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New Directions in Plant Material Research

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Abstract

The recent discovery of various biological activities of natural resources has focused much attention on their efficacy, and in consequence, the application of medicinal plants has expanded globally. To illustrate, medicinal plants are used for research on new drug development in primary health care. Nevertheless, natural resource protection policies such as the Nagoya Protocol have promoted global competition, wherein a challenge is posed by the high cost of natural resources. To overcome this challenge, it is essential that attempts are made to discover novel plants among agricultural by-products and tropical plants, which are currently used as simple ornamental plants. Furthermore, it is anticipated that going beyond the use of plants in humans and studying their use in livestock and pets would extend the scope of application for plants.

Keywords: Medicinal plant, agricultural by-product, tropical plant, livestock, pet

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1. INTRODUCTION

Plants have wide versatility that underlies their use in furniture, houses, clothes, food, and medicine. Plant materials have mainly been used in traditional medicine or folk remedies, but owing to the advancement of science and technology that facilitated the isolation and extraction of effective bioactive substances in plants, conventional medicines have also been developed. As a result, studies on plant materials gradual decrease in the commercialization of medicine despite continuously increased, implying a need to explore plant materials and develop new methods of using them. As an effort to meet this challenge, suggestions will be made for previously unused plant materials and their potential. Furthermore, their applications in humans as well as in livestock or pets will be discussed.

2. Medicinal plants

Medicinal plants or herbal medicines were used as therapeutics at the time when medicines were not developed as actively as they are today. Even at present, many countries use native plants as medicines, with developing countries tending to rely more on medicinal plants. According to the World Health Organization (WHO), around 80% of people in Africa resort to plants for their primary health care [1]. Moreover, some medicinal plants were used to develop the medicines used today. The most well-known example is "Taxol" originating from pacific yew (*Taxus brevifolia*), whose powerful anti-cancer effect discovered in the mid-20th century has led to its use to this day [2]. "Aspirin" is used as a painkiller, and it comprises salicin from white willow (*Salix alba*) [3]. Cocaine is extracted from the coca plant (*Erythroxylum coca*) and is used as an anesthetic or a narcotic [4]. This diverse efficacy comes from plant secondary metabolites (PSMs). Although they are not essential during metabolism, the production of PSMs increases in the presence of an environmental stress involving water, temperature, and malnutrition, or a stress caused by a virus or an insect, whereby they play a key role in imparting stress tolerance to the plant and enhancing its viability [5]. PSMs can be obtained from various plants including herbs, spices, trees, and flowers. Thousands of different kinds of PSMs exist, and are broadly classified into alkaloids, terpenoids, essential oils, and polyphenols based on their structures [6]. When an animal ingests these PSMs, different bioactivities result from each specific type of ingested PSM. Mostly, they exhibit antioxidant and anti-inflammatory effects, and alkaloids are often used as painkillers; essential oils are frequently used as spices and as agents that increase nutrient absorption based on their high volatility [7]. Flavonoids are the most abundant among polyphenols, and play a crucial regulatory role in flower petal coloration while exhibiting immunity-enhancing and anti-inflammatory effects in animals [8]. As another type of polyphenols, tannins in plants regulate their growth and act as natural insecticides while helping with digestion in animals [9]. Mucilages contained in succulent plants such as tropical cacti may help protect the intestinal tract (Table 2) [10].

Table 2. Bioactivity of plant secondary metabolites

PSMs	Classification	Effects
Alkaloids	Morphine, Cocaine	Pain killer
Terpenoids	Monoterpenes, Diterpenes	Anti-cancer, anti-inflammatory, antioxidant effect
Essential oils	-	Antioxidant effect, improve nutrient absorption and appetite
Polyphenols	Flavonoids	Stimulate immune system, anti-inflammation, remove the toxins from the body
	Tannins	Reduce digestive enzyme degradation, antioxidant, and anti-inflammatory effect
Mucilages	-	Protect intestinal barrier, prevent bacterial pathogens accumulation

Source: [10]

