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Bioresources and Bioprocessing

REVIEW

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Current status of cow dung as a bioresource for sustainable development

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Abstract
Cow dung, an excreta of bovine animal, is a cheap and easily available bioresource on our planet. Many traditional uses of cow dung such as burning as fuel, mosquito repellent and as cleansing agent are already known in India. Cow dung harbours a diverse group of microorganisms that may be beneficial to humans due to their ability to produce a range of metabolites. Along with the production of novel chemicals, many cow dung microorganisms have shown natural ability to increase soil fertility through phosphate solubilisation. Nowadays, there is an increasing research interest in developing the applications of cow dung microorganisms for biofuel production and management of environmental pollutants. This review focuses on recent findings being made on cow dung that could be harnessed for usage in different areas such as medicine, agriculture and industry.

Keywords: Cow dung, Biogas, Bioremediation, Enzymes, Antibiotics, Antimicrobial

Background

Cow dung can be defined as the undigested residue of consumed food material being excreted by herbivorous bovine animal species. Being a mixture of faeces and urine in the ratio of 3:1, it mainly consists of lignin, cellulose and hemicelluloses. It also contains 24 different minerals like nitrogen, potassium, along with trace amount of sulphur, iron, magnesium, copper, cobalt and manganese. The indigenous Indian cow also contain higher amount of calcium, phosphorus, zinc and copper than the cross-breed cow (Garg and Mudgal 2007; Randhawa and Kullar 2011). Cow dung harbours a rich microbial diversity, containing different species of bacteria (*Bacillus* spp., *Corynebacterium* spp. and *Lactobacillus* spp.), protozoa and yeast (*Saccharomyces* and *Candida*) (Nene 1999; Randhawa and Kullar 2011). Sawant et al. (2007) have isolated many different bacterial genera such as *Citrobacter koseri*, *Enterobacter aerogenes*, *Escherichia coli*, *Klebsiella oxytoca*, *Klebsiella pneumoniae*, *Kluyvera* spp., *Morgarella morganii*, *Pasteurella* spp., *Providencia alcaligenes*, *Providencia stuartii* and *Pseudomonas* spp. from cow dung.

In India, 69.9 % population resides in rural areas (The Hindu 2011), where cow (*Bos indicus*) is major cattle and generates 9–15 kg dung/day (Werner et al. 1989; Brown 2003). Waste is generally meant for discarding because it may act as a source of pollution (Pongrácz and Pohjola 2004). However, if it is used in some other process such as feedstock it may be considered as co-product (Brown 2003). People in Indian villages use cow dung for cooking purpose by direct burning. It is also used in plastering of walls and floor in rural houses for providing insulation during winter and summer. Application of smoke generated from the burnt cow dung as mosquito repellent and subsequent ash as cleaning agent for kitchen utensils is an age old practice. Accordingly, different usage of cow dung by village peoples reflect the native knowledge associated with it. It also depict that cow plays an important role in village economy and has high socio-economic value (Dhama et al. 2005a).

Cow dung in India is also used as a co-product in agriculture, such as manure, biofertiliser, biopesticides, pestrepellent and as a source of energy (Dhama et al. 2005a). As per ayurveda, it can also act as a purifier for all the wastes in the nature (Randhwa and Khullar 2011). Therefore in India, Cow (*B. indicus*) is not only

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just milk-producing animal but also truly considered as Gomata (mother of all) and Kamdhenu (Dhama et al. 2005a; Jarald et al. 2008). Detailed study of cow dung is gaining interest around the world and few attempts have been made for utilising its potential in the field of energy production, pharmaceutical products. The review intends to highlight the possible applications of cow dung particularly in the area ranging from energy, agriculture and environment to medicine for human welfare.

