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REVIEW

Valorization of Cow Urine and Dung: A Model Biorefinery

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Abstract
Cow is one of the most common livestock of Indian farmers. Small farm households are strongly dependent on livestock for income as it contributes nearly 16% of their total earnings. As much as two-thirds of rural community depends on livestock for their livelihood. Farmers in India maintain a hybrid farming system, that is, a combination of crop cultivation and livestock, which are complementary to each other. Traditionally, the output of one enterprise is the input of another enterprise. Recent research suggests that in addition to milk, urine and dung obtained from cow are valuable resources of bioactive compounds, which can be converted into value-added products. In this review, we provide an outline for the physicochemical composition and valorization of cow urine and dung. They are utilized in agriculture as a pesticide, manure, and acts as a soil rejuvenator. Cow dung is used for bio energy production by fermentation and gasification. Medicinal and cosmetic products are prepared following ayurvedic formulations described in 'Panchagavya'. Cow dung ash is used as adsorbent, construction material, mosquito repellent and electrolyte. A case study of manufacturing unit producing arrays of products from cow urine and dung is also presented.

Keywords Cow urine · Cow dung · Waste utilization · Bio gas

Introduction

Traditionally, India is rich in livestock resources. The economy of this country depends on livestock, as approximately 20.5 million people depend on this for their livelihood. Small farm households are strongly dependent on livestock for income as it contributes to nearly 16% of their total earnings. Two-thirds of rural community gets their livelihood from livestock alone. Rural economy is benefited by live stock in terms of income, employment, food, and social security. Reports indicate that approximately 8.8% of the Indian population gets their employment from livestock farming. Indian economy is agriculture based, contributing 17% of the total GDP, of which 25.6% is contributed by the livestock sector (or 4.2% of the total GDP) [1].

According to the 2012 livestock census, the population of cattle (cow and oxen) in India is 190.9 million and ranks second in the world population. Cattle offers food, fiber and skins, draught (male only), dung and other animal waste materials, weed control, cultural significance, sports/recreation, and companion animals.

Hindus consider cow as a holy animal with its products viz. milk, dung and especially its urine as a curator for many diseases [2]. The cow urine is an important ingredient in 'Panchagavya' that has been widely used as medicinal formulations since ancient times [*Charaka Saṃhitā, Sushruta Samhita, Vridhabhaga bhatt, Atharvaveda, Bhava Prakash, Rajnighantu, Amritasaga*] [3]. Several studies have been conducted over the past few years to show the usefulness of cow urine in treating hypertension, respiratory, peripheral, gynecological, skin related problems, sensory and many other major metabolic disorders and AIDS, cancer etc. [1–3]. In addition to its use as a therapeutic agent for treating several ailments, cow urine has multiple uses in agriculture and sericulture sectors.

Cow: Description and Common Indian Breeds

Thirty-seven different breeds of Indian cows can be found in different parts of the country. On an average the cow weighs about 500 kg and has a life span of about

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18–30 years. A cow may drink as much as 130 L of water daily and can eat 45 kg of green grass/day or 16 kg of hay a day. Additional nutrients and supplements are provided through grain mixture moistened with water/molasses and salt blocks. On an average, a cow produces about 13 L urine/day, and 30 kg of dung. The average milk yield per animal in India is just about half as much as of global average of 6.6 kg. More details can be found in literature [4–6].

This study was carried out with a view to compile various utilizations of cow urine and summarize it. Cow urine is the main product obtained from cow, whereas milk is only a secondary product as a cow gives urine right from the birth to death unlike milk, which is produced only for a short period. If the cow's urine is used properly, it is the most advantageous product obtained from cow. Furthermore, the use of cow urine in industries and pharmaceuticals will help in improving the financial condition of farmers and prevent cow slaughter.

Physiochemical Composition of Cow urine [1, 7–10]

Cow urine contains 95% water, 2.5% urea, and 2.5% salts. These include inorganic matter such as salts of sodium, potassium, calcium, nitrogen, sulfur, manganese, iron, silicon, magnesium and traces of gold and silver. It also contains organic moieties such as citric acid, succinic acid, lactose, carbolic acid, enzymes, creatinine, and vitamins, steroids, estrogens and hormones.

Useful Enzymes in Cow Urine

All living organisms (bacteria, plants, and animals) produce proteins called enzymes which are highly selective as catalysts in transforming one molecule into another. The life supporting enzymes possess the abilities to catalyze metabolic reactions while not undergoing any changes themselves (i.e., catalyst). Several studies have demonstrated the presence of much essential enzymes in cow urine (Fig. 1).

