Research Article

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An appraisal of eighteen commonly consumed edible plants as functional food based on their antioxidant and starch hydrolase inhibitory activities

Yian Hoon Lee,[a] Candy Choo,[a] Mindani I Watawana,[b] Nilakshi Jayawardena[b] and Viduranga Y Waisundara[b*]

Abstract

BACKGROUND: Eighteen edible plants were assessed for their antioxidant potential based on oxygen radical absorbance capacity (ORAC), 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity, total phenolics, vitamin C content and various lipophilic antioxidants. The inhibitory activities of the plant extracts against the enzymatic activities of α-amylase and α-glucosidase were also evaluated.

RESULTS: The antioxidant and starch hydrolase activities of the plants varied widely across a single batch of analysis. The ORAC and DPPH radical scavenging EC_{50} values varied between 298 and 1984 Trolox equivalents g^{-1} fresh weight and between 91 and 533 mg kg^{-1} fresh weight, respectively. The total phenolics and vitamin C contents varied between 32 and 125 mg gallic acid equivalents g^{-1} fresh weight and between 96 and 285 $\mu g\ g^{-1}$ fresh weight, respectively. All the plants contained neoxanthin, violaxanthin, and α- and β- carotene in varying amounts. *Coccinia grandis*, *Asparagus racemosus*, *Costus speciosus*, *Amaranthus viridis* and *Annona muricata* displayed the highest inhibitory activities against starch hydrolases. They were the most efficient against the breakdown of seven starches exposed to the two enzymes as well.

CONCLUSIONS: Overall, the edible plants were observed to display a high antioxidant potential with starch hydrolase inhibitory properties, which were beneficial in their being recognized as functional food.

Keywords: α-amylase; α-glucosidase; DPPH; functional food; ORAC; vitamin C

INTRODUCTION

Functional food has been a rapidly growing area of interest over recent years in the areas of product development and scientific research. By definition, functional food is considered to be similar in appearance to a conventional food, is consumed as part of the usual diet, is demonstrated to have physiological benefits and has the ability to reduce the chances of contracting chronic diseases and/or contain a disease condition which has already been contracted.[1,2] Functional food includes substances which originate from plant sources such as vitamin- and mineral-enriched products, products containing added fiber, pre-, pro- and synbiotics, and omega-3 fatty acids/oils, among others, as well as those which are derived from animals and microorganisms.[3,4] In this aspect, functional food products are commonly known to contain bioactives which are able to prevent or contain disease conditions of a complex nature such as diabetes, cardiovascular disease, cancer, immune and inflammatory disorders and many other diseases related to the aging process.[5,7]

Among all bioactives existing in food which classifies them as being functional, antioxidants have received much attention from a therapeutic perspective.[8−10] Food phenolics have been identified as the major source of antioxidant activity and are commonly present in all parts of plants, including vegetables and fruits.[8] The mechanism by which phenolic compounds exert their beneficial effects may be related, but not limited, to their antioxidant activity.[11] Along the lines of functional food and bioactives, a more recent advance in terms of phytochemicals with a therapeutic value are starch hydrolase inhibitors. These inhibitors retard the absorption of glucose through inhibition of the starch-hydrolyzing enzymes, such as α-amylase and α-glucosidase, which are present in the small intestinal brush border. Inhibitors of these two enzymes in particular can delay starch digestion, causing a reduction in the rate of glucose absorption into the bloodstream and consequently blunting postprandial plasma glucose rise.

The objective of this study was to identify and appraise 18 commonly consumed edible plants as functional food. For the purpose of quantifying the antioxidant potential, the antioxidant

* *Correspondence to: Viduranga Y Waisundara, Institute of Fundamental Studies, Hantane Road, Kandy 20000, Sri Lanka. E-mail: viduranga@gmail.com*

a *Temasek School of Applied Science, Temasek Polytechnic, Singapore 529757,*

b *Institute of Fundamental Studies, Kandy 20000, Sri Lanka*

capacity of hydrophilic fractions of the plants was assessed using the oxygen radical absorbance capacity (ORAC) and 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity assays. Neither of these assays was performed on lipophilic fractions of the plants since they were found in previous studies to contain less than 10% of their antioxidant capacity as compared to their hydrophilic fractions.[12] The individual lipophilic antioxidant compounds were measured instead using high-performance liquid chromatography (HPLC) to provide a more accurate quantification as well as better identification of the lipophilic compounds contributing to the antioxidant potential. The total phenolics and vitamin C contents were also evaluated. The α-amylase and α-glucosidase inhibitory activities of these edible plants were determined, in addition to their ability to reduce the breakdown of some commonly consumed starches which were exposed to the enzymatic activity of α-amylase and α-glucosidase. Overall, the study was able to identify the therapeutic potential of these edible plants in terms of antioxidant and starch hydrolase inhibitory activities.

EXPERIMENTAL

Chemicals

Anhydrous sodium carbonate, Folin–Ciocalteu phenol reagent, KH_2PO_4 and K_2HPO_4 were obtained from Merck (Darmstadt, Germany). Gallic acid and Trolox were purchased from Acros Organics (Morris Plains, NJ, USA). 2,2-Azobis(2-amidinopropane) dihydrochloride (AAPH), fluorescein disodium salt, vitamin C, neoxanthin, violaxanthin, lutein, zeaxanthin, lycopene, α- and β-carotene and metaphosphoric acid were purchased from Sigma Chemicals (St Louis, MO, USA). Sulfuric acid (95%) was obtained from BDH (UK). Tetrahydrofuran, *n*-hexane, methanol, *n*-butanol, ethyl acetate, acetone and acetonitrile (HPLC/Spectro grade) were purchased from Tedia (Fairfield, OH, USA). Absolute ethanol, butylated hydroxytoluene (BHT) and disodium sulfate (analytical grade) were obtained from Merck (Darmstadt, Germany). α-Amylase from porcine pancreas (type VI-B) and α-glucosidase in the form of rat intestine acetone powder were purchased from Sigma-Aldrich (St Louis, MO, USA). Corn, rice and wheat starches (whole wheat) were purchased from Sigma-Aldrich (St Louis, MO, USA), while atta (durum wheat of *Triticum* spp.), cassava, finger millet/ragi/kurakkan (*Eleusine coracana*) and kitul (*Caryota urens*) starches were purchased from Bangkok International Food Co. Ltd (Bangkok, Thailand).