Source of energy

Dependence of mankind on non-renewable source of energy such as coal, oil and gases is increasing worldwide. In India, the main source of energy is coal, which accounts for 44 % of total energy consumption. Our country is now facing the shortage of coal supplies despite being the third largest coal producer in the world. According to energy information administration (EIA), our dependency on imported fossil fuels has risen to 38 % (USEIA 2014). Because of the limited availability of coal, an easily available, economical as well as environment friendly renewable source of energy is required. According to the United Nations Food and Agriculture Organisation (FAO), the animal waste on this planet produces around 55–65 % methane, which upon release in the atmosphere can affect global warming 21 times higher than the rate CO_2 does. Biogas, a mixture of different gases produced by anaerobic fermentation of organic matter from methanogenic bacteria, mainly constitutes methane (50–65 %) and CO_2 (25–45 %) (Sharma 2011). One kilogram of cow manure can produce 35–40 l of biogas when mixed with equal amount of water with hydraulic retention time (HRT) of 55–60 days maintained at an ambient temperature of 24–26 °C (Kalia and Singh 2004). Li et al. (2009) reported 67 ml/g methane yield from anaerobic digestion of cow manure, whose total and volatile solids were 23.4 and 13.8 g/l, respectively. Green bacteria such as *Pseudomonas* sp., *Azotobacter* sp. and other purple sulphur or purple non-sulphur bacteria are known to produce maximum amount of methane gas in comparison to other photosynthetic bacteria present in cow dung (Rana et al. 2014). The optimum production of biogas depends upon mesophilic (32–38 °C) and thermophilic (50–55 °C) temperature range (Kashyap et al. 2003). The inability of mesophilic microorganisms to survive in psychrophilic temperature range results in 70 % reduced production of biogas during winters in hilly areas (Kanwar and Guleri 1994). This may be due to the collapse of cell energy, outflow of intracellular substances or cell lysis of mesophiles at lower temperature (Gounot 1986). But many researchers reported a fare amount of biogas production under psychrophilic range of temperature using some modifications (Safley and Westerman 1990; Kanwar and Guleri 1994).

Cow dung is the major source of biogas or gobar gas production in India. The total population of female cows in India is 190.90 million out of which 151 million are indigenous whilst 39 million are crossbreed (Livestock Census 2012). Cow dung generated from 3–5 cattle/day can run a simple 8–10 m^3 biogas plant which is able to produce 1.5–2 m^3 biogas per day which is sufficient for the family 6–8 persons, can cook meal for 2 or 3 times or may light two lamps for 3 h or run a refrigerator for all day and can also operate a 3-KW motor generator for 1 h (Werner et al. 1989). A 1-m^3 biogas plant has produced 28.78 l/kg (0.028 m^3) and 32.76 l/kg (0.032 m^3) of biogas respectively when daily feed with 22 kg of dung/m^3 which is mixed with equal amount of water with 9–10 % of total solids. The maximum production of biogas from that plant is 39.00 l/kg (0.039 m^3) and 40.04 l/kg (0.04 m^3) respectively when operated at the temperature of 23.5 °C (Kalia and Singh 2004). On the other hand, farmer also gains 13.87 metric tons of organic fertiliser per year from the biogas plant. This co-production of biofertiliser also allow farmer to recover the initial investment for setting up of a biogas plant (Sharma 2011).

Though cow dung is solely used as the prime source for biogas production, but research continues to verify the potential of other sources for instance, addition of pig dung was found to have an enhanced effect. Mixture of cow and pig dung (60:40) showed 10 % increase in methane production as investigated by Li et al. (2014). Use of potato pulp and cow manure in the ratio of 20:80 also produced fair amount of methane in comparison to pure cow dung (Sanaei-Moghadam et al. 2014). Besides this, there are reports on comparative studies for biogas production where various feedstocks such as kitchen waste, corn waste and spent tea waste have been used along with cow dung in a ratio of 1:1 producing less average biogas after 25–30 days; however, cow dung alone produced approximately 50 % more biogas than these mixtures (Munda et al. 2012), thereby suggesting that other organic sources may produce biogas but cow dung still remains a potential source. In the light of above-discussed facts, biogas production can also be considered as an effective way of treating organic waste which may produce green house gases if remain untreated.

