Chapter 17

# Comprehensive review of the prospectives and development for the production of bioalcohols using nanoparticles

N. Prabhu[1], S. Karthikadevi[2] and T. Gajendran[2]
[1]*Department of Biotechnology, Vivekanandha College of Engineering for Women, Tiruchengode, India,* [2]*Department of Biotechnology, Bharathidasan Institute of Technology, Anna University, Tiruchirappalli, India*

## 17.1 Introduction

Bioalcohols are simple sugars derived from dead plant biomass and other forms of life. After several years of decomposing the contained polysaccharides are digested by the action of other micro- and macromicrobes (i.e., bacteria, fungi, etc.) producing the final metabolic product (Kim & Lee, 2016). This type of metabolic product is known as bioalcohols. These metabolic products occur in three forms: liquid, solid, and gas. Depending on its nature it can be utilized in various commercial applications including automobile industries, petrochemical industries, etc. (Jeon, Park, Ahn, & Kim, 2017). The combustion characteristics of extracted bioalcohols from biological sources are modified by applying external thermal energy, pressure, and the addition of other essential catalysts (e.g., nanoparticles) (Adzmi, Abdullah, & Naqiuddin, 2019). Biomass from various biological sources such as crop waste, wood residues, animal waste, and municipal solid waste is converted into bioenergy through the action of decomposition in a biochemical and thermal process (Liu et al., 2016).

Bioethanol is produced through a fermentation process, where the lignocellulosic and other biomasses are pretreated using various alkaline and acid treatments (Shuttleworth et al., 2014). The soluble sugars produced during pretreatment are submerged in a reactor containing lignocellulose-degrading microbial culture (Kang et al., 2014). These substrates are then fermented by the enzymes that are produced by the microbes and bioproducts of interest

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are produced. Finally, the microbial culture containing bioethanol is separated and purified by using a distillation method (Tan & Lagerkvist, 2011).

This chapter discusses nanoparticle-based enhanced production of bioalcohols through novel approaches. When applying nanoparticles in bi-alcohol production, not only is bioalcohol production enhanced, it also helps to reduce the harmful bioalcohol-based environmental effects.

## 17.2 Role of nanoparticles in bioalcohol production

Naturally derived biofuels have a highly viscous nature with low volatility, making them unsuitable for operating vehicle engines. When applying these fuels directly to a motor engine, due to their incomplete combustion, the working conditions of the motor are affected. Therefore some modifications are required to enhance their combustion capabilities (Agarwal & Agarwal, 2007). Much research has reported that there are many types of nano-sized metal ions such as iron (Fe), manganese (Mn), platinum (Pt), cerium (Ce), copper (Cu), and aluminum (Al), which act as a good catalysts to improve the ignition of bioalcohol-based biofuels.

There have been several scientific reports stating that nanoparticles such as hydroxyapatite, $Fe_3O_4$/alginate nanocomposite, nickel cobaltite ($NiCo_2O_4$), ZnO, and iron oxide maintain a high level of cellulose enzyme production through optimization of their environmental conditions such as pH and temperature (Dutta, Mukhopadhyay, Dasgupta, & Chakrabarti, 2014; Srivastava, Singh, Srivastava, Ramteke, & Mishra, 2015; Verma, Chaudhary, Tsuzuki, Barrow, & Puri, 2013). The biohydrogen production is enhanced by the addition of gold, hematite, and silver nanoparticles (Han, Cui, Wei, Yang, & Shen, 2011; Zhang & Shen, 2007). $MnO_2$ nanoparticle-immobilized cellulase produced from *Aspergillus fumigatus* were utilized in the high-level production of bioethanol from lignocellulosic biomass waste. Here, $MnO_2$ nanoparticles enhanced the activity of fungal cellulase enzyme (Cheriana, Dharmendirakumar, & Baskar, 2015). Liu et al. (2016) illustrated that the presence of bioalcohol in water was condensed by the addition of iridium nanoparticles that were attached with hierarchical porous N-doped carbon. In syngas fermentation of bioethanol, production from *Clostridium ljungdahlii* was enhanced by the presence of silica-based nanoparticles at a concentration of 0.3 wt.% (Kim, Park, Lee, & Yun, 2014). Metal oxide (i.e., $Fe_2O_3$ and MgO) mediated nanoparticles induced a huge amount of NADPH generation in the energetic pathway of engineered *Synechocystis* sp. PCC 6803, giving a high ethanol production volume (Velmurugan & Incharoensakdi, 2019). Production of bioethanol from *Saccharomyces cerevisiae* yeast culture was enhanced by the addition of $Fe_3O_4$ nanoparticles under a magnetic field (Konapacka, Rakoczy, & Konopacki, 2018). The enhanced production of bioethanol and biohydrogen from *Citrobacter fruendii* fermented culture obtained by addition of *Boerhavia diffusa* leaf extract mediated bimetallic nanoparticles such as Co and Ni salts as a catalytic precursor (Kodhaiyolii, Mohanraj, Rengasamy, & Pugalenthi, 2019).