Selection and authentication of edible plants and preparation of their extracts

Table 1 lists the edible plants used in the study, chosen mostly based on their therapeutic properties and popularity among consumers as documented in the authoritative literature and market studies.[13–16] The plants were collected from the central province of Sri Lanka in representative locations and identified by comparison with the respective herbarium specimen available at the National Herbarium of the Peradeniya Botanical Gardens in Kandy, Sri Lanka, while voucher specimens were appropriately placed in the same location. The registration numbers of plants are indicated against their scientific names in Table 1. The plants were intensively dried and ground to powder. The powder (0.5–1.0 g) was extracted three times with acetone–water–acetic acid (8.0 mL, 70:29.5:0.5; AWA), which was the same solvent used by Wu *et al.*[12] After the addition of AWA solvent, the tube was vortexed for 30 s, followed by sonication for 15 min, with temperature maintained between 37 and 39 °C. The tube was shaken once in the middle of the sonication step to suspend the sample. After sonication, the tube was vortexed for 30 s and cooled to room temperature. The tube was then centrifuged and the supernatant was collected in a 25 mL volumetric flask and topped up to the mark with AWA for analysis. Isabelle *et al.*[16] had shown that the procedure for extraction was able to extract most of the phenolics, with less than 5% of the total phenolics content (TPC) detected in the fourth extraction supernatant.

Table 1. Botanical, registration numbers and family names of edible plants

Botanical name and registration number	Family
Adhathoda vasica (pdn A 4 1 4 3)	Acanthaceae
Amaranthus viridis (pdn A 6 9 3 2)	Amaranthaceae
Alternanthera sessilis (pdn A 3 10 2 3)	Amaranthaceae
Annona muricata (pdn A 2 1 1 3)	Annonaceae
Artocarpus heterophyllus (pdn A 5 2 7 1)	Moraceae
Asparagus racemosus (pdn A 6 1 4 1)	Asparagaceae
Centella asiatica (pdn A 3 1 1 2)	Mackinlayaceae
Coccinia grandis (pdn A 6 1 5 1)	Cucurbitaceae
Costus speciosus (pdn A 2 8 5 1)	Zingiberaceae
Desmodium gangeticum (pdn A 3 1 5 1)	Fabaceae
Gymnema sylvestre (pdn A 1 4 2 3)	Asclepiadaceae
Ipomoea aquatica (pdn A 8 3 1 2)	Convolvulaceae
Mimosa pudica (pdn A 3 2 3 4)	Fabaceae
Momordica charantia (pdn A 6 4 1 2)	Cucurbitaceae
Psidium guava (pdn A 3 2 6 5)	Myrtaceae
Sesbania grandiflora (pdn A 7 3 1 2)	Fabaceae
Solanum americanum (pdn A 4 5 7 2)	Solanaceae
Wattakaka volubilis (pdn A 7 2 1 9)	Asclepiadaceae

ORAC assay

The assay was carried out according to the method of Prior *et al.*,[17] with a few modifications, in 96-well microplate format using a Thermo Scientific Multiskan FC microplate reader. Fluorescein disodium was used for the kinetic monitoring of free radical quenching and AAPH was used as the free radical source. Excitation and emission wavelengths were 485 and 528–538 nm, respectively. The following components were added to a single well: (i) blank (phosphate-buffered saline)–Trolox standard–sample: 20 µL; (ii) fluorescein working solution: 160 µL; and (III) AAPH: 20 µL. Reaction kinetics were monitored for 2 h at 37 °C, following which the area under the curve was used to calculate the ORAC value compared with those of the Trolox standards. Results were expressed as µmol TE per gram fresh weight (µmol TE g^{-1} FW) of extract.

Determination of the DPPH radical scavenging activity

Extract concentrations of 62.5, 125, 250, 500 and 1000 mg kg^{-1} were prepared by dilution with 75 mmol L^{-1} phosphate buffer (pH 7.4). A 96-well microplate was used for the analysis, in which 140 µL of the respective extracts of the leaves were pipetted along with 60 µL of 400 µmol L^{-1} DPPH (prepared in 75 mmol L^{-1} phosphate buffer solution). The blank wells consisted of 200 µL of the phosphate buffer solution, while the control wells consisted of 140 µL of the phosphate buffer solution and 60 µL of the DPPH solution. The microplate was incubated at 37 °C for 30 min and

absorbance was measured at 517 nm, using a Thermo Scientific Multiskan FC microplate reader. Each sample concentration was added in triplicate to the microplate. Vitamin C was used as the positive control. Antioxidant activity was calculated as % DPPH radical scavenging activity by substituting the absorbance values into the following equation:

$$\%\ \text{DPPH radical scavenging activity} = \frac{\text{Abs}_{\text{Control/Extract}} - \text{Abs}_{\text{Blank}} \times 100}{\text{Abs}_{\text{Control}}}$$

The % DPPH scavenging activity of 10 replicates of each sample was used to calculate the EC_{50} values (in mg kg^{-1} FW) of the extracts.