Supercapacitors are the in-between arrangement in electrochemical batteries which can store a large amount of energy that can be delivered with high power for few milliseconds (Gamby et al. 2001). They have high power density (10^3–10^4 W/kg), long cycle life (>10^6 cycles), pulse power supply, low maintenance cost, simplicity and better safety compared to secondary batteries. The use of porous carbon as electrode material is widespread in supercapacitors. This porous carbon is synthesised by many different methods such as using silica or surfactant, aerogels, organometallic compounds, chemical activation and physical activation. All these processes are costly and consume expensive precursors and time (Lee et al. 2006; Fang et al. 2009; Kim et al. 2012; Yang et al. 2012; Bhattacharjya et al. 2013; Inamdar et al. 2013; Bhattacharjya and Sung 2014; Yang et al. 2014). Now focus is shifting towards natural biomass as a potential source for carbon precursors. Several natural biomasses have been explored for production of activated carbon (Demiral and Demiral 2008; Hu et al. 2010; Li et al. 2010, 2011; Wei et al. 2011; Xu et al. 2012; Biswal et al. 2013; Falco et al. 2013; Huang et al. 2013; Wang et al. 2013; Bhattacharjya and Sung 2014). Activated carbon has recently been synthesised from cow dung by a modified chemical activation method, in which partially carbonised cow dung was treated with potassium hydroxide in the ratio of 2:1. The synthesised activated carbon when tested as supercapacitor electrodes in practical showed specific capacitance of 124 F/g at 0.1 A/g and retained up to 117 F/g at 1.0 A/g current density. It is also durable for long-term operations (Yang et al. 2012). The synthesis of activated carbon having high surface area along with optimum micropore and mesopore volume reflects excellent electrochemical application of cow dung for supercapacitors. The literature also suggest that biological waste like cow dung can be converted into a electrode material for other energy storage and conversion systems such as Li-ion batteries and fuel cells.

Agriculture management

Human population is increasing worldwide giving rise to intensive farming system and unsuitable cropland management that ultimately results in reduced soil fertility (Onwudike 2010; Bedada et al. 2014). Extensive use of chemical fertilisers is suggested for replenishment of nutritional deficiencies to increase crop yield. Many disadvantages of widespread use of chemical fertilisers include increase in soil acidity, mineral imbalance and soil degradation (Kang and Juo 1980; Ayoola and Makinde 2008) and even farmers nowadays do not prefer chemical fertilisers (Bedada et al. 2014). In composting, microorganisms decompose organic substrate aerobically into carbon dioxide, water, minerals and stabilised organic matter (Bernal et al. 2009; Kala et al. 2009; Vakili et al. 2015). Compost is added into the soil to improve nutrients and water-holding capacity (Arslan et al. 2008; Vakili et al. 2015). Recently, researchers observed that addition of cow dung to biomass generated from palm oil industries improves the physical and chemical properties including nutritional composition of compost. Palm oil biomass mixed with cow dung in the ratio of 1:3 significantly improved the compost quality with respect to various parameters such as pH, electrical conductivity and C:N ratio (Vakili et al. 2015). Thus, cow dung may not only act as a substitute for chemical fertilisers because it supplements organic matter, but also as a conditioner for soil (Garg and Kaushik 2005; Yadav et al. 2013; Be´langer et al. 2014). Slurry from biogas plant is also a nutrient-rich source but it cannot be used at large scale because of its drawbacks such as eutrophication and leaching of the soil nutrients (Garg et al. 2005; Wachendorf et al. 2005; Islam et al. 2010; Lu et al. 2012; Guo et al. 2014).

Organic amendments alone may not offer sufficient nutrient supply to meet the demand (Palm et al. 1997; Gentile et al. 2011; Bedada et al. 2014). One way to counter this soil fertility problem is ISFM, i.e., Integrated Soil Fertility Management, a technique that makes use of both organic and inorganic resources resulting in greater yield response and better nutrient storage (Bedada et al. 2014; Ewusi-Mensah et al. 2015). For example, combination of cow dung with NPK (15:15:15) in the concentration of 3 t/ha and 100 kg/ha, respectively, showed marked increase of 8.9 t/ha in the yield of potato tuber in comparison to control that yielded only 1.8 t/ha. The organic carbon of the soil after treatment with this combination was found to be significantly increased from 1.33 to 3.21 %. The combination also improved soil organic matter, phosphate availability, exchangeable ions, effective cation exchange capacity and pH in comparison to untreated soil (Onwudike 2010). The same combination has also been reported to increase the yield of maize (Ayoola and Makinde 2008; Bedada et al. 2014).

