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Antidiabetic green leafy vegetables currently sold in Trincomalee District in Sri Lanka

Günümüzde Sri Lanka'nın Trincomalee Bölgesi'nde satılan antidiyabetik etkili yeşil yapraklı sebzeler

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ABSTRACT

Diabetes is a disease in which the body does not produce insulin or cannot use insulin effectively. In Sri Lanka, 1.2 million people among the age group of 20 to 79 were affected by diabetes in 2019. Biomedicine antidiabetic medications cause common side effects such as bladder cancer, dehydration, sinusitis, kidney illness, and urinary infections. Consumption of green leafy vegetables minimizes the risk of developing diabetes. Hence, this work aims to identify and document the green leafy vegetables currently sold in Trincomalee District in Sri Lanka by performing fieldwork visits to the main markets and the surrounding green leafy vegetable kiosks, shops, superstores, and streets from January 2019 to June 2021. The levels of antidiabetic scientific evidence available for the identified green leafy vegetable species were assessed by recognizing the relevant published works in the electronic databases Web of Science, PubMed, Scopus, etc., until September 2021. A total of 99 green leafy vegetable species from 43 families were recognized. The majority of the green leafy vegetables had in vivo (33%), followed by in vitro (16%) and clinical (9%) as scientific evidences. Also, 49 antidiabetic compounds were already isolated from the identified green leafy vegetables. This study forms a foundation for further studies using the green leafy vegetable species in Trincomalee.

ÖZ

Diyabet, insülinin vücut tarafından üretilmediği veya etkili bir şekilde kullanılamadığı bir hastalıktır. 2019 yılında, Sri Lanka'da 20 ila 79 yaş arası 1,2 milyon kişi diyabetten etkilenmiştir. Biyomedikal antidiyabetik ilaçlar, mesane kanseri, dehidratasyon, sinüzit, böbrek hastalığı veya idrar yolu enfeksiyonları gibi yaygın yan etkilere neden olabilir. Yeşil yapraklı sebzelerin tüketilmesi diyabet gelişme riskini azaltır. Bu çalışmada, Ocak 2019-Haziran 2021 tarihleri arasında, Sri Lanka'nın Trincomalee Bölgesi'nde bulunan başlıca pazarlarda ve yeşil yapraklı sebze satan büfeler, dükkanlar, süpermarketler ve sokak satıcıları ziyaret edilerek yapılan saha çalışması sonucunda satılan yeşil yapraklı sebzeleri belirlemek ve raporlamak amaçlanmaktadır. Tespit edilen yeşil yapraklı sebze türleri için mevcut antidiyabetik etkisine yönelik bilimsel kanıt seviyeleri, Web of Science, PubMed, Scopus vb. elektronik veri tabanlarında Eylül 2021'e kadar yayınlanmış ilgili çalışmalar tanınarak değerlendirilmiştir. Toplamda 43 familyaya ait 99 yeşil yapraklı sebze tanımlanmıştır. Bilimsel kanıt olarak, yeşil yapraklı sebzelerin çoğu üzerinde yapılmış in vivo (33%) çalışmalar olup daha sonra, in vitro (16%) ve klinik çalışmalar (9%) gelmektedir. Ayrıca belirlenmiş yeşil yapraklı sebzelerden izole edildiği bilinen 49 antidiyabetik etkili bileşik bulunduğu belirlenmiştir. Bu çalışma, Trincomalee'deki yeşil yapraklı sebze türlerinin kullanımına yönelik sonraki çalışmalar için bir kaynak oluşturacaktır.

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1. INTRODUCTION

Diabetes is a disease in which the body does not produce insulin or cannot use insulin effectively. Diabetes is classified into three types: 1. Type 1 diabetes, 2. Type 2 diabetes, and 3. Gestational diabetes. The symptoms of diabetes include weight loss, urinating a lot, extreme thirst, feeling tired, unclear vision, infections, delayed

wound healing, and excessive appetite (American Diabetes Association, 2021). Now, type 1 diabetes cannot be prohibited. Diabetics are at an increased risk of getting a lot of severe health issues. High blood glucose levels regularly can lead to serious illnesses affecting the teeth, cardiovascular system, nerves, eyesight, and kidneys (MedlinePlus, 2021). Diabetes is managed in biomedicine with biguanides (Metformin), meglitinides and sulfonylureas, DPP-4 inhibitors, thiazolidinediones or glitazones, alpha-glucosidase inhibitors, SGLT2 inhibitors, bile acid sequestrants, dopamine receptor agonists, pramlintide, and insulin therapy. These medications cause adverse side effects such as abnormalities in urination, bladder cancer, bloating, constipation, reduced hunger, dehydration, diarrhea, dizziness, a decrease in the number of red blood cells, swellings, headache, heartburn, rash, reactions to hypersensitivity, hypoglycemia, hypotension, fractures, nausea, runny nose, sinusitis, stomach discomfort, stomachache, a rise in cholesterol, kidney illness, liver disease, nasopharyngitis, respiratory infections, urinary infections, fatigue, and excess weight (Mayo Foundation for Medical Education & Research, 2021; International Diabetes Federation, 2021a).

In Sri Lanka, 1.2 million people among the age group of 20 to 79 were affected by diabetes in 2019. Further, as per the trend in the increase of diabetic patients, within the next 25 years, another 0.3 million people will be affected. Almost US$ 244 million was spent on treating diabetic patients in the year 2019 (International Diabetes Federation, 2021b).

Green leafy vegetables are part of a healthy diet. Consumption of green leafy vegetables minimizes the risk of developing diabetes (WHO, 2017; Oduro et al., 2018). Green leafy vegetables are consumed as a part of the usual daily diet in Sri Lanka (Senadheera & Ekanayake 2013). Green leafy vegetables are a major element of Sri Lankan cuisine. These green leafy vegetables are less costly and more widely available (Dolson, 2008).

As previously said, biomedicine medicines and therapies have several worse side effects and are costly. As a result, it is advantageous to discover natural and inexpensive medicines that have few or no adverse effects when used to control diabetes. As a result, the goal of this work was to identify and document the green leafy vegetable species that are presently being marketed in Sri Lanka's Trincomalee District. The levels of scientific antidiabetic evidence available for the recorded green leafy vegetable species were then evaluated. This study enables the general public to manage or prevent diabetes naturally and cost-effectively by ingesting antidiabetic green leafy vegetables. Furthermore, this work is beneficial for researchers to investigate prospective green leafy vegetable species to find potential antidiabetic active extracts and chemicals. These compounds have the potential to be lead chemicals in future antidiabetic drugs.

