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Review Article

# Mulberry (*Morus* spp.): An ideal plant for sustainable development

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ABSTRACT

Mulberry (*Morus* spp.) of Moraceae family is regarded as a unique plant on this earth due to its broader geological distribution across the continents; ability to be cultivated in different forms; multiple uses of leaf foliage and its positive impact in environmental safety approaches such as ecorestoration of degraded lands, bioremediation of polluted sites, conservation of water, prevention of soil erosion and improvement of air quality by carbon sequestering. Mulberry is also used as a medicinal plant in improving and enhancing the life of human beings by utilizing the biologically active pharmacokinetic compounds found in leaf, stem and root parts. Further industrial exploitation of mulberry through preparation of various products in pharmaceutical, food, cosmetic and health care industries has gained the attention of industrialists. As mulberry is being exploited by sericulture, pharmaceutical, cosmetic, food and beverage industries along with its utilization in environmental safety approach; it is appropriate to call it as a most suitable plant for sustainable development. Through this review paper, all the important characteristics of mulberry were put together for considering it as an ideal plant in providing sustainable future.

## 1. Introduction

Plants play an important role in keeping the mother nature under constant phase by reducing the global warming through uptake of carbon dioxide from atmosphere and in return produce and release oxygen into the environment; which purifies the air and provide life to animals and other organisms. Plants also contribute to soil health; retains water in soil sub-surface and cools overheated urban areas through its evapotranspiration mechanism of water cycle (Katul and Novick, 2009). Ecological recycling of minerals from plants back to the nature enables maintenance of fertility in soil and forests (Barot et al., 2007). Beauty of plants is that; several species of plants can co-exist together in a place or unit of area (Anten, 2005) within same environment and with same resources (air, water, soil nutrients and predatory organisms); leading to formation of a sustainable ecosystem.

Before the spread of humans, the earth is protected and has vast biodiversity with negligible disturbances (Bowman et al., 2011). But, right from 19th century; due to rapid urbanization and increased human population; high amounts of non-degradable solid wastes, 1iquid chemicals and harmful gases were being released in to nature from our domestic homes, vehicles and industries (Zhu et al., 2009). Wastes like plastics, pesticides, chemical fertilizers has found its way into soil and water which resulted in reduction of soil fertility leading to decrease in agricultural productivity and also reduction in number and diversity of soil microbes and decomposers (Hussein and Mona, 2018).

By the above mentioned activities in the name of economic growth, human beings have disturbed the balance of earth and nature leading to natural calamities like rise in global temperatures, floods, loss of biodiversity, soil erosion, poor air quality with decreased oxygen density (Perera, 2017). The consequence of human activities over last two centuries has led to the raise of global issues of the present day such as: *climate change, greenhouse effect, protection and safety of environment, depletion of natural energy resources* and *sustainable environment for future generation* (Owusu and Samuel, 2016). All these issues have raised the concern about the protection of '*Mother Nature'* and strategies needed to overcome these ecological disturbances; in providing a sustainable environment for the future generations.

Mother nature can operate on its own to overcome these disturbance or interventions caused by the mankind, provided the damage caused is minimum or less than the threshold level (Dai et al., 2009). Plants play a major role in keeping the environment in a balanced way and among the plants; tree species has most significant role as they can absorb or utilize more quantity of environmental pollutants from air, water and soil (Ghosh et al., 2017). Along with the role of environmental safety, plants also contribute to economic generation, promotion of human health through the active biological compounds present in leaf, bark, root and stem regions (Chen et al., 2016).

Among the tree species, some are efficiently used for phytomerediation of soil contaminated with pesticides, chemical fertilizers or heavy metals (Hashemi and Tabibian, 2018); some species are efficiently used in removal of hazardous substances from air and water

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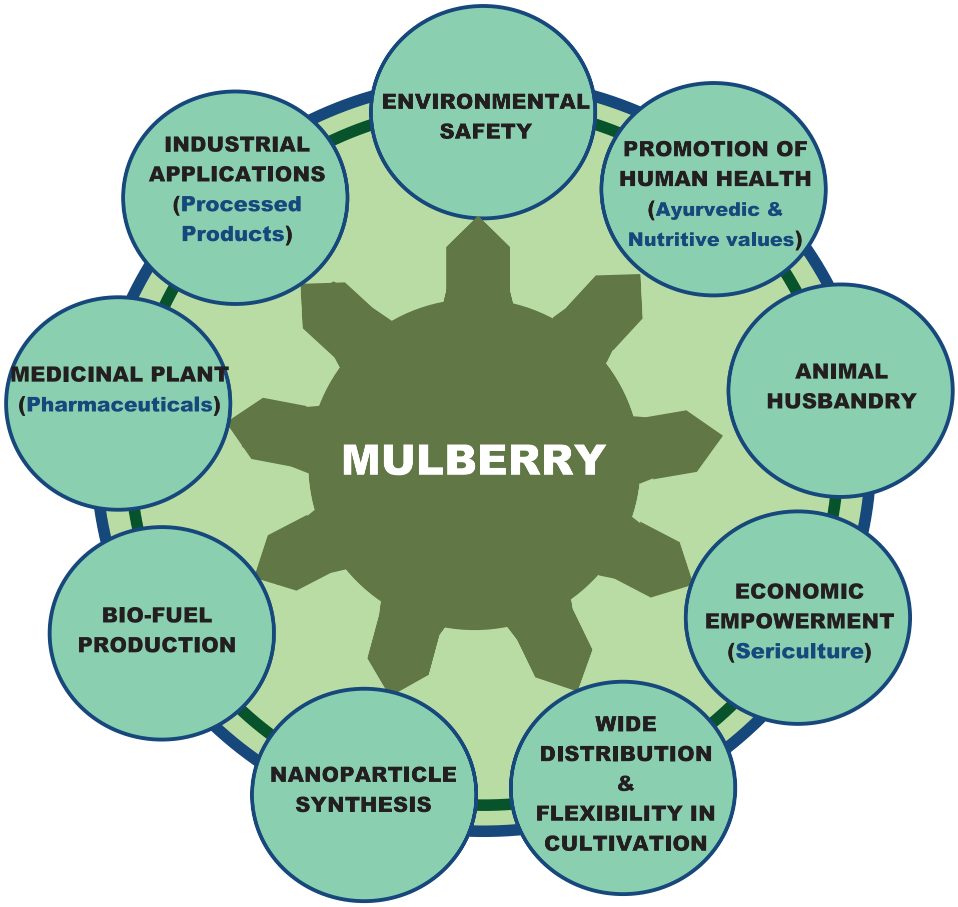


**Fig. 1.** Role of mulberry as a multipurpose plant.

(Raskin and Ensley, 2000); some are used for ecorestoration and soil conservation (Shi et al., 2005); some species are being used in economy generation and other species are exploited for the promotion of human health (Del et al., 2013). From the above mentioned points, it was evident that all the characteristics of environmental safety, economy generation, promotion of human health and industrial exploitation are not present in a single type of plant or tree species, but mulberry (*Morus* spp.), has all these characteristics to be considered it as the most beneficial plant of our plant for the sustainable development, as discussed below.

Mulberry (*Morus* spp.) is a fast growing, deciduous woody tree species of Moraceae family with perennial nature and origin in Himalayan foot hills of India and China (Soo-ho et al., 1990; Vijayan, 2010; Khan et al., 2013; Yuan and Zhao, 2017; Rohela et al., 2020). Mulberry is widely recognized for its economic importance in producing the mori silk through feeding of leaf to silkworm (*Bombyx mori*) larvae (Vijayan et al., 1998, 2004). Mulberry leaf foliage is also used as feeding material for domesticated animals (Datta et al., 2002). From centuries, mulberry was known as a plant used for silk production and feeding domesticated animals, but its ecological significance is neglected. Now in recent years, this plant species is well regarded as a multipurpose plant due to recognition of its role in environmental safety approach, as a medicinal plant and its industrial exploitation across various sectors (Fig. 1). Further mulberry has been regarded as a unique plant on this earth due to its wider distribution across the globe with better adaptability under diversified climates, soil conditions and in altitudes of sea level to 4000 m above mean sea level (Ercisli and Orhan, 2007; Khan et al., 2013; Sarkar et al., 2017). Wide distribution of mulberry across the continents under diversified conditions indicates its better adaptability to varied environmental conditions.

It can be cultivated in different forms of land *i.e.* mountains, plains and valleys under rain fed as well as irrigated conditions (Srivastava et al., 2003) and also in harsh conditions of humid and semi-arid lands; with varied modes (bush, dwarf and tree) of cultivation (Fig. 2). It has highest impact in protection of the environment through ecorestoration of degraded lands, bioremediation of polluted sites, air purification through carbon sequestration and conservation of soil and water through its deeply rooted dense network of rooting system (Huang and Wang, 2012; Qin et al., 2012). Mulberry is also recognized as a medicinal plant in improving and enhancing the life of human beings by their biologically active ingredients present in leaf, stem and root parts (Venkatesh and Chauhan, 2008; Bao et al., 2016). As every part of mulberry is utilized in preparation of various products in pharmaceutical, food, cosmetic and health care industries, now it is exploited industrially (Yang et al., 2010a; Zhang et al., 2018).

Due to all of the above mentioned characteristics, it is appropriate to call mulberry as an ideal plant for sustainable future. This paper reviews the importance of mulberry in environmental safety approach, promotion of human health, animal husbandry, economic empowerment and its industrial exploitation.