Determination of total phenolics content

The method, as described by Huang *et al.*,[18] was used for determining the total phenolic content of the plant extracts. Gallic acid was used as the standard to plot a curve, in which concentrations of 50.0, 25.0, 12.5, 6.2 and 3.1 mg mL^{-1} were prepared by carrying out serial dilutions using deionized (DI) water. The following constituent volumes were added to a single well: Folin–Ciocalteu reagent: 100 µL; sample–blank (DI water)–gallic acid standard: 20 µL; Na_2CO_3 (30 g L^{-1}): 80 µL. The microplate was incubated at room temperature for 15 min, following which the absorbance was read at 540 nm using the Thermo Scientific Multiskan FC microplate reader. Dilutions were performed on the leaf extracts as deemed necessary, for the absorbance values to fit within the gallic acid standard curve. Results were expressed as milligrams of gallic acid equivalents per gram fresh weight (mg GAE g^{-1} FW).

Determination of vitamin C content

Ascorbic acid was extracted and analyzed in triplicate following the method from Sánchez-Mata *et al.*,[19] with a slight modification. Plant powders (10–70 mg) were extracted with 1.4 mL of 4.5% metaphosphoric acid for 15 min using a plate shaker (Heidolph Rotamax 120) at 300 rpm and 25 °C. The sample was centrifuged and the supernatants were filtered through 0.45 µm filters. Analysis was carried out using a Waters 2695 separation module equipped with a model 2996 PDA detector (Milford, MA, USA) and a Waters Atlantis T3 C18 column (5 µm, 250 mm × 4.6 mm i.d.). Each sample (20 µL) was injected into the HPLC system. H_2SO_4 (0.01%) in water was used as the mobile phase and the flow was maintained at 1.0 mL min^{-1}. Vitamin C peak was monitored at 245 nm. Quantification was performed using a vitamin C standard curve with concentrations ranging from 5 to 320 mg L^{-1}.

Determination of lipophilic antioxidant content

Sample extraction and HPLC analysis for the lipid-soluble antioxidants were carried out according to the internal standard (IS) method by Lee *et al.*[20] At least triplicate extractions were performed for each sample. IS solution was prepared weekly according to the method by Lee *et al.*. For calibration, 100 µL of the IS solution were mixed with 100 µL of standard mixtures of various concentrations. Stock solutions of each standard were prepared individually with relevant solvents as described by Lee *et al.*[21]

Assays of α-amylase and α-glucosidase inhibitory activities and evaluation of the extracts' effects on breakdown of starches

The α-amylase inhibitory activity of leaf extracts was carried out according to the method by Liu *et al.*,[22] and the α-glucosidase inhibitory activity was carried out according to the method by Koh *et al.*.[23] Acarbose was used as the positive control for both assays and the data were expressed as both IC_{50} (mg mL^{-1}) and micromoles of acarbose equivalents per gram fresh weight basis (µmol AE g^{-1} FW). The plant extracts were prepared for comparison of α-amylase and α-glucosidase inhibitory activity with seven different starch sources (i.e. atta, cassava/manihoc, corn, finger millet/ragi/kurakkan, kitul, rice, wheat) according to the method described by Liu *et al.*[22] The area under the curve of each concentration was calculated, and the data were expressed as both IC_{50} (mg mL^{-1}) and µmol AE g – 1 FW.

Statistical analysis

All data are presented as means (± SEM) of at least three independent experiments ($n \geq 3$); each experiment had a minimum of three replicates of each sample. For comparisons between samples, data were analyzed by ANOVA and Tukey's multiple comparison test (SPSS, version 17). A probability of 5% or less was accepted as statistically significant.

RESULTS

Antioxidant potential of hydrophilic extracts of edible plants

The ORAC values, DPPH EC_{50} values and vitamin C content of the edible plants are shown in Table 2. The table is arranged in decreasing order of ORAC values. The mean ORAC value of the plant extracts was 998.8 µmol TE g^{-1} FW, while the mean DPPH EC_{50} value was 266.7 mg kg^{-1} FW. The mean total phenolics content was 67.3 mg GAE g^{-1} FW. The mean vitamin C content was 188.3 mg g^{-1} FW. *Coccinia grandis*, *Asparagus racemosus* and *Costus specious* had the highest ORAC values, the lowest DPPH EC_{50} values and the highest total phenolics content. In comparing the ORAC and the DPPH EC_{50} values, the former had a better correlation with the total phenolics content, while they were also comparable with the values of a similar study conducted by Wu *et al.*[12] Given the two different approaches of quantifying the antioxidant capacity, both assays were carried out in this study to cover all possible reaction mechanisms of the antioxidants. However, the ORAC values may have had a better correlation with the total phenolics content, as the phenolic compounds present in the leaf extracts may have been better scavengers of peroxyl radicals which are generated in the ORAC assay rather than DPPH.[24] The ORAC values to total phenolics ratio was in the range of 10–20. The high ratio would have been due to the presence of non-phenolic antioxidants in the extracts, or the presence of phenolic antioxidants having strong radical scavenging activity. Nevertheless, as previously shown by Isabelle *et al.*,[25] as well as Wu *et al.*,[12] the total phenolics content was observed to be a good indicator of the antioxidant capacity for the edible plants.

Most edible plants are regarded as good source of vitamin C, which is a powerful antioxidant, effective in scavenging superoxide radical anion, hydrogen peroxide, the hydroxyl radical, singlet oxygen and reactive nitrogen oxide.[26] The vitamin C content in the edible plants of this study correlated poorly with both total phenolics content and the ORAC values ($R^2 < 0.5$). Since vitamin C reduces the Folin–Ciocalteu reagent, subtraction of its contribution is necessary to obtain a more accurate total phenolics content.

