2014) in their study reported that global poly lactic acid (PLA) market is expected to reach USD 2,169.6 million by 2020, whiles that of lactic acid reaching USD 4,312.2 million by the same year. This is attributed to the growing acceptance of bioplastics as a packaging material of which PLA forms the major component. PLA can be composted and is environmentally friendly; therefore, it is ideal for food packaging and other consumer products. Global lactic acid demand was 714.2 kilo tons (647911.3 MT) in 2013, which is expected to reach 1,960.1 kilo tons (1778172.8 MT) by 2020, growing at a current annual growth rate (CAGR) of 15.5% from 2014 to 2020. With the same years under review global PLA demand was estimated to be 360.8 kilo tons in 2013, which is expected to reach 1,205.3 kilo tons by 2020, growing at a CAGR of 18.8% from 2014 to 2020.

In Ghana plastics are most popular packaging materials and according to Accra Metropolitan Assembly (AMA) about 315 tons of plastic waste is generated daily in Accra (Teye & Holmberg, 2012). The management of this waste is very difficult for AMA as it litters and pollutes the environment. AMA admitted the challenges involved in collecting and recycling plastic waste in the City and reported that over 35 million Ghana cedis was realised as environmental tax from plastic recycling in 2011(AMA, 2014).

Plastic products from petrochemical sources have their environmental challenges in polluting the environment. In Ghana waste segregation at point of generation is non-existing although many attempts have been made over the years to educate the populace on the advantages of waste segregation. Few waste recycling plants operate in the city but they are faced with high cost of energy and water for their operations.

Most of the garbage generated is mixture of plastics and organics. In order to avert the environmental menace caused by plastic waste, it is very important to exploit the use of bioplastics for packaging. Lactic acid which is the raw material for the production of PLA becomes a very useful resource worth considering in Ghana.

Tonnes of agro-residues are generated annually in Ghana (Table 1) and technologies in lactic acid production have been developed utilising lignocellulosic materials (Table 2). The establishment of lactic acid production plants in Ghana has the potential of utilising most of the crop residues generated annually, thereby providing available jobs for the teeming unemployed youth. Rural urban migration of youth in search for non-existing jobs would be minimised as these companies when established at the farming communities in the Northern part of Ghana where most of the cereals are produced would provide available job opportunities for the youth. About 420,750 tonnes of maize cobs, 549,000 tonnes of millet stalk, 287,000 tonnes of sorghum stalk and 813,491 724,007 tonnes of rice straw (Table 2) are generated annually in Ghana and these amounts can generate about 199,856 tonnes, 244,305 tonnes, 127,715 tonnes and 362,003 tonnes of lactic acid at 50 % utilization from maize cob, millet stalk, sorghum stalk and rice straw respectively for the international market.

7.0 Conclusion

The production of lactic acid from fossil fuel is now widely accepted as unsustainable due to depleting resources and the accumulation of environmentally hazardous chemicals. Cheap raw material is one of the key inputs to cost effective production of Lactic acid. Bio-renewable biomass has been widely studied and employed due to their availability and cost. Various fermentation technologies have been employed using fungi and lactic acid bacteria to generate different yields of lactic acid. Both starchy and lignocellulosic biomass have been extensively used, however lignocellulosic biomass in Ghana is generated in large volumes as crop residues and mostly considered waste although some amount is used as animal feed. These crop residues are readily available as cheap raw materials for lactic acid production. Crop residues from cereals are among the most potential raw materials in Ghana which can be used for lactic acid production because of their availability in large quantities. By employing appropriate fermentation processes about 199,856 tonnes, 244,305 tonnes, 127,715 tonnes and 362,003 tonnes of lactic acid at 50 % utilization can be generated from maize cobs, millet stalk, sorghum stalk and rice straw respectively for the international market.

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Table 1: Production of Different Agricultural Crops in Ghana for 2011 and Estimated Potential of Residues, Calculated Using Residue to Product Ratio

Crop	Production ('000) MT	Residue type	Residue to Product ratio (RPR)	Residue Wet ('000)MT
Maize	1,683	Maize stalk	1.5	2524.5
		Maize Cob	0.25	420.75
		Maize Husk	0.2	336.6
Millet	181	Millet Stalk	3	549
Rice	463	Rice Straw	1.757	813.491
		Rice Husk	0.267	74.226
		Rice Bran	0.0625	27.78
Sorghum	287	Sorghum Stalk	1	287
Cassava	14240	Cassava Peel	0.267	3802.08
		Cassava Stalk	0.192	2734.08
Cocoa	903.646	Cocoa Pod	1	903.646
		Cocoa Shells	1	903.646
Oil Palm	2103.6	Oil Palm EFB	0.25	525.9
		Palm kernel	0.06	126.216
		Palm kernel shell	0.06	126.216
Sugarcane	145	Sugarcane baggas	0.3	43.5
		Sugarcane Tops	0.3	43.5
Groundnut	465.1	Groundnut shells	0.5	232.55
		Groundnut stalk	2.3	1069.73
Banana	65	Waste Fruit	0.02	0.988
		Banana Stalk	0.12	7.884

Source (Bayitse et al., 2013)

Table 2: Potential Lactic Acid Production from Lignocellulosic Biomass in Ghana by Lactic Acid Bacteria

Raw Material	Annual Production ('000)MT**	Microorganisms*	Fermentation Process*	Lactic acid yield*	Expected Annual Lacitic acid yield ('000)MT
Maize stalk	2524.5	Lb. pentosus ATCC 8041	Fed-Batch SSF	0.65 g/g	1640.925
Maize Cob	420.75	Lb. delbrueckii ZU-S2	Batch/continuous	0.95 g/g	399.7125
Maize Husk	336.6	Lb. pentosus ATCC 8041	Fed-Batch SSF	0.65 g/g	218.79
Cassava Peel	3802.08	L. delbrueckii NCIM 2025, L. casei	Batch SSF	0.98 g/g	3726.0384
Cassava Stalk	2734.08	Lb. delbrueckii NRRL-B445	SSF	0.18 g/g	492.1344
Rice Straw	813.491	Lactobacillus coryniformis ssp. torquens ATCC 25600	SSF	0.89 g/g	724.00699
Millet Stalk	549	Lactobacillus coryniformis ssp. torquens ATCC 25600	SSF	0.89 g/g	488.61
Sorghum Stalk	287	Lactobacillus coryniformis ssp. torquens ATCC 25600	SSF	0.89 g/g	255.43
Banana Stalk	0.988	Lactobacillus coryniformis ssp. torquens ATCC 25600	SSF	0.89 g/g	0.87932
Wood	360	E. faecalis RKY1	Batch	0.93 g/g	334.8
Rice Bran	27.78	Lactobacillus sp. RKY2	Batch	0.95 g/g	26.391

(Abdel-Rahman et al., 2010; John et al., 2009)* (Bayitse et al., 2013)**