Mineral soil phosphorus, a key nutrient limiting plant growth, is divided into three categories as per availability to plants, i.e., phosphorous soluble in the soil solution and available for plant uptake, labile phosphorous in the solid phase ready to be solubilised in soil solution and insoluble or fixed phosphorous in the solid phase (Kuhad et al. 2011; Swain et al. 2012). High amount of inorganic phosphates is added to soil but phosphorus ions are very reactive and most of the inorganic phosphorous is converted into insoluble phosphorous by immobilisation and chelation with metal ligands present in the soil, thereby becoming unavailable for plant uptake (Macias et al. 2003; Barroso et al. 2006; Kuhad et al. 2011; Swain et al. 2012). One of the methods for making insoluble phosphorous available to the plants is solubilisation through microorganisms (Arcand and Schneider 2006; Reyes et al. 2006; Swain et al. 2012). The recent areas where cow dung microorganisms are being used are in promoting soil fertility to improve crop yield. In this study by Swain et al. (2012), thermotolerant *Bacillus subtilis* strains have been recovered from cow dung with great potential in phosphate solubilisation. These *Bacillus* strains also possessed antagonistic activities against plant pathogens along with production of growth regulators. The findings are significant as isolated bacterial strains being thermotolerant may possibly be used as bio-inoculant in agriculture of tropics where temperature during summer rises up to 42–45 °C (Swain et al. 2012).

Many biodynamic preparations obtained from cow dung have shown antagonistic effect against plant pathogens such as *Rhizoctonia bataticola* (Rupela et al. 2003; Somasundaram et al. 2007; Radha and Rao 2014). An investigation by Mary et al. (1986) revealed cow dung extract to be more effective than antibiotics like Penicillin, Paushamycin and Streptomycin in controlling bacterial blight of rice. *B. subtilis* strains are the most predominant isolates from culturable cow dung microflora. A few reports have shown the antagonistic properties of these *B. subtilis* strains against plant pathogens such as *Fusarium soalni*, *Fusarium oxysporum* and *S. Sclerotiorum* (Basak and Lee 2002; Swain et al. 2006; Stalin et al. 2010; Swain et al. 2012). Plant pathogenic nematodes are one of the important pathogens of crops. Recently, a work by Lu et al. (2014) investigated 219 bacterial strains from cow dung for nematicidal activity against model nematode *Caenorhabditis elegans* and out of these, 17 strains killed more than 90 % of the tested nematode within 1 h. The strains identified included *Alcaligenes faecalis*, *Bacillus cereus*, *Proteus penneri*, *Providencia rettgeri*, *Pseudomonas aeruginosa*, *Pseudomonas otitidis*, *Staphylococcus sciuri*, *Staphylococcus xylosus*, *Microbacterium aerolatum* and *Pseudomonas beteli*. Out of these 14 strains also inhibited another nematode *Meloidogyne incognita*. This was for the first time that strains in the genera *Proteus*, *Providencia* and *Staphylococcus* from cow dung displayed nematicidal activity. Cow dung is conventionally applied in Indian subcontinental agriculture to enhance soil fertility. It not only improves the different properties of soil but also acts as a source of microorganisms producing biological nematicidal agents with no negative effect on environment. Therefore, use of cow dung should be promoted in the field of agriculture.

Bioremediation of environment pollutants

Toxic chemicals find their way into the human body, plant tissue and animals through absorption (Adams et al. 2014). Active pharmaceutical ingredients (API) serve as a blend of various drugs that are well known to pollute the aquatic environment (Kessler 2010). Agriculture run-off also contributes towards the pollution of water bodies through which water is supplied for human consumption. Presently, in India only 10 % of total waste water is treated and rest is discharged untreated (Singh and Kohli 2012). In industrial treatment plant in Patancheru, near Hyderabad (India), 0.9 mg ciprofloxacin per gram organic matter was found downstream from common contaminated river sediment (Kristiansson et al. 2011; Larsson 2014). This condition is not only in India but also in China, U.S. and European countries as discharge of pharmaceuticals is also reported from these regions (Babic et al. 2007; Thomas et al. 2007; Fick et al. 2009; Kristiansson et al. 2011; Phillips et al. 2010; Larsson 2014). These practices are adversely affecting the environment quality which is directly related to the quality of life on earth. Discharge of these toxic compounds imparts negative effect on human health hence rejuvenation of environment is today's utmost need (Dhami et al. 2013; Adams et al. 2014).