## 2. Mulberry in environmental safety approach

In the present era of human dominance, the synthetic or artificial compounds of polymeric, aromatic and highly complex nature in the form of harmful gaseous, liquid and solid compounds has find its way to every environmental segment. The entry of harmful xenobiotic compounds in to the environment is mainly due to over intense population in urban areas which has led to rapid urbanization, industrialization, increased transportation and increased usage of synthetic hazardous compounds in daily life.

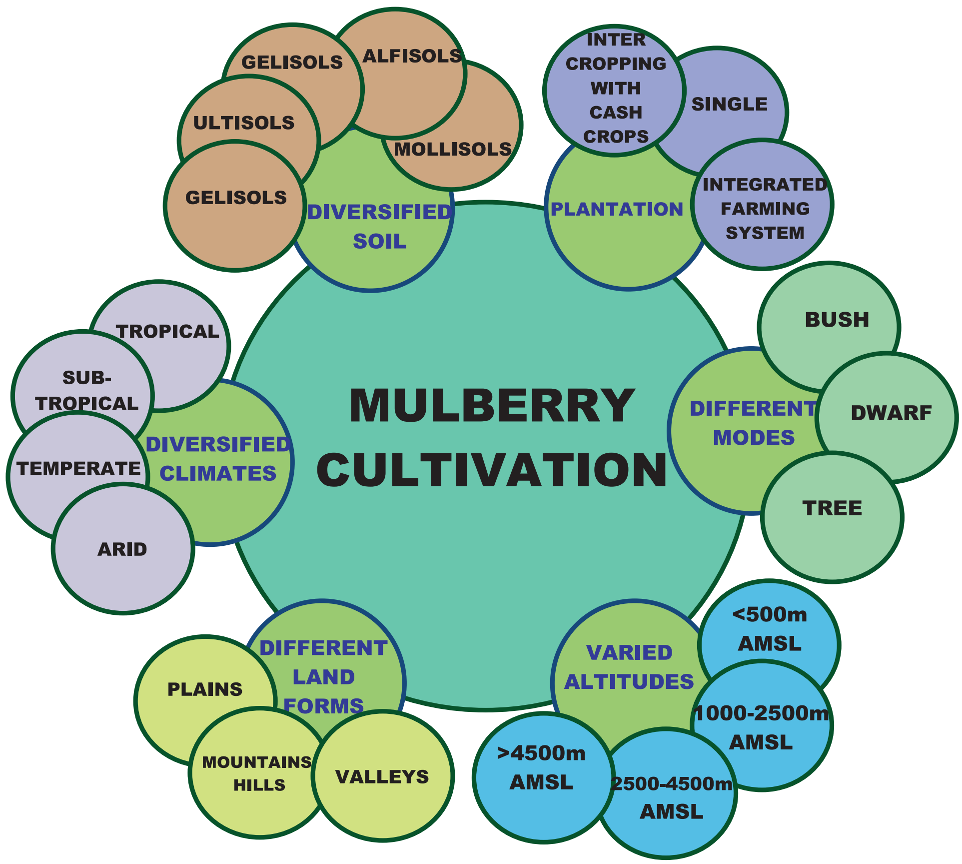


**Fig. 2.** Mulberry cultivation under diversified climates, soil conditions, land forms and at different altitudes.

Mulberry plant with its salient feature of perennial and woody nature with deep and wide spreading nature of root system (Vijayan et al., 2000) and high biomass production is better suitable and adopted to be planted in environments contaminated with diversified soil pollutants including heavy metals like lead, cadmium and copper (Peng et al., 2012; Jothimani et al., 2013; Zhou et al., 2015). Mulberry plants in tree mode of cultivation are better suitable for conservation of water and soil (Du et al., 2001). This plant species is also widely suitable for removal of gaseous carbon pollutants from the atmosphere through its high rate of carbon sequestration process (Lu et al., 2004). Different roles of mulberry in environmental safety approach is classified and described here in separate headings as role of mulberry in *ecorestoration, afforestation, carbon sequestration, soil conservation* and *bioremediation of pollutants* (Fig. 3).

### 2.1. Role of mulberry in ecorestoration

Mulberry plants can grow well in fertile land with deep, sandy or clayey soil with porous nature, but can also grow in barren lands with soil consisting of coarse type and poor in nutrients (Han, 2007). Mulberry with strong and deep root system forms a greatly tangled and dense network with secondary and tertiary roots in any type of soil, which enables it to withstand the dry and unfavorable spells of environment (Huang and Wang, 2012). These characteristics also allowed the mulberry plants to withstand the sand storming and wind currents. This enabled mulberry plants to be cultivated even in barren lands with highly contaminated pollutants or in lands present at greater altitudes or heights which were prone to high wind currents.

Mulberry also grows well in disturbed lands of water logging conditions, under drought stress, and in salinity conditions (He et al., 2007; Vijayan et al., 2003, 2011; Gao and Han, 2013); this is majorly due to its deeper and wider rooting system and its wider adaptability under arid, semi-arid areas with varied conditions of soil pH (Dai et al., 2009; Su, 1998). Mulberry has the ability to grow even under barren lands with lesser nutrients (Han, 2007) and in adverse environmental conditions of −30 °C of chilling temperature to highest temperature of above 40 °C (Zhao, 2009). Desert mulberry is an ecotype of mulberry which was successfully planted in desert areas of Xinjiang parts of china. This ecotype enables the mulberry plants to be cultivated in deserted conditions with minimum levels of irrigation, hence it is recommended for natural restoration of empty deserted lands and desertificated grasslands (Qin et al., 2012). Mulberry plants also utilized and successfully demonstrated for ecorestoration of salinated lands and stony deserted areas (Qin et al., 2012).

### 2.2. Role of mulberry in afforestation

Mulberry is a fast growing and highly heterozygous plant with perennial nature which is better adapted to be grown in diversified conditions of varied altitudes, soil, temperature and pH conditions. Mulberry is regarded as most suitable tree species for landscaping in urban areas, as it is resistant against floods, drought and wind currents. It can be cultivated under irrigated as well as rain fed conditions with a range of 600–2500 mm annual rainfall. It can be easily cultivated in different land forms of plain, hilly, valleys and sloppy areas. In cities, it can be cultivated along the road sides, along the banks of rivers, along the flood plains, in public parks, gardens, edges of field crops, as street trees and in recreation club areas (Qin et al., 2012).

Afforestation with mulberry plantation will enable the restoration of soil carbon, maintenance of water holding capacity of soils, preventing soil erosion during floods and water logging conditions; improvement in soil nutrients, nurturing of soil micro flora, improvement of air quality and can sustain the wind currents and sand storms (Zhang et al., 1997; Lu et al., 2004; Lin et al., 2008). Further mulberry plantation can allow the intercropping with grass, vegetables or other cash crops (Shi et al.,

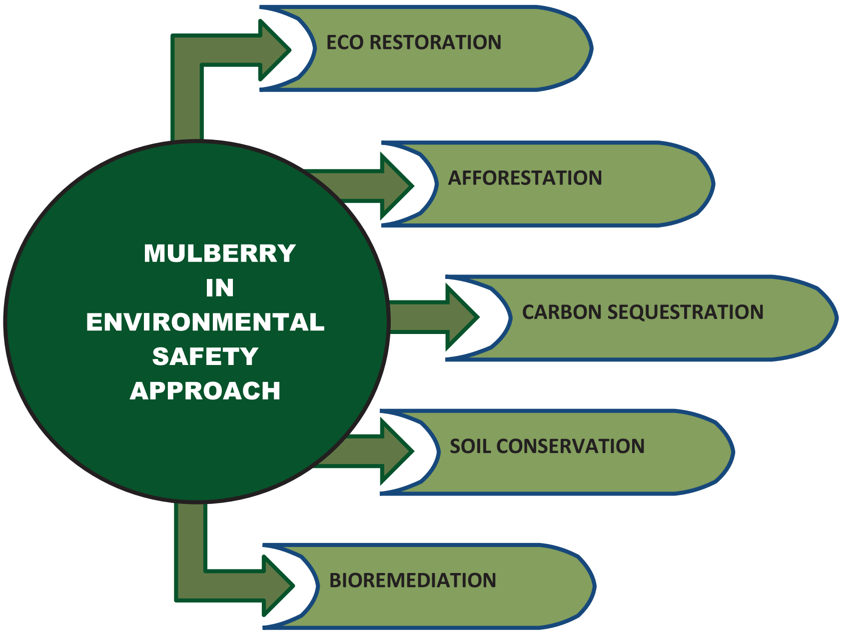


**Fig. 3.** Role of mulberry in environmental safety approach.

2005; Qin et al., 2012). For instance, mulberry plantation demonstrated encouraging results in improving soil conditions (Farrar, 1995), improving air quality (Lu et al., 2004), conserving soil and water (Shi et al., 2005), sustaining the adverse environmental conditions (Hashemi and Tabibian, 2018; Dai et al., 2009) with a major role in economy generation (Datta, 2000). Hence, mulberry is mostly opted as a plant for afforestation drives across the countries and hence, it is regarded as a green afforestation tree species (Wang et al., 2010).

