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Review

Harnessing Opportunities Provided by the Invasive *Chromolaena odorata* to Keep It under Control

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Abstract: Invasive alien plants (IAPs) have been well-documented as socio-ecological change drivers in most countries globally. Billions of dollars have been spent worldwide on IAP management projects with varying degrees of success. Understanding the contribution of IAPs to human well-being and livelihoods could provide insights into potential sustainable incentives that could be used to achieve effective IAP management. A review was conducted to assess the benefits of the invasive *Chromolaena odorata* on human well-being and livelihoods. Literature was gathered using keyword searches in electronic databases. The findings from this review showed that *C. odorata* is utilised in bioenergy production, crop production and protection, ethnopharmacology, human nutrition, and livestock production. However, most of these benefits were reported on the Asian/West African biotype. There was only one ethnopharmacological benefit record on the southern African biotype. This shows that, although *C. odorata* has significant negative impacts on the environment and livelihoods, its benefits have been integrated into human well-being and livelihoods. Therefore, *C. odorata* utilisation in bioenergy production, crop and livestock production, crop protection, and ethnopharmacology could create an economic incentive for species control in invaded sites. However, for utilisation to be effective, it should be used as a complementary control strategy.

Keywords: biodiversity; bioenergy; crop production and protection; economic incentive; ecosystem services; ethnopharmacology; food source; human well-being; livelihoods; livestock production

1. Introduction

Invasive alien plants (IAPs) are now well recognised as one of the key drivers of global socio-ecological change. This is because they affect biodiversity and ecosystem services [1,2], thus in turn affecting human well-being and livelihoods. The IAPs invade both human-modified and natural ecosystems [3], thus reducing their biodiversity and ability to deliver ecosystem services needed to maintain and enhance human well-being and livelihoods [4]. To counteract biodiversity and ecosystem services loss, millions of dollars are spent around the globe annually to manage IAPs [5]. For example, South Africa is currently spending more than US$101 million per year in the management of IAPs [6].

IAPs can have both negative and positive impacts on human well-being and livelihoods [4]. Human well-being is comprised of security, access to basic material to sustain good life, health, personal freedom, and good social relations [7]. Livelihood includes capabilities, assets, and activities needed to earn a living [8]. IAPs' negative impacts pose significant threats to human well-being and livelihoods in many parts of the world, but the impacts are severe in developing countries where most people (especially in rural areas) are more dependent on ecosystem services [9–11]. Most research has been focused on IAPs' ecological impacts [9,10,12], but currently the focus is also shifting towards IAPs' impacts on human well-being and livelihoods [4–13].

Environmental managers are often faced with a challenge of limited resources to manage IAPs, thus necessitating the need for alternative economic incentives that could be used to augment IAP management [14]. For example, a South African government agency, the Working for Water programme, is faced with a serious challenge to advocate for more IAP management budget allocation because several socio-economic initiatives are competing for the same pool of funds [15]. A few IAPs have both benefits and disbenefits [12,16,17], which are influenced by multiple socio-ecological factors that are context-specific [9,10,18]. Therefore, research on the role of IAPs in human well-being and livelihoods is crucial to identify benefits that could be used as incentives to promote sustainable IAP management while reducing a burden on limited funding pools. However, the research should also consider IAPs' benefits and disbenefits trade-offs to avoid creating a conflict of interest between different stakeholders [4–19].

Chromolaena odorata (L.) R.M. King & H. Rob. (Asteracea), synonym: *Eupatorium odoratum* (L.) King & H. (Eupatoriae), is a perennial, deciduous, and multi-stemmed shrub native to South and Central America, but which now has invaded various ecosystems such as grasslands, savannas, and tropical rainforests [20–22]. *Chromolaena odorata* can grow up to 2 m as a freestanding shrub. However, it can reach a height of 10 m as a climber on other plants [17]. *Chromolaena odorata* can create dense monospecific stands, thus outgrowing most native vegetation, and restricting human and animal access to invaded areas [23,24].