Hasannuddin et al. (2018) reported that the various forms of nano-sized materials such as nanofibers, nanoparticles, nanotubes, and nanosheets play a major role in the production of bioalcohol from microbial fermentation. Rao, Sathiavelu, and Mythili (2017) reviewed that the nanomaterials produced from various metal ions give better binding support for various types of enzymes (for their immobilization) that were utilized in the production of bioalcohol from biomass wastes. Zada, Mahmood, and Malik (2013) found that the production of biohydrogen and bioethanol from water hyacinth (*Eichhornia crassipes*) plants was enhanced by the consumption of lignocellulolytic microbial culture with iron nanoparticles added. Table 17.1 contains some examples of nanoparticles used in bioalcohol production.

## 17.3 Potential effects of nanoparticles in bioethanol production

The presence of various aspects of nanoparticles such as their chemical, physical, and electrical properties induce a huge amount of bioalcohol production by the biological process. Here the crucial prospect of nanoparticles is in overstimulating the particular factor that is responsible for the bioenergy synthesis in a certain system. During bioenergy production using nanoparticles there are several kinds of biological expressions that occur within their bio-interactions (i.e., interactions of nanoparticles with biosources).

During microbial fermentation, the specific sugar fermentable microbes (e.g., yeast cells) present in the reactor ferment the simple sugars that are produced from lignocellulosic biomass and produce an alcoholic bioproduct (i.e., bioethanol). Bioethanol is also called ethyl alcohol (Song et al., 2019). At the time of sugar fermentation by microbes, the production of ethanol is enhanced by various nanotechnology-based approaches. Here the activities of enzymes that are responsible for monosugar fermentation are induced by enzyme immobilization on specific nanoparticles via covalent bonding (Velmurugan & Incharoensakdi, 2019). The addition of some metal ion nanoparticles at the time of microbial fermentation also improves the activity of microbes to enhance the ethyl alcohol production. In the absence of oxygen the microbes consume the simple sugars present in the surrounding environment and process these sugars within their cytoplasm, and finally bioethanol is produced extracellularly (Ritslaid et al., 2010). Fig. 17.1 presents the various metal nanoparticles in the production of bioethanol from sugar fermentation.

In some cases bioethanol is produced from syngas using carbon nanotubes loaded with rhodium nanoparticles. These acts as a rector for bioethanol production from syngas containing a CO and $H_2$ mixture. Some examples of nanoparticles involved in bioethanol production from lignocellulosic and other organic biomass wastes are listed in Table 17.2.

**TABLE 17.1** Role of nanoparticles in bioalcohol production and their effects on its characteristics

| Nanomaterials | Size (nm) | Substrates | Method of preparation | Intention | Bioproducts | References |
|---|---|---|---|---|---|---|
| $MnO_2$ nanoparticles | 76 nm | Jackfruit waste and sugarcane leaves | Submerged fermentation (*Aspergillus fumigatus*) | To improve the cellulase enzyme activity | Bioethanol | Cheriana et al. (2015) |
| Ir nanoparticles | 4.5 nm | – | – | To condense the bioalcohols from water molecules | Bioalcohol | Liu et al. (2016) |
| Silica nanoparticles | – | *Clostridium ljungdahlii* culture | Syngas fermentation | To enhance the gas–liquid mass transfer rate | Bioethanol | Kim et al. (2014) |
| Metal oxides ($Fe_2O_3$ and MgO) nanoparticles | – | Engineered *Synechocystis* sp. PCC 6803 | Fermentation | To enhance the generation of NADPH | Bioethanol | Velmurugan & Incharoensakdi, 2019 |
| Ferrimagnetic ($Fe_3O_4$) nanoparticles | 9.3 nm | *Saccharomyces cerevisiae* yeast culture | Fermentation | To enhance the yeast cell proliferation | Bioethanol | Konapacka et al. (2018) |