Table 2. ORAC values, DPPH EC_{50}, total phenolics and vitamin C content of edible plants

Botanical name	Moisture content (%)	ORAC(μmol TE g^{-1} FW)	DPPH EC_{50} (mg kg^{-1})	Total phenolics content (mg GAE g^{-1} FW)	Vitamin C (μg g^{-1} FW)	Corrected total phenolics content (mg GAE g^{-1} FW)[a]
Coccinia grandis	91.6 ± 1.2	1984.3 ± 21.1	91.2 ± 7.5	125.1 ± 13.5	156 ± 23.5	124.9 ± 12.4
Asparagus racemosus	92.3 ± 2.1	1828.4 ± 18.6	91.2 ± 7.2	118.3 ± 13.6	128.9 ± 36.1	118.1 ± 10.3
Costus speciosus	89.7 ± 1.4	1744.2 ± 16.1	102.2 ± 10.1	99.8 ± 14.6	102.6 ± 29.1	99.7 ± 12.4
Amaranthus viridis	90.7 ± 2.1	1660.2 ± 19.1	97.5 ± 10.4	90.6 ± 9.8	114.6 ± 30.6	90.5 ± 10.1
Annona muricata	92.4 ± 0.9	1536.2 ± 11.9	98.9 ± 9.1	86.5 ± 14.8	169.3 ± 19.5	86.3 ± 13.6
Sesbania grandiflora	91.4 ± 1.3	1487.2 ± 15.9	118 ± 9.0	82.6 ± 6.5	96.8 ± 39.1	82.5 ± 6.1
Desmodium gangeticum	89.6 ± 1.5	1395.1 ± 18.1	146.4 ± 11.1	83.4 ± 5.5	201.4 ± 20.4	83.2 ± 4.8
Mimosa pudica	88.2 ± 2.1	1187.9 ± 11.3	243.2 ± 8.9	70.2 ± 5.5	259.1 ± 11.5	69.9 ± 8.3
Momordica charantia	92.4 ± 1.4	1097.1 ± 16.5	283 ± 12.7	69.6 ± 9.6	274.5 ± 23.0	69.4 ± 8.6
Alternanthera sessilis	90.2 ± 1.8	596.2 ± 11.2	313 ± 12.5	56.8 ± 5.9	208.2 ± 16.5	56.6 ± 6.3
Artocarpus heterophyllus	89.3 ± 1.3	587.2 ± 14.3	315.6 ± 11.9	54.3 ± 6.9	165.9 ± 17.3	54.2 ± 6.1
Adhathoda vasica	93.6 ± 2.2	560.1 ± 11.1	326.5 ± 18.1	52.3 ± 8.6	311.5 ± 18.6	52.0 ± 8.3
Psidium guava	92.9 ± 1.6	531.1 ± 13.1	354.4 ± 16.3	51.3 ± 9.2	245.4 ± 17.5	51.1 ± 7.4
Solanum americanum	91.6 ± 1.4	490.1 ± 20.3	389.6 ± 14.5	48.1 ± 6.9	219.5 ± 16.0	47.9 ± 6.3
Gymnema sylvestre	93.4 ± 1.4	412.2 ± 16.3	476.0 ± 21.4	46.1 ± 7.5	226.3 ± 15.7	45.9 ± 7.2
Centella asiatica	92.1 ± 0.8	369.8 ± 10.8	519.3 ± 22.1	40.6 ± 5.9	284.7 ± 16.3	40.4 ± 5.5
Wattakaka volubilis	91.7 ± 1.5	325.4 ± 18.5	511.2 ± 10.2	40.7 ± 6.8	103.6 ± 28.9	40.6 ± 6.2
Ipomoea aquatica	88.5 ± 2.1	289.5 ± 10.9	533.7 ± 12.4	36.4 ± 6.1	119.4 ± 27.4	36.3 ± 5.7

[a] Corrected total phenolics content obtained from deducting the vitamin C contribution (1 mg vitamin C = 0.873 mg GAE).

The vitamin C standard was assayed using the method for quantifying total phenolics content, and it was found to possess a reducing activity of 0.873 mg GAE g^{-1} vitamin C – consistent with the value obtained by Isabelle *et al.*[25] For each edible plant, the vitamin C contribution was calculated by multiplying the vitamin C content by 0.873. The corrected total phenolics content of the vegetables is presented in Table 2. Overall, the analyses indicated the edible plants to be a good source of vitamin C.

Lipophilic antioxidant content of edible plant extracts

The lipophilic antioxidant content is listed in Table 3. In general, all the edible plants contained neoxanthin, violaxanthin and α- and β-carotene in varying amounts. *Coccinia grandis*, *Costus speciosus*, *Annona muricata*, *Momordica charantia* and *Wattakaka volubilis* had the highest amount of total carotenoids of the 18 edible plants. The total carotenoids were obtained from the sum of neoxanthin, violaxanthin, lutein, zeaxanthin and α- and β-carotene, while the total vitamin E vitamers were obtained from the sum of α-, δ- and γ- tocophercol. The highest vitamin E vitamers were present in *Asparagus racemosus*, *Amaranthus viridis*, *Wattakaka volubilis*, *Centella asiatica* and *Sesbania grandiflora*. α-Tocopherol was identified to be the most abundant active form of vitamin E in the edible plants. This observation was further supported by the results in the study by Isabelle *et al.*[25] No clear relationship was observed between the relationships of ORAC, total carotenoids and vitamin E content ($R^2 < 0.5$ for all).