2. MATERIAL AND METHOD

2.1. The study region

This research was conducted in the District of Trincomalee in the Eastern Province of Sri Lanka (Figure 1). Trincomalee District has a total size of 2,727 km^2 with a population of 378,182 people in 2017. The study region is home to Tamil and Sinhala speakers (District Secretariat – Trincomalee, 2021).

2.2. Data collection

This research was carried out between January 2019 and June 2021. The authors performed at least three fieldwork trips to each of the Trincomalee District's main market places and the surrounding green leafy vegetable kiosks, shops, superstores, and street markets. Each market and the surrounding region were explored by the authors for at least two hours. The following are the main marketplaces visited, and also the latitudes and longitudes of each location:

1. Trincomalee Town – 08°34’37.77” N, 81°14’03.3” E
2. Nilaveli – 08°40’48.18” N, 81°11’41.77” E
3. Kuchchaveli – 08°49’07.61” N, 81°05’47.8” E
4. Padavi sripura – 08°55’20.47” N, 80°48’23.6” E
5. Morawewa – 08°37’40.83” N, 81°02’01.27” E
6. Kinniya – 08°30’01.93” N, 81°11’29.73” E
7. Kantale – 08°21’07.42” N, 81°00’31.47” E
8. Thampalakamam – 08°30’00.04” N, 81°05’39.52” E
9. Muthur – 08°27’21.07” N, 81°17’02.62” E
10. Seruwila – 08°22’27.59” N, 81°19’11.56” E

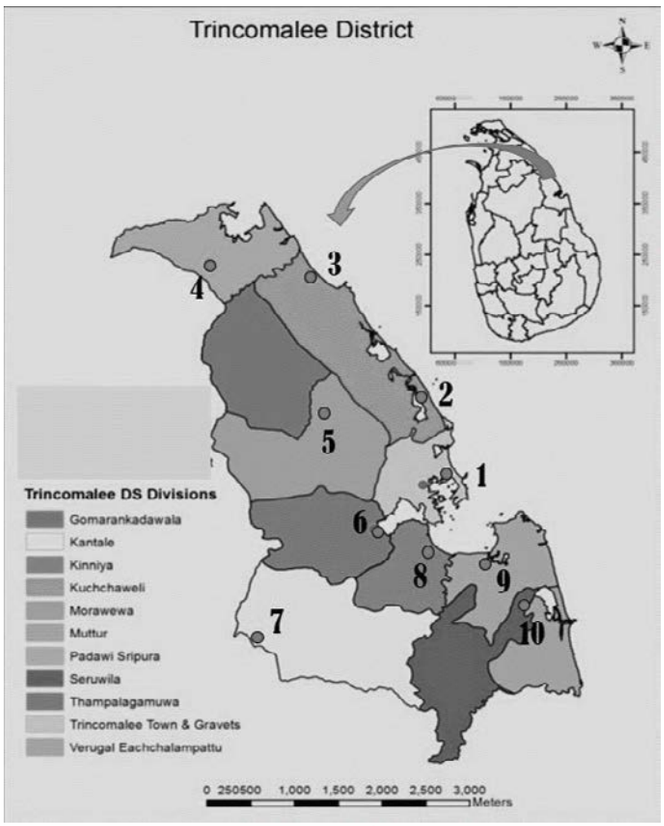

Figure 1. The study region and the fieldwork carried out on the main markets in Trincomalee District, based on data from the Survey Department of Sri Lanka (2014). 1. Trincomalee Town, 2. Nilaveli, 3. Kuchchaveli, 4. Pathavisripura, 5. Morawewa, 6. Kinniya, 7. Kantale, 8. Thambalakamam, 9. Muthur, and 10. Seruwela.

2.3. Green leafy vegetables identification

Dr. Pholtan Rajamanoharan identified and confirmed all of the green leafy vegetables offered for sale at each site (Provincial Herbal Garden Management Center, Trincomalee 31000, Sri Lanka).

2.4. Voucher specimens

From January 2019 to June 2021, voucher specimens of the specified green leafy vegetable species that were locally accessible were gathered in the Trincomalee District. Dr. Pholtan Rajamanoharan, once again, identified and confirmed all of the plant species. The voucher specimens were placed in the herbarium of the Provincial Herbal Garden in Trincomalee. The Kew Science (2021) and Global Biodiversity Information Facility (2021) were used to authenticate all of the scientific names and families of the recognized green leafy vegetable plant species.

2.5. Data analysis

All of the recognized and verified green leafy vegetable species in the fieldwork were given a record that included their scientific name, family name, Tamil name, and herbarium voucher specimen number (if relevant). The Web of Science, PubMed, Scopus, SpringerLink, ScienceDirect, Wiley Online Library, and Directory of Open Access Journals (DOAJ) was employed to find published relevant studies through September 2021. Plant species specified in the American Herbal Pharmacopoeia-Verified Botanical Reference Materials, (2021); American Herbal Pharmacopoeia: Botanical Pharmacognosy-Microscopic Characterization of Botanical Medicines (Upton et al., 2016); European Medicines Agency's Committee on Herbal Medicinal Products (2021); World Health Organization Monographs on Selected Medicinal Plants - Volumes 1 to 4 (2004, 2007, 2009, 2017); Brendler (2010). were deemed to be extremely well investigated for global plant species. As a result, these plant species were eliminated from the identification of antidiabetic activity-related publications. As a search phrase, the scientific name of each plant species was utilized. In this study, only the leaves of the identified green leafy vegetable species with antidiabetic properties were evaluated. The existing scientific data of each species' antidiabetic potential was then evaluated.

3. RESULTS AND DISCUSSION

3.1. Antidiabetic green leafy vegetables currently sold

Trincomalee Town and Kantale were mostly identified as having green leafy vegetables, followed by Pathavisripura, Morawewa, Seruwela, Kinniya, Thambalakamam, Muthur, Kuchchaveli, and Nilaveli. Entirety 99 green leafy vegetable species from 43 families were recognized in this investigation as listed in Table 1. Furthermore, the greatest number of the green leaves were from *Fabaceae,* followed by Amaranthaceae, Convolvulaceae, Lamiaceae, Apiaceae, Asteraceae, Brassicaceae, Phyllanthaceae, Cucurbitaceae, and Solanaceae families. The majority of the identified green leaves were *Ipomoea*, followed by *Amaranthus, Brassica, Senna, Solanum, Allium, Ocimum, Passiflora, Premna*, and *Talinum* genus.