### 2.3. *Role of mulberry in carbon sequestration*

Leaves of mulberry plants has strong absorption ability to absorb the air pollutants like carbon dioxide, carbon monoxide, hydrogen fluoride, sulfur dioxide and chlorine from atmosphere (Lu et al., 2004; Ghosh et al., 2017) and its roots have high ability to uptake the carbon pollutants and heavy metal pollutants from the soil (Olson and Fletcher, 1999). Mulberry can absorb sulfur dioxide of 5.7 g per kg dry leaves and mulberry forestry can absorb huge amounts of sulfur dioxide gas on each day (Lu and Jiang, 2003). Hence mulberry is classified as a sulfur dioxide pollution resistant tree species (Qin et al., 2012). Mulberry roots are larger in diameter near the stem portion and then decreases rapidly in size; a long rope like structure with secondary and tertiary roots along with root hairs forms a fibrous mat like structure which enables them to uptake high concentrations of carbon pollutants from the soil (Bunger and Thomson, 1938; Farrar, 1995). As aerial parts can absorb air pollutants and roots can absorb soil pollutants, the mulberry plants are regarded as good carbon sink and heavy metal resistance plants.

According to Ghosh et al., 2017, one mulberry tree is able to absorb 4162 kg of carbon dioxide and release 3064 kg of oxygen each year. Mulberry plants were considered as natural resistance towards chlorine, as their leaves were noticed as undamaged even at higher levels of chlorine pollution (Lu et al., 2004). These abilities have made mulberry plant to be used efficiently in bioremediation of air pollutants in urban areas and phytoremediation of carbon pollutants in contaminated soil sites around the areas of industries and chemical factories (Olson and Fletcher, 1999). As mulberry has the abilities of controlling environmental pollution by improving air quality and remediation of carbon and heavy metal pollutants, it was reported as a plant for sustainable development (Jian et al., 2012).

### 2.4. *Role of mulberry in water & soil conservation*

Availability of ground water, water holding and water retention capacity of different soils has gained lot of importance during the last two decades for optimum agricultural productivity and maintenance of ecological balance under the soil subsurface. Maintenance of ecological balance under the soil subsurface is vital for the existence of soil microbes, decomposers and other beneficiary organisms which plays an important role in biogeochemical cycles where nutrients and minerals are recycled humus and other sources by which soil fertility is maintained. Similarly prime importance is also given for soil conservation; as soil erosion during raining and floods will lead to unfertile soil with disturbance in its ecosystem.

Mulberry plants in tree mode of cultivation are reported as better suitable plants for conservation of water and soil (Du et al., 2001). In lands/soils maintained with mulberry plantation, the reduction in runoff during flooding can be up to 10–20% (Shi et al., 2005). The annual runoff in mulberry plantation sites of plain lands can be reduced by 38% under 5 years old and by 91% under 10 years old bush plantations respectively in comparison with slope lands (Du et al., 2001).

The water retention capacity of soils planted with mulberry plants is reported to be higher than that of the open land (Han et al., 2007; Ghosh et al., 2017). The deep and wide spreading rooting system of mulberry has enabled the soils to retain and hold the water in increased rates in comparison with other plant species. Deep and densely tangled network of root system of mulberry is reported to improve the shear strength of soils and thereby increase the anti-erosion capacity of lands planted with mulberry. According to the experiments the soil shear strength was increased from 75.2 kPa to 138.4 kPa in mulberry fields (Shi et al., 2005). Mulberry was also reported for the production of root exudates which nurtures and increases the soil micro flora and fauna (Chen et al., 2006).

### 2.5. *Role of mulberry in bioremediation of heavy metals*

Carbon based pollutants like insecticides, fungicides, fumigants, rodenticides and weedicides will get degraded slowly in the soil over the long durations of 10–50 years *i.e.* soil microbes utilize these pollutants as a carbon source and mediate their degradation through the metabolic activities (Shimp et al., 1993), but the rate of remediation is slow and time consuming. On the other hand heavy metal pollutants were treated as highly toxic and undegradable in nature (Xu et al., 2015). Because, neither soil microbes utilize heavy metals as their metabolites nor do the plants utilize them as nutrients and minerals. If heavy metals make their entry through the water system or by other means into the human body it will lead to malfunctioning of organs with severe effects on human health system (Nazarian et al., 2016) Thus it is highly essential to prevent the heavy metal pollution in soil and water and also there is an urgent need to remediate these highly harmful and toxic pollutants.

Among the different strategies adopted for remediation of heavy metals, phytoremediation (*i.e.* remediation of pollutants by plants) is considered as the most effective method as it is eco-friendly, cost effective and exploiting possibilities in a broad level (Cunningham et al., 1995; Raskin and Ensley, 2000). Plants have the better ability to uptake the water soluble heavy metal pollutants from the soil and then accumulate it in specialized structures like vacuoles (Fletcher et al., 1990). Plant selection and analysis of contaminated soil sites plays a major role in phytoremediation process (Hegde and Fletcher, 1996; Lombi et al., 2001) of heavy metals, as climatic conditions should favor the growth of a plant species being used and level of heavy metal contamination should also be pre-determined for effective remediation process (Houben et al., 2013; Hashemi and Tabibian, 2018).

Among the various plant species, tree species are better suited for phytoremediation of heavy metals from the contaminated soil sites; due to its wide spreading nature of root system (Mattina et al., 2003; Pulford and Watson, 2003). Among the different tree species, mulberry with wider, deeper and better rooting system has greater potential to remediate heavy metals from the contaminated soils (Jothimani et al., 2013; Zhou et al., 2015). Heavy metals like chromium, lead, copper, nickel, cadmium, zinc, manganese and mercury are being remediated by using different species of mulberry (Chen et al., 1999; Tewari et al., 2008; Ashfaq et al., 2009, 2012; Rafati et al., 2011; Shoukat et al., 2014; Xu et al., 2015).

Hashemi and Tabibian (2018), studied about the accumulation of mercury heavy metal in leaf, stem and root parts of *Morus nigra.* Mercury nitrate in different concentrations (30, 50 and 70 mg/L) were initially added to the soil, 2 year old saplings of *Morus nigra* were planted in treated soil and grown for eight months duration. After eight months the plant parts were separated and dried in an oven at 70 °C and made it to fine powder, followed by determination of mercury levels in samples of every plant part by atomic absorption spectroscopy method. Highest and lowest concentrations (mg/kg) of 55.67 and 22.2 in leaf, 58.00 and 28.6 in stem and 65.00 and 35.3 in root parts were recorded at 70 mg/L and 30 mg/L densities respectively (Hashemi and Tabibian, 2018). The results clearly indicate that the absorption of mercury metal was recorded higher in root parts, compared to leaf and stem portions.

The report of Hashemi and Tabibian (2018) suggests that, even though mercury may not be utilized as a nutrient but it gets easily absorbed by the roots of mulberry (*Morus nigra*). Hence mulberry can be recommended for the phytoremediation of mercury contaminated soils. Overall mulberry was successfully reported for phytoremediation of soils contaminated with heavy metals like lead, mercury, cadmium, chromium, nickel, manganese, zinc, copper and cobalt (Jiang et al., 2017).

## 3. Mulberry in human health

### 3.1. Role of mulberry in ayurvedic system of medicine

Plants are the natural sources of biologically active compounds (Ji et al., 2009), which have received increased attention of medicinal practitioners and pharmaceutical industries across the globe over the years. Plant derived natural products were being used in preventing and curing the common diseases of human beings (Cao et al., 2018). Among the different plants, mulberry has been known worldwide for their biologically active biomolecules like phenols, alkaloids, terpenoids, amino sugars, stilbenoids etc. (Iqbal et al., 2012; Kiran et al., 2019). In India, mulberry is known as 'Kalpa Vruksha' as all the parts of it used in traditional system of ayurvedic medicine (Datta, 2000). It is highly recognized as a source of important phytopharmaceuticals, mineral ions (Zhang et al., 2017) and other nutritive compounds (Fig. 4). Hence extracts of this plant parts were being used traditionally in Indian ayurvedic system of medicine in curing several health ailments and for improving the human health (Ghosh et al., 2017).

*Morus nigra*, a wild species of mulberry is being used traditionally by ayurvedic practitioners to cure rheumatis and arthritis (Perez et al., 2011). In Japan and Korea, mulberry leaves were consumed as an anti-diabetic medicine by diabetic patients as the leaves possess anti-diabetic molecules like 1-deoxynojirmycin, isobavachalcone, morachalcon, fagomine, quercetin etc. (Wang et al., 2013; Kiran et al., 2019). In China, mulberry leaves have been in use since hundreds of years ago to treat various diseases like hypertension, hyperglycemia, inflammation, fever, cough and cancer (Bown, 1995). Similarly, in China the young shoot tips and young leaf tips were boiled along with tea to control the blood pressure (Datta, 2000; Qin et al., 2012).

High anthocyanin content and antioxidant activities associated with phytochemicals present in the berries (mulberry fruits) have made them very popular and hence included in the human diet (Eyduran et al., 2015). Berries provide potential health benefits to human beings such as delay in aging process, protection from cardiovascular diseases, antidiabetic activity and reduced risk of cancer (Mnaa et al., 2015). Mulberry fruits were reported to possess high antioxidising nature (Guo et al., 2003), can prevent liver and kidney damage (Chen et al., 2016), improve eyesight (Yang et al., 2010a), strengthening the joints (Shizhen, 2008), treatment of sore throat, reduce blood pressure (Zhou et al., 2017), treatment of anemia, hypertension (Ma, 2002; Gong and Zhu, 2008), anti-helminthic (Gungor and Sengul 2008), anti-thrombotic (Yamamoto et al., 2006); anti-inflammatory (Kim and Park, 2006); can prevent formation of premature white hair formation (Liu et al., 2008) in human beings.