Starch hydrolase inhibitory activities

Table 4 shows the α-amylase and α-glucosidase inhibitory activities of the plant extracts. The mean α-amylase inhibitory activity of the extracts was 186.3 μmol AE g^{-1} FW, while it was 16.6 μmol AE g^{-1} FW for α-glucosidase. *Coccinia grandis*, *Asparagus racemosus*, *Costus speciosus*, *Amaranthus viridis* and *Annona muricata* had the highest inhibitory activities against both α-amylase and α-glucosidase. It is noteworthy that the five plants with the highest inhibitory activities have been consistently used in traditional medicinal systems as antidiabetic treatments or consumed together with starch-based products as salads or incorporated into porridge.[27,28] Of the two enzymes, all the plant extracts were observed to inhibit α-amylase better than α-glucosidase. Tables 5 and 6 shows the α-amylase and α-glucosidase inhibitory activities of the 18 plants against the breakdown of the seven gelatinized starches. *Coccinia grandis*, *Asparagus racemosus*, *Costus speciosus*, *Amaranthus viridis* and *Annona muricata* were identified to possess the highest inhibitory activities in this instance as well. However, statistical analysis of the data revealed the relative standard deviation (RSD) of α-amylase and α-glucosidase inhibition activity for all the plant extracts to be less than 20%, suggesting that variability of the sources of starch had no effect on the inhibitory activities of any of the extracts. The starches analyzed in this study are commonly used in culinary applications around the world and also happened to cover a range of glycemic index (GI) values. The amylose content of these starches is known to vary between 0% and 40%.[29] Numerous studies have classified atta, finger millet/kurakkan/ragi and kitul as low GI compared with milled polished rice, and it has been widely recommended as a suitable food for diabetics.[30–32]

DISCUSSION

Functional foods are viewed as a novel therapeutic intervention in the West.[14] In contrast, food has been viewed as medicine in many of the traditional medicinal systems of the East. Thus many of the functional food which have been identified from Asia have been associated with disease prevention for many years.[33] In fact, it is the lack of scientific investigations and systematic studies which have been preventing the functional food in these traditional diets from coming into the limelight as disease-preventing agents. Better

Table 3. Lipophilic antioxidant content of edible plant extracts[a]

Botanical name	Neoxanthin	Viola xanthin	Lutein	Zea xanthin	Lycopene	Carotene α	Carotene β	Tocopherol α	Tocopherol δ	Tocopherol γ	Total Carotenoids[c]	Total vitamin E vitamers[d]
Coccinia grandis	39.63	5.95	13.65	7.31	1.12	0.06	0.25	0.08	0.06	0.05	67.97	0.19
Asparagus racemosus	2.61	1.55	5.26	1.32	ND[b]	0.06	3.58	0.45	0.08	6.55	14.38	7.08
Costus speciosus	32.25	6.21	12.95	6.18	0.95	0.08	0.38	0.19	0.15	0.18	59.00	0.52
Amaranthus viridis	14.81	5.94	3.46	5.49	1.05	1.15	1.16	2.06	1.95	1.88	33.06	5.89
Annona muricata	20.46	6.51	ND	3.54	ND	0.65	0.28	0.41	0.07	0.34	31.44	0.82
Sesbania grandiflora	12.95	12.66	3.44	3.68	ND	0.54	1.68	0.55	0.52	0.41	34.95	1.48
Desmodium gangeticum	10.84	1.29	0.90	0.29	0.05	0.22	0.28	0.09	0.08	0.06	13.87	0.23
Mimosa pudica	9.86	6.57	7.75	ND	0.62	0.19	0.25	0.25	ND	ND	25.24	0.25
Momordica charantia	18.65	2.58	17.64	0.55	0.36	0.21	0.25	0.08	0.06	0.06	40.24	0.18
Alternanthera sessilis	3.69	4.58	4.20	0.69	0.49	0.35	0.47	0.28	0.04	0.06	14.47	0.38
Artocarpus heterophyllus	4.55	6.48	ND	ND	0.61	0.58	0.34	0.07	0.06	0.06	12.56	0.19
Adhathoda vasica	3.19	3.54	6.58	6.47	0.94	0.64	0.85	0.07	0.06	0.05	22.21	0.18
Psidium guava	8.64	3.67	5.50	6.35	0.84	0.38	0.81	0.07	ND	ND	26.19	0.07
Solanum americanum	5.87	4.31	3.84	0.90	0.55	0.20	0.80	0.10	0.08	ND	16.47	0.18
Gymnema sylvestre	14.38	5.64	2.80	1.24	0.47	0.14	0.61	0.84	0.39	0.41	25.28	1.64
Centella asiatica	17.96	3.22	3.64	1.58	1.47	0.26	0.24	0.81	0.37	0.54	28.37	1.72
Wattakaka volubilis	11.38	10.55	4.28	4.20	1.28	1.24	0.34	0.83	0.71	0.69	33.27	2.23
Ipomoea aquatica	9.64	11.68	2.65	ND	0.82	0.34	0.57	0.88	0.24	0.75	25.70	1.87
Lower detection limit	0.02	0.02	0.05	0.05	0.05	0.01	0.04	0.01	0.02	0.02		
Lower quantification limit	0.05	0.07	0.13	0.12	0.15	0.04	0.12	0.03	0.05	0.05		
Analytical CV	12%	14%	11%	12%	13%	12%	10%	12%	11%	11%		

[a] Data expressed as micrograms per gram fresh weight basis (μg g^{-1} FW) and presented as mean. The order of edible plants is arranged to be the same as in Table 3.
[b] ND, not detected.
[c] Total carotenoids obtained from the sum of neoxanthin, violaxanthin, lutein, zeaxanthin and α- and β-carotene expressed as micrograms of carotenoids per gram fresh weight.
[d] Total vitamin E vitamers obtained from the sum of α-, δ- and γ- tocophercol expressed as micrograms of vitamin E per gram fresh weight.