Table 1. Green leafy vegetable species sold in markets in Trincomalee District.

Scientific name	Family	Tamil	Herbarium specimen
Abutilon indicum (L.) Sweet	Malvaceae	துத்தி (Thuththi)	SV01
Achyranthes aspera L.	Amaranthaceae	நாயுருவி (Naayuruvi)	SV02
Adenanthera pavonina L.	Fabaceae	மஞ்சாடி (Manjaadi)	SV03
Aegle marmelos (L.) Corrêa	Rutaceae	வில்வை (Vilvai)	SV04
Allium ampeloprasum L.	Amaryllidaceae	இலீக்சு (Ileekksu)	NA
Allium cepa L.	Amaryllidaceae	வெங்காயம் (Venkayam)	SV05
Aloe vera (L.) Burm.f.	Asphodelaceae	கற்றாழை (Katraalai)	SV06
Alternanthera sessilis (L.) R.Br. ex DC.	Amaranthaceae	பொன்னாங்கண்ணி (Ponnaanganni)	SV07
Amaranthus cruentus L.	Amaranthaceae	செங்கீரை (Sengkeerai)	SV08
Amaranthus spinosus L.	Amaranthaceae	முட்கீரை (Mutkeerai)	SV09
Amaranthus viridis L.	Amaranthaceae	முளைக்கீரை (Mulaikkeerai)	SV10
Anisomeles indica (L.) Kuntze	Lamiaceae	பேராமட்டி (Peraamatti)	NA
Apium graveolens L.	Apiaceae	சிவரிக்கீரை (Sivarikkeerai)	NA
Aporosa cardiosperma (Gaertn.) Merr.	Phyllanthaceae	வெட்டில் (Vettil)	NA
Argyreia thwaitesii (C.B.Clarke) D.F.Austin	Convolvulaceae	சிண்டுக்கொடி (Sindukkodi)	SV11
Artemisia dracunculus L.	Asteraceae	தரகொன் (Tharagon)	NA
Basella alba L.	Basellaceae	கொடிப்பசளி (Kodippasali)	SV12
Beta vulgaris L.	Amaranthaceae	செங்கிழங்கு (Sengkilangu)	NA
Biophytum reinwardtii (Zucc.) Klotzsch	Oxalidaceae	நிலத்தென்னை (Nilththennai)	SV13
Blechnum orientale L.	Aspleniaceae	பரக்கொக்கு (Parakkokku)	NA
Boerhavia diffusa L.	Nyctaginaceae	மூக்கரட்டை (Mookkarattai)	SV14
Brassica napus L.	Brassicaceae	பச்சையவல் (Pachchaiyaval)	NA
Brassica oleracea L.	Brassicaceae	கோவா (Kovaa)	NA
Brassica rapa L.	Brassicaceae	கோசுக்கிழங்கு (Kosukkilangu)	NA
Breynia androgyna (L.) Chakrab. & N.P.Balakr.	Phyllanthaceae	தவசிமுருங்கை (Thavasimurugai)	SV15
Canthium coromandelicum (Burm.f.) Alston	Rubiaceae	காரை (Kaarai)	SV16
Cardiospermum halicacabum L.	Sapindaceae	முடக்கொத்தான் (Mudakkoththan)	SV17
Cassia fistula L.	Fabaceae	கொன்றை (Konrai)	SV18
Celosia argentea L.	Amaranthaceae	பண்ணைக்கீரை (Pannaikkeerai)	NA
Centella asiatica (L.) Urb.	Apiaceae	வல்லாரை (Vallaarai)	SV19
Clitoria ternatea L.	Fabaceae	காக்கணம் (Kaakkanam)	SV20
Coccinia grandis (L.) Voigt	Cucurbitaceae	கொவ்வை (Kovvai)	SV21
Colocasia esculenta (L.) Schott	Araceae	சேம்பு (Sembu)	NA
Commelina diffusa Burm.f.	Commelinaceae	கஞ்சாட்டை (Kanjaattai)	SV22
Cordia monoica Roxb.	Boraginaceae	நறுவிலி (Naruvili)	SV23
Coriandrum sativum L.	Apiaceae	கொத்தமல்லி (Koththamalli)	NA
Cucurbita maxima Duchesne	Cucurbitaceae	பூசணி (Poosani)	SV24
Cyanthillium cinereum (L.) H.Rob.	Asteraceae	சீதேவியார் செங்கழுநீர் (Seetheviyaar Sengaluneer)	SV25
Cymbopogon nardus (L.) Rendle	Poaceae	சோரப்புல் (Sorappul)	NA
Eclipta prostrata (L.) L.	Asteraceae	கரிசிலாங்கண்ணி (Karisalaangkanni)	SV26
Eryngium foetidum L.	Apiaceae	மல்லிச்சீரை (Mallichcheerai)	NA
Erythrina variegata L.	Fabaceae	முருக்கு (Murukku)	SV27
Exallage auricularia (L.) Bremek.	Rubiaceae	இம்பூரல் (Impooral)	SV28
Ficus racemosa L.	Moraceae	அத்தி (Aththi)	SV29
Flueggea leucopyrus Willd.	Phyllanthaceae	மடுப்புல்லாந்தி (Maduppullaanthi)	SV30
Grona triflora (L.) H.Ohashi & K.Ohashi	Fabaceae	சிறுபுள்ளடி (Sirupulladi)	SV31
Gymnema sylvestre (Retz.) R.Br. ex Sm.	Apocynaceae	சிறுகுறிஞ்சா (Sirukurinjaa)	SV32
Hellenia speciosa (J.Koenig) S.R.Dutta	Costaceae	வெண்கோட்டம் (Venkottam)	SV33
Hygrophila auriculata (Schumach.) Heine	Acanthaceae	நீர்முள்ளி (Neermulli)	SV34
Ipomoea aquatica Forssk.	Convolvulaceae	வள்ளல் (Vallal)	SV35
Ipomoea batatas (L.) Lam.	Convolvulaceae	வற்றாளை (Vattraalai)	SV36