Dietary fiber of mulberry fruits was reported to decrease lipids in liver and increases the activity of low density lipoprotein (LDL) receptor (Venkatesan et al., 2003), hence consumption of mulberry fruits can be prescribed for lipid lowering action of hypercholesterolemia patients (Sirikanchanarod et al., 2016) and for reducing the risk of atherosclerosis (Chen et al., 2005). In addition consumption of mulberry fruits is proved beneficial in curing the brain damages like Alzheimer (Shih et al., 2010; Choi et al., 2012), Parkinson (Kim et al., 2010; Strathearn et al., 2014) and cerebral ischemia (Kang et al., 2006) and this fruit is also consumed for anti-aging effects (Shizhen, 2008; Zheng et al., 2014), anti-epileptic and anti-stress activities on human beings (Nade et al., 2010).

Mulberry fruit is rich in polyphenols like flavones, flavonols, isoflavanols, stilbenes, lignans, tannins, anthocyanins, catechins (Liu, 2004). Intake of berry fruits rich in polyphenols is associated with the reduced risk of cardiovascular diseases, cancers and neurodegeneration (Han et al., 2007; Del et al., 2013). Mulberry fruit extracts was also reported to prevent gastric cancer (Huang et al., 2011). Combination of leaf and fruit extracts of mulberry was reported for anti-diabetic and anti-obesity activity (Lim et al., 2013). Mulberry fruit extracts prevent the olfactory dysfunction and degeneration of dopaminergic neurons (Gu et al., 2017). Polysaccharide components of mulberry fruit were reported to possess the better preventive effects of inflammation and apoptosis than the polysaccharides of straw berry (Liu and Lin, 2014).

The mulberry fruit and syrup are also used to treat urine inconsistency, constipation, dizziness, throat infection, tinnitus, dyspepsia, melancholia, fever, depression and endemic malaria (Jain and De Filipps, 1991; Shivakumar et al., 1995). It is used for balancing internal secretions of humans and for enhancing immunity against infections (Venkatesh and Chauhan, 2008). Fruit syrups and recipes were used against insomnia, constipation, premonitory, antiaging and apoplexy (Singh, 1997). Decoctions made from mulberry fruits are well known in treating severe and critical diseases like kidney asthenia, cerebral

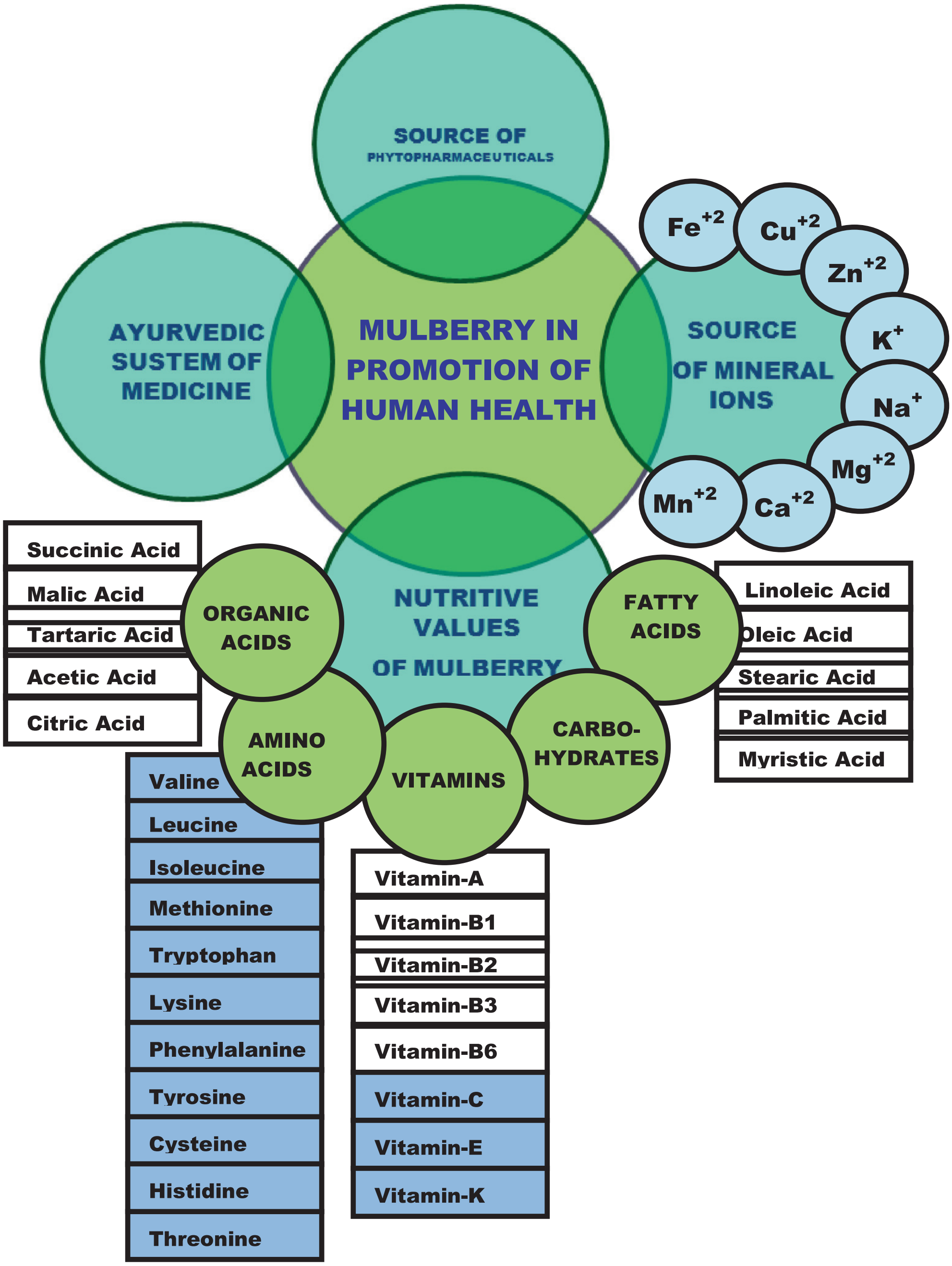


**Fig. 4.** Role of mulberry in promotion of human health.

arteriosclerosis, central retinitis, chronic nephritis and nasopharyngeal cancer (Singhal et al., 2010).

In humans, a decreased level of melatonin over the age is associated with physiological changes and in turn making a person susceptible to various diseases (Cardinali et al., 2008). Mulberry fruits and fruit wine with high levels of melatonin are recommended to boost the human health (Wang et al., 2016). Pyrrole alkaloids of mulberry fruits were reported to possess macrophage activating activity (Kim et al., 2013, 2014). Kang et al., 2006 has reported about the free radical scavenging and inflammation suppression activity of anthocyanin's present in the mulberry fruit.

### 3.2. Nutritive values of mulberry

Leaf and fruits of mulberry were being consumed from ancient days by the human beings for its nutritive values such as proteins, carbohydrates, lipids, vitamins, minerals, amino acids and organic acids (Fig. 4). Mulberry leaves were used as a source of antioxidant molecules like phenols, flavonoids, flavonols and terpenoids (Iqbal et al., 2012). Leaves possess essential polyunsaturated fatty acids linoleic acid & linolenic acid and essential amino acids (branched side chain possessing amino acids, aromatic amino acids) needed by the human beings for normal metabolic activities and growth. Mulberry leaves were also reported to possess important minerals such as iron, sodium and calcium which are required for the normal growth of humans (Datta, 2000; Sarkar et al., 2018).

Fresh fruits of mulberry possess higher content of proteins (1.44 g/100 g) (Yuan and Zhao, 2017) than strawberries (Giampieri et al., 2012), blue berries (Kaume et al., 2012) and raspberries (Rao et al., 2010). Human beings has to depend on plant and animal origin of food for the essential amino acids and essential fatty acids required by them and mostly plant based food products fulfill this requirement, but for this human beings as to consume several plant products derived from different plant species located/available at different places. Mulberry is a unique plant, where all the required essential nutrients were available in its leaf and fruits. Hence mulberry was now recognized as a nutritional as well as a medicinal plant from which fresh or processed products were consumed on an increased rate by the human beings for the normal metabolism, growth and promotion of health (Xiao et al., 2017a, 2017b).

It was recently reported that mulberry fruit contains almost all the essential amino acids (valine, tyrosine, phenylalanine, tryptophan, methionine, isoleucine, leucine, lysine, cysteine, histidine and threonine) required by the human beings (Jiang and Nie, 2015). As all the nine essential amino acids were found in fruits of mulberry, it can be consumed as a high protein food at par with other protein foods such as milk and fish (Jiang and Nie, 2015). Kusano et al. (2002) has isolated and determined the structures of six new amino acids *viz.* morusimic acid A, morusimic acid B, morusimic acid C, morusimic acid D, morusimic acid E and morusimic acid F by using spectroscopic methods.

Mulberry fruit was also reported to possess important minerals of iron, copper, zinc, potassium, sodium, magnesium, calcium and manganese (Jiang and Nie, 2015). Jiang and Nie (2015) also reported about the presence of organic acids (malic acid, succinic acid, tartaric acid, acetic acid and citric acid) and fattyacids (myristic acid, palmitic acid, stearic acid and linoleic acid) in fruits of mulberry. Chinese mulberry fruits were reported to possess 7.55% of total lipids with 87.5% of unsaturated fatty acids with highest content of linoleic acid (79.4%) followed by palmitic acid (8.6%) and oleic acid (7.5%) (Yang et al., 2010a). Fruits of Turkish mulberry also reported to possess highest content of linoleic acid (57.3%) and palmitic acid (22.4%) among the total lipids (Ercisli and Orhan, 2007). The polyunsaturated fatty acids (PUFA) content is more than monounsaturated (MUFA) and saturated fatty acids (SA) in the mulberry fruit (Yuan and Zhao, 2017). PUFA content is more in fruits of mulberry (76%) than strawberry (72%) and *Ziziphus jujuba* (68–72%) (Giampieri et al., 2012; San and Yildirim, 2010). It was evident that Linoleic acid, an essential polyunsaturated fatty acid is found as predominant fatty acid in mulberry fruits and plays an important role in development, promotion of health and disease prevention in humans (Whelan, 2008; Le et al., 2013; Farvid et al., 2014).

