Indian Journal of Natural Products and Resources
Vol. 10(3), September 2019, pp. 165-174

Piscicidal plants of Northeast India and its future prospect in aquaculture - A comprehensive review

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Received 21 August 2018; Revised 30 November 2019

Traditional knowledge and some indigenous techniques still serve as a reliable tool for harvesting resources from nature. Different species of plants (approx. 114) are used as piscicides by various people inhabiting Northeast India from a long period of time for fish harvesting purpose. The principle bioactive compounds present in the plant part (leaves, seed, kernels & bark) have varying potencies and mode of action depending on whether it is applied directly or in the forms of extracts (aqueous & alcohol) used. Aquaculture is one of the major sources of livelihood and protein in Northeast India. Although rich numbers of piscicidal plants are available, it cannot be commercially utilized in aquaculture unless detailed accounts of these plants are known. Bioactive compounds like saponins, rotenone, tannins, alkaloids etc. present in the plant may help to control the unwanted/predatory fish for healthy aquaculture. In the present review, the focus is given to all the plants used as a piscicide in Northeast India and its bioactive compounds, extraction medium, effective dose, test fish species and their biochemical, physiological and behavioural changes on some commercially important fish in India. Uses of herbal piscicides in aquaculture may help in replacing the harmful chemical piscicides of the environment.

Keywords: Bioactive compound, Herbal piscicide, Northeast India, Sustainable aquaculture, Traditional knowledge.

IPC code; Int. cl. (2015.01)- A61K 36/00, A61K 125/00, A61K 127/00, A61K 129/00, A61K 131/00, A61K 135/00, A01N 65/00

Introduction

The success of sustainable aquaculture depends on the eco-friendly management practice of targeted water bodies. Northeast India has tremendous potential for becoming an aquaculture hotspot because of its rich and unique ecological diversity and rich ethno-fisheries knowledge. Northeast India is blessed with a diversity of endemic flora and fauna having a harmonious relationship with several indigenous groups of people inhabiting throughout the region. Northeast India, consists of eight states, namely- Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, and Tripura, each have unique ecological variations. The diversity within the freshwater ecosystems in this region, forming part of the Himalayas and the Indo-Burma is both highly diverse and of great regional importance in terms of livelihood and economic condition of the people living around it[1]. Northeast India has 2 of the 36 biodiversity hotspots[2] listed by Conservation International, the Himalayas and the Indo-Burma[3]. It has the richest reservoir of plant diversity in India and is one of the 'biodiversity hotspots' of the world supporting about 50% of India's biodiversity[4]. It includes grassland, meadows, marshes, and swamps, scrub forests, mixed deciduous forests, humid evergreen forests, temperate and alpine vegetation. About 50% of Indian flowering plants are found in this region, 40% are endemic. A rich diversity of fish found in the rivers, springs, streams, ponds and beels provide a healthy source of protein for the local people and thus fishery has become an important economic activity of this region[5]. Different tribes of these regions use traditional knowledge (plant products) for harvesting fish from natural water bodies and management of aquaculture activity. Fish catching with the aid of plants is an ancient practice as they can easily stupefy and poison the fish[6].

Efficient fish culture can be possible only when a favourable environment is achieved for the targeted species. Removal of unwanted or weed fish also become a necessary step for a healthy aquaculture environment[7]. Unwanted fish in a nursery, rearing or stocking ponds not only compete for food and

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dissolved oxygen but also compete for space with the cultivable variety of fishes. And these fishes have high fecundity and sexually mature very fast[8]. There are good numbers of plant derivatives which could be used for fish poisoning across the world[9-12]. Generally, to avoid the hazardous effects of chemicals, some less toxic native plant derivatives are now used in India as fish poisons[13]. In non-intensive aquaculture practice, plant-derived saponins have been used widely throughout Asia and Africa and are attractive for the control of aquatic pests because of their low toxicity to human[14]. However, the most common herbal poison used in the fish pond is rotenone, inherent in derris (*Derris elliptica*) root powder. Rotenone is the main piscicide used internationally for eradicating and controlling pest fishes in freshwater[15]. Chemical eradication using rotenone has been used for fisheries management in Canada and the USA since several decades[16]. Rotenone is a piscicidal agent, which is used by the farmers of Bangladesh[17]. Other plant derivatives used in fish ponds are tea seed cake, tobacco waste and powdered croton (*Croton tiglium*) seed etc[18-20].