Scientific name	Family	Tamil	Herbarium specimen
Ipomoea sagittifolia Burm.f.	Convolvulaceae	மஞ்சிகை (Manjigai)	NA
Ipomoea triloba L.	Convolvulaceae	நறுந்தாளி (Narunthaali)	SV37
Kalanchoe pinnata (Lam.) Pers.	Crassulaceae	சதைக்கரைச்சான் (Sathaikkaraichchaan)	SV38
Lactuca sativa L.	Asteraceae	சலாதிலை (Salaathilai)	NA
Lagenaria siceraria (Molina) Standl.	Cucurbitaceae	சுரை (Surai)	SV39
Lasia spinosa (L.) Thwaites	Araceae	கொயிலை (Koyilai)	SV40
Leucas zeylanica (L.) W.T.Aiton	Lamiaceae	முடிதும்பை (Mudithumbai)	SV41
Manihot esculenta Crantz	Euphorbiaceae	மரவள்ளி (Maravalli)	SV42
Melastoma malabathricum L.	Melastomataceae	கருணவி (Karunavi)	NA
Melissa officinalis L.	Lamiaceae	சிற்ரனெல்லா (Sitranellaa)	NA
Mentha arvensis L.	Lamiaceae	புதினா (Puthinaa)	SV43
Moringa oleifera Lam.	Moringaceae	முருங்கை (Murungai)	SV44
Murraya koenigii (L.) Spreng.	Rutaceae	கறிவேம்பு (Karivembu)	SV45
Ocimum basilicum L.	Lamiaceae	திருநீற்றுப்பச்சை (Thiruneetruppachchai)	SV46
Ocimum tenuiflorum L.	Lamiaceae	துளசி (Thulasi)	SV47
Osbeckia octandra DC.	Melastomataceae	காட்டு முத்துக்குளை (Kaattuu Muththukulai)	SV48
Ouret lanata (L.) Kuntze	Amaranthaceae	தேங்காய்ப்பூக்கீரை (Thengaaippookkeerai)	SV49
Oxalis corniculata L.	Oxalidaceae	புளியாரை (Puliyaarai)	SV50
Pandanus amaryllifolius Roxb. ex Lindl.	Pandanaceae	இறம்பை (Irambai)	SV51
Passiflora edulis Sims	Passifloraceae	கொடித்தோடை (Kodiththodai)	SV52
Passiflora foetida L.	Passifloraceae	சிறுபூனைக்காலி (Sirupoonaikkaali)	SV53
Petroselinum crispum (Mill.) Fuss	Apiaceae	வோக்கோசு (Vokkosu)	NA
Phyllanthus amarus Schumach. & Thonn.	Phyllanthaceae	கீழ்காய்நெல்லி (Keelkkaainelli)	SV54
Piper longum L.	Piperaceae	திப்பிலி (Thippili)	SV55
Polyscias balfouriana (André) L.H.Bailey	Araliaceae	கொப்பா	NA
Pontederia hastata L.	Pontederiaceae	கருங்குவளை (Karungkuvalai)	NA
Portulaca oleracea L.	Portulacaceae	பருப்புக்கீரை (Paruppukkeerai)	SV56
Premna procumbens Moon	Lamiaceae	பிரேமனா (Piremanaa)	NA
Premna serratifolia L.	Lamiaceae	பசுமுன்னை (Pasumunnai)	SV57
Raphanus raphanistrum L.	Brassicaceae	முள்ளங்கி (Mullangi)	SV58
Rivea ornata (Roxb.) Choisy	Convolvulaceae	முசுட்டை (Musuttai)	SV59
Scoparia dulcis L.	Plantaginaceae	காட்டுக்கொத்தமல்லி (Kaattukkoththamalli)	SV60
Senna auriculata (L.) Roxb.	Fabaceae	ஆவாரை (Aavarai)	SV61
Senna occidentalis (L.) Link	Fabaceae	தகரை (Thaharai)	SV62
Senna tora (L.) Roxb.	Fabaceae	ஊசித்தகரை (Oosiththaharai)	SV63
Sesbania grandiflora (L.) Poir.	Fabaceae	அகத்தி (Ahaththi)	SV64
Solanum americanum Mill.	Solanaceae	மணித்தக்காளி (Maniththakkaali)	SV65
Solanum melongena L.	Solanaceae	வட்டு (Vattu)	SV66
Solanum trilobatum L.	Solanaceae	தூதுவளை (Thoothuvalai)	SV67
Sphaeranthus indicus L.	Asteraceae	கொட்டைக்கரந்தை (Kottakkarandai)	SV68
Talinum fruticosum (L.) Juss.	Talinaceae	பசளி (Pasali)	SV69
Talinum paniculatum (Jacq.) Gaertn.	Talinaceae	மரப்பசளி (Marappasali)	SV70
Thespesia populnea (L.) Sol. ex Corrêa	Malvaceae	பூவரசு (Poovarasu)	SV71
Trianthema portulacastrum L.	Aizoaceae	சாரணை (Saranai)	SV72
Trichopus zeylanicus Gaertn.	Dioscoreaceae	நிலத்தேங்கை (Nilaththengai)	SV73
Wattakaka volubilis (L.f.) Stapf	Apocynaceae	பெருங்குறிஞ்சா (Perungkurinjaa)	SV74
Xenostegia tridentata (L.) D.F.Austin & Staples	Convolvulaceae	முடியாகூந்தல் (Mudiyaakoonthal)	SV75
Ziziphus oenopolia (L.) Mill.	Rhamnaceae	சூரை (Soorai)	SV76

Abbreviation: NA: Not applicable

The green leaves of *Abutilon indicum, Achyranthes aspera, Adenanthera pavonina, Aegle marmelos, Allium ampeloprasum, A. cepa, Aloe vera, Alternanthera sessilis, Amaranthus cruentus, A. spinosus, A. viridis, Anisomeles indica, Argyreia thwaitesii, Basella alba, Beta vulgaris, Boerhavia diffusa, Brassica oleracea, Breynia androgyna,*