With the discovery of the diverse efficacy of medicinal plants based on PSMs, their potential values in application have steadily risen. The development of phytomedicines using medicinal plants comprises a high proportion of drug development, and the overall global market concerning medicinal plants has reached an annual size of 43 billion USD and the size of the market in the USA alone is 5 billion USD [1]. Nonetheless, while the diversity of PSMs promises myriads of possibilities for commercializing purified products of medicinal plants such as phytomedicines, it may also be a constraint. The efficacy of medicinal plants depends on PSMs, making their content vitally important; and quality control of medicinal plants becomes crucial because environmental changes influence the production of PSMs [11]. The supply of medicinal plant materials may be hindered owing to factors such as plant growth rate and spatial environment, and attempts have been made to chemically synthesize PSMs. However, PSMs like Taxol, whose molecular structure is complex, can only be extracted from plants, which led to the investigation of *in vitro* methods of culturing plant cells [11, 12].

2.1. New way to develop phytogenics

At present, approx. 450,000 plant species exist on earth [13], among which 20,000 are edible plants, but only 20 of them comprise 90% of the global food. In Africa, over 5,400 plant species are being used for therapeutic purposes [14], and in China, around 100,000 species are medicinal plants as the country is known to harbor the largest variety of medicinal plants. All of them put together, however, comprise only 6% of the total species of plants; i.e. 28,187 plants are currently being used or were once used for therapeutic purposes [15]. The WHO estimates around 70,000 species at maximum [1]. In sum, approximately 96% are plants that humans do not eat and approximately 94% are those that have not been previously used as medicines. Previous studies on the use of plant materials mostly focused on verifying the efficacy of the known edible plants or medicinal plants. Thus, to develop ways to use novel plant materials, research should explore plant species that are yet to be investigated.

To discover novel plant materials, two methods of investigation may be useful. One is to study the unused parts of the plant that have already been in use, and the other is to study an entirely new plant species. Although most prior studies on plant functionality mainly dealt with the plant parts in use for food or drug development, studies today have extended their scope to more diverse plant parts that have not been in use, but from which an equivalent or enhanced efficacy has been identified. An example would be the discovery of anticancer and immunoregulatory effects from cob and husk that humans rarely ate, while corn was being commonly used as food for humans or feed for livestock [16, 17]. The number of studies on new plants that have never been investigated in the past has also increased. Most medicinal plants today are produced in China; however, since the Nagoya Protocol (Nagoya Protocol on Access and Benefit Sharing; ABS) took effect in 2014, a proportion of the profit should be paid to the country of origin when products made of plant materials from overseas are to be merchandised in countries such as the USA. This encouraged studies on native plants in most countries; the developing countries in tropical regions where two-thirds of the world's plant species are found, are developing ways to use various native plants to lay the ground for economic growth [18]. In South America, the number of plant-based studies soared, whereby related articles increased from 14 times to 100 times over the past 25 years in each country [19].

The discovery of new materials entails the development of novel methods of application, and at present, studies are focusing on the bioactivity of functional plants and plant-originating substances for use in humans. Nevertheless, clinical trials on humans carry considerable risks even in large corporations inthe USA and the EU, and it is difficult for developing countries in tropical regions to even attempt clinical trials as they require much time and funds. In Africa, in fact, although approximately 5,400 species of medicinal plants are found—about half the amount in China—less than 10% have been commercially adapted. One solution to this may be the use of functional plant materials in animals.

3. Agricultural waste to byproducts

Early humans procured food from the wild through hunting, and farming is presumed to have begun around 10,000 years ago [20]. Through farming, the sedentary lifestyle began, and the human population increased as the supply of food stabilized. The agricultural products also provided most necessities of daily life such as fuel, clothing, and shelter, while increased population led to increased agricultural land as well as improved yield based on the use of various techniques ranging from fertilizers, genetics, and soil analysis [21]. As an inevitable consequence, "*agricultural waste*" also increased. Agricultural waste is the waste generated by agricultural activities including livestock and crop production; breeding livestock can generate agricultural waste such as manure, straw litter, carcasses, antibiotics [22], parts of crop that have not been used, [23] and food waste [24]. At one time, agricultural waste was recycled as fertilizer or feed in a virtuous cycle with agricultural production; however, since the development of nitrogen fertilizers allowed an unparalleled yield in modern agricultural production [25], agricultural waste increased [26]. The problem is the environmental pollution caused by agricultural waste. The disposal of agricultural waste via landfill or incineration causes soil and ground water contamination [27], and agricultural waste produces around six billion tons of greenhouse gases each year causing air pollution [28]. Such environmental pollution caused by agricultural waste reduces the agricultural yield and inflicts harm to the health of farmers and the general public, posing a grave threat to the earth and mankind [28, 29]. Thus, a global need has arisen for new methods of agricultural waste treatment and application [30].