Mulberry fruit possess Vitamin-A ($\beta$-carotene), Vitamin-B1 (thiamine), Vitamin-B2 (riboflavin), Vitamin-B3 (niacin), Vitamin-B6, Folate, Vitamin-C (ascorbic acid) Vitamin-E ($\alpha$-tocopherol) and Vitamin-K (phylloquinone) (Yuan and Zhao, 2017). Freeze dried mulberry fruit powder contains dietary fiber, Vitamin-C and Vitamin-E (Yang et al., 2010a). Among the different colored fruits of mulberry, red mulberry was reported to possess higher content of ascorbic acid and $\beta$-carotene than the purple and purple red mulberry (Aramwit et al., 2010). Mulberry fruits also rich in anthocyanin pigments (Jiang et al., 2013), which can scavenge the free radicals and can inhibit the oxidation of low density lipoprotein (Huang et al., 2013; Lee et al., 2017).

Naturally occurring sugars and amino sugars of plant origin were used as therapeutic agents for the management of several diseases and metabolic disorders (Hu et al., 2019). Mulberry fruit also possess various types of polysaccharides which play a significant role in physiological activities of human beings (Zhao et al., 2015; Xie et al., 2016). Polysaccharides characterized from mulberry fruits were reported to possess bioactivities such as antioxidant activity (Chen et al., 2015, 2016), hypo glycemic activity (Chen et al., 2015, Chen 2016a, Chen 2016b), immunomodulation, anti-obesity (Lee et al., 2013; Choi et al., 2016a, 2016b), anti-inflammatory and anti-apoptotic activity (Tian, 2014; Liu and Lin, 2014).

### 3.3. As a source of phytopharmaceuticals

There are several reports about the presence of pharmaceutically important phytochemicals in the leaf, root and fruit parts of mulberry (Kim et al., 1999; Phiny et al., 2003; Hansawasdi, 2006; Li et al., 2009; Kojima et al., 2010; Naowaratwattana et al., 2010; Yang et al., 2010a; Madhumitha et al., 2012; Flaczyk et al., 2013). Nazaruk and Kluczyk (2015) opined that extracts of mulberry are possessing promising biochemical compounds required for the development of multi target bioactive drugs. Mulberry leaf and fruits were being exploited for their pharmaceutical compounds like $\gamma$-aminobutyric acid, arylbenzofuran, carotenoids, coumarins, cyanidin-3-O-beta-D glucopyranoside, 1-deoxynojirimycin, ethyl acetate, flavonoids, moran, moranolin, polyphenols, pyrrole alkaloids, polyhydroxy alkaloids and vitamins (Sheng-qin and Wu, 2003; Kang et al., 2005; Singab et al., 2005; Fallon et al., 2008).

The pharmacological activity of the already isolated compounds from leaf and fruit extracts of mulberry (Table 1) has revealed their role in improving the human health through their anti-allergic action (Chai et al., 2005), anti-aging effects, anti-atherogenic, antibacterial, anti-cancer activity (Zhang et al., 2009a,b), anti-hypertensive (Kojima et al., 2010), anti-inflammatory action (Chatterjee et al., 1983), anti-obesity action (Oh et al., 2010), anti-oxidant activity (Hong et al., 2004; Katsube et al., 2006), anti-schistosomal activity, antiviral activity; cardiovascular protectant, free radical scavenging activity, hepatoprotective activity, hypoglycaemic activity (Andallu et al., 2001; Andallu and Varadacharyulu, 2002), inflammation suppression (Kang et al., 2006), lipid-lowering action (Li et al., 2005; Liu et al., 2009), macrophage activating activity (Kim et al., 2013), neuroprotective action (Naowaboot et al., 2009), reducing blood pressure, vasoactive action (Sakagami et al., 2006) and controls skin infections (Fang et al., 2005). Pharmacological activities of already identified phytochemicals of mulberry are summarized in Table 1.

## 4. Mulberry in animal husbandry

Integrated farming system has potential to double the income of farming community in modern agriculture era. This system was also promoted by Government agencies. There are many integrated farming models. Most of the models having raising of livestock along with crop production. However, increase in global population and industrialization; limit the area for producing green fodder to feed the cattle. Therefore, certain tree species become the alternative to fodder crops to feed the domestic animals as they don't need much care like regular irrigation and heavy dose of fertilizer. They can be planted in any waste land, hilly areas, at river/ canal bund and as border plantation. Out of many tree species, mulberry species displayed good source of nutrition as forage to cattle especially for ruminant animals (Sanchez, 2002).

Mulberry plants are present in varied agro-climatic zone from tropical to temperate conditions and it can be grown as shrub as well as tree. They mostly grown for silkworm rearing as they are the only source of food to silkworm. In addition to its usage in silkworm rearing, its leftover leaf and braches were given to domestic animals in India, China and Korea (Sujathamma et al., 2013) (Fig. 5). In general, mulberry leaves are rich in protein, carbohydrates, and minerals with high digestibility. The biochemical compositions of young mulberry leaf are 20–23% of crude protein, 8–10% of total sugar and 12–18% of minerals (Sanchez, 2001; Venkatesh et al., 2015). This may varies with the season and age of mulberry leaf. Besides its nutritional quality, its presence in most countries makes it popular as green fodder for dairy cattle.

Cereal straws and grasses are commonly used as animal feed in the developing countries. But, these animal feed do not provide balanced nutritional supplements. Sometimes these feeds are supplemented with green grasses for balanced nutrition. However, limitation of land resources restriction the cultivation of green grasses. Therefore, tree leaves especially mulberry leaves provide sufficient supplement along with others cereal straws (Majumdar et al., 1967a). The high digestibility and high palatability of mulberry leaves make it suitable for animal feed especially for dairy cattle and monogastric animals (Venkatesh et al., 2015) (Fig. 5). Supplementation of mulberry leaves with ammoniated rice straw improved the lamb growth rate (Liu et al., 2000). Similarly,