Conventional methods such as dredging, incineration, use of sorbent materials, sinking and dispersion are not only economical but also environmentally unsustainable (Hilyard et al. 2008; Umanu et al. 2013; Adams et al. 2014). Biological methods are based upon application of appropriate microbes that can improve biodegradation in situ and ex situ (Cookson 1995; Freeman and Harris 1995; Umanu et al. 2013). Different methods which are used in removing of hydrocarbons are bioaugmentation, biostimulation, mycoremediation, phytoremediation, biosparging, bioventing and composting (Bahadure et al. 2013). Amongst these, bioremediation is the most common method in use for removal of hydrocarbons since 30 years (Ryan et al. 1991; Bahadure et al. 2013; Umanu et al. 2013). It involves the use of microorganisms with diverse metabolic capabilities to rapidly degrade hazardous organic pollutants to environmental safe level (Orji et al. 2012; Williams et al. 2013; Buvaneswari et al. 2013; Passatore et al. 2014).

Cow dung contains diverse group of microorganisms such as *Acinetobacter*, *Bacillus*, *Pseudomonas*, *Serratia* and *Alcaligenes* spp. which makes them suitable for microbial degradation of pollutants (Adebusoye et al. 2007; Akinde and Obire 2008; Umanu et al. 2013). Cow dung slurry maintained in the ratio of 1:10 or 1:25 is able to degrade the rural, urban and hospital wastes, including oil spillage to five basic elements (Randhawa and Kullar 2011). A study by Orji et al. (2012) highlights the importance of cow dung isolates, both bacterial and fungal, for reducing total petroleum hydrocarbons to 0 % in polluted mangrove soil. The bacterial isolates involved in the process belonged to genera *Pseudomonas*, *Bacillus*, *Citrobacter*, *Micrococcus*, *Vibrio*, *Flavobacterium* and *Corynebacterium*, whilst fungal isolates were the species from *Rhizopus*, *Aspergillus*, *Penicillium*, *Fusarium*, *Saccharomyces* and *Mucor*. The natural ability of cow dung microflora to degrade hydrocarbons in soil contaminated with engine oil is recently being investigated by Adams et al. (2014) where total petroleum hydrocarbon reduced up to 81 % by the metabolic activities of cow dung microorganisms such as *Bacillus*, *Staphylococcus*, *Pseudomonas*, *Flaviobacterium*, *Arthobacter*, *Enterobacter*, *Trichoderma*, *Mucor* and *Aspergillus* spp. Umanu et al. (2013) suggested that the application of cow dung in an appropriate concentration may prove very efficient in biodegradation of water contaminated with motor oil. Some researchers also suggested the metabolic pathway for microbial degradation of polycyclic aromatic hydrocarbons. A *Mycobacterium* sp. isolated from contaminated soil of gaswork plant has shown the ability to degrade pyrene up to 60 % within 8 days maintained at 20 °C with several degrading products such as Cis-4,5-pyrene dihydrodiol, 4-5-phenanthrene dicarboxylic acid, 1-hydroxy-2-naphthoic acid, 2-carboxybenzaldehyde, phthalic acid and protocatechuic acid were recognised (Rehmann et al. 1998; Haritash and Kaushik 2009). Lignolytic fungi *Irpex lacteus* has also shown the ability to degrade phenanthrene to phenanthrene-9,10-dihydrodiol (Cajthaml et al. 2002; Haritash and Kaushik 2009). All these findings indicate that cow dung can supply nutrients and energy required for microbial growth thereby resulting in the bioremediation of pollutants.