A novel method of application for agricultural waste that has attracted much attention is "*bioenergy*." Through fermentation, organic waste arising mainly from agricultural and fishery products is turned into ethanol and diesel that can be used as biofuel. Bioenergy was once a groundbreaking solution to save the cost at farms for treating agricultural waste while creating new jobs and reducing environmental pollution at the same time. However, numerous side effects were reported soon after. The UN reported that the cultivation of minor crops such as sugarcane and corn increased rapidly because plants with high sugar content ensured high efficiency of bioenergy production, and in turn, land, herbicides, fertilizers, and energy consumption for agriculture increased. Also, studies reported that biodiesel produced larger amounts of greenhouse gases than fossil fuels, which raised the question of sustainability of bioenergy [31].

As such, the restricted application of agricultural waste resulted in financial burden at farms for waste treatment. In the future, new possibilities should be created for using agricultural by-products to resolve the problem of continuously increasing agricultural waste. For this, a method converting agricultural waste into by-products has received much attention. As economic strength and life expectancy increased, an increasing number of people consume food that has health benefits,unlike in the past, when agricultural products were consumed simply for nutrition and taste. Nonetheless, due to the limited variety of plant species that can be cultivated or consumed by humans, studies have also focused on discovering novel efficacy from the by-products. While the beneficial effects of fruit peels and seeds are widely known and studied (Table 3), their mass-production faces a challenge as they are mostly distributed as part of a whole fruit, except in canned products. Thus, the fruit stems, roots, and leaves that are currently being discarded in large amounts as waste at farms, may be more suitable candidates for large-scale industrialization.

Table 3. Physiological activity of food waste

Plants	Parts	Effects
Purple passion fruit	Peels	Reduce wheeze and cough, improvement in breathing of asthmatic patients [32]
Pomegranate fruit	Peels	Antimicrobial activity [33]
Bitter Gourd	Peel, pulp, seed	Inhibit skin papillomagenesis[34]
Grape	seed	Antioxidant effect, and cholesterol uptake inhibition [35, 36]

4. Ornamental plants: Tropical plants

Ornamental plants are plants that people tend not for food or by-products but for decorative or aesthetic purposes. They refer to all plants grown in outdoor gardens and indoors. The most common ornamental plants are flowers such as tulips, roses, and orchids, but they also include turfs and trees. Traditionally, the selection of ornamental plants has prioritized the appearance desired by the consumer depending on the purpose of ornamentation. Such biased preference on appearance with regard to ornamental plants has now expanded with the discovery of diverse inherent functions of the plants. Phytoremediation is the most representative new interest in ornamental plants, which involves the use of plants in purifying the environment. Air purification plants are capable of purifying the air by removing toxic substances such as benzene from the atmosphere, and succulent plants *Crassulaportulacea*, *Apicradeltoideae*, and *Kalanchoe marmorata*, are known for their outstanding air purification capacity [37, 38]. Some ornamental plants are also known to tolerate lower indoor temperature[38], or have psychological effects such as reducing unpleasant feelings [39, 40]. Tropical plants have attracted much interest recently as global trade became activated and potential use of ornamental plants has widened. As a result, new attempts have been made to launch a market for ornamental plants from Africa. Based on the report (*Plasmerijer J* and *Yanai C*, February 2012, Market News Service: Floriculture Products) of the International Trade Center (ITC), despite 50 years of effort to cultivate native plants for commercialization, they currently occupy a mere 0.5% of the global flower market. Likewise, although tropical regions possess two-thirds of the world's plant species, their commercialization and market values have not been competitive.

As a way to meet this challenge, countries in tropical regions should be encouraged to develop the functionality of their native plants, which is highly promising. The values of native plants have increased since the Nagoya Protocol took effect, indicating the vast potential of the large variety of plants comprising two-thirds of the world's plant species.