Chromolaena odorata was unintentionally introduced in Southeast Asia, Africa, and Oceania [25]. There are two biotypes in the introduced countries; i.e., the Asian/West African biotype and the southern African biotype [26,27]. *Chromolaena odorata* is among the worst 100 invasive alien species worldwide [28]. Both *C. odorata* biotypes cause significant threats to biodiversity, human well-being, and livelihoods by displacing native plants through shading, increasing fire intensity and frequency, and altering soil properties [13,24–31]. Livelihoods are largely threatened through reduced grazing capacity and impacts on agricultural land, crop yield, livestock, medicinal plants, eco-tourism, and trophy-hunting potential [13,32–34].

Chromolaena odorata is difficult to control due to rapid attainment of reproductive maturity and large production of seeds, short-term persistent seed banks [35], and production of multiple stems (resprouts) from basal stems following severe disturbances like fire and cutting [24–36]. A 10-year old shrub can produce more than 860,000 seeds of which 48% is germinable [35]. Between 1995 and 2008, South Africa spent 171.8 million rand in controlling *C. odorata*, but the extent of invasion has increased despite the control efforts [37]. Furthermore, biological control of *C. odorata* has also been less successful in South Africa, despite the release of multiple biological control agents [38]. Consequently, as the extent of invasion increases, the vulnerability of the rural poor, whose well-being and livelihoods are heavily dependent on ecosystem services, also increases due to lack of capital and/or techniques to control *C. odorata* [9]. However, utilisation of IAPs can contribute to their ultimate control and should form part of their management strategy [39]. To the best of my knowledge, no attempt has been made to synthesise *C. odorata's* benefits on human well-being and livelihoods. The published studies have either focussed on *C. odorata's* benefits in animal and crop production, and ethnopharmacology [40–42]. Therefore, this review aimed to assess the potential benefits of *C. odorata* on human well-being and livelihoods and show how these benefits can be used as incentives geared towards its sustainable management. Furthermore, knowledge gaps for future research were identified.

2. Materials and Methods

Electronic databases, i.e., Google Scholar, Science Direct, Scopus, Springer, and Web of Science, were used to source published literature on *C. odorata* or *E. odoratum*. All the above-mentioned databases were used to increase the chances of acquiring all the relevant literature. The following keywords were used to search relevant literature: "*Chromolaena odorata*", "*Eupatorium odoratum*", and "siam weed" in combination with "animal production", "benefits", "bioenergy", "biogas", "control methods", "crop production", "disbenefits", "disservices", "ecosystem services", "ethnopharmacological use", "human well-being", "livelihood impacts", "impacts", "medicinal use", and "socio-economic benefits". A literature search was conducted between August 2019 and February 2020, and only literature published in the English language was considered. Books, proceedings papers, reports, research papers, review papers, and theses (referred to as papers in this review) that mentioned *C. odorata*, *E. odoratum*, or siam weed invasion status, distribution, human well-being, and livelihood benefits (e.g., crop and livestock production, and insecticidal or medicinal potential), negative and positive impacts on society and the environment, and species management strategies, were selected. The search yielded more than 1000 articles that were screened to identify relevant papers. After screening, 728 papers were found relevant. All 728 papers were read in detail to identify papers that investigated the potential benefits of *C. odorata* on human well-being and livelihoods. Furthermore, papers on *C. odorata's* negative impacts and control methods were also considered to inform an effective utilisation strategy that will help keep the species under control. Based on the review of papers that investigated *C. odorata's* potential benefits, six categories were developed; namely, (1) animal production, (2) bioenergy, (3) crop production, (4) crop protection, (5) ethnopharmacology, and (6) food source.

3. Results and Discussion

Out of 728 papers, 54 papers investigated the potential benefits of *C. odorata* on human well-being and livelihoods. Out of 54 papers, 17 papers investigated ethnopharmacological benefits, followed by crop production, animal production, crop protection, bioenergy, and then food source (Figure 1). Fifty-three out of 54 studies were from the countries where the Asian/West African biotype is invasive, and one study was from the countries where the southern African biotype is invasive.