**Table 1**
Pharmacological activities of biochemical compounds isolated from different parts of mulberry.

| # | Pharmacological Activity | Biochemical Compound | Plant Part | Species | Reference |
|---|---|---|---|---|---|
| 1 | Anti-Diabetic | 2-Arylbenzofuran | Root bark | *Morus alba* | Singab et al., 2005 |
| | | Volatile Glycoside | Leaves | *Morus alba* | Hunyadi et al., 2014 |
| | | Inorganic anions | Leaves | *Morus alba* | Bazylak et al., 2014 |
| | | 1-Deoxynojirmycin | Leaves, Stem bark, Root bark | *Morus alba* | Kiran et al., 2019 |
| | | Flavonoids | Fruit | *Morus* spp. | Xiao et al., 2017 |
| | | Anthocyanins | Fruits | *Morus alba.* | Choi et al., 2016 |
| | | Hydrophobic flavonoids | Leaves | *Morus* spp. | Fallon et al., 2008 |
| | | Quercetin | Fruits | *Morus alba.* | Wang et al., 2013 |
| | | Isobavachalcone, Morachalcone | Fruits | *Morus alba.* | Wang et al., 2013 |
| | | Fagomine | Leaves | *Morus alba* | Kiran et al., 2019 |
| 2 | Anti-Atherogenic | Quercetin-3-(6-malonylglucoside) | Leaves | *Morus alba* | Enkhmaa et al., 2005 |
| | | Anthocyanins | Fruits | *Morus* spp. | Chen et al., 2005 |
| 3 | Anti-Hyperlipidemia | 1-Deoxynojirmycin | Leaves, Stem bark, Root bark | *Morus alba* | Chen and Li, 2007 |
| | | Moracin-C | Leaves, Fruits | *Morus indica* | Andallu and Varadacharyulu 2002 |
| | | Moracin-M | Root Bark | *Morus alba* | Singab et al., 2005 |
| | | Moracin-C | Fruits | *Morus alba* | Pel et al., 2017 |
| | | Flavonoids | Leaves | *Morus* spp. | Li et al., 2005 |
| | | Chlorogenic acid | Leaves | *Morusindica* | Ana et al., 2017 |
| 4 | Anti-Oxidant | 1-Deoxynojirmycin | Leaves | *Morus alba* | Katsube et al., 2006 |
| | | Carotenoids and Vitamins A, C & E | Leaves | *Morus indica* | Andallu et al., 2009 |
| | | Ascorbic Acid | Leaves | *Morus alba* | Butt et al., 2008 |
| | | Kaempferol-3,7-glucopyranoside | Leaves | *Morus nigra* | Eva et al., 2015 |
| | | Coumaric Acid | Leaves | *Morus nigra* | Ionica et al., 2017 |
| | | Cyanidin-3-O-rutinoside | Fruits | *Morus nigra* | Senem et al., 2013 |
| | | Anthocyanins | Fruits | *Morus rubra* | Ozgen et al., 2009 |
| | | *p*-hydroxybenzoic acids | Leaves & Fruits | *Morus laevigata* | Memon et al., 2010 |
| | | Anthocyanins | Fruits | *Morus atropurpurea* | Shih et al., 2010 |
| | | 2-Arylbenzofuran | Leaves | *Morus alba* | Yang et al., 2010b |
| | | Ascorbic Acid | Fruits | *Morus nigra* | Eyduran et al., 2015 |
| | | Caffeic Acid | Leaves | *Morus nigra* | Gundogdu et al., 2017 |
| | | Chlorogenic acid & Rutin | Fruits | *Morus alba* | Natic et al., 2015 |
| | | 4-O-Caffeoylquinic acid | Leaves | *Morus* spp. | Ganzon et al., 2017 |
| | | Non-anthocyanin phenolics | Leaves & Fruits | *Morus alba* | Zhang et al., 2009 |
| | | Pelargonidin 3-*O*-glucoside | Fruit Juice | *Morus* spp. | Chen et al., 2015 |
| 5 | Anti-Fungal | Albanin | Shoots | *Morus* spp. | Shirata et al., 1983 |
| | | Kuwanon G | Root Bark | *Morus alba* | Nomura and Fukai, 1980 |
| | | Morusin | Shoots | *Morus* spp. | Takasugi et al., 1979 |
| | | Albafuran A & B | Shoots | *Morus* spp. | Takasugi et al., 1982a |
| | | Albafuran C | Shoots | *Morus* spp. | Takasugi et al., 1982b |
| 6 | Anti-Cancer | 3,8-diprenyl-4,5,7-trihydroxyflavone | Leaves | *Morus alba* | Dat et al., 2010 |
| | | Lectin | Leaves | *Morus* spp. | Deepa et al., 2011 |
| | | Odisolane | Fruits | *Morus alba* | Lee et al., 2016 |
| | | Anthocyanins | Fruits | *Morus* spp. | Chen et al., 2016 |
| | | 5-2′-dihydroxiflavanone-7, 4′-di-OD-glucose | Root bark | *Morus alba* | Zhang et al., 2009 |
| | | Cyanidin 3-rutinoside | Fruits | *Morus* spp. | Chen et al., 2006 |
| | | Prenylated Flavonoid (7, 2′, 4′,6′-tetrahydoroxy-6-geranylflavanone) | Root | *Morus alba* | Kofujita et al., 2004 |
| 7 | Neuroprotective | Cyanidin-3-Glucoside | Fruits | *Morus* spp. | Kang et al., 2006; Du et al., 2008 |
| | | Cyanidin-3-O-beta-D glucopyranoside | Leaves | *Morus alba* | Kang et al., 2005 |
| | | $\gamma$-amino butyric acid | Leaves | *Morus alba* | Kang et al., 2005 |
| | | Prenylated arylbenzofuran | Fruits | *Morus alba* | Seo et al., 2015 |
| | | Quercetin | Leaves | *Morus* spp. | Ansari et al., 2009 |
| | | Oxyresveratrol | Fruits | *Morus* spp. | Chao et al., 2008 |
| | | Oxyresveratrol | Wood | *Morus alba* | Weber et al., 2012 |
| | | Anthocyanin's | Fruits | *Morus alba* | Kim et al., 2010 |
| | | Artoindonesianin O (AIO) | Leaves | *Morus spp.* | Qiao et al., 2015 |
| | | Proanthocyanidins | Fruits | *Morus alba* | Strathearn et al., 2014 |
| | | Mulberroside-A | Root | *Morus alba* | Wang et al., 2014 |

(*continued on next page*)

**Table 1** (*continued*)

| # | Pharmacological Activity | Biochemical Compound | Plant Part | Species | Reference |
|---|---|---|---|---|---|
| 8 | Anti-Bacterial | Kuwanon G | Root Bark | *Morus alba* | Park et al., 2003 |
| | | Mulberrofuran G | Root Bark | *Morus mongolica* | Sohn et al., 2004 |
| | | Albanol B | Root Bark | *Morus alba* | Sohn et al., 2004 |
| 9 | Anti-Inflammatory | Melatonin (N-acetyl-5-methoxytryptamine) | Fruit | *Morus* spp. | Wang et al., 2016 |
| | | 1-Deoxynojirmycin | Leaves | *Morus alba* | Park et al., 2013 |
| | | Mulberroside-A | Root | *Morus alba* | Wang et al., 2014 |
| | | Oxyresveratrol | Shoot | *Morus alba* | Chen et al., 2013 |
| 10 | Vasoactive Action | Ethyl Acetate extract | Leaves | *Morus alba* | Xia et al., 2008 |
| | | Morin | Leaves | *Morus* spp. | Fang et al., 2005 |
| 11 | Macrophage Activating Activity | Pyrrole Alkaloids | Fruits | *Morus alba* | Kim et al., 2013 |
| 12 | Anti-Hypertensive | 1-Deoxynojirmycin | Leaves | *Morus* spp. | Kojima et al., 2010 |
| | | Moracenin A | Root Bark | *Morus* spp. | Oshima et al., 1983a |
| | | Moracenin B | Root Bark | *Morus* spp. | Oshima et al., 1983b |
| | | Moracenin C | Root Bark | *Morus* spp. | Oshima et al., 1980 |
| | | Moracenin D | Root Bark | *Morus* spp. | Oshima et al., 1981 |
| | | Mulberrofurans F& G | Root Bark | *Morus lhou* Koidz | Fukai et al., 1985 |
| 13 | Anti-Aging | Polyphenols | Leaves | *Morus* spp. | Zheng et al., 2014 |
| 14 | Anti-Fatigue | $\gamma$-aminobutyric acid | Leaves | *Morus alba* | Chen et al., 2016c |
| 15 | Anti-Viral | Leachianone G | Root Bark | *Morus alba* | Du et al., 2003 |
| 16 | Anxiolytic | moralbosteroid | - | *Morus alba* | Gupta et al., 2013 |
| 17 | Promotesincreased synthesis of estrogen and progesterone | Kaempferol-3-O-glucoside | Fruits | *Morus alba* | Wei et al., 2016 |

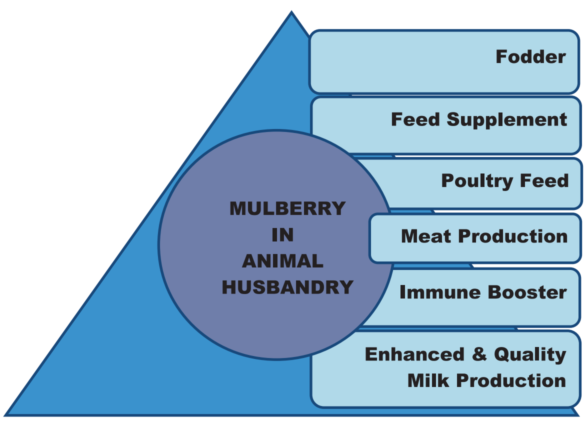


**Fig. 5.** Role of mulberry in animal husbandry.

there is an improvement in sheep body weight of up to 3.44%, when mulberry leaves was supplemented with feed (Jayal and Kehar, 1962). In many countries like France, Italy and Latin America, many reports indicated the use of mulberry leave as animal feed (Vezzani, 1938; Maymone et al., 1959; Armand and Meuret, 1995).

In addition to high digestibility and palatability of mulberry leaf, milk production from dairy animal was increased when mulberry leaf was provided as feed supplement (Fig. 5). Venkatesh et al. (2015) observed that after 60 days of feeding of mulberry leaves the milk protein content was enhanced up to 36.75% in both cow and goat whereas the carbohydrate content in the milk of cow and goat was 56.46% and 59.26% respectively. Further the lipid content in cow milk was enhanced by 4.5% and in goat milk 4.9% were recorded after 60 days of mulberry leaves feeding (Venkatesh et al., 2015). Similarly, Datta et al. (2002) found that the mulberry feeding resulted in increase in milk yield and fat content of cow milk.

The economic benefits including reduction in commercial feeding cost was also observed, when mulberry leaf to a certain extent was substituted in place of commercial concentrate to the growing pig and rabbit (Trigueros and Villalta, 1997; Sanchez, 2002). The reduction of concentrate was 17.5 g per day from 110 g per day in case of rabbit. Deshmukh et al. (1993) reported that mulberry leaves can provide sufficient nutrition to the growing rabbit. Supplementation of mulberry leaf to the hen resulted in increase in egg size and improvement in its yolk color (Narayana and Setty, 1977). Similar observations like better yolk color, increase in beta-carotene and vitamin K was reported by many researchers, when mulberry leaves was provided to the poultry birds as feed (Tateno et al., 1999a, b and Sudo et al., 2000).

Improvement in growth and reproductive performance was reported when diet having mulberry leaf and *Trichantera gigantea* leaves as protein source in combination with other energy sources like rice bran, molasses, and cassava root meal was provided compared to the diet of commercial concentrates and grasses (Le et al., 1996). In conclusion, the study clearly shows that mulberry improved the feed quality, growth performance, milk yield and better economic return.

## 5. Mulberry in economic empowerment

Mulberry plantation generates direct or indirect employment to the farmers. Apart from sericultural practices mulberry is also utilized in other sectors for providing employment and in revenue generation (Fig. 6). Other sectors such as animal husbandry, food industries, cosmetic industries, dyeing industries and pharmaceutical industries are utilizing the leaf, stem and root parts of mulberry for production of processed commercial products.