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5. Plant material utilization in the animal industry

Like plants, animals are also intimately related to humans in various fields such as their advancement and food. Around 11,000 years ago, ten centuries after the beginning of agriculture and settlement of mankind, livestock breeding began [41]. On the other hand, humans began to live with companion animals (pets) around 12,000 years ago, preceding agriculture [42]. The rising population and advancing science and technology have steadily increased the livestock production, and the economic value of the livestock industry is approx. 1.4 trillion USD [43]. Global Livestock Production and Health Atlas (GLiPHA) dataset analyzed the present status of livestock population, and reported the largest proportion from poultry, among which the number of broiler chickens has exponentially increased since 2005 to record the largest number around six billion in 2012. Then followed cattle and dairy cattle together, in the order of pigs, sheep, and goats (Fig. 5.1).

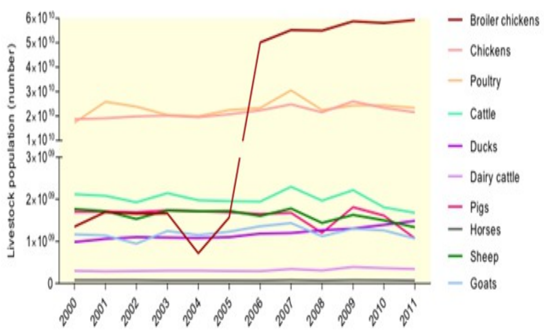

Fig. 5.1. Global livestock population by species.
Source: Data are obtained from GLiPHA dataset of FAO.

In addition, a comparison among different countries showed that the highest population of livestock breeding came from China for all major livestock animals including chickens, cows, and pigs (Table 5.1).

Table 5.1. *Livestock populations by countries and species*

	USA (2007)	China (2009)	Brazil (2007)
(×10^5)	19,404	50,192	10,250
(×10^5)	963	1,059	2,052
(x10^5)	672	4,399	380
(×10^5)	58	1,423	169
(×10^5)	31	1,434	92

For overall livestock breeding, the feed cost occupies around 70%, the largest proportion and over half the total cost, indicating that increasing the feed intake efficiency is crucial for improving economic feasibility [44]. Nonetheless, the cost of crop feed used in almost all livestock breeding is continuously increasing to aggravate the livestock production [44]. Thus, the animal feed additives market is growing so that livestock production and efficiency of livestock feed intake may improve (Fig. 5.2).

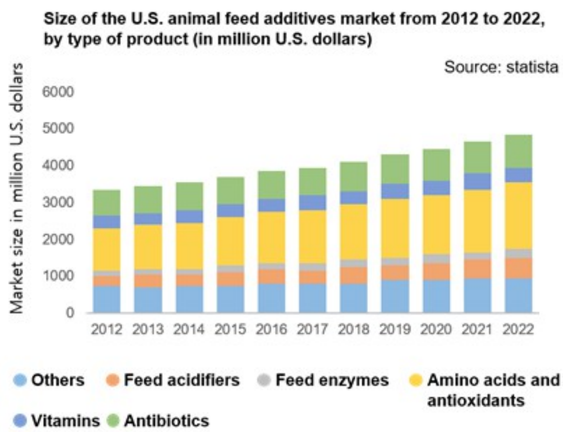

Fig. 5.2. Global animal feed additives market revenue, by product, US$ Mn, 2015, 2021 and 2026
Source: statista

With the growth of the livestock market, the companion animal industry market is also rapidly growing, as they are the two markets bisecting the animal industry market. As the relationship between pets and humans has become more intimate, the new term "*companion animal*" is replacing the term "*pet*" first used in Austria in 1983. However, most mammalian companion animals including canines (dogs) and felines (cats) have shorter lifespans than humans so they die before their owners. The death of a companion animal causes the owner to feel profound loss and pain regardless of the cause of death [45]. This underlies the tendency of the owners to provide higher quality feed and medical care for the health of their companion animals. According to the 2018 report {Pet Food Market - Analysis of Growth, Trends, and Forecast (2018 - 2023)} of Mordor Intelligence, the current companion animal food market size is estimated at 78.76 billion USD. Moreover, the 2018 report of "Grand View Research" estimates the companion animal care market size at 202.6 billion USD. The 2017 data of Euromonitor International and GlobalPETS reported that the largest companion animal industry market was in North America, with a size of 48.8 billion USD. Also, when the companion animal industry growth rate in each country between 2012 and 2017 was compared, the highest growth rate was 16.3% in India, followed by 14.7% in China, and 12.2% in Thailand and Vietnam, implying a substantial rate of increase in Asian countries. Comparison by continent also showed the highest rate of increase in the Asia pacific regions (Table 5.2).