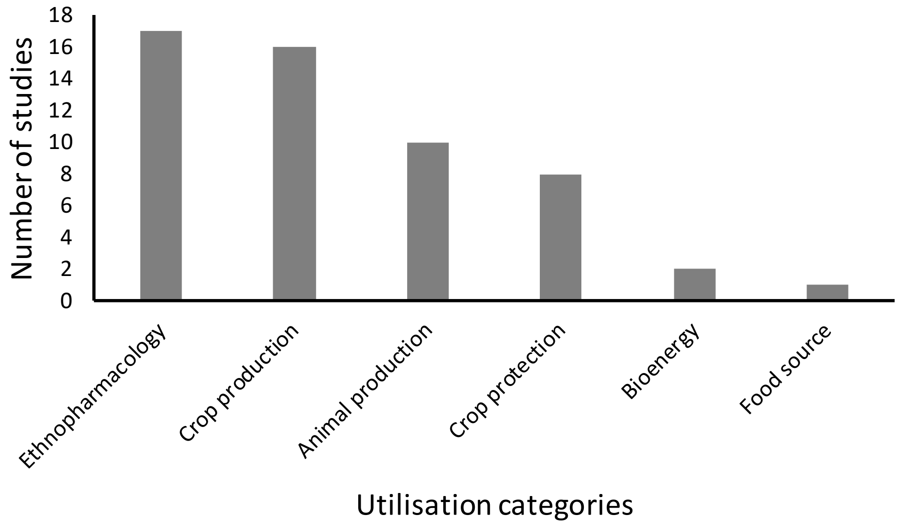

Figure 1. Papers on *Chromolaena odorata's* benefits to human well-being and livelihoods.

3.1. Ethnopharmacological Uses

Despite *C. odorata*'s invasive status in Asia and West Africa, it has been integrated into traditional medicine. *Chromolaena odorata* aqueous extract and decoction from the leaves are widely used to treat wounds, burns, and diseases such as diabetes and eye problems, in countries such as Vietnam, Malaysia, Thailand, Nigeria, and Ivory Coast [43–46]. A considerable number of scientific studies have confirmed the pharmacological efficacies of *C. odorata. Chromolaena odorata* contains anticancer, antidiabetic, antifungal, anti-hepatotoxic, anti-inflammatory, antimalarial, antimicrobial, and antioxidant properties [43–55]. In Vietnam, formulations prepared from leaf aqueous extracts and decoctions are licensed for clinical use [56]. Ethnopharmacological uses of *C. odorata* in humans from different countries are reported in Table 1. Given *C. odorata*'s traditional utilisation in Asia and West Africa, information on *C. odorata* utilisation in traditional medicine is very limited in eastern and southern Africa [41], except one record from Shackleton et al. [13]. According to Omokhua et al. [41], the non-utilisation of *C. odorata* in eastern and southern Africa can be partly explained by four hypotheses. Firstly, the locals might be still trying to fully comprehend *C. odorata's* benefits as the species' introduction is recent. Although one can argue that the species was introduced more than seven decades ago in South Africa [38], its spread and a substantial increase in density occurred between the 1950s and 1980s [33]. Secondly, traditional medicine practitioners may be lacking ethnopharmacological knowledge of the plant because it is only found in the eastern parts of the country. Thirdly, studies on traditional usage of the plant are still lacking. Lastly, the southern African biotype might be lacking medicinal properties that are contained in the Asian/West African biotype [41]. However, Naidoo et al. [57] showed that the southern African biotype has potential use in traditional medicine. Their findings showed that leaf methanol extract inhibited *Bacillus cereus*, *Bacillus subtilis*, *Staphylococcus aereus,* and *Staphylococcus epidermidis* (Gram-positive bacteria), and *Escherichia coli* (Gram-negative bacterium).

Apart from ethnopharmacological uses, in India, *C. odorata* leaves are used to treat wounds in livestock [58].

Table 1. Ethnopharmacological uses of *Chromolaena odorata* in different countries.