### *5.1. Livelihood security for small and marginal farmers through sericulture*

The farmers on increasing note are taking up agricultural enterprises like dairy, poultry, pigeon, fishery, sericulture, apiculture etc., which are suited to agro-climatic and socioeconomic conditions of specific areas. Sericulture is an allied sector of agriculture where economy is being generated among the women and poor people of rural areas. Mulberry leaves are primarily used in sericulture for feeding the larvae of silkworm (*Bombyx mori* L.) and there by producing mori silk. Sericultural practices proved as a subsidiary occupation ideally suited to poor, marginal and small farmers across the countries of Asian continent (Datta, 2000). Other countries which are socio-economically and agro-climatically suitable for sericulture have already planted the mulberry plants and started sericulture with the main aim of providing employment to rural people. As mulberry is easy to cultivate through stem cuttings; now this plant species is widely cultivated across the continents.

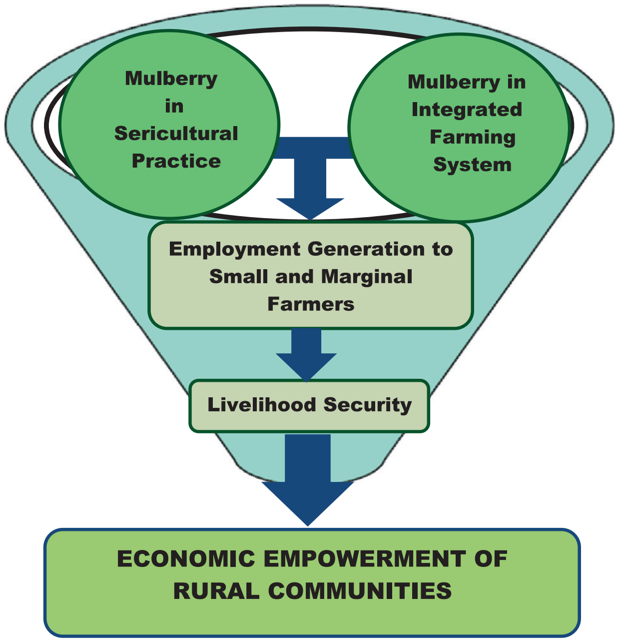


**Fig. 6.** Role of mulberry in economic empowerment of people.

### 5.2. As a component of integrated farming system

The integrated system links mulberry cultivation to sericulture, animal husbandry, poultry and fish farming to increase food production for human consumption and there by gaining commercial benefits (Astudillo et al., 2014). Integrated farming system with mulberry cultivation can be done, where grass can be cultivated as an intercrop for generating feed and fodder for domesticated animals and there by producing meat and milk (Doran et al., 2007) . Other routine agricultural cash crops, vegetable crops and medicinal plants can also be taken as intercropping with mulberry for generating additional revenue. Dried leaves of mulberry can be utilized for mushroom production during autumn seasons (Hugar et al., 2016). Dried leaf powder of mulberry leaf is also utilized as a protein supplement in poultry feedings. Mulberry is also utilized as a bioenergy crop in India (Guha and Reddy, 2013).

The integrated farming system with mulberry; provides meat, milk, eggs, mushroom, fodder, vegetables etc. Thus, this integrated system holds great promise and potential for increasing the production of food materials, enhancing the rural economy, improving household nutrition and overall helps in employment generation across the rural sectors (Reddy et al., 2008). In India, integrated farming system has a special significance, as it can play an important role in improving the socioeconomic status of economically weaker sections of society and rural communities, especially the tribal communities who depends mostly on natural resources for their livelihood.

Sericulture linked integrated fish farming systems utilizes the organic waste of rearing in the form of silkworm feces as fish feed. The organic waste of 40–50 kg is converted into one kg of fish (Zhong, 1982). Silkworm pupae are also used as fish feed. Integration of mulberry cultivation, silkworm rearing with fish farming system results into a terrestial aquatic ecosystem, where economy is generated at higher rate with complete utilization of waste output of silkworm rearing (Baishya et al., 2004). Hence, in integrated sericulture with fish farming system a complete recycling of waste can be achieved (Astudillo et al., 2015).

### 5.3. By-product utilization in sericulture

Mulberry leaf was recently recognized for its potential pharmaceutical compounds for anti-diabetic (1-deoxynojirmycin, isobavachalcone, morachalcone), anti-cancer (3,8-diprenyl-4,5,7-trihydroxyflavone, cyanidin 3-rutinoside), neuroprotective (cyanidin-3-O-beta-D glucopyranoside), anxiolytic (moralbosteroid), anti-hypertensive mulberrofurans F & G), anti-inflammatory (n-acetyl-5-methoxytryptamine) etc. (Kang et al., 2005; Gupta et al., 2013; Wang et al., 2016; Chen et al., 2016; Kiran et al., 2019). Thus additional revenue can be generated by diverting the left over leaf of mulberry for pharmaceutical industries, after silkworm rearing practices.

On the basis of research findings, following by-product utilization from silkworm is emphasized: (a) Silk worm pupa can be utilized as protein diet for humans, (b) Silkworm pupa cake left after extraction of oil for commercial purpose to be used as fish meal (Baishya et al., 2004), (c) Utilization of oil extracted from pupae by pharmaceutical industries, (d) Silkworm litters to be used as compost in agricultural fields (Baishya et al., 2004), (e) Usage of sericin in cosmetic industries (Astudillo et al., 2014).

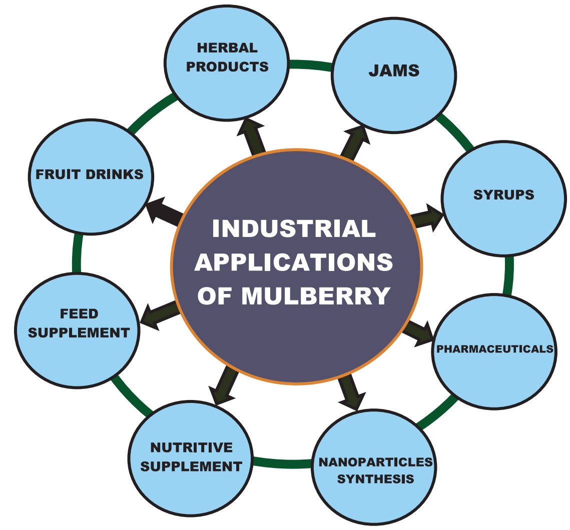


**Fig. 7.** Industrial applications and processed products of mulberry.

## 6. Industrial applications of mulberry

Mulberry leaf and fruit possess health promoting essential phytonutrient compounds like minerals, amino acids, fatty acids, sugars, phenolics, flavonoids, vitamins etc. (Wang et al., 2013). However, mulberry leaf and fruits are available only in a particular season of every country based on country's geographical location and also fresh leaf and fruits cannot be stored for long durations with intact and same biochemical content. As the fresh leaves and fruits of mulberry cannot be stored for long durations, alternatively man has processed the mulberry leaf and fruits at industry level to get yearlong health benefits of processed mulberry products (Fig. 7). Mulberry based products are already been produced by pharmaceutical, food, beverage, herbal and cosmetic industries across the world (Doi et al., 2001). Majorly European countries are more advanced in exploitation of mulberry, especially its fruits in food and beverage industries. Industrial utilization of leaf and fruits has enabled additional income generation to mulberry farmers and also availability of processed mulberry products to the people throughout the year.

### 6.1. Processed products of mulberry leaf

Mulberry leaf powder with varied biochemical content and antioxidant molecules is being used to prevent heat stroke (Ganzon et al., 2017). Beverage or decoction made up of mulberry leaf powder is used as a remedy for sore throat (Pieroni et al., 2004; Chau and Wu, 2006).

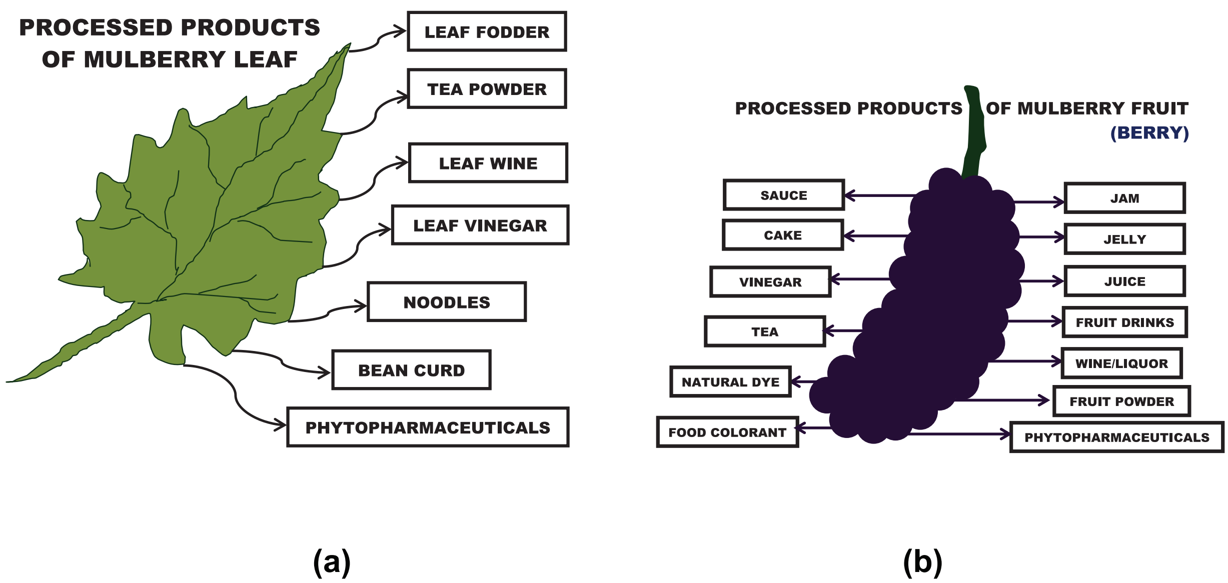


**Fig. 8.** (a). Processed products of mulberry leaf.
(b): Processed products of mulberry fruits.

Leaf powder is also used for the treatment of hypertension, cancers, hyperlipidaemia, arteriosclerosis, liver and kidney damage and as a neuroprotective agent (Sugiyama et al., 2016; Rynko et al., 2016; Chen et al., 2016). Mulberry leaf with high content of protein and carbohydrates were processed into leaf fodder for feeding domesticated animals. Other processed products of mulberry leaf *viz.* tea powder, leaf wine, leaf vinegar, noodles and bean curd has attracted the attention of nutritionists across the world ((Fig. 8a).