Table 4. α-Amylase and α-glucosidase inhibitory activity of edible plant extracts

Botanical name	μmol AE g^{-1}	μmol AE g^{-1}
Acarbose	1547.8	1547.8
Coccinia grandis	325.2 ± 11.3	49.6 ± 0.7
Asparagus racemosus	316.7 ± 18.5	41.8 ± 3.1
Costus speciosus	289.2 ± 20.5	38.7 ± 1.3
Amaranthus viridis	252.6 ± 19.6	37.3 ± 2.6
Annona muricata	208.9 ± 16.5	25.0 ± 2.3
Sesbania grandiflora	201.6 ± 15.2	16.8 ± 1.3
Desmodium gangeticum	195.6 ± 13.6	18.6 ± 1.6
Mimosa pudica	189.3 ± 9.2	6.6 ± 0.5
Momordica charantia	180.3 ± 9.6	6.9 ± 0.9
Alternanthera sessilis	175.6 ± 8.9	11.3 ± 1.6
Artocarpus heterophyllus	169.5 ± 8.1	4.6 ± 0.5
Adhathoda vasica	154.3 ± 7.9	3.1 ± 0.6
Psidium guava	148.6 ± 10.7	3.6 ± 0.1
Solanum americanum	134.8 ± 8.6	8.9 ± 1.2
Gymnema sylvestre	121.6 ± 7.5	8.3 ± 1.2
Centella asiatica	108.6 ± 8.1	3.6 ± 0.4
Wattakaka volubilis	92.6 ± 7.6	7.4 ± 0.9
Ipomoea aquatica	88.2 ± 8.5	6.9 ± 0.5

yet, functional food with a traditional presence and of ancient origin have been 'clinically tested' for years, with their recipes fine-tuned across the generations; it requires minimal processing, easing their incorporation into the fast-paced modern lifestyle of urban populations, where diseases related to the diet seem to be comparatively more prevalent.[34,35] The edible plants analyzed in this study have a traditional presence where they have been part of the diet for many centuries, either for medicinal purposes or for general health and wellness. Therefore, despite the scientific evidence provided by the study, it could be highlighted that these edible plants have been generally regarded as functional food due to their traditional usage.

Diets biased towards plant-based components are known to provide high amounts of antioxidant phytochemicals, which offer protection against reactive oxygen species (ROS)-induced cellular damage.[33,36] Oxidation of DNA, lipids and proteins by ROS play an important role in aging and its associated disease conditions.[34,37] Although the presence of ROS in the body has been justified as a mechanism of defense against foreign organisms, striking an optimum balance in terms of ROS concentration has been highlighted as a key element in maintaining well-being and good health, thereby reducing the risk of disease contraction and increasing the containment of contracted diseases.[37] This study has focused on both hydrophilic and lipophilic antioxidant capacities and components. However, since these edible plants are typically prepared in households using water for broth or porridge, or simply as salads, upon consumption, the principal contribution of the antioxidant potential of these leaves may be hypothesized to be drawn from the water-soluble antioxidant components. This is further complemented by the vitamin C content present in the edible plant extracts. The values indicate the selected plants to be good sources of vitamin C, where the compound itself is known to be a water-soluble antioxidant.[34]

Table 5. α-Amylase inhibitory activities of edible plant extracts *versus* the different starches. The plant extracts which had the highest starch hydrolase inhibitory activities are shown in bold