Table 5.2 Companion animal market size and growth rate in 2016

	Latin America	North America	Western Europe	Eastern Europe	Middle East and Africa	Asia Pacific	Australasia
Market size (billion USD)	10.9	48.8	28.6	5.7	0.9	11.7	3.2
Growth rate % (2016 vs 2015)	3.4	1.8	0.8	5.4	4.5	6.9	0.6

5.1. Livestock: Antibiotics & functional feed additives

Antibiotics (anti-bacterials) are a type of weaponry microorganisms utilize to attain superiority in nature over others and prevail in interspecies competition. The early concept was as a substance produced by microorganisms themselves to inhibit the growth of other microbial species, but with the increased number of chemically synthesized or modified antibiotics, the term antibiotics today refers to all substances that can inhibit growth or induce death of microorganisms [46]. It is generally known that the first commercialized antibiotic was penicillin discovered by *Alexander Fleming* in 1928, although its mass-production and use in human microbial infection came in 1941 based on the efforts of *Howard Florey* and *Ernst Chain*[47]. Around the same time, the term *"antibiotic"* was first used by an American scholar *Selman Waksman*, and the commercialization of penicillin elicited the development of various antibiotics such as rifampicin and tetracycline [48]. It was due to the high potential value of antibiotics.

Antibiotics enabled the prevention and treatment of human infections; during the 2nd world war, penicillin saved countless lives of the injured and ensured safe surgeries in general hospitals. It provided a great support for medical technology to advance far and for the growth of mankind [47, 49]. Furthermore, naturally and inevitably, antibiotics began to be used in the livestock industry. Since the discovery of the growth-enhancing and hence productivity-improving effects of antibiotics in the 1950s, a large variety of antibiotics were applied to livestock. Just as in humans, antibiotics at first appeared a miraculous substance for livestock; before half a century has passed, however, problems arose [50]. Antibiotic-resistant bacteria (ARB) emerged and caused serious problems to public health. Methicillin-resistant *Staphylococcus aureus* (MRSA) is one of the most well-known ARBs, and its infection has a five-time higher death rate than the non-resistant strain [51]. The Centers for Disease Control and Prevention (CDC) reported that ARB infection caused 48,000 deaths in the EU and the USA [52] and 58,000 deaths in India alone [53] each year. The WHO anticipated that none of the newly developed antibiotics would be effective against ARBs, as all currently available antibiotics have a strain that has developed resistance against them.
Both the CDC and WHO points to the excessive use of antibiotics in livestock as a cause for the ARB problem [54]. Across the globe, less than 5% of the total antibiotics use is for humans and more than half is for livestock, implying an urgent need for cutting the indiscreet use of antibiotics in livestock [54, 55]. Thus, the EU has prohibited the use of growth promoting antibiotics (GPAs) since the end of the 20th century; however, the problem of reduced livestock production led to the increased use of therapeutic antibiotics (TAs) [56].

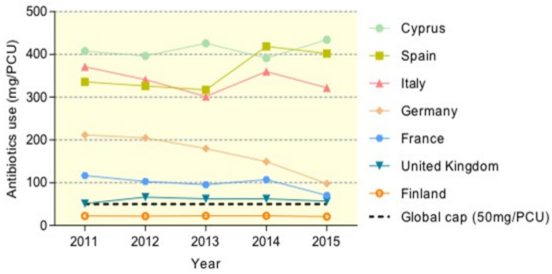

Fig. 5.3. Livestock antibiotics use in the EU by year. Source: [56], Livestock antibiotics use in the EU from 2011 to 2015. Data was normalized to a population-corrected unit (PCU). The figure was made by reconstructing the data of Hannah Ritchie. (2017) "How do we reduce antibiotic resistance from livestock?" from Our World in Data.