Mulberry tea made from young shoots and leaves contains proteins composed of 15 types of essential amino acids which are required for optimum metabolism of human body (Qin et al., 2012). Mulberry tea is rich in $\gamma$-aminobutyric acid, a compound known to reduce the blood pressure (Suttie, 2005). Mulberry tea is considered as a health drink which is suitable to all age groups and it is consumed from ancient days to overcome the problems of liver, in improving eye sight and for other health benefits of humans (Wang et al., 2011). Most of the biological activities of mulberry leaf is confined to the presence of phenolics (rutin, quercetin, isoquercetin, scopolin etc.), flavonoids (astragalin, cyclomulberrin, cyclomurusin, kaempferol etc.), chlorophylls, fatty acids, vitamins, carbohydrates, chalcones and phenolic acids (Jia et al., 1999; Doi et al., 2001; Yang et al., 2012), all of which can easily get absorbed by human body and provide good health to humans (Qin et al., 2012).

Apart from these mulberry leaf based processed products, in last two decades several commercial pharmaceutical compounds were identified in mulberry leaf along with their pharmacological activities. These commercial bioactive compounds were extracted, purified and formulated into mulberry based natural pharmaceutical drugs. Among the mulberry leaf based pharmaceutical compounds, most important are 1-deoxynojirimycin, 2-arylbenzofuran, quercetin-3-(6-malonylglucoside), kaempferol-3,7-glucopyranoside, cyanidin-3-O-beta-D glucopyranoside, $\gamma$-amino butyric acid and fagomine (Enkhmaa et al., 2005; Eva et al., 2015). Among these compounds, 1-deoxynojirimycin and fagomine are mostly recognized biomolecules with good commercial value due to their antidiabetic activity by inhibiting $\alpha$-glycosidase enzyme (Kimura et al., 2007; Hu et al., 2013; Hao et al., 2018).

Mulberry leaf was also utilized for the synthesis of nanoparticles like nano silver, nano copper, aluminum silica nanoparticles (Rohela et al., 2019a). These nanoparticles were effectively used for combating the grasserie disease of silkworm (*Bombyx mori.* L) (Govindaraju et al., 2011). The biogenic nano silver was reported as an antiBmNPV agent against nuclear polyhedrosis virus (NPV), a causative agent of grasserie disease in silkworms worms (Tamilselvan et al., 2012). Bactericidal and viricidal effects of silver nanoparticles against bacterial and viral pathogens of silkworm and mulberry was also reported (Wenchu et al., 2013). Nanosilica can be used to combat mulberry leaf webber's (*Diaphania pulverulentalis* & *Glyphodes pyloalis*) and nanocopper can be used to combact muscardine disease of silkworm, whose causative agent is a fungal pathogen (Rohela et al., 2019a).

At industrial level, now researchers should focus on utilizing the leaf explant based callus and cells suspension cultures to produce above mentioned commercial pharmaceuticals at large scale through bioreactors. This will enable the industrialists to produce phytopharmaceuticals and other secondary metabolites in continuous state throughout the year and more importantly without sacrificing the mulberry plants. There are reports about the production of mulberry based secondary metabolites like quercetin, rutin, morusin, mulberroside A, cyclomorusin etc. through suspension cultures of leaf derived callus (Lee et al., 2011; Inyai et al., 2015). As discussed above, high demanding and most important commercial biomolecules of 1-deoxynojirimycin and fagomine should be produced at industrial level in large scale from leaf callus derived suspension cultures for economy generation and also for health benefits.

### 6.2. Processed products of mulberry fruit

Mulberry fruits are syncarpous in nature, similar to other berries it is an aggregate of several small sized fruits called drupes. After pollination the ovary base of each female flower in catkin inflorescence gets swollen, converts to fruit and gets altered in biochemical content, color and texture during the ripening process. Fruits of mulberry are similar to raspberries and blackberries but they have a stalk which distinguishes them from other type of berries. Fully ripened berries of different genotypes have fleshy skin which is white, pink, deep red, black, violet black or purplish black in color. Among the different species, *Morus nigra* is famously known for its best flavoured black coloured berries which are highly juicy, softer in nature, sweeter in taste and found as most suitable mulberry fruit in wine preparations across the world (Singhal et al., 2010).

In majority of the mulberry growing countries of Asia, Europe, America and Australia mulberry fruit is consumed in fresh forms or in processed forms (jam, jelly, wine and juice) through industrial applications for making it more delicious with pleasing color and odor (Yuan and

Zhao, 2017). These processed products are consumed at large scale in all developed as well as developing countries, as they are best regarded as low calorie foods with high nutrient content composed of essential biochemical compounds (essential amino acids, essential fatty acids and vitamins) which are required for proper metabolism of foods and for human growth. Based on its importance in growth and metabolism, now human beings are highly exploiting these mulberry fruits at industrial level for making commercial products (Fig. 8b) like juice, jam, pies, jelly, pulp, fruit drink, wine, tea, sauce, cake, liquor, vinegars, fruit powder, natural dyes, food colorant, cosmetics etc. (Singhal et al., 2010).

Among the above listed processed products of mulberry fruits; jam and wine are having huge demand in the market of western and other developed countries (Yuan and Zhao, 2017). Jam is a daily based essential food stuff required for having early breakfasts across all the countries. Jam made out of mulberry fruits is highly attractive due to its deep red color, characteristic mulberry flavor, sweeter taste and due to consistency in jam thickness. Moreover, in the last two decades, awareness about the mulberry jam as a natural product and its health benefits over other jams has increased among the people. Taste and color of mulberry fruit based jam is majorly based on species and cultivar type, degree of fruit ripening, total amount of pigments, sugar content, ascorbic acid, pH of prepared jam and storage temperature (Hermann, 1972; Wrolstad, 1976; Francis, 1989; Withy et al., 1993; Sundfor, 2001). Whereas quality of jam depends on its recipe, procedure of preparation, type of jar used, packaging type and storage conditions with regard to light and temperature (Ochoa et al., 1999; Garcia et al., 1998; Qin et al., 2010).

Wine prepared by the fermentation of mulberry fruits is considered as a popular alcoholic drink in Asian countries and consumed famously all over the world due to its active biological ingredients (Tchabo et al., 2017). It is purple black in color and possesses abundant phenolic compounds which serve as antioxidants and aging of wine adds pleasant odor to it (Hornedo Ortega et al., 2017). The bioactive contents of mulberry wine *i.e.* anthocyanins, phenolics, tannins and flavonoids proved to impart potential health benefits to the consumers (Xiao et al., 2017a, 2017b).

Across the countries mulberry fruit products were majorly consumed for potential health benefits and for curing several health disorders. Processed mulberry fruit products like juice, jelly and jam is used as a good appetizer and as a carminative. They are also used for the treatment of loss of appetite, for controlling intestinal parasites like tapeworm (Singhal et al., 2010). Even though herbal medicinal plant products and processed fruit products were reported as harmless and safe by several researchers (Eddy, 2005; Jordan et al., 2010). However safety of mulberry based leaf and fruit products as to be assessed for their side effects and safety. Mulberry fruit based products are examined for health risks in humans and results haven't shown any carcinogenic effects on humans (Mehmood et al., 2016). Hence, compared to chemicals based processed drinks and other industrial products, mulberry fruit based products are considered to be much safer and free of health risks (Mehmood et al., 2016).

## 7. Conclusion and future prospectives

From hundreds of years, mulberry plant was mainly recognised across the world as a food plant for silkworms (*Bombyx mori.*L). But as discussed above, this plant is now considered as a multipurpose plant by utilizing in environmental safety approach, promotion of human health and in promoting animal husbandry through quality milk production and enhanced meat production. As mulberry has huge role in environmental cleanup through bioremediation of polluted sites (land, air and water) and carbon sequestration; this plant species should be recommended by the respective authorities for plantation drive across the cities/urban areas (as it can be cultivated across the globe) along the road sides and in social forestry for increasing the green cover and reduction of pollution. At present, ecological safety and sustainable development has become one of the important components of world's safety and hence mulberry plants should be potentially exploited to address the ecological issues.

Similarly, more emphasis should be given by the researchers and industrialists to exploit the mulberry at large scale for the health benefits of humans, economic generation and for environmental protection. By considering all the facts of mulberry *i.e.* role in sericulture industry, role in health promotion of humans, role in soil conservation, role in ecorestoration of degraded lands, role in bioremediation of polluted sites, role in carbon sequestration, role in animal husbandry, role in nanoparticle synthesis, role in industrial utilization and economic empowerment of people; it can be considered as a most suitable and beneficial plant for sustainable future.

## Declaration of Competing Interest

The authors declare that there are no conflicts of interest in this research study.

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