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|---|---|---|---|---|---|---|
| *Boerhavia diffusa*-mediated cobalt-nickel (Co−Ni) nanoparticles | < 100 nm | *Citrobacter freundii* NCIM No. 2489 culture | Fermentation | To enhance the glucose utilization efficiency | Biohydrogen and bioethanol | Kodhaiyolii et al. (2019) |
| Iron nanoparticles | 11.59 nm | Water hyacinth (*Eichhornia crassipes*) plant | *Saccharomyces cervisiae* yeast fermentation | To enhance the hydrogen yield | Biohydrogen and bioethanol | Zada et al. (2013) |
| Methyl-functionalized silica and methyl-functionalized cobalt ferrite-silica ($CoFe_2O_4$@$SiO_2$ and $CoFe_2O_4$@$SiO_2$−$CH_3$) nanoparticles | 300 nm | *C. ljungdahlii* culture | Syngas fermentation | To enhance the gas−liquid mass transfer rate | Bioethanol | Kim and Lee (2016) |

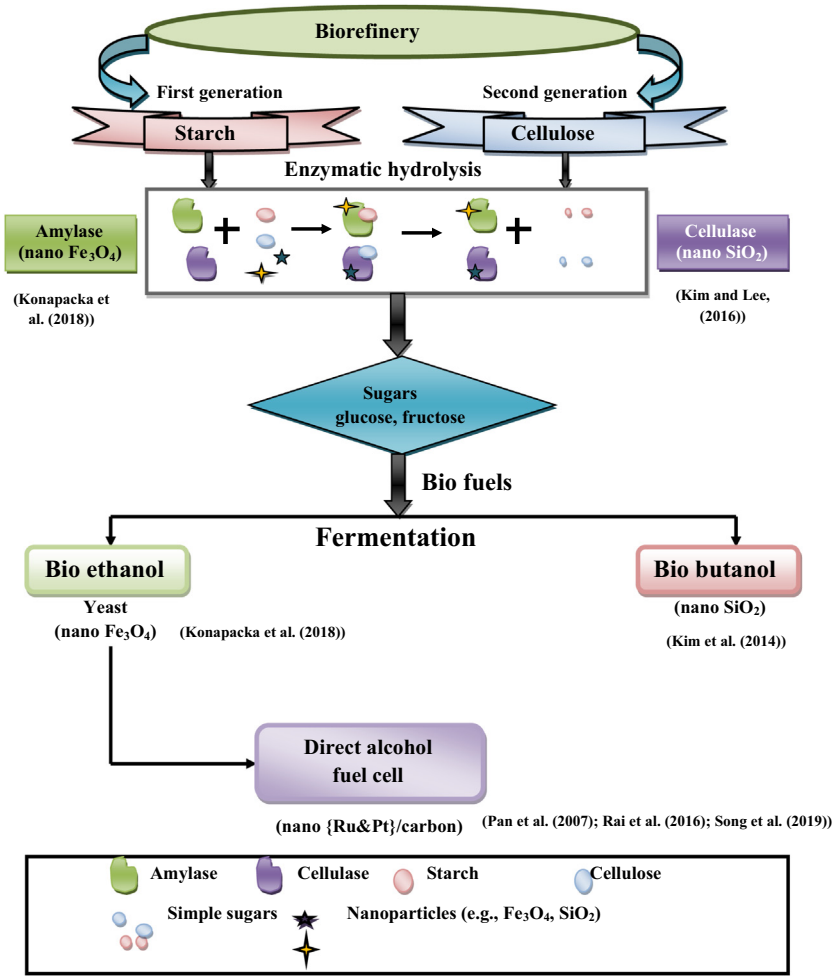



**FIGURE 17.1** Nanoparticle-assisted bioethanol production (references are in the figure).

## 17.4 Role of novel sources on nanoparticle-assisted bioalcohol production

Biomass produced from various natural sources such as agri-food waste, bioenergy crops, forestry residues and microalgae are favorable raw materials for bioalcohol production via sugar fermentation with specific microbial species (Tiwari & Troy, 2015). Kunwar et al. (2017) produced bio-oil (77% liquid yield, 3.9% O) from microalgae such as *Chlorella* with the addition of Pd nanoparticles that were synthesized from bacterial biomass (i.e., *Desulfovibrio desulfuricans* NCIMB 8307). Ivanova, Petrova, and Hristov (2011) reported that immobilized *S. cerevisiae* cells with alginate/magnetic

**TABLE 17.2** Nanoparticles in bioethanol production

| Nanomaterials | Method of synthesis | Bioproduct | References |
|---|---|---|---|
| Carbon nanotube-assisted Rh nanoparticles | Biotransformation | Bioethanol | Pan et al. (2007) |