Plant Part	Uses	Country	Refrences
Leaves	Cholesterol, dyspepsia, hypertension, vertigo, and diet	Indonesia	[59]
Leaves	Cough	Thailand	[52]
Leaves	Diarrhea	Nigeria	[60]
Leaves	Diabetes and eye problems	India	[46]
Leaves	Gonorrhea	Guatemala	[61]
Leaves	Insecticide	Nepal	[62]
Leaves	Malaria	Benin and Ghana	[44,55,63]
Leaves	Skin infections	Vietnam	[44]
Leaves	Wound	Ghana, India, Nigeria, Thailand	[45,64–67]
Leaves	Wound	Vietnam	[50,51,67]
Leaves	Wound	Ivory Coast	[68]
Leaves	Wound	Nepal	[62]
Not mentioned	Not mentioned	Tanzania	[13]

3.2. Crop Production

The application of organic mulching is effective in soil physicochemical properties enhancement, weed growth control, soil temperature reduction, soil moisture conservation, and soil erosion reduction, thus increasing crop yield and quality [69–72]. *Chromolaena odorata* fallow crops and mulch increase soil macro-invertebrates (e.g., earthworms) and nutrients (e.g., nitrogen, phosphorus, potassium, magnesium, and calcium) [73–78]. As a result, *C. odorata* is widely used as a fallow crop and mulch for soil fertility and crop yield improvement in countries where it is invasive (Table 2). For example, in Nigeria, Agbede et al. [78] found that *C. odorata* mulch (5 t ha^{-1}) produced an average of 35.4 t ha^{-1} of *Dioscorea rotundata* Poir. over two seasons compared to control (23.2 t ha^{-1}). In Ghana, Fening et al. [79] reported higher *Zea mays* L. yield under *C. odorata* mulch (3 t ha^{-1}) compared with control (2.23 t ha^{-1}). These findings show that *C. odorata* can be used as an alternative source of fertilizer by impoverished farmers who cannot afford inorganic fertilizer.

Table 2. *Chromolaena odorata* utilisation in crop production.

Practice	Crop	Country	Reference
Fallow	*Arachis hypogaea* L.	Cameroon, Ghana, Nigeria	[75,80,81]
Fallow	*Dioscorea rotundata* Poir	Ghana	[81]
Fallow	*Manihot esculenta* Crantz	Cameroon, Ghana, Nigeria	[75,80,82]
Fallow	*Oryza sativa* L.	Laos	[83]
Fallow	*Zea mays* L.	Cameroon; Ghana, Ivory Coast; Nigeria	[75,76,81,84]
Fallow	Not mentioned	Cameroon	[85]
Fallow	Not mentioned	Ivory Coast	[71]
Liquid organic fertilizer	*Oryza sativa* L.	Indonesia	[86]
Mulch	*Abelmoschus esculentus* L. Moench	India	[87]
Mulch	*Brassica campestris* L.	India	[88]
Mulch	*Dioscorea rotundata* Poir	Nigeria	[78]
Mulch	*Oryza sativa* L.	India	[88]
Mulch	*Zea mays* L.	Nigeria, Ghana	[79,89]
Mulch	*Zingiber officinale* Rosc.	India	[90]

3.3. Animal Production

Livestock such as goats and cattle avoid foraging on *C. odorata* in its natural state (i.e., fresh leaves) [40–91], and this is attributed to the strong odour of essential oils in the leaves [40]. Furthermore, there have been reports of cattle that died after consuming *C. odorata* fresh leaves [4,40]. The strong odour is greatly reduced when the leaves are sun-dried [92]. As a result, *C. odorata* leaf meal is used as a feed additive. This is because *C. odorata* is rich in crude protein, amino acids (e.g., arginine, histidine, leucine, lysine, and methionine) [92–94], and minerals such calcium, phosphorus, magnesium, potassium, zinc, and iron [95].

A considerable number of studies have reported on *C. odorata* utilisation as a feed additive in livestock diets, while some studies showed that *C. odorata* leaf meal has the potential to be used as a feed additive (Table 3). In Nigeria, Fasuyi et al. [96] assessed the effect of *C. odorata* leaf meal-based diets (0, 2.5, 5, and 7.5%) on layer chickens' feed intake, body weight, and total egg production, weight, and yolk colour over eight weeks. The highest feed intake, body weight, and total egg production were achieved under the 5% of *C. odorata* leaf meal inclusion, while the highest egg weight and yolk colour were achieved under 5% and 7.5%, respectively [96]. Furthermore, in Nigeria, Aro et al. [40] also recorded the highest total egg production under the 5% *C. odorata* leaf meal inclusion over eight weeks.