Canthium coromandelicum, Cardiospermum halicacabum, Cassia fistula, Celosia argentea, Centella asiatica, Clitoria ternatea, Coccinia grandis, Colocasia esculenta, Commelina diffusa, Cordia monoica, Cucurbita maxima, Cyanthillium cinereum, Eclipta prostrata, Erythrina variegate, Exallage auricularia, Ficus racemosa, Flueggea leucopyrus, Grona trifloral, Gymnema sylvestre, Hellenia speciosa, Hygrophila auriculata, Ipomoea aquatica, I. batatas, Kalanchoe pinnata, Lactuca sativa, Lagenaria siceraria, Lasia spinosa, Leucas zeylanica, Manihot esculenta, Mentha arvensis, Moringa oleifera, Murraya koenigii, O. basilicum, Ocimum tenuiflorum, Osbeckia octandra, Ouret lanata, Oxalis corniculate, Pandanus amaryllifolius, P. edulis, Passiflora foetida, Phyllanthus amarus, Piper longum, Portulaca oleracea, Premna serratifolia, Raphanus raphanistrum, Rivea ornata, Scoparia dulcis, Senna auriculata, S. occidentalis, S. tora, Sesbania grandiflora, Solanum americanum, S. melongena, S. trilobatum, Sphaeranthus indicus, Talinum fruticosum, T. paniculatum, Thespesia populnea, Trianthema portulacastrum, Trichopus zeylanicus, Wattakaka volubilis, Xenostegia tridentata, and *Ziziphus oenopolia* were frequently identified in all the markets. While *Brassica rapa, Ipomoea sagittifolia*, and *Premna procumbens* were infrequently identified in the fieldwork studies.

Figure 2: Some of the green leafy vegetables currently sold.

3.2. Levels of scientific evidence of identified green leafy vegetable species

Approximately 10% were globally distributed and very well-studied plant species identified in this investigation. A literature overview assessment of 89 green leafy vegetable species found that 57% of the species had antidiabetic scientific evidence. So far, 49 antidiabetic compounds have been isolated from the assessed green leafy vegetable species. About, 39% of plant species recorded in this study were also used to treat diabetes in Sri Lankan traditional medicines especially, Sri Lankan Siddha Medicine based on previously published research works. For example, *Abutilon indicum, Achyranthes aspera, Aegle marmelos, Allium cepa, Aloe vera, Alternanthera sessilis, Basella alba, Boerhavia diffusa, Cardiospermum halicacabum, Cassia fistula, Coccinia grandis, Coriandrum sativum, Cyanthillium cinereum, Eclipta prostrata, Erythrina variegata, Ficus racemosa, Flueggea leucopyrus, Gymnema sylvestre, Hellenia speciosa, Ipomoea aquatica, Moringa oleifera, Murraya koenigii, Ocimum tenuiflorum, Ouret lanata, Passiflora edulis, Phyllanthus amarus, Piper longum, Rivea ornata, Scoparia dulcis, Senna auriculata, Senna occidentalis, Senna tora, Sesbania grandiflora, Thespesia populnea,* and *Wattakaka volubilis* (Vivekanandarajah, 2021a; 2021b; 2021c; 2021d; 2021e; Vivekanandarajah et al., 2015; 2016; 2017; 2018).

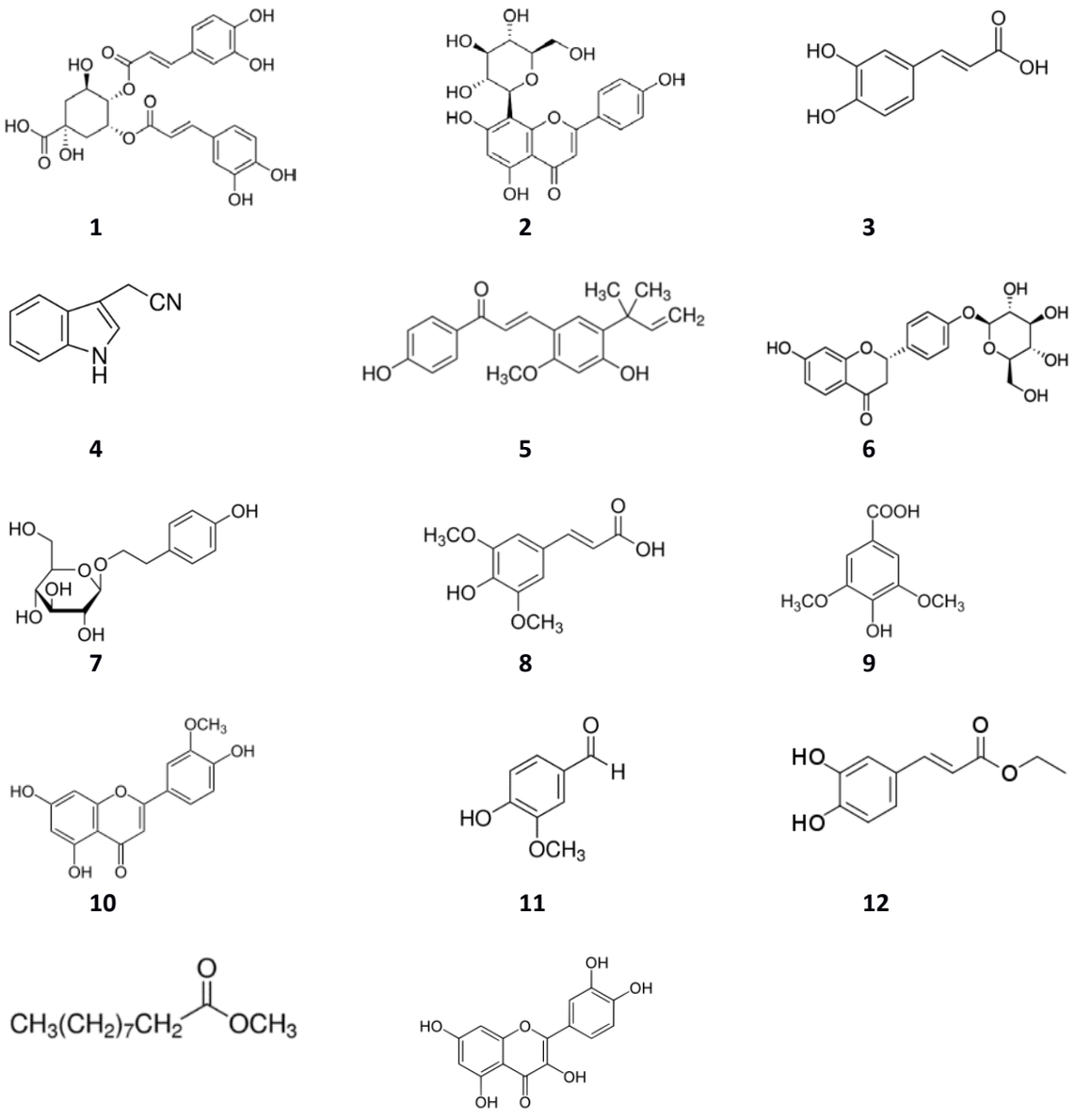

Figure 3. Some of the chemical structures of antidiabetic compounds isolated from the green leafy vegetables identified in this study. **1.** 4,5-Di-O-caffeoylquinic acid; **2.** Vitexin; **3.** Caffeic acid; **4.** Indole-3-acetonitrile; **5.** Licochalcone A; **6.** Liquiritin; **7.** Salidroside; **8.** Sinapic acid; **9.** Syringic acid; **10.** Chrysoeriol; **11.** Vanillin / 4-Hydroxy-3-methoxybenzaldehyde; **12.** Ethyl caffeate; **13.** Methyl decanoate; **14.** Quercetin.