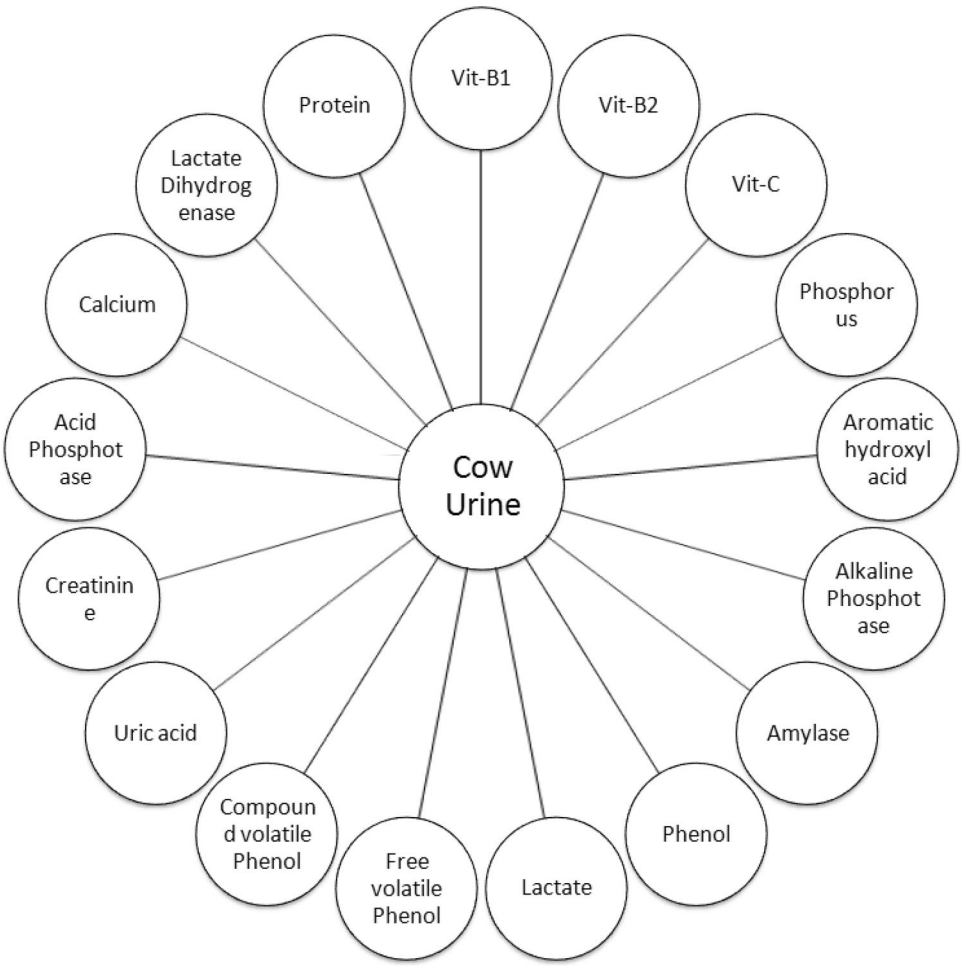

Fig. 1 Enzyme analysis of cow urine

Uses of Cow Urine

Cow urine has various applications in agriculture, pharmaceuticals, and other fields, which are pictorially depicted in Fig. 2. In general, cow urine filtrate is used as a raw material in these fields but sometimes its distillate and unfiltered cow urine is also used. There are some household uses also, but there is a lack of studies to verify the use while some studies are ongoing. Cow urine is also used in various Hindu rituals and festivals for various purposes.

Agricultural

Cow urine finds many applications in agriculture and sericulture sectors (Fig. 3).

Rhizome Rot Inhibitor [11]

Most agricultural products of commercial, societal and medicinal use are often seen to be infected by one or the other microbial species causing loss in yield and sometimes even the quality. Thus, for instance, Ginger (Family: Zingiberaceae) known for its aromatic rhizomes and used as spice and medicine gets infected by bacteria, fungi, viruses, mycoplasma, and nematodes. Among the bacterial wilt caused by *Ralstonia solanacearum*, rhizome rot caused by *Pythium, Fusarium*, and *Sclerotium* species are more prevalent. Use of cow urine extracts of some select herbs show marked inhibition of rhizome rot pathogens that supports its possible use in agriculture as potent agents against pathogens.

Anthracnose Inhibitor [12]

Similarly chili crop is infected by anthracnose that results in drastic reduction in yield. Again the antifungal property of cow urine against bugs from anthracnose of chili is highly inhibitive. In general, cow urine shows the powerful detrimental activity towards several phytopathogenic fungal and bacterial species.

Pesticides [13]

Mustard crop is often infected by Aphid (*Lipaphis crysimi*) that can reduce its yield to less than 10%. Extracts of neem leaf and kernel prepared in cow urine shows effective pesticide potential to control mustard aphid and *L. erysimi* Kalt. It is also observed that the use reduces mustard aphid and leads to increase in mustard grain. Usually 3–4 foliar sprays containing cow urine and 3% neem kernel extract with or without a reduced dose of dimethoate (0.03%) can lead to safe disposal of problem.

Urine extracts of any plant or herb, according to Ayurveda, enhances in a multi-fold way the potency of drug making it more effective for controlling various pests and protecting mustard and other plants.