Plant extracts are referred to as botanicals and when noxious to fish are called piscicides[21]. Saponins, tannins, alkaloids, alkenylphenols, di and tri-terpenoids etc. are the compounds found in several plants belonging to different families are used to control predatory fish species[22]. Application of synthetic pesticides is one of the methods used to control fish population but due to their long-term persistence, slow degradability in the water body, it becomes toxic to other organisms[23] and ultimately accumulates inside the fish body, thus adversely affects the aquatic environment[24,25]. As compared to the chemical toxicants, the plant-derived piscicides are environmentally safe because they are easily biodegradable and act as manures in due course[26]. They are believed to be less hazardous to farmers and non-target species, do not result in resistance problem, are easily bio-degradable than the synthetic ones. There are several studies which have been carried out on the possibility of using local plants as fish poison[27].

Piscicidal plants used by the different community of Northeast India

The Northeastern states have 200 diverse ethnic groups of plants; most of the documented work has been done on ethnomedicinal plants, some of which were reported as highly poisonous. Among these plants, some of them have been used as a herbal piscicide in nursery pond management. Knowledge of harvesting fish with the help of poisonous plants is an age-old practice among the tribal community of Northeast India[28]. Traditional use of 45 species of ichthyotoxic plants of Manipur has been reported along with their mode of application by local people[29]. Mizo tribe practice community herbal fishing method for which they use leaf, bark, root, fruit and other plant materials[30]. Arunachal Pradesh has about 500 species of medicinal plants having pharmacological significance, out of which 30% plants are used as fish poison[31]. Plants like *Acacia pennata*, *Aesculus pavia*, *Ageratum conyzoides*, *Athyrium filix-femina*, *Zenthoxylum* sp. along with numbers of other plants are reported to be used by the Adi, Galo, Miri and Tagin tribe of Arunachal Pradesh[31-33]. Similarly, a rich ethno-fisheries technique of harvesting fish is reported from Assam[34]. Extensive use of *Polygonum hydropiper*, as fish toxicant, is found among the Karbi community of Assam[35]. Sundriyal *et al.*[36] reported 6 piscicidal plants from Sikkim. In Meghalaya, the Khasi community practices a similar type of harvesting technique for the collection of fish[37].

In the present review, varieties of the piscicidal plant used by tribal communities of Northeast India have been summarized (Table 1). Several literatures reported that a total of 114 plants are being used by different communities of Northeast India which belongs to 83 genera and 44 families. Out of which Asteraceae (11), Fabaceae (11), Leguminosae (9), Euphorbiaceae (11), Polygonaceae (6) and Rubiaceae (7) are found to be dominantly used throughout the region. Some families like Annonaceae, Apocynaceae and Mimosaceae have fewer numbers of species but they are found to be highly effective as well also. It has been reported that different plant parts such as roots, seed, stem, fruits, leaves, flowers as well as whole plant are being applied in the water bodies[30,32]. Plant-like small annual herbs like *Polygonum hydropiper* L. of *Polygonaceae* family to a tall evergreen tree, *Mesua assamica* (King and Prain) are also used in poisoning the different fish species. The roots of some plant species like *Derris* sp., *Engelhardia* sp., *Annona* sp., *Maesa* sp., *Euphorbia* sp. are also employed. Moreover, leaves and bark of *Aesculus* sp., *Canthium* sp., *Albizia* sp., and fruits and seed of *Acacia* sp., *Croton* sp., *Millettia* sp., are also used. Techniques for using these plant products are different. Some are first well ground before use (day 1)