3.2.1. Green leafy vegetable species had no antidiabetic scientific evidence

A total of 43% of green leafy vegetables did not have any antidiabetic scientific evidence. For example, *Allium ampeloprasum, Amaranthus cruentus, Anisomeles indica, Aporosa cardiosperma, Argyreia thwaitesii, Biophytum reinwardtii, Boerhavia diffusa, Brassica napus, Breynia androgyna, Commelina diffusa, Cordia monoica, Cyanthillium cinereum, Cymbopogon nardus, Exallage auricularia, Flueggea leucopyrus, Grona triflora, Hellenia speciosa, Hygrophila auriculata, Ipomoea sagittifolia, Ipomoea triloba, Lagenaria siceraria, Leucas zeylanica, Ouret lanata, Piper longum, Polyscias balfouriana, Pontederia hastata, Portulaca oleracea, Premna procumbens, Rivea ornata, Senna tora, Solanum melongena, Sphaeranthus indicus, Talinum fruticosum, Talinum paniculatum, Trianthema portulacastrum,*

Trichopus zeylanicus, Xenostegia tridentata, and *Ziziphus oenopolia.*

3.2.2. Green leafy vegetable species had *in vitro* antidiabetic scientific evidence

Nearly 16% (14 out of 89) of green leafy vegetable species had *in vitro* scientific evidence and are listed in Table 2. A total of six antidiabetic compounds were isolated from *Eclipta prostrata* (3β,25-Dihydroxy-23E-lemmaphyll-8,23-diene; 3β-Hydroxy-17-epi-28-norolean-12-en-16-one 3-O-β-d-glucopyranoside) and *Solanum americanum* (N-trans-p-coumaroyloctopamine; N-trans-p-coumaroyltyramine; N-trans-p-feruloyl octopamine; N-trans-p-feruloyltyramine) (Yu et al., 2020; Silva et al., 2017).

Table 2. Green leafy vegetable species had *in vitro* evidence

Scientific name	Extract / compound	Assay	Reference
Adenanthera pavonina L.	Methanol	α-Amylase inhibitory	Wickramaratne et al., 2016
Alternanthera sessilis (L.) R.Br. ex DC.	Methanol	α-Glucosidase inhibitory	Chai et al., 2016, Manalo et al., 2020
Alternanthera sessilis (L.) R.Br. ex DC.	Methanol	α-Amylase inhibitory	Manalo et al., 2020
Blechnum orientale L.	Aqueous	α-Glucosidase inhibitory	Chai et al., 2015
Eclipta prostrata (L.) L.	3β,25-Dihydroxy-23E-lemmaphyll-8,23-diene; 3β-Hydroxy-17-epi-28-norolean-12-en-16-one 3-O-β-d-glucopyranoside	α-Glucosidase inhibitory	Yu et al., 2020
Lactuca sativa L.	Ethanol	α-Glucosidase inhibitory; α-Amylase inhibitory	Timothy & Geetha, 2019
Lasia spinosa (L.) Thwaites	Aqueous	α-Amylase inhibitory	Shafie et al., 2018
Lasia spinosa (L.) Thwaites	Ethanol	α-Glucosidase inhibitory	Shafie et al., 2018
Manihot esculenta Crantz	Acetone; Ethanol	α-Glucosidase inhibitory; α-Amylase inhibitory	Okoro, 2020
Mentha arvensis L.	Methanol	α-Glucosidase inhibitory; α-Amylase inhibitory	Agawane et al., 2018
Oxalis corniculata L.	Ethanol	α-Glucosidase inhibitory; α-Amylase inhibitory	Das & Himaja, 2015
Petroselinum crispum (Mill.) Fuss	Aqueous	Antiglycation	Tupe et al., 2016
Petroselinum crispum (Mill.) Fuss	Ethanol	Antiglycation	Bashkin et al., 2021
Petroselinum crispum (Mill.) Fuss	Methanol	α-Amylase inhibitory	Mahomoodally, 2012
Premna serratifolia L.	Aqueous; Ethanol	α-Glucosidase inhibitory; α-Amylase inhibitory	Simamora et al., 2020
Raphanus raphanistrum L.	Not stated	α-Amylase inhibitory	Hussein et al., 2020
Solanum americanum Mill.	N-trans-p-coumaroyloctopamine; N-trans-p-coumaroyltyramine; N-trans-p-feruloyloctopamine; N-trans-p-feruloyltyramine	α-Glucosidase inhibitory	Silva et al., 2017

3.2.3. Green leafy vegetable species had *in vivo* antidiabetic scientific evidence

A major part (33%) of the identified green leafy vegetable species had *in vivo* evidence (Table 3). Overall, 35 antidiabetic compounds were isolated from *Artemisia dracunculus* [2',4'-Dihydroxy-4-methoxydihydrochalcone; 4,5-Di-O-caffeoylquinic acid; and 6-Demethoxycapillarisin], *Beta vulgaris* [Acacetin 8-C-β-D-glucopyranoside; and Vitexin], *Brassica rapa* [(3β, 20E)-Ergosta-5, 20 (22)-dien-3-ol; 2-Phenylethyl β-glucopyranoside; 4-Methoxyindole-3-acetonitrile; Adenosine; Caffeic acid; Indole-3-acetonitrile; Indole-3-aldehyde; Licochalcone A; Liquiritin; Salidroside; Sinapic acid; and Syringic acid], *Cardiospermum halicacabum*