| Ni, Ti, Co, Mg, Fe, $Fe_3O_4$, FeCO, FePt, $\gamma$-$Fe_2O_3$, $SiO_2$, $H_2WO_4$-Pt/$ZrO_2$, $Fe_3O_4$/alginate nanocomposite, $MnO_2$, cellulosic nanocrystals, MgO, Co−Ni | Fermentation | Bioethanol | Rai et al. (2016); Song et al. (2019); Srivastava et al. (2015); Cheriana et al. (2015); Duran, Lemes, Duran, Freer, and Baeza (2011); Velmurugan & Incharoensakdi, 2019; Kodhaiyolii et al. (2019) |

nanoparticles and chitosan particles containing cellulose-coated magnetic nanoparticles show a prospective effect on ethanol fermentation using corn starch biomass. Mahmood, Hussain, and Malik (2010) proved that the production of ethanol and other biofuels from water hyacinth was increased with the utilization of Ni and Co nanocatalysts in high temperature (50°C−400°C) at atmospheric pressure. Manasa, Saroj, and Korrapati (2017) increased the activity of cellulase enzyme through immobilization with zinc ferrite nanoparticles for high-level production of ethanol from alkaline pretreated *Crotalaria juncea* biomass. They also found that nanoparticle-immobilized enzymes were highly stable at 60°C and their activity was retained for up to three cycles at the time of ethanol production. Hastuti et al. (2019) illustrated that the presence of TEMPO-oxidized nanocellulosic fibers from oil palm empty fruits enhanced biobutanol production in broth containing *Clostridium saccharoperbutylacetonicum* N1−4 by improving their growth. Islam et al., (2019) proved that biomass waste from banana stem acts a good raw source for production of ethanol via yeast (*S. cerevisiae*) fermentation. Faramarzi, Anzabi, and Malmiri (2019) increased the bioethanol production by using sugar beet molasses with selenium supplement as a substrate in yeast (*S. cerevisiae*) fermentation. They produced a high level of ethanol (55 g/L) at a concentration of 15 μg of selenium supplement with molasses. Tsukamoto, Duran, and Tasic (2013) produced bioethanol and nanocellulose through sugar fermentation using microbes [*Candida parapsilosis* strains IFM 48375 and NRRL Y-12969 (ATCC 22019)] isolated from orange waste. Table 17.3 shows examples of bioalcohol production based on nanoparticles combined with various biomasses.