Table 1 — Piscicidal plants of Northeast India

S. No.	Family	Name of the plants	Part used	Available	Reference
1	Achariaceae	*Gynocardia odorata* R.Br.	Fruits	AP & MI	30,53
		Hydnocarpus kurzii (King) Warb.	Fruits and bark	MA	29
2	Annonaceae	*Annona squamosa* Linn.	Seed, root, and leaves	AS	55
		Melodorum bicolor Hook.f.	Root	ME	37
3	Apocynaceae	*Nerium indicum* Mill.	Leaves	NA	28
		Thevetia peruviana (Pers.) K. Schum.	Stem and seed	AS	34
4	Araceae	*Arisaema tortuosum* Schott.	Shoots, leaves, and stem	MA	29
		Raphidophora decursiva Schott	Fruits	AP	33
5	Araliaceae	*Trevesia palmata* (Roxb.) Ves.	Fruits	AP	33
6	Arecaceae	*Phoenix dactylifera* L.	Whole plant	AP	53
7	Aristolochiaceae	*Apama tomentosa* Engl.	Stem and leaves	MA	29
8	Asclepiadaceae	*Asclepias curassavica* Linn.	Stem, root, and leaves	MA	29
9	Asteraceae	*Acmella paniculata* (Wall. ex DC.) R.K. Jansen	Whole plant	AP	53
		Ageratum conyzoides L.	Whole plant	AP, AS & NA	32,33
		Artemisia vulgaris Linn.	Leaves, shoots, and bark	SI	36
		Blumea balsamifera (Linn.) DC.	Leaves	MA	29
		Chromolaena odorata Linn.	Leaves and root	All NE states	55
		Eupatorium odoratum L.	Whole plant	MA	29
		Mikania cordata (Burm.) B.L. Robinson.	Stem, leaves, and root	MA	29
		Mikenia scandens Willd.	Whole plant	All NE states	55
		Sphaeranthus indicus Linn.	Stem, root, and leaves	MA	29
		Spilanthes acmella Linn.	Whole plant	AP, AS & MI	30,33
		Spilanthes peniculata L.	Whole plant	AP	33
10	Athyriaceae	*Athyrium filix-femina (L.) Roth*	Whole Plant	AP	31
11	Burseraceae	*Canarium strictum* Roxb.	Leaves	AP	33
12	Calophyllaceae	*Mesua assamica* (King & Prain*)* Kosterm	Fruits	AP & AS	33
13	Cornaceae	*Alangium longiflorum* Merr.	Leaves	MA	29
14	Cucurbitaceae	*Trichosanthes bracteata* (Lam.) Voigt.	Fruits	AS	34
15	Ebenaceae	*Diospyros lanceaefolia* Roxb.	Bark, root, and fruits	NA	28
		Diospyros montana Roxb.	Leaves and fruits	MA	29
		Diospyros pilosula (A.DC.) Wall. Ex Hiem.	Fruits	MI	30
16	Ericaceae	*Rhododendrum arboreum* Smith.	Leaves	NA	28
17	Euphorbiaceae	*Croton tiglium* Linn.	Leaves and flowers	AP	32
		Croton wallichii Mull. Arg.	Leaves and flowers	MI	30
		Emblica officinalis Gaertn.	Bark	MI	30
		Euphorbia nerifolia Linn.	Root	AS	34
		Euphorbia tirucalli Linn.	Root	AS & ME	55
		Exoecaria agallocha Linn.	Latex	AS & NA	28,34
		Jatropha curcas L.	Root	MA & NA	28,29
		Jatropha gossypifolia Linn.	Bark and leaves	MA	29
		Phylanthus ninuri Linn.	Leave juice	AS	56
		Phyllanthus urinaria Linn.	Stem, root, and leaves	MA	29
		Ricinus communis L.	Seed	AS, ME & NA	34,54,55
18	Fabaceae	*Albizia chinensis (*Osbeck*)* Merr.	Bark	AP, AS, MA & NA	28,29,33, 34
		Albizia lebbeck Linn.	Bark and leaves	NA	28
		Albizia marginata (Lam.) Merr.	Bark	SI	36
		*Albizia procera (*Roxb.) Benth.	Bark	AP, MI & NA	28,30,33

(*Contd.*)

Table 1 — Piscicidal plants of Northeast India (*Contd*.)