[Apigenin-7-o-β-d-glucuronide; Chrysoeriol; and Kaempferol-3-o-α-l-rhamnoside], *Ipomoea batatas* [3,4,5-TriCQA; 4-Hydroxy-3-methoxy benzaldehyde; Benzyl β-d-glucoside; Cis-N-feruloyltyramine; Ethyl caffeate; Methyl decanoate; Protocatechualdehyde; Quercetin; Quercetin 3-O-β-D-sophoroside; Trans-N-(p-coumaroyl)tyramine; and Trans-N-feruloyltyramine], and *Sesbania grandiflora* [Loliolide; Quercetin; and Vomifoliol] (Adisakwattana & Pudhom, 2015; Ahmad et al., 2013; Kumar et al., 2011a; Girija et al., 2011a; Parthasarathy et al., 2009; Kaushik et al., 2010; Krisanapun et al., 2011; Mishra et al., 2012; Daisy & Rajathi, 2009; Kavitha, 2018; Mazhar & Mazumder, 2013; Sinaga et al., 2019; Saha et al., 2011; Panigrahi et al., 2016 Veerabhadrappa & Raveendra Reddy, 2017; Girija et al., 2011b; Kumar et al., 2011b; Swastika et al., 2019; Kavitha, 2018; Sharma et al., 2017; Krisanapun & Peungvicha, 2009; Setyaningsih et al., 2021; Maulidiani et al., 2015; Balamurugan et al., 2014; Thissera et al., 2020; Emmanuel et al., 2010; Prasanna et al., 2017; 2020; Veerabhadrappa & Raveendra Reddy, 2017; Doss et al., 2009; Lingappa et al., 2019; Gopal & Mandal, 2013). Only chrysoeriol isolated from *Cardiospermum halicacabum* had *in vivo* evidence (Swastika et al., 2019). Furthermore, quercetin was isolated from both *Ipomoea batatas* and *Sesbania grandiflora* leaves and showed antidiabetic activities in the 3T3-L1 cell, α-amylase inhibitory, and α-glucosidase inhibitory assays (Thissera et al., 2020; Prasanna et al., 2017).

3.2.4. Green leafy vegetable species had clinical antidiabetic scientific evidence

A total of 9% of the documented green leafy vegetable species had clinical scientific evidence and are listed in Table 4. Eight antidiabetic active compounds [4-Epi-scopadulcic acid B; Apigenin; Betulinic acid; Hispidulin; Luteolin; Scutellarein Coixol; and Glutinol] were identified in *Scoparia dulcis* leaves (Sharma et al., 2017). All these compounds had *in vitro* evidence.

Table 3. Green leafy vegetable species had *in vivo* evidence

Scientific name	Extract / compound	Model	Reference
Abutilon indicum (L.) Sweet	Aqueous	Streptozotocin-induced diabetic	Girija et al., 2011; Uddin et al., 2016
Abutilon indicum (L.) Sweet	Methanol	Streptozotocin-induced diabetic	Malik et al., 2016
Achyranthes aspera L.	Ethyl acetate	Diabetic	Maulidiani et al., 2015; Setyaningsih et al., 2021
Amaranthus spinosus L.	Methanol	Alloxan-induced diabetic	Kumar et al., 2011b; Maurya et al., 2011
Amaranthus spinosus L.	Methanol	Streptozotocin-induced diabetic	Patil et al., 2013; Subhash et al., 1997
Amaranthus spinosus L.	Petroleum ether	Nicotinamide-Streptozotocin-induced diabetic	Kumar et al., 2014; Shetti et al., 2013
Amaranthus viridis L.	Ethanol	Dexamethasone-induced diabetic	Swastika et al., 2019
Amaranthus viridis L.	Ethanol	Neonatal-Streptozotocin-induced diabetic	Swastika et al., 2019
Amaranthus viridis L.	Methanol	Streptozotocin-induced diabetic	Singh et al., 2017
Artemisia dracunculus L.	Aqueous	Normal	Paramesha et al., 2014
Artemisia dracunculus L.	Ethanol	KK-A^{y}; Streptozotocin-induced diabetic	Swastika et al., 2019
Basella alba L.	Aqueous	Streptozotocin-induced diabetic	Arokoyo et al., 2017
Basella alba L.	Aqueous	Diabetes-induced oxidative stress	Arokoyo et al., 2018
Basella alba L.	Aqueous	Diabetes-induced oxidative stress	Kumari et al., 2020
Basella alba L.	Methanol	Streptozotocin-induced diabetic	Singh et al., 2017
Beta vulgaris L.	Methanol	Alloxan-induced diabetic	Singh et al., 2017
Brassica rapa L.	Aqueous	Type 2 diabetic	Arokoyo et al., 2018
Brassica rapa L.	Ethanol	Streptozotocin-induced diabetic	Swastika et al., 2019
Canthium coromandelicum (Burm.f.) Alston	Ethanol	Alloxan-induced diabetic	Swastika et al., 2019
Cardiospermum halicacabum L.	Chrysoeriol	Streptozotocin-induced diabetic	Swastika et al., 2019
Cardiospermum halicacabum L.	Ethanol	Streptozotocin-induced diabetic	Ekambe et al., 2016; Rajeswari et al., 2014; Rajeswari et al., 2014; Smail et