In Nigeria, Jiwuba et al. [97] assessed the effect of *C. odorata* leaf meal-based diets (0, 4, 8, and 12%) on broiler chickens' carcass weight over 49 days. The highest weight (2952 g) was achieved by broilers that were fed a 4% *C. odorata* leaf meal-based diet, followed by broilers (2771 g) that were not fed a *C. odorata* leaf meal-based diet [97]. Contrary to Jiwuba et al. [97]'s findings, Donkoh et al. [98] in Ghana, Enkenyem et al. [99] in Nigeria, and Bonsu et al. [100] in Ghana found that broilers that were fed a 0% *C. odorata* leaf meal-based diet gained more weight than broilers fed with (1% to 7.5%) *C. odorata* leaf meal-based diets, although there were no significant differences. Nevertheless, Donkoh et al. [98] concluded that the weight of *C. odorata* leaf meal-fed broilers might be increased if tannins in *C. odorata* leaves could be eliminated or neutralised. Enkenyem et al. [99] recommended that *C. odorata* leaf meal (5%) could be used as a cheaper ingredient in broiler diets, while Bonsu et al. [100] recommended that only 3% should be included in broiler finisher diets.

In Tanzania, Shao [101] assessed the effect of *C. odorata* leaf meal-based diets (0, 5, 10, and 15%) in Small East African goats' performance (weight gain) over a three-month period. Goats that were fed a 5% *C. odorata* leaf meal-based diet had the highest weight (4.88 kg), which was significantly greater than those fed 0% (3.18 kg), 10% (2.5 kg), and 15% (2.25 kg) diets [101]. In Nigeria, Ogadu [102] also assessed the effect of *C. odorata* leaf meal-based diets (0, 2, 4, and 6%) in West African dwarf goats' performance (weight gain) over three months. Goats that were fed a 4% *C. odorata* leaf meal-based diet had the highest weight (6.20 kg), which was significantly greater than those on 0% (4.8 kg), 6% (4.5 kg), and 2% (5.00 kg) diets [102].

The overall findings suggest that to achieve the highest egg and meat production, the optimal level of *C. odorata* leaf meal inclusion in chicken (broilers and layers) and goat diets should be between 4% and 5%. However, *C. odorata* leaf meal should be prepared before plant maturity (i.e., seed set) to obtain higher nutritive value and to avoid the dispersal of the weed to uninvaded areas [101,103].

Table 3. *Chromolaena odorata* utilisation as a livestock feed additive in different countries.

Plant Part	Livestock	Country	References
Leaf meal	Layer chickens	Nigeria	[40,92,96]
Leaf meal	Broiler chickens	Nigeria	[99]
Leaf meal	Broiler chickens	Ghana, Nigeria	[97,100]
Leaf meal	Goats	Nigeria, Tanzania, Vietnam	[91,101,102]
Leaf meal	Rabbits	Nigeria	[104]

3.4. Crop Protection

Due to negative environmental impacts associated with synthetic insecticides, botanical insecticides are regarded as the best alternatives owing to their environmental-friendly pest management [105]. However, impoverished small-holder farmers cannot afford commercially available botanical insecticides such as Pyrethrum and azadirachtin [103]. *Chromolaena odorata* is regarded as a cheaper and effective botanical insecticide against pests of various crops. This is because it is readily available and doesn't require organic solvents, and complex apparatus to extract the insecticide [79,103]. In countries where *C. odorata* is invasive, impoverished small-holder farmers are using *C. odorata* leaves and leaf extract to control pests in the field and during harvest storage (Table 4).