**TABLE 17.3** Novel sources of nanoparticle-based bioalcohol production

| Sources | Microbes | Nanoparticles | Bioalcohol | References |
|---|---|---|---|---|
| Corn starch | *Saccharomyces cerevisiae* | Cellulose-coated magnetic nanoparticles | Bioethanol | Ivanova et al. (2011) |
| Water hyacinth (*Eichhornia crassipes*) | *S. cerevisiae* | Ni and Co nanoparticles | Bioethanol | Mahmood et al. (2010) |
| Syngas | *Clostridium ljungdahlii* | Cobalt ferrite-silica nanoparticles | Bioethanol | Kim and Lee (2016) |
| Sugarcane leaves | Baker's yeast | $MnO_2$ nanoparticles | Bioethanol | Cheriana et al. (2015) |
| Cheese whey | *Kluyveromyces marxianus*, *S. cerevisiae* | Silicon dioxide nanoparticles | Bioethanol | Beniwal, Saini, Kokkiligadda, and Vij (2018) |
| Plant cellulose | *Aspergillus niger* | $Fe_3O_4$ nanoparticles | Bioethanol | Verma et al. (2013) |
| Spent tea (*Camellia sinensis*) | *A. niger* | Cobalt nanoparticles | Bioethanol and biomethanol | Mahmood et al. (2010) |
| Jackfruit waste | Baker's yeast | $MnO_2$ nanoparticles | Bioethanol | Cheriana et al. (2015) |
| Orange waste | *Candida* sp. and *S. cerevisiae* | Nanocellulose | Bioethanol | Tsukamoto et al. (2013) |
| Sugarcane molasses and sugarcane bagasse | *S. cerevisiae* | Magnetite nanoparticles | Bioethanol | Ingale, Parnandi, and Joshi (2019) |

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|---|---|---|---|---|
| Potato waste | *S. cerevisiae* | $Fe_2O_3$ nanoparticles, ZnO nanoparticles, iron(III) oxide nanoparticles, $Fe_3O_4$/Ag nanoparticles, $Ag_2O$ nanoparticles, CoO nanoparticles, NiO nanoparticles, $MnO_2$ nanoparticles, CuO nanoparticles | Bioethanol | Sanusi, Faloye, and Kana (2019) |
| Dry biomass of water hyacinth | *S. cerevisiae*, *Clostridium bacillus* | ZnO nanoparticles | Bioethanol | Zada, Mahmood, Malik, and Zaheer-ud-din (2014) |
| Syngas | *C. ljungdahlii* | Methyl-functionalized silica nanoparticles | Bioethanol | Kim et al. (2014) |
| CO and $H_2$ (syngas) | – | Rh particles inside CNTs | Bioethanol | Pan et al. (2007) |
| – | – | Silver nanoparticle-decorated polycrystalline zinc oxide nanosheets | Bioethanol | Lin et al. (2016) |
| Sugar beet molasses | *S. cerevisiae* | Selenium nanoparticles | Bioethanol | Faramarzi et al. (2019) |
| *Crotalaria juncea* biomass | *Trichoderma reesei* | Zinc ferrite nanoparticles | Bioethanol | Manasa et al. (2017) |
| Oil palm biomass | *Clostridium saccharoperbutylacetonium* | Nanocellulose | Biobutanol | Hastuti et al. (2019) |
| Sugarcane | – | Copper nanoparticles | Bioethanol | Santos, Paim, Silva, and Stradiotto (2016) |
| Bacterial biomass (*Desulfovibrio desulfuricans*) | *Chlorella* microalgae | Pd nanoparticles | Bio-oil | Kunwar et al. (2017) |

(*Continued*)

**TABLE 17.3** (Continued)

| Sources | Microbes | Nanoparticles | Bioalcohol | References |
|---|---|---|---|---|
| Lignocellulosic biomass | *S. cerevisiae, Wickerhamomyces anomalus* | Platinum nanoparticles | Bioethanol | Joshi et al. (2019) |
| – | *Synechocystis* sp. | Metal oxides $Fe_2O_3$ and MgO nanoparticles | Bioethanol | Velmurugan and Incharoensakdi (2019) |
| Biomass feedstock | *S. cerevisiae* | $Fe_3O_4$ nanoparticles | Bioethanol | Konapacka et al. (2018) |
| *Boerhavia diffusa* leaf | *Citrobacter fruendii* | Co–Ni nanoparticles | Bioethanol | Kodhaiyolii et al. (2019) |
| Water hyacinth (*E. crassipes*) | *S. cerevisiae* | Iron nanoparticles | Bioethanol | (Zada et al., 2013) |
| Cassava starch | *Enterobacter aerogenes* | Ferric oxide nanoparticles | Hydrogen production, bioethanol production | Lin et al. (2016) |