S. No.	Family	Name of the plants	Part used	Available	Reference
		Albizia odoratissima Benth.	Bark	All NE States	54
		Cassia alata L.	Leaves	AP	33
		Cassia javanica L.	Fruits	MI	30
		Cassia nodusa Buch.-Ham ex Roxb.	Root powder	AP	33
		Gymnocladus burmanicus C.E. Parkinson	Bark and leaves	AP	33
		Millettia pachycarpa Benth.	Fruits	AP, AS, MI & NA	30,33
		Senna alata (L.) Roxb.	Bark	AP	53
19	Gnetaceae	*Gnetum montanum* Markgraf.	Stem, root, bark, and leaves	MA	29
20	Juglandaceae	*Juglans regia* Linn.	Bark and unripe fruits	MI & NA	30
	J	*Engelhardia polystachya* Blume.	Root	AS, ME & SI	34,36,55
21	Lamiaceae	*Eremostachys vicaryi* Benth.	Whole plant	AP	53
22	Lecythidaceae	*Barringtonia acutangula* (L.) Gaertn.	Bark, root, and seed	AP & MA	29,33
23	Leguminosae	*Dalbergia stipulacae* Willd.	Bark	AS and ME	34,53
		Derris elliptica (Wall.) Benth.	Root	All NE states	33
		Derris ferruginea Benth.	Root	MA	29
		Derris robusta Benth.	Root	MA	29
		Derris scandens (Roxb.) Benth.	Root	AP & MA	33
		Pongamia paniculata Graham	Seed	AS, ME & NA	55
		Pongamia pinnata (L.) Pierre	Root and seed	AS & MA	29,34
		Pterocarpus dalborgiodes Roxb.	Bark, leaves, and root	MA	29
		Tephrosia candida (Roxb.) DC.	Seed and leaves	AP	32
24	Loganiaceae	*Buddleia macrostachya* Benth.	Leaves	All NE States	54
25	Lythraceae	*Duabanga grandiflora* (DC.) Walp.	Bark	MA	29
26	Menispermeceae	*Anamirta cocculus* Wight & Arn.	Fruits	AP	32
		Anamirta paniculata Caleber	Fruits	AS & ME	55
27	Mimosaceae	*Acacia pennata* (L.) Willd.	Bark	AP, ME, MI & NA	28,30,32, 33,37
		Acacia rugata (Lamk.) Voigt.	Stem powder	AP & MI	30,33
		Entada phaseoloides Merrill.	Whole plant	MA	29
28	Myricaceae	*Myrica esculenta* Buch & Ham.	Bark	NA	28
29	Poaceae	*Stipa sibirica* (L.) Lam.	Seed and leaves	AP	53
30	Polygalaceae	*Polygala elonggata* Klein	Whole plant	AP	53
31	Polygonaceae	*Persicaria barbata* (L.) H. Hara	Whole plant	AP	33
		Persicaria lapathifolia (L.) Delarbre	Whole plant	MA	29
		Polygonam hydropiper Linn.	Whole plant	All NE States	33,35
		Polygonum pubescens BI.	Whole plant	AP	33
		Polygonum strigosum R.Br.	Whole plant	MA	29
		Polygonam chinense Linn.	Root	MI	30
32	Primulaceae	*Maesa chisia* Buch. Ham. ex D. Don	Bark, root, and leaves	MA	29
		Maesa indica (Roxb.) A.DC.	Bark, root, and leaves	MA & SI	29,36
33	Ranunculaceae	*Delphinium brunonianum* Royle.	Whole plant	AP, AS, MI & ME	53
34	Rubiaceae	*Canthium dicoccum* Merill.	Bark and leaves	AP	33
		Canthium gracilipes Kurz.	Whole plant	AP	29
		Catunaregam uliginosa (Retz.) Manilal & Sivar	Fruits	NA	28

(*Contd*.)

Table 1 — Piscicidal plants of Northeast India (*Contd.*)

S. No.	Family	Name of the plants	Part used	Available	Reference
		Gardenia campanulata Roxb.	Fruits	AS	34
		Lasianthus longicauda Hook.f	Whole plant	AP	33
		Psydrax dicoccos Gaertn.	Root	AP	53
		Randia dumentorum Poir.	Fruits	AS & NA	28
35	Rutaceae	*Aegle marmelos* Correa	Root and bark	AS	34
		Zanthoxylum acanthopodium DC.	Fruits and leaves	All NE states	54
		Zanthoxylum armatum DC.	Fruits	AP, NA & MA	28,29,33
		Zanthoxylum nitidum (Roxb.) DC.	Fruits	AP and MA	29,32,33
		Zanthoxylum rhetsa (Roxb.) DC.	Fruits	AP	33
36	Sapindaceae	*Acer oblongum* Wall. ex DC.	Fruits	ME	37
		Aesculus assamica Griff.	Pounded bark	AP, AS & MA	29,33,37
		Aesculus pavia (Linn.) Willd.	Bark and leaves	AP	32
		Aesculus flava Sol.	Leaves	AP	32
		Sapindus mukorossi Gaert.	Fruits	NA & MI	28,30
37	Solanaceae	*Solanum xenthocarpum* Schrad. & H. Wendl.	Fruits	AS	56
38	Taxaceae	*Taxus baccata* Wall.	Bark and leaves	NA	28
39	Theaceae	*Schima wallichii* (DC) Korth.	Bark	MI & NA	28,30
40	Thelypteridaceae	*Cyclosorus extensus* (Blume) Holtt.	Whole plant	AP	32
		Thelupteris herbacea Hottum.	Whole plant	NA	28
41	Thymelaeacea	*Linostoma decandrum* (Wallichi)	Root	AS & MI	30
42	Verbenaceae	*Duranta plumier* Jacq.	Seed	AS & MI	30,34
43	Vitaceae	*Parthenocissus semicordata* (Wall.) Planch.	Fruits	AP	53
		Vitis himalayana (Royle) Brandis	Fruits	AP	33
44	Zingiberaceae	*Costus speciosus* (Koening) Sm.	Root	MA	29