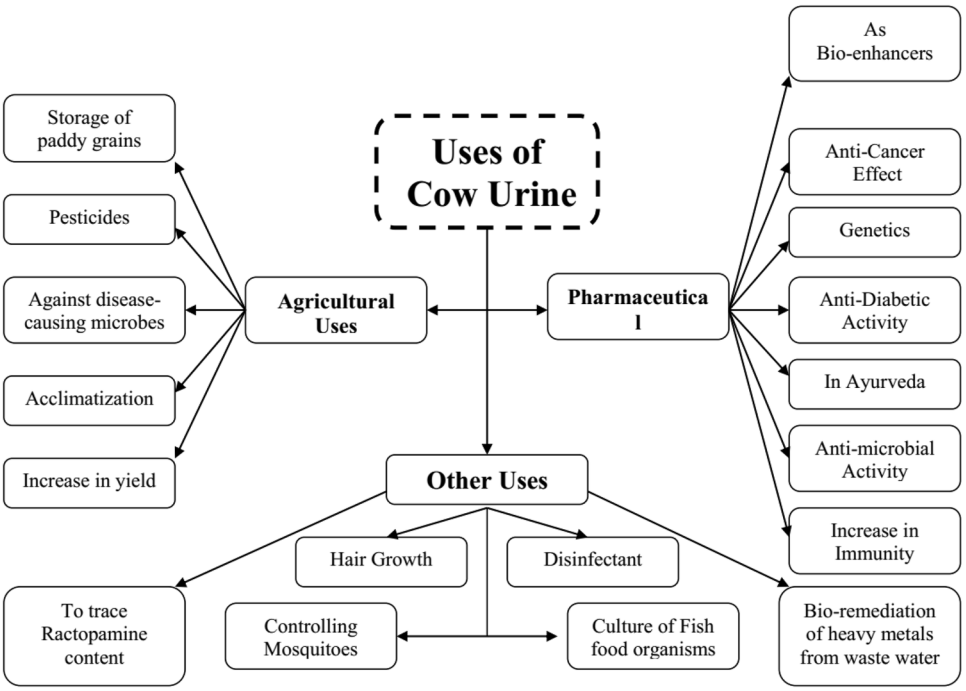

Fig. 2 Application of cow urine in various fields

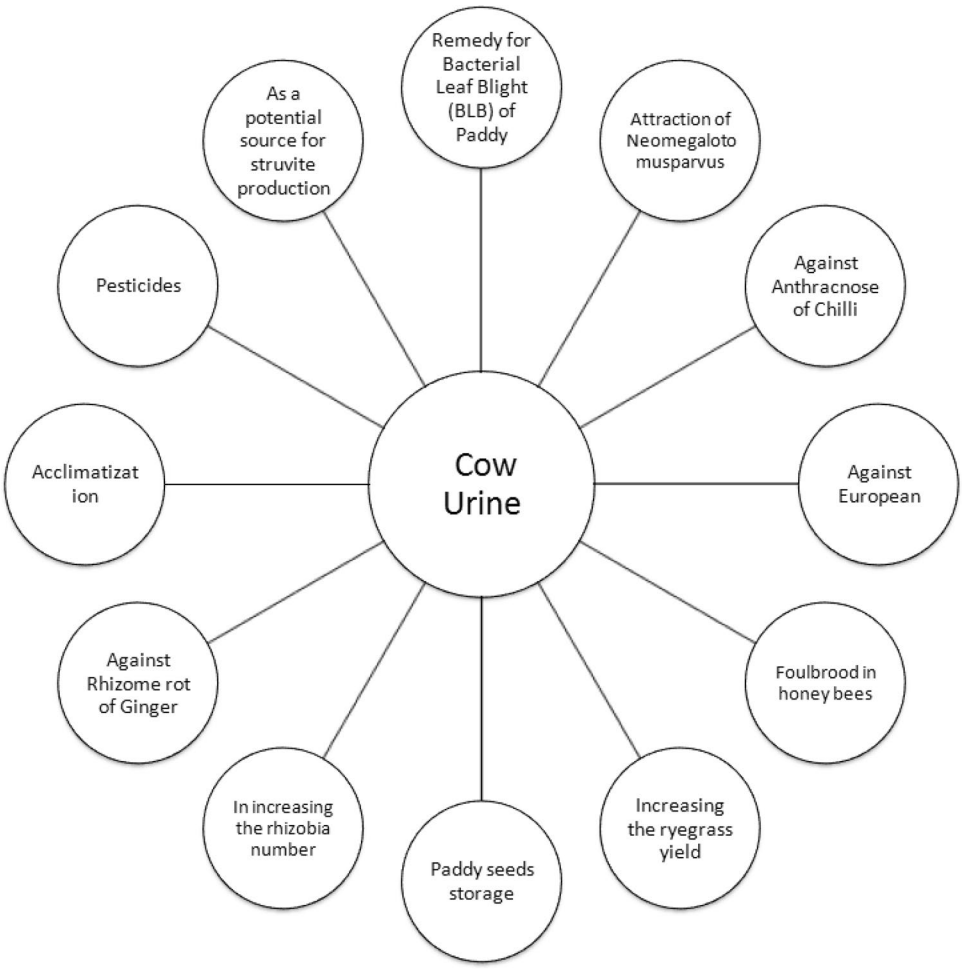

Fig. 3 Agricultural uses of cow urine

Neomegalotomus parvus (Westwood) Trap Attraction [6]

The presence of *N. parvus*is not easily detected in agricultural fields because these insects fly when disturbed. da Silva et al. studied and concluded that cow urine can be used as an attractant for stinkbug species that affect soybean growth. Thus, traps baited with cow urine and ammonia can be excellent sources for attracting *N. parvus*.

A Potential Source for Struvite [14]

Struvite is a naturally occurring material in rock phosphate and can be extracted and used as a source of phosphate for agriculture. However it can also be recovered from cow urine leading to sustainable agricultural development. Struvite is a crystalline material containing equimolar qualtities of magnesium ammonium and phosphate ions ($MgNH_4PO_4{\cdot}6H_2O$). It acts as a rich source of phosphorus as well as a slow-release fertilizer. Cow urine and brine (a source of Mg) in different proportions can be used along with rock phosphate for struvite crystallization. The results of Prabhu et al. showed that to obtain the optimal concentration, cow urine and brine should be mixed in the ratio of 3:1.

European Foulbrood in Honey Bee [15]

Honey bees do the silent but very useful job of pollination besides the production of honey and other bee products (e.g., wax, royal jelly, propolis, pollen, and bee venom). The colonies are prone to microbial induced diseases which can cause economic losses to bee keepers and industry worldwide. Use of cow urine as such in the form of a spray (25–100%) or along with terramycin (125 mg/L/colony) can be used to treat the infected honeybee combs. This formulation was found to be very useful for management of honeybee colonies.

Use of Cow Urine in Paddy Seeds Storage [16]

It is now widely accepted that we must reduce the use of chemical fertilizers and pesticides. Alternatives such as the use of microorganisms or bio fertilizers or biocontrol agents are increasingly looked at. They can be applied to seed or

roots and help enhance plant growth and control diseases through a variety of mechanisms. During storage, loss of seed vigor and viability are associated with aging and thus result in poor stand and performance in the field. Shakuntala et al. found that presoaking seeds in modified cow urine prevented the infections of pests and fungi while increasing seed germination.

Cow Urine in Increasing the Rhizobia Number [17]

Rhizobium is an important index for sustainable agriculture. An efficient inoculation requires more than 1000 rhizobia/gm of soil. The calliterpenone is a plant growth promoter in many monocotyledons and di cotyledons as well as in herbaceous plant species. It is known to possess several plant growth-promoting abilities. Kalra et al. reported that cow urine and calliterpenone promoted the number of rhizobia by ten times in vermicompost. Thus, it increases the quality of vermicompost and consequently the soil quality.

Indigenous Pest Management Practices [18]

Farmers in the Uttarakhand area use cow urine and dung as a solution for spraying on diseased plants by mixing these with water (organic pesticide). Whenever plants in kitchen garden show wilting symptoms, cow urine is sprayed on the affected plants. Some even use cow dung solution for controlling onion blight.

Increasing the Ryegrass Yield [19]

Mohanty et al. Observed boost in annual ryegrass yield when cow urine is used, as this increases the nitrogen component of the soil. Cow urine has very high, total nitrogen up to 22 g N/L, most of it (69%) as urea. Cow urine enhances the nitrate fraction of grass as well as its potassium concentration.

Indigenous Technology Knowledge-Based Disinfectant/Pest Control [20]

Lal and Verma carried out a study in several remote villages with a view to identify the local practices followed by farmers, termed as indigenous technology knowledge (ITK), for managing insect pests of different crops. Ash was the most commonly used material against chewing and sucking type of insect pests while the use of an aged cow urine for treating several pests control including those on pests of cabbage, wheat, peas, grams, and other crops was seen.

The study was essential to record the economically viable and innovative and ecofriendly ways that small farmers can use and adopt. Indigenous bio insecticides can reduce the amount of insecticides sprayed otherwise and lower the environment and ecosystem impact.

Termites Inhibitor [21]

Termites are highly destructive polyphagous insect pests that attack on everything from household materials to agricultural crops including fodder and sugarcane, millet, barley, and paddy. They ruin the soil by tunneling in subtropical and tropical soils. It is customary to use various synthetic chemicals for their control. Upadhyay et al. used pure cow urine with seasoned wood sticks to effectively control the attack of termite.

The undesirable loss of paddy (upto 60%) caused due to Bacterial leaf blight (BLB) infections due to *Xanthomonas oryzae* pv. *oryzae* (Xoo) can be avoided and reversed through the use of chemicals and bactericides. This, however, causes several human health and environmental issues. Murugan et al. [22] showed that condensed cow urine along with acceptable organic solvents and watery fractions of *Pongamia pinnata* Linn seed can destroy oryzae effects.

Acclimatization [23]

Gantait et al. showed that mixtures of autoclaved sand, soil, and cow urine and sand, soil, tea leaves extract along with cow urine in equal proportion acts as a source and media for acclamatisation, growth and survival rates of plants that are seen to be higher than the general process. A basic and simple cost-effective process of acclimatization can provide 95% survival rate of ornamental plants with attractive flowers.