In a field trial in Ghana, Ezena [106] assessed the insecticidal potential of *C. odorata* against cabbage (*Brassica oleracea* var. *capitata* L.) pests over two seasons. The treatments consisted of three doses of *C. odorata* (10, 20, and 30g/L of water) and a synthetic insecticide, Sunhalothrin® (active ingredient: Lambda-cyhalothrin, EC), produced by Wynca Sunshine Products, Sikasso, Mali. All *C. odorata* dosages had the highest marketable cabbage yield, 20 g/L (8.18 t/ha^{-1}), 10 g/L (6.53 t/ha^{-1}), and 10 g/L (6.19 t/ha^{-1}) compared to Sunhalothrin® (5.85 t/ha^{-1}). The highest cost-benefit ratios were obtained from *C. odorata* leaf extracts (20 g/L (1:34.2), 10 g/L (1:26.9), and 30 g/L (1:26.2)) rather than Sunhalothrin® (1:19.3). Furthermore, crops treated with 20 g/L of *C. odorata* had significantly higher populations of natural enemies, such as spiders, ladybird beetles, earwigs, red ants, and mason wasps, than those treated with Sunhalothrin® [106]. Amoabeng et al. [103] also conducted a field trial in Ghana to assess the insecticidal potential of *C. odorata* leaf extract against cabbage pests *Brevicoryne brassicae* (L.) (Hemiptera: Aphididae) and *Plutella xylostella* (L.) (Lepidoptera: Plutellidae). The treatments consisted of *C. odorata* leaf extract (30 g/L) and synthetic insecticide Attack® (active ingredient: emamectin benzoate), produced by PGG Wrightson, Wellington, New Zealnd. *Chromolaena odorata* suppressed *P. xylostella* significantly better than the synthetic insecticide Attack®, while *B. brassicae* suppression was comparable. Furthermore, *C. odorata* was less toxic to natural enemies such as ladybirds, hoverflies, and spiders than Attack® [103]. As a result, *C. odorata* had a higher cost-benefit ratio (1:29) than Attack® (1:25) [107]. These findings show that *C. odorata* leaves and leaf extract provide effective and economically feasible alternative pest control biopesticides.

Table 4. *Chromolaena odorata* utilisation in crop protection.

Formulation	Crop	Pest Controlled	Country	References
Leaf extract	*Brassica oleracea* var. *capitata* L.	*Plutella xylostella* (L.)	Ghana	[103]
Leaf extract	*Brassica oleracea* var. *capitata*	*Brevicoryne brassicae* (L.)	Ghana	[103]
Leaf extract	*Brassica oleracea* var. *capitata*	Various	Ghana	[106]
Leaf extract	*Vigna unguiculata* (L.) Walp.	*Anoplocnemis* spp., *Clavigralla* spp., *Nezara viridula* L. and *Riptortus* spp.	Nigeria	[108]
Leaf extract	Various vegetables	*Musca domestica* L.	Philippines	[109]
Leaf extract	*Zea mays* L. grain	*Sitophilus zeamais* Motschulsky	Ghana	[110]
Leaf powder	*Vigna unguiculata* grain	Post-harvest pests	Ghana	[111]
Leaf powder	*Zea mays* grain	Post-harvest pests	Ghana	[111]
Leaves	*Zea mays* grain	*Sitophilus zeamais* Motschulsky	Nigeria	[112]

3.5. Bioenergy

With the ever-increasing demand for energy coupled with the emission of greenhouse gases and the declining supply of fossil fuels, alternative renewable energy sources are becoming more imperative [113,114]. Although IAPs present more disservices than services, research is evolving on the bioenergy potential of IAPs that are already present in the environment [115–120]. In Nigeria, Dahunsi et al. [121] found that *C. odorata* has the potential to be used for biogas production, because they obtained a gas yield of more than 49.2%. In South Africa, Melane [120] found that *C. odorata* is the best species to be utilised as feedstock for combustion in low-technology reactors to produce heat and electricity via steam turbines owing to its physical, chemical, and economic viability.

3.6. Food Source

Some IAPs are utilised as traditional leafy vegetables owing to their nutritional value, thus making a significant contribution to human well-being [122–124]. In southern parts of Nigeria, *C. odorata* leaves are consumed as a vegetable, and this is largely attributed to high nutritional content in the leaves [41].