*AP-Arunachal Pradesh, AS-Assam, MA-Manipur, ME-Meghalaya, MI-Mizoram, NA-Nagaland, SI-Sikkim & T-Tripura

and thereafter introduced into the source of running water[30]. Fish like *Channa punctatus* (Bloch), *Botia dario* (Ham.), *Barilius bendelisis* (Ham.), *Labeo dero* (Ham.), *Tor tor* (Ham.) are reported to be caught by using piscicidal plants in Nagaland[28] (Table 1). The toxicity of aqueous extracts of leaf and stem bark of four plants belonging to family Euphorbiaceae and Apocynaceae has also been studied on freshwater fish, *Channa punctatus*[38]. *Fabaceae* is reported to be the commonly used piscicidal plant family among the Adi tribe of Arunachal Pradesh[33].

Toxicity of piscicidal plants of Northeast India on economically important fishes

Different species of plants applied as piscicides have different effects, depending on the species of fish targeted[39]. The bioactive compounds present in the plants (leaves, seed, kernels and bark) have varying potencies and mode of action depending on whether it is applied directly and the forms of extracts (aqueous and alcohol) used. A large number of plants have been used traditionally by the local community for fish harvesting purpose but in literature, only a few species have been experimentally tested for obtaining the knowledge of their effectiveness and how these plants act as a poison in fish. In the present review, attention is being paid to some of the plants found in Northeast India which has been already tested for their bioactive compounds, extraction method, the test specimen and behavioural or physiological change that occurred after the administration of particular plant material for effective use in the aquaculture industry (Table 2).

Evaluation of acute toxicity of the seeds of *Anamirta cocculus* (L.) has been studied on three species of freshwater fish *Clarias batrachus* (L.), *Channa striatus* (Bloch.) and *Mystus vitattus* (Bloch.) and found higher susceptibility in *Mystus vitattus* (Bloch.)[40]. The higher LC_{50} in *C. batrachus* and *C. striatus* could be attributed due to the presence of accessory respiratory organs. Ethyl alcohol extract of leaves of *Nerium indicum* was used against predatory fish, *Channa punctatus* and showed significant behavioural changes in the studied fish[41]. Alcoholic

Table 2 — Toxicity of piscicidal plants of Northeast India

S. No.	Name of the plant	Bioactive compounds	Type of extraction	Test species	Nature of response
1	*Acacia pennata*	Terpenoids, Flavonoid glycoside[57]	Water	*Ophiocephalus punctatus*	Restlessness with erratic movement, laboured breathing, and rapid opercular beat[48].
2	*Anamirta cocculus*	Picrotoxin, Triterpinoids, Alkaloids[58]	Powdered seed	*Clarias batrachus, Channa striatus* and *Mystus vitattus*	Respiratory distress[40].
3	*Euphorbia tirucali*	4-deoxy phorbol[44]	Water and alcohol	*Channa punctatus, Guppies* and *Tilapia*	Respiratory pathway abnormality & inhibition of carbonic anhydrase activity[43].
4	*Jatropha gossipifolia*	Apigenin[50]	Ethyl alcohol	*Channa punctatus*	Neurotoxic to fish, irregular, erratic and jerky movement is common[59].
5	*Polygonam hydropiper*	Plygodial, Flavonoid, Oxymthyl anthraquinones, Polygonic acid[60]	Water	*Heteropneustes fossilis*	Swimming abnormality[61].
6	*Pongamia pinnata*	Flavonoids, Karangin, Pongamol, Pongagalabrone, Pongapin, Pinnat in and Kanjone[62]	Ethyl alcohol	*Heteropneustes fossilis*	Degenerative changes in the intestine, liver and gill[63].
7	*Nerium indicum*	Phenolics, Glycosides, Alkaloids, Tannin, Flavonoid etc.[64]	Water and Ethanol	*Channa punctatus* and *Channa faciata*	Decrease in opercular movement and suppress energy production[41].
8	*Thevetia peruviana*	Apigenin-5-methyl Flavonoids, Triterpenoid glycosides[65]	Acetone	*Catla catla*	Decrease protease and acid alkaline phosphatase activity[46].
9	*Zanthoxylum armatum*	Sesquiterpenes, Linalool, Limonene, Methylcinnamate[66]	Ethyl alcohol	*Heteropneustes fossilis*	Inhibit Mg and Na-K ATPase activity[67].
10	*Zanthoxylum rhetsa*	Tetrahydrofuran lignans, Alkaloid (Columbamine) Triterpenoid (Lupeol)[68]	Water	*Heteropneustes fossilis*	Excessive mucus secretion[47].