Pharmaceutical

Cow urine is known for its germicidal and antibiotic activity that destroys all pathogenic organisms, improve immunity and cures large number of diseases. More elaboration of these uses can be found elsewhere [1] and the accompanying Fig. 4 captures its essential domains of activity and use.

Purification and Processing of Poisonous Medicinal Herbs [24]

Cow urine is one of the important media that has the ability to remove toxic substances from herbs. It is also used to clean the roots of the medicinal trees. Ilanchezhian et al. have proved the presence of strychnine and brucine in milk after *Shodhana* of 'Nux Vomica' highlighting the role of media for Shodhana. The Ayurvedic practioners use the scientific methodology called Shodhana to transform poisonous herbs into effective drugs for treating various ailments. Mercury is one such substance.

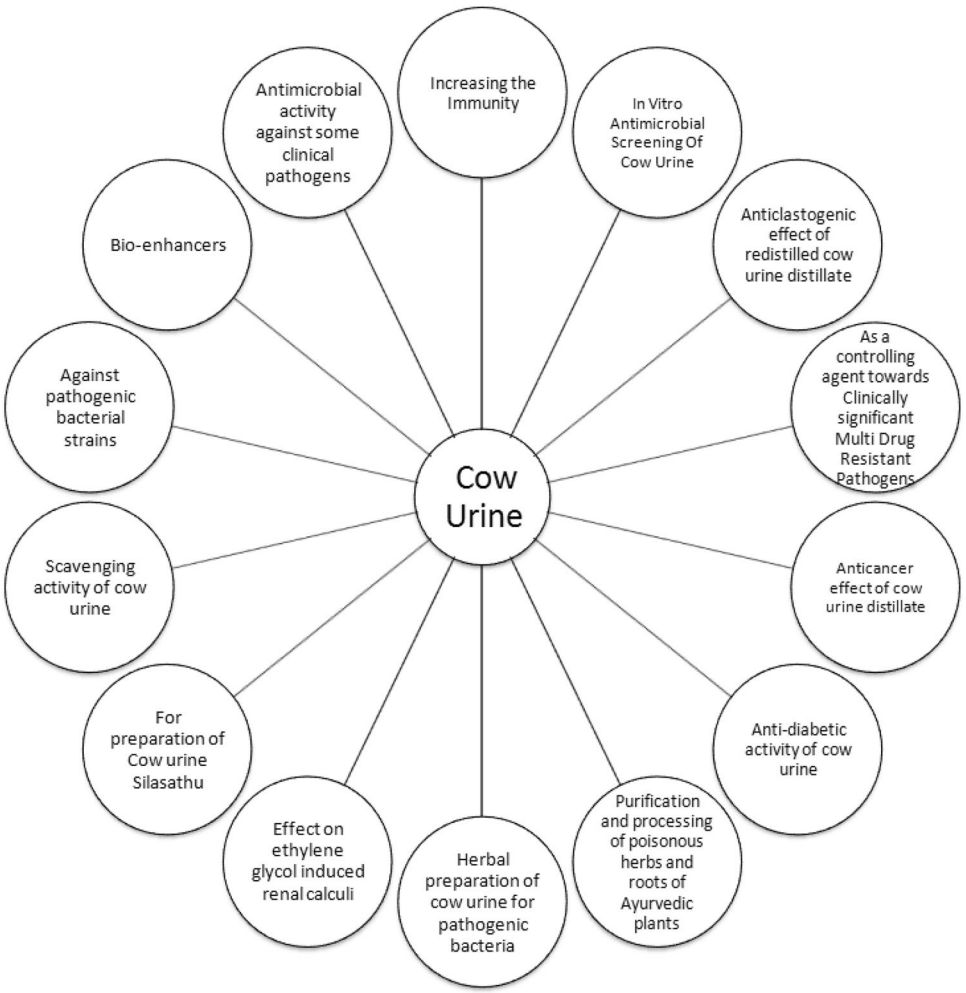

Fig. 4 Pharmaceutical uses of cow urine

Treatment of Chronic Bacterial Infections [25]

Cow urine containing *Dalbergia sissoo* and *Datura stramonium (DSDS)* shows excellent ability to treat chronic bacterial infections caused due to both Gram-positive and Gram-negative bacteria. The efficacy of this formulation was evaluated as against standard antibiotic drugs and seen to be much more active. The results showed that the cow urine extract of DSDS can be used as a potent antiseptic preparation for prevention and treatment of chronic bacterial infections.

A Natural Antimicrobial Agent [26]

Indian households, particularly living in rural areas, use cow urine for treating worm infestations, wound healing, etc. Rana and De evaluated the antimicrobial activity of cow urine, and compared it with the standard antibiotics as well as isolated biologically active functional compounds. The antifungal activity of the isolated active fraction is comparable or better than that of amphotericin B (50 µg), indicating its potential as a natural antifungal agent. Cow urine has a great potential as a natural antimicrobial agent and further studies to isolate the active compound/compounds are necessary.

The imbalance between the pro and anti-oxidants state in the body generates stress condition. Fresh cow urine helps to improve protein digestibility and adjusts blood glucose levels and improve the histopathology of colon mucosa in rats fed with high-fat diet. The use of cow urine reduced oxidative stress by increasing the antioxidant potential, which in turn prevents cellular damage and helps in regulating metabolic activities [27].

Immunity Stimulant [28]

Cow urine helps in increasing immunity. It aids in B-cell blastogenesis, T-cell blastogenesis and improves serum IgG level, serum IgM level, among others, thus triggering antibacterial action and prohibiting bacterial or viral infections. Feeding a specific dose of various plant/herb extract with cow urine and its distillate in a scheduled vaccination

regimen helps in achieving higher immunity and response to bacterial, viral and other diseases.

Cow Urine *Silasathu* [29]

Cow urine *Silasathu* is one of the ingredients in many herbomineral formulations. It tonifies the activity of the seven body constituents (*Sapta Dhatus*), which include plasma, blood, muscle, fat, bone, bone marrow, and reproductive tract fluids. *Silasathu Parpam* is prescribed for *sopanaskalitham* (nocturnal emission), *megam* (venereal disease), *premegam* (gonorrhea), *koruku* (contagious ulcers), and *kiranthi* (glandular swelling). A previous study [26] investigated the physicochemical composition of cow urine *silasathu parpam* and standardized it. In that study, an elemental analysis of Silasathu using ICP-OES and CHN was performed, this proved its spermatogenic activity and its therapeutic potential.

Cow urine extract of *Azadirachta indica* [22] showed superior antimicrobial activity against five MDR clinical isolates. Also, the results with cow urine extract of *A. indica* shows higher antibacterial activity against MDR *Escherichia coli* and *Klebsiella pneumoniae*. A phytochemical test for flavonoids, alkaloids, quinine, coumarin, tannin, saponin, and phenol were positive. Thus, *A. indica* exhibited a synergic effect with cow urine.