## 17.5 Conclusion

Physically/chemically altered nanomaterials like nanotubes, nanoparticles, etc., help to reduce the various economical and harmful effects of bioalcohol production and enhance its utilization in commercial applications. During the combustion of bioalcohol in a motor engine there are several environmental problems (e.g., air pollution) that occur due to the emission of carbon-rich gases. Functionally modified metal/other oxide nanoparticles control these types of harmful emissions by proper mixing of altered nanoparticles with bioalcohols produced from organic/other biomasses. Nanoparticles immobilized with various types of enzymes are responsible for the degradation of lignocellulosic biomass which enhances bioalcohol production. The stability and activity of these enzymes are strengthened by their interactions with nanoparticles via covalent bonding. Nanoparticles that are synthesized from some metal ions induce the activity of microbes that are involved in bioalcohol production through increases in the activity of metalloenzyme. The functionally altered nanoparticles have a crucial impact on bioalcohol production and utilization in the current scenario.

## References

Adzmi, M.A., Abdullah, A., & Naqiuddin, A. (2019). Combustion characteristics of biodiesel blended with $Al_2O_3$ and $SiO_2$ nanoparticles. In *Proceedings of the 3rd international conference on automotive innovation green energy vehicle 2059*, 020052-1-020052-9.

Agarwal, D., & Agarwal, A. K. (2007). Performance and emissions characteristics of Jatropha oil (preheated and blends) in a direct injection compression ignition engine. *Applied Thermal Engineering*, *27*, 2314–2323.

Beniwal, A., Saini, P., Kokkiligadda, A., & Vij, S. (2018). Use of silicon dioxide nanoparticles for β-galactosidase immobilization and modulated ethanol production by co-immobilized *K. marxianus* and *S. cerevisiaein* deproteinized cheese whey. *LWT – Food Science and Technology*, *87*, 553–561.

Cheriana, E., Dharmendirakumar, M., & Baskar, G. (2015). Immobilization of cellulase on to $MnO_2$ nanoparticles for bioethanol production by enhanced hydrolysis of agricultural waste. *Chinese Journal of Catalysis*, *36*, 1223–1229.

Duran, N., Lemes, A. P., Duran, M., Freer, J., & Baeza, J. (2011). A minireview of cellulose nanocrystals and its potential integration as co-product in bioethanol production. *Journal of Chilean Chemical Society*, *56*, 672–677.

Dutta, N., Mukhopadhyay, A., Dasgupta, A. K., & Chakrabarti, K. (2014). Improved production of reducing sugars from rice husk and rice straw using bacterial cellulase and xylanase\ activated with hydroxyapatite nanoparticles. *Bioresource Technology*, *153*, 269–277.

Faramarzi, S., Anzabi, Y., & Malmiri, H. J. (2019). Selenium supplementation during fermentation with sugar beet molasses and *Saccharomyces cerevisiae* to increase bioethanol production. *Green Process Synthesis*, *8*, 622–628.

Han, H., Cui, M., Wei, L., Yang, H., & Shen, J. (2011). Enhancement effect of hematite nanoparticles on fermentative hydrogen production. *Bioresource Technology*, *102*, 7903–7909.

Hasannuddin, A. K., Yahya, W. J., Sarah, S., Ithnin, A. M., Syahrullail, S., & Sidik, N. A. C. (2018). Nano-additives incorporated water in diesel emulsion fuel: Fuel properties,

performance and emission characteristics assessment. *Energy Conversion Management - Journal*, *169*, 291–314.

Hastuti, N., Darmayanti, B. F., Hardiningtyas, S. D., Kanomata, K., Sonomoto, K., Goto, M., & Kitaoka, T. (2019). Nanocellulose from oil pam biomass to enhance microbial fermentation of butanol for bioenergy applications. *BioResources*, *14*, 6936–6957.

Ingale, S., Parnandi, V.A., & Joshi, S.J. (2019). Bioethanol production using *Saccharomyces cerevisiae* immobilized in calcium alginate–magnetite beads and application of response surface methodology to optimize bioethanol yield. sustainable approaches for biofuels production technologies, Springer International Publishing AG, part of Springer Nature.