Due to the lack of reliable alternatives, GPAs are still being used in many countries (Fig. 5.3) [56], and in the USA with the largest meat export in the world, 130,000 tons of antibiotics were used for livestock in 2013 and the use is expected to increase to 200,000 tons in 2030 [57]. Thus, to ensure the reduced use of livestock antibiotics, a reliable alternative to GPAs should be developed. The growth-promoting effect of antibiotics in livestock has been attributed to the anti-bacterial activity of antibiotics [58], and recent studies showed that the efficacy of GPAs is based on their ability to remove toxic microorganisms in the gut and the feed to prevent excessive immune reactions and inflammation [59][60]. Thus, a potential alternative to GPAs can be a substance capable of antimicrobial activity by which the toxic microorganisms in the intestines of livestock animals are selectively inhibited, and which regulates the immune responses in livestock animals.

The most promising alternative to GPAs at present is functional feed additives. The FDA defines feed additives as a supplement that provides the nutrients in which common feed is deficient, mostly comprising vitamins, amino acids, and fatty acids. However, feed additives with as high economic and functional efficiency as GPAs have not yet been developed, making it difficult to completely replace GPAs. For this, plant materials have received much focus as novel functional feed additive materials [61].

The antioxidant, anti-inflammation, and antimicrobial effects exhibited by plant materials make them eligible as the alternative to GPAs [62, 63]. Although in far less amount than GPAs, several plant materials have already been used as PFAs. Thymol and caryacrol found in thyme and oregano have powerful antiseptic and antimicrobial effects (Table 5.3) [46].

Table 5.3. Herbs and spices with known benefits for farm animals

Herb/spice	Main constituents	Benefits
Oregano	Carvacrol, thymol	Anti-microbial, antioxidant
Thyme	Thymol, carvacrol	Antioxidant, anti-microbial
Garlic	Diallyldisulfide, allin, alliciin	Lipid digestion, anti-microbial
Horseradish	Allyl-isothiocyanate	Immunity booster
Chili, Cayenne Pepper	Capsaicin	Appetite, palatability
Peppermint	Menthol, carvacrol	Stomach, improving gut peristalsis
Cinnamon	Cinnamaldehyde	Antimicrobial, appetizing
Anise	Anethol	Appetite, stomach peristalsis

Based on these benefits, PFAs have been used in many countries, and the survey of livestock farmers reported that over 50% of the reasons for using PFAs was digestibility enhancement, with the other top four reasons being antimicrobial effects, GPAs replacement strategy, growth promotion and anti-inflammatory effects that allow the replacement of GPAs (Fig. 5.4). This provided evidence that PFAs were already being used as an alternative to GPAs [64].

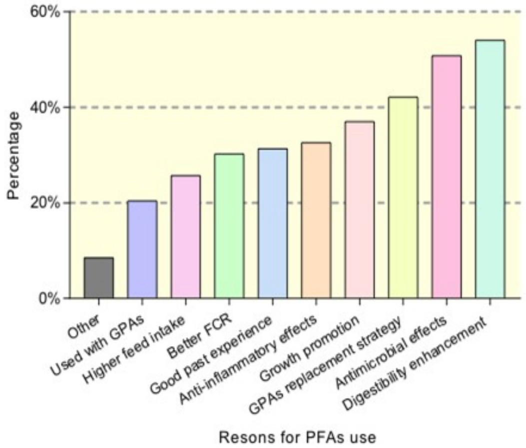

Fig.5.4. The reasons of PFA use.

Figure 5.4. was made by reconstructed the data of Noonan et al. [64]. Data was obtained from "2017 BIOMIN Phytogenic Feed Additives Survey results".