Anticlastogenic Effect of Redistilled Cow Urine Distillate [30] Clastogen, the mutagenic agents inducing deletion, addition or rearrangement of sections of chromosomes can be reversed or stopped by redistilled cow urine as tested in human polymorpho nuclear leukocytes (HPNLs) and human peripheral lymphocytes in vitro. Manganese dioxide and hexavalent chromium are known to cause breakages in DNA-strand, chromosomal disruptions and formation of micronucleus. The cow urine distillate is antigenotoxic and anticlastogenic due to the antioxidants present in it.

Antidiabetic activity of cow urine [31] was tested using herbal formulation prepared using cow urine and known herbs for sugar control [*Gymnema sylvestre* R. Br. (Asclepiadaceae), *Momordica charantia* Linn. (Cucurbitaceae), *Eugenia jambolana* Lam. (Myrtaceae), *Aegle marmelos* Correa (Rutaceae), *Cinnamomum tamala* Buch.-Ham. (Lauraceae), *Aloe barbadensis* Linn.(Liliaceae), and *Trigonella foenum-graecum* L. (Leguminosae)]. The herbal preparations in water alone and in cow urine were evaluated against the standard insulin (1 U/kg, i.p.) in hyperglycemic rats to show the superios effects of preparation in cow urine.

Anticancer effect of cow urine distillate was evaluated for a pharmaceutical preparation containing optimal amount of bioactive fractions and was seen to be an anticancer antibiotic and therapeutic, and nutraceutical agent [10]. This preparation demonstrated cow urine distillate as activity enhancer improving bioavailability for bioactive molecules for anti-infective and anticancer agents. Raghunandan et al. observed that the formulation drastically reduces the dosage levels.

Antimicrobial activity of cow urine and its combination with essential oils [32] was tested by Sathasivam et al. against various pathogenic microorganisms. The antibacterial activity of cow urine distillate in various doses (5–15% w) showed excellent activity for commonly known strains, although the efficacy varied for different strains with *Pseudomonas aeruginosa showing the maximum effect. Similarly the* antifungal activity of cow urine distillate as seen for *Aspergillus niger* and *Aspergillus flavus* showed maximum growth suppression for the former.

Cow urine distillate and/or its combination with essential oil also shows higher remedial efficacy. Thus, for instance, neem oil alone is good enough to control *S. pneumoniae*, whereas neem oil in combination with cow urine is seen to perform better for *B. cereus, L. acidophilus, Micrococcus luteus, K. pneumonia*, and *S. pneumonia*. Bavanchi oil and cow urine combination similarly shows higher retardation against *K. pneumoniae*. Photo-activation of cow urine act homogeneously against all bacterial/fungal strains of various origins.

The distillate of Cow urine is more potent than cow urine itself [8] in treating fungal, bacterial or microbial infestations. It acts as a bio-enhancer along with antibiotics and antifungal and anticancer drugs as claimed in US Patents [33–35]. Figure 5 depicts use of cow urine against pathogenic bacterial strains. Example of enhanced activity of paclifaxel treating a human breast cancer cell line, (in vitro) or the enhanced activity of rifampicin (5–7 times) against *E. coli* and Gram-positive bacteria (3–11 times) provide the evidence. The cow urine distillate besides bio enhancer and improved immunization efficacy also modulates adverse effects. Cow urine reduces the toxicity of cadmium chloride whereas it enhances bioavailability of zinc. Fertility index of the animals exposed to cadmium chloride + cow urine + zinc sulfate showed higher fertility rate with excellent viability and lactation indices.

Other Uses

Among other uses of cow urine it is also effective in control of malaria [19] via producing ovipositor cues to *Anopheles gambiae* and *Culexquinque fasciatus*. Fresh as well as a week old cow urine samples due to aging and microbial activities generate chemical compounds that might influence ovipositor attraction and deterrence cues for various mosquito species. Cow urine is a locally available, cheap, and reliable material that can be used in aggregating mosquitoes' larval habitats for use in the therapeutic management of malaria.

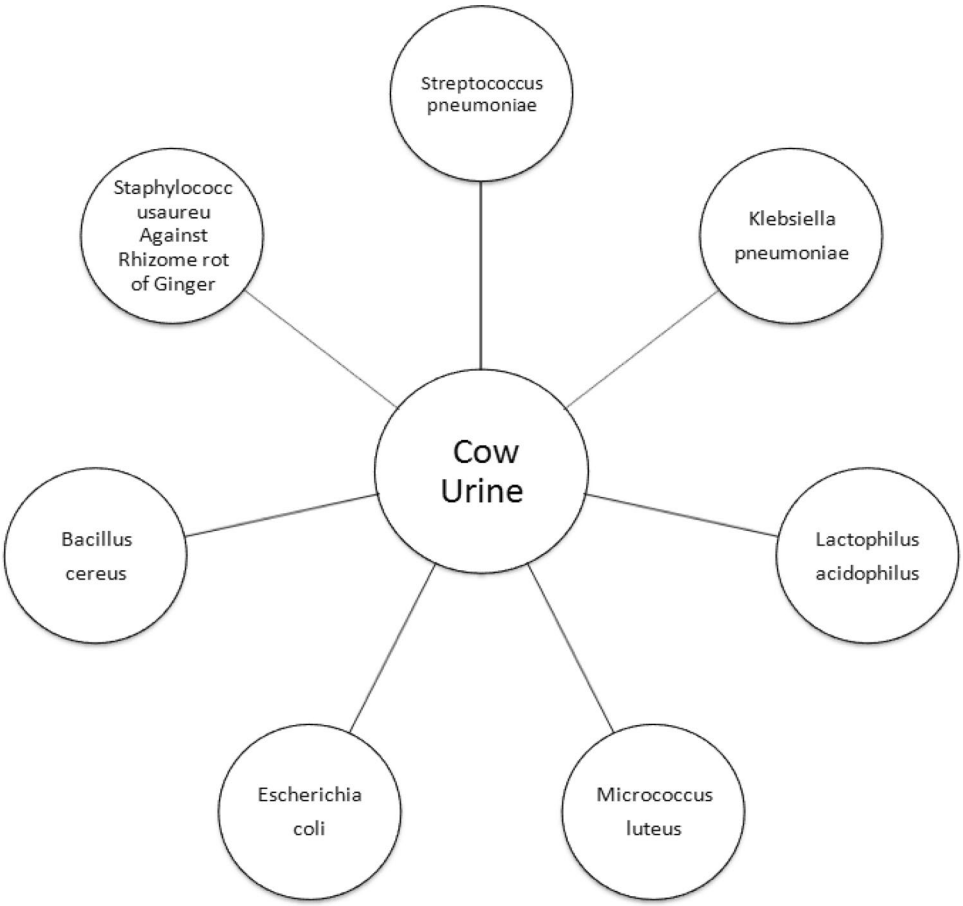

Fig. 5 Cow urine against pathogenic bacterial strains

Analysis of Cow Urine to Trace the Ractopamine Content [36]