	Atta		Cassava/manihoc		Corn/maize		Finger millet/Ragi/Kurakkan		Kitul		Rice		Wheat	
	IC_{50} μg mL^{-1}	μmol AE g^{-1}	IC_{50} μg mL^{-1}	μmol AE g^{-1}	IC_{50} μg mL^{-1}	μmol AE g^{-1}	IC_{50} μg mL^{-1}	μmol AE g^{-1}	IC_{50} μg mL^{-1}	μmol AE g^{-1}	IC_{50} μg mL^{-1}	μmol AE g^{-1}	IC_{50} μg mL^{-1}	μmol AE g^{-1}
Acarbose	3.7 ± 0.2	1547.6 ± 1.4	4.7 ± 0.3	1543.5 ± 1.3	4.9 ± 0.1	1542.6 ± 1.4	3.8 ± 0.3	1547.5 ± 1.3	3.6 ± 0.4	1548.1 ± 1.2	4.6 ± 0.2	1545.9 ± 2.0	4.8 ± 0.1	1547.3 ± 1.8
Coccinia grandis	**25.2 ± 2.3**	**271.5 ± 18.5**	**31.6 ± 3.1**	**251.2 ± 16.5**	**36.2 ± 2.5**	**240.2 ± 15.4**	**26.9 ± 3.2**	**264.3 ± 18.5**	**27.6 ± 3.5**	**267.5 ± 17.5**	**41.2 ± 2.4**	**243.1 ± 18.4**	**42.9 ± 2.7**	**223.1 ± 19.1**
Asparagus racemosus	**27.4 ± 3.9**	**249.8 ± 20.6**	**29.8 ± 5.8**	**249.1 ± 17.5**	**39.7 ± 6.1**	**218.6 ± 16.3**	**29.4 ± 4.3**	**226.3 ± 19.1**	**36.9 ± 4.0**	**206.3 ± 14.9**	**44.6 ± 8.1**	**209.4 ± 20.9**	**47.9 ± 3.1**	**199.8 ± 10.5**
Costus specious	**31.4 ± 6.3**	**229.0 ± 15.6**	**36.1 ± 6.0**	**209.8 ± 9.6**	**38.1 ± 7.7**	**204.6 ± 14.6**	**37.1 ± 5.4**	**208.9 ± 17.8**	**46.2 ± 6.8**	**189.6 ± 13.4**	**42.6 ± 7.1**	**196.3 ± 13.5**	**46.7 ± 5.2**	**210.6 ± 11.2**
Amaranthus viridis	**53.6 ± 2.9**	**185.2 ± 9.6**	**58.9 ± 5.5**	**175.6 ± 7.1**	**48.9 ± 5.9**	**195.6 ± 11.9**	**57.6 ± 6.3**	**187.3 ± 13.6**	**57.9 ± 6.5**	**185.3 ± 9.8**	**57.6 ± 8.6**	**183.9 ± 9.6**	**59.3 ± 6.4**	**180.3 ± 8.9**
Annona muricata	**67.3 ± 4.8**	**165.3 ± 10.5**	**68.5 ± 5.4**	**159.5 ± 8.3**	**59.3 ± 6.1**	**186.2 ± 9.6**	**64.2 ± 6.2**	**181.3 ± 10.3**	**68.9 ± 5.3**	**183.2 ± 8.2**	**70.2 ± 7.9**	**183.5 ± 8.5**	**66.5 ± 7.4**	**175.6 ± 5.6**
Sesbania grandiflora	77.6 ± 6.2	126.9 ± 6.2	88.9 ± 7.3	123.6 ± 6.0	82.6 ± 6.6	124.3 ± 7.3	92.3 ± 5.3	118.6 ± 6.3	86.3 ± 6.5	123.5 ± 8.1	87.3 ± 7.6	125.3 ± 7.9	89.6 ± 8.6	125.6 ± 5.8
Desmodium gangeticum	98.6 ± 8.8	96.3 ± 6.2	102.3 ± 6.8	95.6 ± 7.2	97.2 ± 9.5	95.2 ± 6.8	94.5 ± 6.3	98.2 ± 5.2	94.2 ± 2.2	93.6 ± 6.3	90.5 ± 5.2	91.5 ± 6.6	91.5 ± 8.0	91.0 ± 5.4
Mimosa pudica	125.4 ± 9.3	81.3 ± 7.3	152.3 ± 9.8	80.5 ± 6.8	143.8 ± 10.4	81.5 ± 6.9	138.6 ± 8.1	81.5 ± 9.5	138.7 ± 5.8	82.5 ± 6.9	142.3 ± 9.8	81.6 ± 7.8	143.0 ± 8.4	81.6 ± 6.5
Momordica charantia	139.5 ± 8.1	75.6 ± 6.8	128.3 ± 7.9	71.6 ± 6.6	130.5 ± 9.6	73.6 ± 7.2	135.8 ± 8.0	70.6 ± 8.9	135.6 ± 6.0	68.2 ± 5.0	131.2 ± 7.9	71.2 ± 7.2	139.5 ± 7.9	70.6 ± 7.9
Alternanthera sessilis	173.6 ± 10.2	61.2 ± 6.5	177.5 ± 9.6	60.3 ± 8.1	174.5 ± 8.5	60.3 ± 6.3	178.6 ± 8.1	63.5 ± 8.7	176.2 ± 8.6	61.5 ± 8.6	174.6 ± 9.0	58.6 ± 6.0	179.5 ± 11.9	57.9 ± 8.1
Artocarpus heterophyllus	196.3 ± 11.2	53.6 ± 6.0	195.3 ± 9.8	50.3 ± 6.9	189.6 ± 8.8	49.5 ± 5.8	192.3 ± 6.3	51.3 ± 6.0	197.6 ± 8.0	51.0 ± 6.1	190.5 ± 8.5	49.6 ± 5.5	193.5 ± 8.9	49.6 ± 8.1
Adhathoda vasica	205.9 ± 13.6	42.6 ± 5.5	211.9 ± 10.8	41.5 ± 6.5	219.6 ± 9.5	40.5 ± 6.1	221.8 ± 9.2	42.6 ± 6.3	225.8 ± 10.5	43.6 ± 6.6	228.9 ± 11.6	41.9 ± 5.9	234.6 ± 11.9	40.9 ± 6.1
Psidium guava	259.6 ± 14.9	35.8 ± 6.1	278.6 ± 17.9	32.6 ± 6.1	284.6 ± 8.9	31.9 ± 5.5	279.5 ± 8.8	32.2 ± 5.8	297.6 ± 16.8	31.9 ± 5.9	294.6 ± 13.8	33.5 ± 6.2	284.1 ± 12.8	34.2 ± 6.3
Solanum americanum	302.5 ± 16.9	24.6 ± 5.4	335.9 ± 14.9	20.9 ± 4.9	328.9 ± 19.8	23.9 ± 5.4	331.6 ± 15.9	22.8 ± 3.9	309.6 ± 17.8	23.5 ± 5.8	348.9 ± 19.4	20.9 ± 7.1	345.6 ± 17.8	21.8 ± 3.8
Gymnema sylvestre	337.6 ± 18.7	20.1 ± 5.0	359.8 ± 15.8	19.8 ± 5.5	359.8 ± 20.5	18.9 ± 5.3	368.9 ± 21.8	18.7 ± 4.4	364.9 ± 21.3	18.9 ± 5.2	389.5 ± 21.9	20.6 ± 5.8	373.6 ± 16.9	19.5 ± 3.9
Centella asiatica	359.6 ± 14.9	18.5 ± 4.9	377.9 ± 17.6	18.2 ± 5.1	384.6 ± 17.8	18.8 ± 4.9	375.9 ± 19.5	15.9 ± 4.3	389.6 ± 18.5	17.1 ± 5.2	365.8 ± 19.6	18.5 ± 3.6	388.2 ± 19.6	18.6 ± 3.5
Wattakaka volubilis	402.6 ± 22.9	14.9 ± 2.9	406.9 ± 19.8	15.5 ± 3.1	405.9 ± 12.9	12.9 ± 3.2	411.8 ± 13.9	13.6 ± 2.9	420.3 ± 21.9	14.3 ± 3.3	428.9 ± 28.1	14.2 ± 1.8	443.6 ± 18.2	14.9 ± 3.6
Ipomoea aquatica	405.6 ± 20.3	13.9 ± 2.5	409.6 ± 19.9	11.9 ± 2.4	408.6 ± 16.8	12.5 ± 3.1	405.8 ± 21.3	10.9 ± 2.4	410.8 ± 19.7	15.7 ± 2.2	410.1 ± 19.7	18.5 ± 2.3	407.4 ± 20.4	15.6 ± 3.6