For PFAs to be established as a potential alternative to GPAs, a few constraints should be resolved. First, the quality of the plant that provides the source may cause problems, which would lower the economic feasibility of PFAs in terms of synthesis and mass-production that are possible with GPAs [65]. To guarantee consistent quality of PFAs, the following is essential: well-defined formulation, standardized raw materials, and effective quality control. Since the content of bioactive substances of the plant materials determines the efficacy of PFAs, regular composition analysis for bioactivity should be performed to maintain high quality of PFAs. For the propagation of PFAs, an equivalent or lower cost than GPAs is a prerequisite, and plant materials suitable for resolving such concerns are agricultural by-products (ABPs). ABPs may exhibit far more outstanding bioactivity than the parts of the plant used for food or other purposes, and rather than being discarded or consumed as fertilizers, they can bring additional income to the farms and a substantial financial advantage to the entire agricultural and livestock industry. Furthermore, since different substances may be toxic to humans and livestock, the selection of ABPs for PFAs should ensure that they do not contain the anti-nutritional factors presented in Table 5.4.

Table 5.4. Anti-nutritional factors in agricultural waste

By-products	Anti-nutritional factors
Rape seed and mustard wastes	Thioglucoside, goitrin, isothiocyanate
Castor seed meal	Ricin, hemagglutinin
Cotton seed cake	Gossypol
Linseed meal	Cyanogens, anti B-6
Peanut meal	Aflatoxin, goitrogen, protease inhibitors, saponins
Guar meal	Protease inhibitors
Sesame meal	Mineral binders
Soybean meal	Hemagglutinins, goitrin, protease inhibitors, saponins
Beet pulp	Saponins

Source : [74]

5.2. Companion animal: medicine

According to the survey of Statista, most companion animals in the USA today are cats (94.2 million) and dogs (89.7 million). The most popular dogs in the USA are the Labrador retriever (the most popular) and golden retriever (the third most popular). Retrievers have stayed as the top preference for 26 years (American Kennel Club). Around the 20th century, the main cause of death of the golden retriever species was renal diseases such as Lyme disease or renal dysplasia, which occupied a quarter of the total deaths [66]. However, a study reported that death due to cancer was greater in proportion than death due to disease progression [67]. In the 21st century, just as in humans, the lifespan of companion dogs increased based on improved lifestyle, and mortality caused by cancer occupies a larger proportion than all other diseases [68]. Likewise, around a third of all causes of death in felines is cancer [69]. This indicates that, to improve the life expectancy of companion animals, an optimized method should be developed for companion animals with respect to cancer prevention and treatment. Nonetheless, in most cases today, the methods used for humans are still applied to companion animals rather than their own cancer treatment methods. The use of a drug that has not been developed specifically for companion animals often causes reduced drug effects and increased medical cost, implying an urgent need for developing anticancer drugs optimized for companion animals.

Plant materials can be highly useful in developing anticancer drugs specific to companion animals. The anti-cancer effects of diverse PSMs and polyphenols in plant materials have been consistently verified both *in vitro* and *in vivo*, and like Taxol, a case of actual drug development has been reported [70, 71]. However, the fact that Taxol is the only drug developed out of thousands of PSMs may raise questions regarding the actual effectiveness of anticancer effects of PSMs. Nevertheless, the probability that a candidate material gets developed into a commercialized drug is extremely low (0.001 - 0.02%), and the cost of development ranges from as little as 500 million USD to up to 2,000 million USD [72]. According to Health for Animals, new drug development for companion animals would require approx. seven years and 22.5 million USD, which is around 1% of the cost required for drug development for humans. Thus, research on anti-cancer drugs for companion animals has the potential for high-efficiency drug development with little investment, which may help reduce the time and cost required by cancer therapeutics for humans [73].

6. Conclusions and outlook

The research so far on natural resources mainly focused on known medicinal plants or species with similar efficacy to the known species. This has constrained the scope of research on the target plant species. As the Nagoya Protocol took effect, an opportunity came for such constraints to be resolved, and different countries began to investigate their own native plants. Through such efforts, novel plant-derived bioactive substances can be discovered and these might provide a golden opportunity for developing countries in tropical regions with diverse native plant species to advance science and economics. Furthermore, suggestions have been made regarding the use of plant materials in animals, which is likely to increase the potential values of their novel application and subsequent commercialization while reducing the time and cost required by the development. The use of agricultural by-products in livestock may be an alternative to solve the problems of environmental pollution and public health caused by the increased number of farms due to increased human population. It has also been suggested that tropical plants may prove useful as an alternative to livestock feed additives in developing medicines for companion animals. Thus, via the proposal of new directions, the potential in plant materials research has been validated.

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