Ractopamine is a β-adrenergic agonist leanness-enhancing agent that was recently approved by the U.S. Food and Drug Administration for use as a swine feed additive. Hogs fed with ractopamine at a dietary level of 20 ppm reached their target market weights about 4 days earlier on average, have leaner carcasses, and consume less feed than similarly managed control animals. A significant drawback is that the economic advantage of using ractopamine in swine could result in animal producers using ractopamine in species for which no approval exists. Mitchell and Dunnavan have reported that β-adrenergic agonists have been used illegally in show animals within the United States. Because of a potential for illegal ractopamine use, and because the European Union has banned the use of growth promoters (including all β-agonists) in farm animals, there is a need for rapid detection methods to identify animals exposed to ractopamine. Analyzing ractopamine in urine samples using biosensor technology has also been developed. This technology allows for the automated and rapid analysis of samples for ractopamine content.

Hair growth promotion [37] using extract of tobacco leaves prepared by microbial biotransformation in cow urine and formulated as a lotion using an oil–water-type base in differing concentrations (10–30%) was verified on shaven skin areas of rats. The experiment showed positive growth of hair with improved serum total protein and total testosterone levels.

Human or cow urine, either alone or as mixture (0.11 mL) can provide the nitrogen needed for mass production of zooplankton *M. micrura* a pre requisite for rearing of commercial fishes [38]. The source is better than vermicompost, cow dung, mixed waste or poultry discards.

Cow Dung-Based Disinfectant [39]

There is overdependence on chemical insecticides to control infection caused by microorganisms. This has actually increased the problem rather than solving it. A natural disinfectant using cow dung mixed with extracts of neem, tulsi, ritha and pine oil has been formulated and evaluated. Experimental results demonstrated that this formulation possesses remarkable disinfectant properties besides pleasant aroma/therapeutic vapor. The herbal disinfectant so produced

using cow urine is easy to use, noncorrosive, safe to skin, ecofriendly, and biodegradable. A typical herbal disinfectant preparation would need 100 mL cow urine mixed with 150 mL extract of neem and tulsi each, supplemented with 80 mL of ritha extract and 20 mL of pine oil in 4 L of water and can be used on any surface with excellent results.

In 2013, Hassan et al. reported some side effects of cow urine therapy, which include diarrhea, itch, pain, fatigue, soreness of the shoulder, and fever. However, these effects are occasional and temporary, if at all they come.

Traditional Uses of Cow Urine

Traditionally, cow urine is used in Hindu culture in everyday life without bothering much about its scientific background as presented in Fig. 6. Following are some of the daily practices in a majority of Hindu families.

Drinking a small glass of cow urine distillate (few cubic centimeter) in the morning, spraying a solution of cow urine in water around the house or alternatively adding a small amount of cow urine in a bucketful of bathing water, spraying a mixture of cow dung, cow urine, and water daily in the mornings in verandas.

Some traditional household cow urine-based remedies passed on from one generation to other include treating fever with (urine, pepper, curd, ghee); Leprolsy (Dhruhardi, urine);

Deformation (Nimbuchal, urine); Conditioning leprosy and Chronic sisleprosy (Vasaka leaves, Kuraila bark, Kaner leaves, neem bark, urine); Epilepsy (Neem bark, Somapada bark, mustard oil, urine); Anemia ((a) Cow milk, urine, triphala (b) Loh Bhasma, urine, milk).

Cow Dung Valorization

The use of cow dung as manure is known to mankind for ages. Rig Veda, the oldest book of the world has references of use of cow dung in farming. Cow dung and urine were the key components of traditional, organic farming practice.

Cow dung is a rich source of nitrogen, potassium, phosphorous and calcium and is a low cost and natural fertiliser.

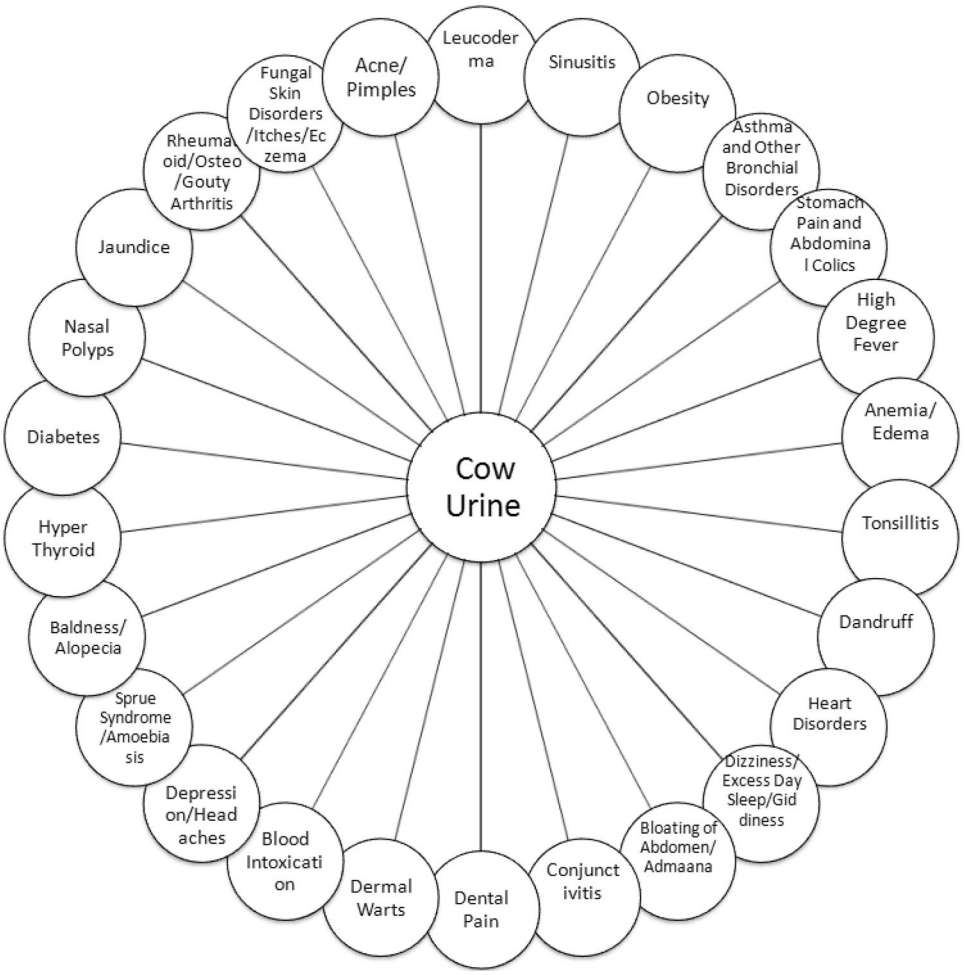

Fig. 6 Traditional application of cow urine in treatment of various diseases

Literature reports relatively high carbon to nitrogen ratio in dung which increases soil fertility [40].