leaf extract of this plant can also inhibit the activity of enzyme acetylcholinesterase which results in decreased operculum movement. Similar kind of behavior could also be observed by the application of organophosphate and carbamate pesticides[42]. The effect of aqueous extract of *Euphorbia tirucalli* bark and latex on *C. punctatus* has been studied and found to decrease total protein level, inhibition of DNA synthesis and adverse effect on the respiratory pathway of fish and also caused energy crisis during stress[43]. An active component, 4-deoxy phorbol, a terpene has been identified as the main bioactive compound in *E. tirucalli*[44]. Alcoholic extracts of *Euphorbia tirucalli* inhibit the activity of carbonic anhydrase in gills (14 to 40%) and muscles (40%) of guppies and blood (60%) in Tilapia[45]. Another study carried out to study the effect of leaf and bark extract of *Thevetia peruviana* on *Catla catla* at the exposure of sub-lethal doses (40 and 80% at LC_{50}, 24 h) caused significant ($p< 0.05$) alterations in the level of total protein, free amino acids, DNA and RNA, protease and acid and alkaline phosphatase activity in various tissues of the fish[46]. A toxicity test was performed to observe the lethal concentration (LC_{50}) value of *Zanthoxylum rhetsa* aqueous seed extracts on catfish, *Heteropneustes fossilis* and observed a direct relationship between the duration of exposure and energy depletion. Excessive mucus secretion and accumulation was also observed in the treated fish[47]. Aqueous and ethanol extracts of *Acacia pennata* (bark), *Catunaregam uliginosa* (fruit), *Diospyros lenceofolia* (fruit) and *Sapindus mukorossi* (fruit) were evaluated as piscicides on the freshwater fish, *Danio dangila*, *Danio rerio*, *Puntius shalynius* and *Heteropneustes fossilis*. In the study, *Catunaregam uliginosa* (fruit) was found to possess relatively higher piscicidal potency[48].

Apigenin is the main bioactive compound found in *Jatropha gossypifolia* leaf and it has molluscicidal[49] as well as piscicidal activity[50]. *C. punctatus* was tested for the toxicity evaluation of *J. gossypifolia* and was found to be a neurotoxin in nature[51]. A detailed