Scientific name	Extract / compound	Model	Reference
			al., 2017; Sri Wahjuni & Ni Wayan Bogoriani, 2020; Swastika et al., 2019
Cardiospermum halicacabum L.	Methanol	Streptozotocin-induced diabetic	Kushwaha et al., 2015; Yadav et al., 2015
Celosia argentea L.	Methanol	Alloxan-induced diabetic	Lee et al., 2016; Zhang et al., 2016
Centella asiatica (L.) Urb.	Ethanol	Streptozotocin-induced diabetic	Veeramani et al., 2008; Veeramani et al., 2015
Centella asiatica (L.) Urb.	Ethanol	High-fat diet-low dose Streptozotocin-induced diabetic	Veeramani et al., 2012; Rajeswari et al., 2014
Centella asiatica (L.) Urb.	Methanol	Fructose fed	Lee et al., 2016
Clitoria ternatea L.	Aqueous	Alloxan-induced diabetic	Logendra et al., 2006
Clitoria ternatea L.	Ethanol	Streptozotocin-induced diabetic	Krishnan et al., 2020
Colocasia esculenta (L.) Schott	Ethanol	Alloxan-induced diabetic	Krishnan et al., 2020
Coriandrum sativum L.	Ethanol	Alloxan-induced diabetic	Veeramani et al., 2008; Veeramani et al., 2015
Coriandrum sativum L.	Methanol	Alloxan-induced diabetic	Luo et al., 2020
Cucurbita maxima Duchesne	Methanol	Streptozotocin-induced diabetic	Luo et al., 2020
Erythrina variegata L.	Methanol	Streptozotocin-induced diabetic	Luo et al., 2020
Ficus racemosa L.	Chloroform	Streptozotocin-induced diabetic	Abd El-Ghffar et al., 2019
Ficus racemosa L.	Ethanol	Streptozotocin-induced diabetic	Krishnan et al., 2020
Ficus racemosa L.	Ethanol	Alloxan-induced diabetic	Veeramani et al., 2015
Ficus racemosa L.	Ethyl acetate	Streptozotocin-induced diabetic	Masola et al., 2018
Ficus racemosa L.	Methanol	Streptozotocin-induced diabetic	Daud & Nasution, 2016; Ogunrinola et al., 2015
Ficus racemosa L.	Not stated	Streptozotocin-induced diabetic	Shetti et al., 2013
Ficus racemosa L.	Petroleum ether	Streptozotocin-induced diabetic	Emmanuel et al., 2010; Onakpa & Ajagbonna, 2012; Shanmugasundaram et al., 2011
Ipomoea batatas (L.) Lam.	Aqueous	Alloxan-induced diabetic; Streptozotocin-induced diabetic	Logendra et al., 2006
Ipomoea batatas (L.) Lam.	Ethanol	Alloxan-induced diabetic	Krishnan et al., 2020
Ipomoea batatas (L.) Lam.	Ethanol	Streptozotocin-induced diabetic	Veeramani et al., 2008
Ipomoea batatas (L.) Lam.	Ethyl acetate	Streptozotocin-induced diabetic	Oyenihi et al., 2019
Ipomoea batatas (L.) Lam.	Not stated	Nicotinamide-Streptozotocin-induced diabetic	Fernando et al., 1990
Ipomoea batatas (L.) Lam.	Petroleum ether	Streptozotocin-induced diabetic	Onakpa & Ajagbonna, 2012
Kalanchoe pinnata (Lam.) Pers.	Aqueous	Streptozotocin-induced diabetic	Weinoehrl et al., 2012
Kalanchoe pinnata (Lam.) Pers.	Ethanol	Normal	Hamzah et al., 2018
Kalanchoe pinnata (Lam.) Pers.	Ethanol	Alloxan-induced diabetic	Veeramani et al., 2012
Melastoma malabathricum L.	Ethanol	Alloxan-induced diabetic	Hamzah et al., 2018
Melastoma malabathricum L.	Methanol	Streptozotocin-induced diabetic	Li et al., 2009
Osbeckia octandra DC.	Aqueous	NS	Ribnicky et al., 2006
Paederia foetida L.	Aqueous	Nicotinamide-Streptozotocin-induced diabetic	Ribnicky et al., 2006
Paederia foetida L.	Ethanol	Nicotinamide-Streptozotocin-induced diabetic	Hamzah et al., 2018
Paederia foetida L.	Methanol	Streptozotocin-induced diabetic	Savita et al., 2015
Senna auriculata (L.) Roxb.	Ethanol	Alloxan-induced diabetic	Hamzah et al., 2018
Senna occidentalis (L.) Link	Methanol	Streptozotocin-induced diabetic	Novrial & Widjojo, 2020; Wicaksono et al., 2016
Senna occidentalis (L.) Link	Methanol	Alloxan-induced diabetic	Shih et al., 2020; Savita et al., 2015

Scientific name	Extract / compound	Model	Reference
Sesbania grandiflora (L.) Poir.	Ethanol	Streptozotocin-induced diabetic	Hamzah et al., 2018; Masola et al., 2018
Sesbania grandiflora (L.) Poir.	Methanol	High fat diet-Streptozotocin induced diabetic	Agüero-hernández et al., 2020; Yuliani et al., 2016
Solanum trilobatum L.	Aqueous	Alloxan-induced diabetic	Arokoyo et al., 2017
Thespesia populnea (L.) Sol. ex Corrêa	Ethanol	Streptozotocin-induced diabetic	Oyenihi et al., 2019
Wattakaka volubilis (L.f.) Stapf	Methanol	Streptozotocin-induced diabetic	Kumar et al., 2013; Menon et al., 2015

Table 4. Green leafy vegetable species had clinical evidence

Scientific name	Extract	Human subject	Reference
Apium graveolens L.	Not stated	Diabetic	Yusni et al., 2018
Coccinia grandis (L.) Voigt	Aqueous	Type 2 diabetic	Wasana et al., 2021
Ipomoea aquatica Forssk.	Raw	Type 2 diabetic	Malalavidhane et al., 2003
Melissa officinalis L.	Aqueous	Normal	Yui et al., 2017
Melissa officinalis L.	Ethanol	Type 2 diabetic	Asadi et al., 2019; Asadi et al., 2018
Melissa officinalis L.	Not stated	Type 2 diabetic	Nayebi et al., 2020
Ocimum basilicum L.	Not stated	Type 2 diabetic	Agrawal et al., 1998
Pandanus amaryllifolius Roxb. ex Lindl.	Aqueous; Ethanol	Normal	Chiabchalard & Nooron, 2015
Passiflora edulis Sims	Not stated	Type 2 diabetic	Chandrasekhar et al., 2019
Scoparia dulcis L.	Not stated	Type 2 diabetic	Senadheera et al., 2015

4. CONCLUSION

The identified and analyzed green leafy vegetables in this investigation show that further researches should be conducted to provide more antidiabetic scientific evidence. Widely available green leafy vegetables are affordable, easily accessible, and cheaper than the rarely available green leafy vegetables. It is recommended that to conduct more investigations into the widely available green leafy vegetables. This will be very useful for the public as well as for researchers who are interested in performing further investigations using these plant species. In addition, more acute toxicity and reaction mechanisms of the plant species that showed antidiabetic activities should be investigated for safety and efficacy purposes. This investigation identified, documented, and examined the available antidiabetic activities of the green leafy vegetables currently sold in the Trincomalee District in Sri Lanka. This research work can be used as a foundation for further research involving the green leafy vegetables sold in Trincomalee.

Conflict of interest

The authors declare that there is no conflict of interest.

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