Traditionally cow dung is used as fertiliser, but for last four decades, it has also been used for cooking food as well, i.e. by producing bio gas. Cow dung has the potential to contribute to meet bio energy demand in the form of biogas and biomass. Cow dung biogas is rich in methane and is used as cooking fuel as well as a stable source of electricity in rural areas of developing countries like India.

Globally there is a debate whether cow dung should be used for manure or for energy production. Agriculture scientists claim that cow dung is a cheap and natural fertilizer. On the other side International Energy Agency claims that bioenergy (which include cow dung as a bio resource) is the next generation clean and green energy source which has the potential to meet a quarter of world transportation fuel demand by 2050.

The ever increasing need of replacing chemical fertiliser by organic manure on one side and replacement of fossil fuel by renewable energy calls for judicious decision making in use of cow dung either for raising food production or as energy for cooking food.

Agarwal and Singh [41] evaluated the option of cow dung as manure and fuel from economical point of view. Surprisingly they found that use of dung as biogas is more efficient than its use as fertiliser.

Energy Production

Abubakar and Ismail [42] studied anaerobic digestion of cow dung for biogas production in batch and semi-continuous bio reactor. They obtained yield of 0.15 L biogas/kg VS (VS is volatile solid) having 47% methane. On the other hand extensive research is done to produce hydrogen rich biogas without any significant amount of methane. Fan et al. used cow dung composts for production of bio hydrogen from beer lees wastes [43] and wheat straw waste [44]. In the batch experiment, in case of beer lees, maximum yield of H_2 of 68.6 mL H_2/g VS and 45% hydrogen content while with wheat straw 68.1 mL H_2/g TV having 52% hydrogen were achieved.

Though biogas production from cow dung is a well proven technology with thousands of plants commissioned globally there are following two common issues which are deterrent for its wider acceptance:

The large hydraulic retention time of 30–50 days,
Low gas production in winter, etc.

Yadvika et al. [45] reviewed different parameters which could contribute to enhancing of biogas production and hence its efficiency. After referring to close to 100 papers Yadvika et al. listed following methods which can be used to enhance biogas production:

i. Use of additives
ii. Recycling of slurry and slurry filtrate
iii. Variation in operational parameters like temperature, hydraulic retention time (HRT) and particle size of the substrate
iv. Use of fixed film/biofilters

Gasification and pyrolysis are processes which involve thermal cracking of carbonaceous materials of organic fuel to produce syngas or producer gas mainly consisting of carbon monoxide, hydrogen and carbon dioxide. In gasification thermal cracking is carried out at temperatures above 700 °C in presence of controlled amount of oxygen and/or steam. Roy et al. [46] conducted gasification of sole cow dung as well as cow dung blended with sawdust. It was observed that use of sole cow dung is technically not feasible as the heating value of the producer gas is low and results in producing large quantity of biochar. However 40–50% blend of cow dung with sawdust resulted in an overall fuel economy. Bircan et al. [47] conducted hydrothermal gasification of cow dung and achieved maximum production of hydrogen gas at following optimised operating conditions: 400 °C; 21 MPa and $Ca(OH)_2$ as an additive.

In the recent past, researchers have reviewed different techniques for improvement of biomethanation processes [48] and even compiled research achievements of biogas production [49, 50]. To respect the length of the paper, the details in the review paper are avoided in this paper while interested readers may refer cited review papers.

Construction

Worldwide there is a search for alternate construction material and exploration of use of waste [51] as a partial replacement for conventional construction material. Globally, building sector shares 40% of world energy consumption and accounts for 30% of global greenhouse gas emissions. Literature reports use of coal fly ash and biomass ash (rice husk ash [49, 50] and baggage fly ash [52]) as construction material.

Rayaprolu and Raju [53] used cow dung ash (CDA) as a supplementary material in mortar and concrete by replacing portland cement upto 30%. They varied the weight percentage of CDA from 5 to 30% and evaluated its effect on compressive strength, setting time, consistency limits, and workability. It was observed that CDA can replace cement maximum upto 10% for applications like flooring and moderate structural stress building component. Ojedokun et al. [54] too recorded similar results and found that CDA offers light weight and thermal insulation to concrete.

Pollution Abatement

Literature reports use of cow dung in pollution control and treatment. Cow dung cake is extensively used for cooking purpose in rural area, producing CDA as combustion remains. CDA is explored as a low cost adsorbent for removal of organics and inorganic pollutants from aqueous bodies. Rattan et al. [55] used CDA for adsorption of textile dyes like N Blue RGB, Green B and EOSIN YWS while Kaur et al. [56] removed organic contaminants from the wastewater. They studied effect of various parameters like adsorbents dose, time, pH and temperature on removal efficacy of contaminant. CDA reduced 66% COD of wastewater using 20 g/L dose in 120 min. Adsorption behaviour of textile dye is a strong function of solution pH. Maximum adsorption of N Blue RGB, Green B and EOSIN YWS was observed at pH 3.74, 7.53 and 4.12 respectively.

Singh, and Fulekar [57] successfully degraded benzene using cow dung. The Pseudomonas putida MHF 7109 was isolated from cow dung microflora and its ability to biodegrade benzene was studied. A weak solution having benzene concentration of 50 ppm was completely degraded in 1 day while solution of 250 ppm took 168 h to degrade 65% benzene.

Miscellaneous

Few researchers explored various applications of cow dung out of shear curiosity. This section discusses such miscellaneous applications of cow dung. Activated carbon of cow dung (ACCD) prepared by chemical activation method using KOH has very high surface area (1500–2000 m^2/g) and has proper of micropore and mesopore volume. Bhattacharya and Yu [58] used ACCD as an electrode in non aqueous electrolyte system. It was found that ACCD based super capacitor exhibited high specific capacitance (124 F/g at 0.1 A/g) and excellent retention at high current density (117 F/g at 1.0 A/g).