Table 3 — Effective dose of some piscicidal plants of Northeast India

S. No.	Name of the plant	Part used	Type of extraction	Dose	Exposure (hours)	Target species	Reference
1	*Acacia pennata*	Bark	Aqueous	85.87 ppm	24	*Denio dangila*	48
			Ethanol	4.24 ppm	12	*Denio dangila*	
2	*Albizia procera*	Seed	Ethyl alcohol	15.0 ppm	24	*Oreochromis mossambicus*	70
			Ethyl alcohol	25.0 ppm	24	*Channa punctatus*	
3	*Anamirta cocculus*	Seed	Heated	62.76 mg/kg	96	*Clarias batrachus*	40
		Seed	Unheated	50.24 mg/kg	96	*Clarias batrachus*	
		Seed	Heated	24.24 mg/kg	96	*Channa striatus*	40
		Seed	Unheated	15.31 mg/kg	96	*Channa striatus*	
		Seed	Heated	3.44 mg/kg	96	*Mystus vitattus*	40
		Seed	Unheated	1.90 mg/kg	96	*Mystus vitattus*	
4	*Catunaregm uliginosa*	Fruits	Aqueous	9.55 ppm	4	*Denio dangila*	48
			Ethanol	1.78 ppm	14	*Denio dangila*	
5	*Diospyros lanceofolia*	Fruits	Aqueous	37.06 ppm	96	*Denio rerio*	48
			Aqueous	32.18 ppm	12	*Denio dangila*	
			Ethanol	14.89 ppm	48	*Denio dangila*	
6	*Euphorbia tirucalli*	Latex	Aqueous	1.31 mg/L	96	*Heteropneustes fossilis*	69
7	*Jatropha gossypifola*	Crude latex	Aqueous	10.49 mg/L	96	*Channa punctatus*	59
8	*Sapindus mukorossi*	Fruits	Aqueous	32.16 ppm	20	*Heteropneustes fossilis*	48
			Ethanol	4.01 ppm	12	*Denio dangila*	
9	*Thevetia peruviana*	Leaf	Acetone	88.80 mg/L	24	*Catla catla*	46
		Bark	Acetone	99.43 mg/L	24	*Catla catla*	
10	*Zanthoxylum rhetsa*	Seed	Aqueous	70.1 mg/L	96	*Heteropnesutes fossilis*	47

account of the potent bioactive compound and their effect on the respective target fish species has been discussed in the present study (Table 2).

Effective dose of some piscicidal plants of Northeast India

Although herbal piscicides are more eco-friendly than to those chemical counterpart used in aquaculture, one major issue related to these plants is that indigenous people often use higher quantities of piscicidal plants/parts to catch the fish than it is necessary, resulting in the loss of biodiversity in the natural aquatic ecosystem. Knowledge of effective dose of a particular plant allows efficient and optimal utilization of locally available, natural and cheap herbal products in aquaculture. Scientifically derived mortality data provides farmers with the required information to eradicate wild fish from culture ponds within a convenient period of time[52]. So, in this review, the emphasis has also been given to the LC_{50} value of some plants used as common piscicides in aquaculture practices in the region.

From the available literature sources, it is observed that different parts of plants, mode of administration and extraction medium have different action upon fish (Table 3). *Anamirta cocculus* seed has different LC_{50} values in different fishes. *Clarias batrachus* exposed to this plant for 96 hours have effective LC_{50} value of 62.76 mg/kg (heated seed) and 50.24 mg/kg (unheated seed)[40]. The effectiveness of the same extract was found to be different in different target fish species. A lower value of LC_{50} of 3.44 mg/kg was tested in *M. vititus*[40]. From the study, it is observed that air-breathing species are more tolerant of piscicidal substances[19]. Acetone extracts of *Thevetia peruviana* (leaves and bark) were administered to *Catla catla* and leaf extract (88.80 mg/L) was found to be more potent as piscicide than the bark extract (99.49 mg/L). The aqueous seed extract of *Z. rhetsa* was tested against *H. fossilis* for 96 hours and the effective dose of LC_{50} was recorded to be 70.1 mg/L. Aqueous and ethanol extract of *Catunaregam uliginosa* fruits were also tested against *Denio dangila* and the study reflected that ethanol extract had lower LC_{50} value (1.78 ppm) and was more effective than aqueous extract (9.55 ppm)[48].

Conclusion

The intensive use of synthetic pesticides in agricultural fields and other water bodies has resulted in serious environmental hazards. With growing awareness of environmental degradation by chemical pesticides, efforts are being made to replace it by plant origin, because of their eco-friendliness, ease of availability, high efficiency, rapid biodegradability and reduced toxicity to non-targeted animals and also manure perspective. So, the vast diversity and traditional knowledge of using piscicidal plants found in Northeast India can be effectively utilized in the aquaculture industry for the eradication of unwanted/predatory fish without giving any residual effect on the environment and non-targeted organisms. However, more scientific investigations have to be made to explore all the potentialities of such plants for a healthy and sustainable environment. Purification of bioactive compounds with the help of reliable and sophisticated methods is necessary for identifying new and effective herbal piscicide with known dose and mode of action. This report will provide the diverse value of plant natural resources available in Northeast India and also render a sustainable path to replace currently used harmful chemical piscicide in the aquaculture practices. And, it will give a huge relief to the fish farmers.

Conflict of interest

The authors declare that they have no conflict of interest.

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