Incineration is a method of choice for disposal of biomedical waste but it is not environmental friendly due to production of toxic gases giving rise to health complications. Another useful application of cow dung microorganisms is in the treatment of biomedical and pharmaceutical waste (Randhawa and Kullar 2011). *Cyathus stercoreus*, isolated from aged cow dung, is not only capable of degrading lignocelluloses in vitro (Wicklow et al. 1980; Freer and Detroy 1982; Wicklow 1992) but also an antibiotic enrofloxacin (Randhawa and Kullar 2011). Research by Pandey and Gundevia (2008) showed complete biodegradation of biomedical waste placed in culture medium of a cow dung fungus, *Periconiella*.

India is the second largest producer of pesticides in Asia with annual production of 90,000 tons out of which 2–3 % is utilised and the rest remain in soil causing environmental problems (WHO 1990; Randhawa and Kullar 2011). Few reports have been published describing the importance of cow dung microbiota in effective disposal of pesticides. Singh and Fulekar (2007) designed a bioreactor for bioremediation of phenol utilising cow dung as a source of biomass. This cow dung microbial consortium that included bacteria, fungi and actinomycetes was found effective in degrading phenol ranging from 100 to 1000 mg/l concentrations. Two bacteria namely *Pseudomonas plecoglossicida* and *Pseudomonas aeruginosa* present in microbial consortium have also been detected to completely degrade hazardous chemicals like cypermethrin and chlorpyrifos (Fulekar and Geetha 2008; Boricha and Fulekar 2009; Randhawa and Kullar 2011). Geetha and Fulekhar (2008) utilised cow dung slurry in the ratio of 1:10 for bioremediation of pesticides namely chlorpyrifos, cypermethrin, fenvalerate and trichlopyr butoxyethyl ester and found that all these pesticides are degraded into some intermediate or less harmful compounds.

Heavy metals enter into food chain through bioaccumulation from sources such as water, soil and air. These metals destroy the growth and metabolism of cells, disrupt the respiratory tract and accumulate in internal organs such as lever, heart and kidneys. Industrial waste is one of the major sources of heavy metal contamination of environment and involved in destruction of flora and fauna of water (Feng et al. 2004; Lakshmi et al. 2008; Kiaune and Singhasemanon 2011; Madu et al. 2011; Soni and Gupta 2011; Ali et al. 2013; Thajeel et al. 2013; Mohan and Gupta 2014). Remediation of heavy metals is commonly done by electrolytic deposition, electrodialysis, electrochemical, evaporation, precipitation, ion exchange, reduction, reverse osmosis, filtration, adsorption, chemical precipitation and distillation (Mohapatra et al. 2007, 2008; Mohan and Gupta 2014). All these methods are expensive and not environment friendly; hence, there is a need of cleaner and greener methods. Cow dung and its microorganisms have recently been tapped for the remediation of heavy metals like chromium, strontium and arsenic. Arsenic can be detoxified by methylation process. The ability of bacteria to methylate arsenic into volatile products mainly arsine, in the form of dimethylarsine, is already known (Bachofen et al. 1995). Mohapatra et al. (2008) have shown that cow dung can act as a major substrate for bacterial growth during removal of arsenic from arsenic-rich sludge by means of volatilisation. It was detected that methanogenic bacteria at substrate, i.e., cow dung concentration of 25 mg/l, could effectively volatilise around 35 % arsenic. Dry cow dung powder has recently been used as a source of adsorption for the removal of chromium from aqueous solution and achieved 73.8 % removal of chromium (Mohan and Gupta 2014). Another heavy metal, i.e., radiotoxic strontium which is very hazardous due to half-life of 29 years, imitates calcium in the body and increases the risk of bone cancer and leukaemia (Peterson et al. 2007; Barot and Bagla 2012). Barot and Bagla (2012) detected biosorption of a radiotoxic strontium (90Sr) by dry cow dung powder. 350 mg of dry cow dung powder along with certain laboratory conditions such as pH 6, contact time of 10 min and agitation speed of 4000 rpm resulted in 85–90 % adsorption of strontium. Thus, dry cow dung powder may be preferred over other synthetic adsorbents because of their production cost, time and energy requirements. Cow dung is a cheap and economically viable resource which is easily available. According to the above-discussed data, cow dung can be employed with or without pre- or post-treatment as an excellent measure to bioremediate nonbiodegradable and potentially toxic pollutants. Using cow dung for bioremediation is a simple and eco-friendly method as it does not produce any harmful by products. However, much more comprehensive studies are required to be done in this field.