3.7. Chromolaena Odorata Management

Although *C. odorata* contributes to human well-being and livelihoods, it is regarded as a destructive species. This is because it was found to have high negative impacts on society and the environment, and low benefits [19]. This is supported by Shackleton et al. [13], who found that in northern-central Tanzania, most research respondents reported significant negative impacts (e.g., loss of grazing land) associated with *C. odorata*, while a few respondents reported its benefits (e.g., medicinal use). The control or eradication (where possible) of destructive species causes little conflict between people who benefit from the species utilisation and those who are responsible for species control (e.g., environmental managers) [19]. All the benefits presented in this review are obtained through the harvest of the species' biomass (leaves and stems). Therefore, *C. odorata* utilisation can provide a win-win solution. However, it should be noted that utilisation alone cannot be effective; therefore, it should be used as a complementary control strategy.

Utilisation should entail repeated cutting of stems at 3 cm above ground at least four times per year, to exhaust plant reserves in the rootstock [125]. This method is effective in reducing the number of resprouts, which cause dense infestations, and also result in plant mortality, usually after the third cutting [125]. This harvesting strategy should also be adopted by people who only derive benefits from *C. odorata* leaves. *Chromolaena odorata* seeds are wind-dispersed, but not greater than 80 m from the source [35–126]. Vehicles are largely responsible for long-distance dispersal [126]. Therefore, biomass harvesting should be done before flowering to combat species introduction into new areas as a result of seed dispersal. Vigilant monitoring should also be carried out in areas adjacent to the infested sites and on roadsides, to eradicate any seedlings present through uprooting. Development of *C. odorata* awareness programmes could also help improve the species' monitoring and control efforts in new areas when detected.

In areas where there is no utilisation, *C. odorata* clearing should be integrated with chemical control (e.g., fluroxypyr and triclopyr/picloram herbicides), followed by biomass burning to reduce species densities [20–36]. However, in habitats where there are indigenous tree species (e.g., woodlands, riparian zones, and forests), controlled burning is recommended as *C. odorata* biomass can create high and intense flames that can end up killing trees [36]. Biomass burning is also effective in reducing reinvasion, because it kills *C. odorata* rootstock and the soil seed bank [23,35,36]. Furthermore, the use of biological control agents can be effective in reducing *C. odorata* spread and densification. For example, biological control agents such as *Cecidochares connexa* (Macquart) (Tephritidae), *Pareuchaetes insulata* (Walker) (Erebidae), and *Pareuchaetes pseudoinsulata* Rego Barros (Erebidae) have been reported to be effective in reducing *C. odorata* infestation densities in some parts of the Pacific, southern and western Africa, and South-East Asia [17–129]. If *C. odorata* utilisation can be integrated with the other effective control methods, there will be a reduction in costs associated with mechanical and chemical control methods, and less burden on people responsible for IAP management.

4. Conclusions

Synthesising information on the contribution of IAPs to human well-being and livelihoods is a vital step in the planning of an effective IAP management plan that incorporates benefits associated with the species. This review showed that *C. odorata* provides benefits that enhance human well-being and livelihoods in countries where it is invasive, as a bioenergy crop, feed additive (leaf meal) in livestock production, organic fertilizer, and biopesticide in crop production and protection, and food (leafy vegetables). Therefore, *C. odorata* utilisation should be integrated with other control methods to achieve sustainable management of the species. Furthermore, people who are benefitting from species utilisation, and environmental managers responsible for species control, should co-develop the species management plan. This is because when all the stakeholders are involved in the co-development of the species management plan, the co-developed control strategies are equitable and non-controversial [19]. However, *C. odorata* utilisation is still limited to Asia and West Africa where the Asian/West Africa biotype is invasive. Therefore, there is a need for studies on the potential benefits of the southern African biotype on human well-being and livelihoods. Given the current rise in renewable energy research, more studies are needed to explore technologies that can optimise biogas extraction in *C. odorata*. Furthermore, there is also a need for studies on the cost-benefit analyses of different *C. odorata* utilisation categories (e.g., crop protection). This will help to identify a utilisation category that offers maximum return on investment.

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