Islam, M. Z, Asad, M. A., Hossain, M. T., & Paul, S. C. (2019). Bioethanol production from banana pseudostem by using separate and cocultures of cellulase enzyme with *Saccharomyces cerevisiae*. *Journal of Environmental Science and Technology*, *12*(4), 157–163. Available from https://doi.org/10.3923/jest.2019.157.163.

Ivanova, V., Petrova, P., & Hristov, J. (2011). Application in the ethanol fermentation of immobilized yeast cells in matrix of alginate/magnetic nanoparticles, on chitosan-magnetite microparticles and cellulose-coated magnetic nanoparticles. *International Review of Chemical Engineering*, *3*, 289–299.

Jeon, H. S., Park, S. E., Ahn, B., & Kim, Y. K. (2017). Enhancement of biodiesel production in *Chlorella vulgaris* cultivation using silica nanoparticles. *Biotechnology and Bioprocess Engineering*, *22*, 136–141.

Joshi, J., Dhungana, P., Prajapati, B., Maharjan, R., Poudyal, P., Yadav, M., ... Sreerama, L. (2019). Enhancement of ethanol production in electrochemical cell by *Saccharomyces cerevisiae* (CDBT2) and *Wickerhamomyces anomalus* (CDBT7). *Frontiers in Energy Research*, *7*, 1–11.

Kang, N. K., Lee, B., Choi, G. G., Moon, M., Park, M. S., Lim, J. K., & Yang, J. W. (2014). Enhancing lipid productivity of *Chlorella vulgaris* using oxidative stress by $TiO_2$ nanoparticles. *Korean Journal of Chemical Engineering*, *31*, 861–867.

Kim, Y. K., & Lee, H. (2016). Use of magnetic nanoparticles to enhance bioethanol production in syngas fermentation. *Bioresource Technology*, *204*, 139–144.

Kim, Y. K., Park, S. E., Lee, H., & Yun, J. Y. (2014). Enhancement of bioethanol production in syngas fermentation with *Clostridium ljungdahlii* using nanoparticles. *Bioresource Technology*, 1–5.

Kodhaiyolii, S., Mohanraj, S., Rengasamy, M., & Pugalenthi, V. (2019). Phytofabrication of bimetallic Co-Ni nanoparticles using *Boerhavia diffusa* leaf extract: Analysis of phytocompounds and application for simultaneous productionof biohydrogen and bioethanol. *Material Research Express*, *6*, 1–13.

Konapacka, A., Rakoczy, R., & Konopacki, M. (2018). The effect of rotating magnetic field on bioethanol production by yeast strain modified by ferromagnetic nanoparticles. *Journal of Magnetism and Magnetic Materials*, 1–17.

Kunwar, B., Deilami, S. D., Macaskie, L. E., Wood, J., Biller, P., & Sharma, B. K. (2017). Nanoparticles of Pd supported on bacterial biomass for hydro processing crude bio-oil. *Fuel*, *209*, 449–456.

Lin, R., Cheng, J., Ding, L., Song, W., Liu, M., Zhou, J., & Cen, K. (2016). Enhanced dark hydrogen fermentation by addition of ferric oxide nanoparticles using *Enterobacter aerogenes*. *Bioresource Technology*, 1–29.

Liu, D., Chen, X., Xu, G., Guan, J., Cao, Q., Dong, B., ... Mu, X. (2016). Iridium nanoparticles supported on hierarchical porous N-doped carbon: An efficient water-tolerant catalyst for bio-alcohol condensation in water. *Scientific reports*, 1–13.

Mahmood, T., Hussain, S. T., & Malik, S. K. (2010). New nanomaterial and process for the production of biofuel from metal hyper accumulator water hyacinth. *African Journal of Biotechnology*, *9*, 2381–2391.

Manasa, P., Saroj, P., & Korrapati, N. (2017). Immobilization of cellulase enzyme on zinc ferrite nanoparticles in increasing enzymatic hydrolysis on ultrasound-assisted alkaline pretreated *Crotalaria juncea* biomass. *Indian Journal of Science and Technology*, *10*, 1–7.