Source of microbial enzymes

Microbial enzymes have got immense application because microbes can easily be cultivated and their enzyme can catalyse wide variety of hydrolytic and synthetic reactions (Illavarasi 2014). Many microbial enzymes have been isolated and studied for their industrial and commercial uses. However, still there is a continuous search for the potential microorganisms that are able to synthesise industrially feasible enzymes and microbial diversity of cow dung makes it a potential source for the said purpose (Dowd et al. 2008). *Bacillus* spp. from cow dung is capable of producing cellulose, carboxymethyl cellulose and cellulase (Das et al. 2010; Sadhu et al. 2013; Illavarasi 2014). In case of poor enzyme production, genetically improved strains can be constructed for enhanced enzyme production. For instance, Sadhu et al. (2014) described that cow dung *Bacillus* spp. can be mutated with NTG to increase the cellulase production from 9.4 to 16.3 U/mg proteins. Teo and Teoh (2011) detected several cow dung isolates producing enzymes like protease, lipase and esterase lipase. Xylanolytic bacteria are receiving increasing commercial interest in several industries such as enzyme-aided bleaching of paper (Encarna et al. 2004; Viikari et al. 1994), production of ethanol from plant biomass (Lamed et al. 1988), animal feed additives (Annison 1992) and in bread making (Maat et al. 1992). One member of xylanolytic bacteria *Paenibacillus favisporus* sp., from cow dung, was found to produce wide variety of hydrolytic enzymes such as xylanases, cellulases, amylases, gelatinase, urease and β-galactosidase (Encarna et al. 2004). Not only as a microbial source but cow dung may also serve as good substrate for enzyme production, for example, in production of detergent-stable dehairing protease by alkaliphilic *B. subtilis* (Vijayaraghavan et al. 2012), alkaline protease by *Halomonas* spp. (Vijayaraghavan and Vincent 2012) and fibrinolytic enzyme from *Pseudoalteromonas* sp. (Vijayaraghavan and Vincent 2014).

Human health management

Microbial products or their derivatives can kill or inhibit the growth of susceptible pathogenic microbes (Willey et al. 2008). However, overuse and misuse of these antimicrobial agents have resulted in the development of resistance amongst pathogens (Aly et al. 2012; Sharif et al. 2013). At present, bacterial resistance against the antibiotics is of great concern for clinicians, public health officials and researchers as it results in substantial morbidity, mortality and increased cost of treatment (Naiemi et al. 2006; Abo-state et al. 2012; Aly et al. 2012; Jeyasanta et al. 2012; Ullah et al. 2012; Sharif et al. 2013). The pharmaceutical industries and healthcare systems of the world are continuously fighting multidrug-resistant strains of bacteria the last 50 years. Following this fundamental need to counter antibiotic resistance, one way is to search for new sources having possibilities for antibiotic-producing microorganisms. Soil is the prominent source from where hundreds of antibiotic-producing organisms have been isolated during the last five decades (Khamna et al. 2009; Hossain and Rahman 2014; Amin et al. 2015). Recently workers have started to explore other sources such as oceans (Wu et al. 2014). Bacteria colonising marine invertebrate (e.g., sponges and corals) are considered responsible for the production of antimicrobials (Zhang et al. 2012; Santos et al. 2015)