Cow dung was used as a resource for production of enzymes and even isolation of bacteria for pathogen control. Vijayaraghavan and Vincent [59] used cow dung as a substrate for solid state fermentation to produce protease. It was found that cow dung supported maximum protease production (1351 U/g) at the following optimum process parameters: the fermentation period (72 h); pH (8.0); initial moisture (140%, v/w) and the inoculum level (15%, v/w). Swain and Ray [60] isolated Bacillus subtilis from cow dung microflora which successfully inhibited growth of pathogenic fungi like Fusarium oxysporum and Botryodiplodia during in vitro and in vivo studies.

Biomass ashes in general are rich source of silica [61] out of which Rice Husk Ash (RHA) has maximum silica (upto 94%) content. Shelke et al. [62] reported process of extraction of silica from RHA. Sivakumar and Amutha [63] extract silica from CDA by alkali digestion and acid precipitation method. CDA was calcined at 650 °C before alkali digestion at 100 °C for 3 h. The digested solution was acid washed to precipitate amorphous silica having 200 nm particle size and very high purity.

Interesting information on the net describing alternative uses of cow dung such as making fibre for creating fashion design apparel or its use to drive car (http://curiosity.com/topics/this isnt-bs-manure-cowture-could-be-the future-of-sustainable fabric-curiosity? utm_source = android app) or converting it into product similar in form to wood logs for heating applications (Narayan Goshala, Jaipur) may appear as fiction or fantacy but the need for conserving environment is driving product development and alternative applications of cow dung. The ashes that remain after burning the cow dung has several ppm level of oxides, in the desirable range for securing health benefits and used traditionally (http://rajivdixitji.com/lab-report-of-gobar-bhasam). Cow dung is used to prepare mosquito coil repellant by blending it with neem leaves and other essential oils [64].

A Case Study

Go Vigyan Anusandhan Kendra (GVAK) (http://www.govigyan.com) shelters around 500 adult cows in a state of Maharashtra in India. GVAK primarily uses cow dung and cow urine to produce arrays of products and has developed cow based integrated bio refinery. Cow excreta is used for manufacturing following categories of products: energy, agro products, cosmetics and ayurvedic medicines as shown in Fig. 7.

Monthly production data can be averaged as follows: Cow urine: 3000 L; cow dung: 189 tonne. The general mass balance tells that 189 tonne of cow dung is allocated to produce energy (38 tonne), agro products (150 tonne) like compost fertiliser and pesticide and rest for production of cosmetic products like soap, face wash and Panchgavya kind of Ayurvedic medicine. GVAK produces 35 different types of medicinal products using cow excreta.

Capacity of the biogas plant in GVAK is 25 m^3. Everyday 500 kg of cow dung is fed with equal amount of water. The retension time of the biodigestor is 40 days with yield of 0.24 m^3 biogas per kg cow dung fed with 74% methane.

Either of the followings in different combinations and proportions are present in various GVAK products: Cow dung; urine; milk, curd and Ghee.

Out of 3000 L of cow urine, 1800 L is used for pharma formulation and 1200 L in making pest repellents. One of the key medicinal product of GVAK is cow urine distillate [34–36] which is extensively used as an antioxidant and anti cancerous applications.

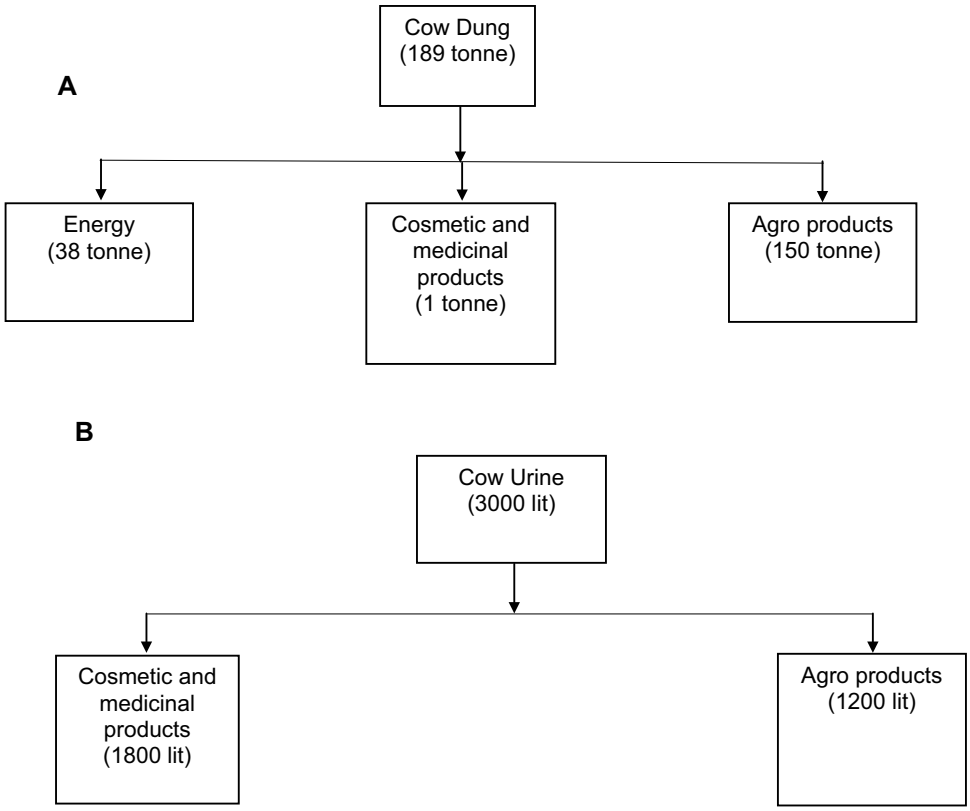

Fig. 7 Cow urine and dung valorisation at GVAK. **a** Material balance of cow dung, **b** material balance of cow urine

Economical analysis reveals that utilisation of cow excreta in energy production and agro product manufacturing achieve 400% value addition while use in cosmetics and pharma products fetch 3000% value addition. Overall annual turnover of GVAK is 16.8 million INR.

Conclusion

As explained in this review, many economically valuable products with medicinal and agricultural applications can be produced from cow urine by employing unit operations and process like solvent extraction, fermentation, and distillation. The cow urine can be utilized in agriculture as pesticide, increasing yield and soil rejuvenator. It also finds its applications in curing diseases, controlling mosquitoes, disinfection and fish food. The major challenge in utilization of cow urine is its collection and testing of quality. Likewise cow dung is used in energy production via fermentation and gasification processes. The cow dung ash has been used in construction as a partial replacement of conventional material and as an adsorbent. Cow Dung and urine based biorefinery is illustrated using a model case of Go Vigyan Anusandhan Kendra (GVAK) (http://www.govigyan.com) situated in India and houses around 500 cows. GVAK manufactures following products using cow dung and urine viz; bioenergy, agro products, cosmetics and ayurvedic medicines. Thus, this review highlights the number of high-value added products that can be produced from cow urine in an eco friendly and cost effective manner.

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