Pan, X., Fan, Z., Chen, W., Ding, Y., Luo, H., & Bao, X. (2007). Enhanced ethanol production inside carbon-nanotube reactors containing catalytic particles. *Nature Materials*, *6*, 507–511.

Rai, M., Santos, J. C., Soler, M. F., Marcelio, P. R. F., Brumano, L. P., Ingle, A. P., ... Silva, S. S. (2016). Strategic role of nanotechnology for production of bioethanol and biodiesel. *Nanotechnology Review*, *5*, 231–250.

Rao, A., Sathiavelu, A., & Mythili, S. (2017). Mini review on nano immobilization of lipase and cellulase for biofuel production. *Biofuels*, 1–10.

Ritslaid, K., Küüt, A., Olt, J., Ritslaid, K., Küüt, A., & Olt, J. (2010). State of the art in bioethanol produc-tion. *Agronomy Research*, *8*, 236–254.

Santos, F. C. U., Paim, L. L., Silva, J. L., & Stradiotto, N. R. (2016). Electrochemical determination of total reducing sugars from bioethanol production using glassy carbon electrode modified with graphene oxide containing copper nanoparticles. *Fuel*, *163*, 112–121.

Sanusi, I. A., Faloye, F. D., & Kana, E. B. G. (2019). Impact of various metallic oxide nanoparticles on ethanol production by *Saccharomyces cerevisiae* BY4743: Screening, kinetic study and validation on potato waste. *Catalysis Letters*, *149*, 2015–2031.

Shuttleworth, P. S., Bruyn, M. D., Parker, H. L., Hunt, A. J., Budarin, V. L., Matharu, A. S., & Clark, J. H. (2014). Application of nanoparticles in biomass conversion to chemicals and fuels. *Green Chemistry*, *16*, 573–584.

Song, H., Wang, P., Li, S., Deng, W., Li, Y., Zhang, Q., & Wang, Y. (2019). Direct conversion of cellulose into ethanol catalysed by a combination of tungstic acid and zirconia-supported Pt nanoparticles. *Chemical Communications*, *55*, 1–3.

Srivastava, N., Singh, J., Srivastava, M., Ramteke, P. W., & Mishra, P. K. (2015). Improved production of reducing sugars from rice straw using crude cellulase activated with $Fe_3O_4$/Alginate nanocomposite. *Journal of Bioresource Technology*, *183*, 262–266.

Tan, Z., & Lagerkvist, A. (2011). Phosphorus recovery from the biomass ash: A review. *Renewable Sustain Energy Review*, *15*, 3588–3602.

Tiwari, B. K., & Troy, D. (2015). *Seaweed sustainability: food and non-food applications*. Academic Press.

Tsukamoto, J., Duran, N., & Tasic, L. (2013). Nanocellulose and bioethanol production from orange waste using isolated microorganisms. *Journal of the Brazilian Chemical Society*, *24*, 1537–1543.

Velmurugan, R., & Incharoensakdi, A. (2019). Nanoparticle mediated NADPH regeneration for enhanced ethanol production by engineered synechocystis sp. PCC 6803, bioRxiv, 529420.

Verma, M. L., Chaudhary, R., Tsuzuki, T., Barrow, C. J., & Puri, M. (2013). Immobilization of b-glucosidase on magnetic nanoparticles improves thermostability: Application in cellobiose hydrolysis. *Bioresource Technology*, *135*, 2–6.

Zada, B., Mahmood, T., & Malik, S. A. (2013). Effect of iron nanoparticles on hyacinth's fermentation. *International Journal of Science*, *2*, 106–121.

Zada, B., Mahmood, T., Malik, S. A., & Zaheer-ud-din. (2014). Effect of zinc oxide nanoparticles on hyacinth's fermentation. *International Journal of Enhanced Research in Science Technology & Engineering*, *3*, 78–92.

Zhang, Y., & Shen, J. (2007). Enhancement effect of gold nanoparticles on biohydrogen production from artificial waste water. *International Journal of Hydrogen Energy*, *32*, 17–23.