A relatively limited number of reports exist on the presence of antagonistic activity amongst cow dung microorganisms and antimicrobial activity of cow dung as a whole. Cow dung possesses antiseptic and prophylactic or disease preventive properties. It destroys the microorganism that causes disease and putrefaction. Medicinal properties of five products collectively known as panchgavya obtained from cow namely milk, ghee, curd, dung and urine are supported by their use in the preparation of various herbal medicines (Pathak and Kumar 2003; Jarald et al. 2008). Panchgavya therapy utilises these five products singly or in combination with herbal or mineral drugs for the treatment of many diseases like flu, allergies, colds, cough, asthma, renal disorders, gastrointestinal tract disorders, acidity, ulcer, wound healing, heart diseases, skin infections, tuberculosis, chickenpox, hepatitis, leprosy and several other bacterial and viral infections. Panchgavya also seems to be beneficial even for the diseases such as cancer, acquired immunodeficiency syndrome (AIDS) and diabetes. Immunostimulatory, immunomodulatory and antiinflammatory effects of panchagavya are also being mentioned in Ayurveda (Chauhan 2005; Dhama et al. 2005a; Donovan 2008; Jain et al. 2010; Sathasivam et al. 2010; Girija et al. 2013; Dhama et al. 2013). Recently, central nervous system action of panchgavya on spontaneous motor activity, muscle tone and pain has been determined in albino rats (Paliwal et al. 2013).

Cow dung has antifungal substance that inhibits the growth of coprophilous fungi (Dhama et al. 2005b; Joseph and Sankarganesh 2011; Dhama et al. 2013). *Eupenicillium bovifimosum* present in cow dung produces patulodine-like compounds viz. CK2108A and CK2801B that possess significant antigungal activity (Dorothy and Frisvad 2002; Lehr et al. 2006). Lauková et al. (1998) detected considerable numbers of enterococci in cow dung water with antilisterial effect. One isolated strain *Enterococcus faecalis* V24 was found to produce a heat stable, largely hydrophobic antimicrobial substance with significant antimicrobial activity against pathogenic Gram-negative bacteria. Possible applications of cow dung microorganisms in pharmaceutical industry has been indicated by Teo and Teoh (2011) and it was shown that isolate K4 possessed antibacterial activity against *E. coli.* Research has also been conducted on water, ethanol and n-Hexane extract of whole cow dung against *Candida*, *E. coli*, *Pseudomonas* and *Staphylococcus aureus* by Shrivastava et al. (2014) revealing their antimicrobial properties.

Mycobacterium vaccae, a non-pathogenic bacterium, first isolated from cow dung possesses antidepressant properties. When inhaled, it enhanced the growth of neuron which stimulates the production of serotonin and norepinephrine in the brain (Lowry et al. 2007). Its effects on anxiety and learning power were also tested on the mice and it showed good results when the mice fed with live *M. vaccae* (Matthews and Jenks 2013). Immunotherapy by killed *M. vaccae* vaccine has also been found effective in the treatment of asthma, cancer, leprosy and psoriasis (Rook and Stanford 1988; Lehrer et al. 1998). These reports suggest that cow dung may serve as a promising untapped source containing microorganisms, which hopefully may be connected to novel antimicrobial metabolites.

Conclusions

Cow dung host a wide variety of microorganisms varying in individual properties. Exploitation of cow dung microflora can contribute significantly in sustainable agriculture and energy requirements. It is one of the bioresources of this world which is available on large scale and still not fully utilised. The understanding of the mechanisms enabling cow dung microbes to degrade hydrocarbons can promote bioremediation of environmental pollutants. With recent advances in scientific research and techniques for complete genome sequences, the genes responsible for bioremediation can be identified. Another exciting area of research for future studies is developing microbial enzymes and antimicrobials. The production of enzymes by microorganisms from this cheap bioresource can find wide applications in various fields such as agriculture, chemistry and biotechnology. The application of cow dung microflora with considerable antimicrobial potential can result in the promotion of human health; however, comprehensive screening of these microorganisms for the production of antibacterial, antifungal and antiviral metabolites needed to be investigated. It is certainly evident that more detailed studies of cow dung are needed, as there is still a tremendous scope for research and development to reach up to the industrial scale production of antibiotics and enzymes. In this way, cow dung may be considered as an easily available bioresource that holds a great potential for sustainable development in the near future.

Abbreviations

USEIA: United States energy information administration; ISFM: integrated soil fertility management; NPK: nitrogen, phosphorus, potassium; NTG: *N*-methyl-*N*′-nitro-*N*-nitrosoguanidine.

Authors' contributions

KKG and DR contributed to the preparation of the manuscript. KRA contributed to the general advice and improving of the manuscript. All authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no competing interests.

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