Table 6. α-Glucosidase inhibitory activities of edible plant extracts *versus* different starches

	Atta		Cassava/manihoc		Corn/maize		Finger millet/ragi/kurakkan		Kitul		Rice		Wheat	
	IC_{50} μg mL^{-1}	μmol AE g^{-1}	IC_{50} μg mL^{-1}	μmol AE g^{-1}	IC_{50} μg mL^{-1}	μmol AE g^{-1}	IC_{50} μg mL^{-1}	μmol AE g^{-1}	IC_{50} μg mL − 1	μmol AE g^{-1}	IC_{50} μg mL^{-1}	μmol AE g^{-1}	IC_{50} μg mL^{-1}	μmol AE g − 1
Acarbose	1.2 ± 0.1	1545.3 ± 0.9	1.6 ± 0.2	1549.4 ± 2.0	1.9 ± 0.2	1544.5 ± 1.8	1.4 ± 0.1	1540.9 ± 1.9	1.1 ± 0.6	1541.1 ± 1.8	1.4 ± 0.1	1543.8 ± 1.3	1.2 ± 0.1	1550.1 ± 2.1
Coccinia grandis	50.2 ± 5.6	42.1 ± 3.8	55.1 ± 6.2	46.3 ± 2.8	60.2 ± 8.2	40.2 ± 3.9	48.7 ± 6.3	39.6 ± 2.9	59.3 ± 9.1	38.5 ± 5.1	63.1 ± 8.6	37.1 ± 6.2	54.3 ± 6.9	44.8 ± 6.9
Asparagus racemosus	59.8 ± 6.7	40.6 ± 6.5	61.2 ± 5.9	41.6 ± 3.5	60.9 ± 6.7	41.5 ± 3.1	51.6 ± 9.0	43.6 ± 5.8	56.7 ± 8.1	36.9 ± 4.0	64.2 ± 7.1	35.0 ± 3.6	57.1 ± 6.1	47.1 ± 6.0
Costus specious	66.5 ± 7.4	41.5 ± 4.5	69.4 ± 2.9	39.6 ± 1.8	71.6 ± 3.5	36.1 ± 3.9	55.2 ± 3.6	43.8 ± 3.4	68.4 ± 6.6	46.0 ± 4.1	71.5 ± 6.1	48.5 ± 4.7	78.6 ± 5.2	53.1 ± 5.5
Amaranthus viridis	79.6 ± 8.1	38.3 ± 8.2	81.3 ± 7.2	38.6 ± 9.0	75.8 ± 6.9	39.5 ± 7.5	76.3 ± 6.4	39.8 ± 6.3	69.3 ± 6.5	35.9 ± 3.8	80.1 ± 6.4	35.1 ± 4.6	88.1 ± 6.8	30.2 ± 8.2
Annona muricata	88.6 ± 7.2	20.3 ± 8.6	90.2 ± 8.7	26.5 ± 6.8	92.3 ± 7.8	24.8 ± 8.2	95.3 ± 8.5	24.8 ± 4.5	98.6 ± 4.4	23.6 ± 4.1	80.1 ± 6.4	23.1 ± 8.6	89.3 ± 6.1	23.5 ± 8.5
Sesbania grandiflora	143.6 ± 8.5	21.3 ± 3.1	153.0 ± 7.9	19.6 ± 3.1	168.5 ± 9.3	18.6 ± 2.6	172.3 ± 8.2	18.3 ± 2.6	175.6 ± 4.3	19.2 ± 2.2	175.3 ± 5.3	20.6 ± 1.9	184.2 ± 8.6	18.9 ± 3.0
Desmodium gangeticum	185.2 ± 13.2	15.0 ± 1.6	194.2 ± 13.8	16.3 ± 4.0	198.3 ± 8.2	17.9 ± 2.0	196.2 ± 10.3	16.9 ± 2.5	188.6 ± 9.8	17.5 ± 2.3	191.5 ± 8.9	15.9 ± 1.8	197.5 ± 9.5	18.2 ± 2.8
Mimosa pudica	312.5 ± 18.9	6.0 ± 0.8	289.6 ± 12.6	6.2 ± 0.9	305.6 ± 18.5	7.5 ± 0.9	295.6 ± 11.3	6.8 ± 1.0	315.6 ± 15.2	7.4 ± 1.1	298.2 ± 11.9	7.2 ± 1.3	290.5 ± 10.5	6.8 ± 0.8
Momordica charantia	369.1 ± 14.6	5.8 ± 0.4	371.9 ± 14.6	5.2 ± 0.3	357.3 ± 16.3	5.5 ± 0.3	366.9 ± 9.8	6.6 ± 0.9	381.6 ± 12.6	6.5 ± 0.8	370.9 ± 16.1	6.6 ± 0.5	361.0 ± 12.5	5.8 ± 0.3
Alternanthera sessilis	389.6 ± 18.9	4.1 ± 0.3	361.5 ± 17.5	4.1 ± 0.1	375.2 ± 10.0	4.3 ± 0.2	381.2 ± 11.5	4.0 ± 0.1	394.5 ± 11.2	4.2 ± 0.6	392.6 ± 14.2	4.4 ± 0.3	388.6 ± 13.2	4.2 ± 0.4
Artocarpus heterophyllus	406.3 ± 17.5	2.9 ± 0.1	412.5 ± 15.6	2.8 ± 0.2	403.6 ± 14.9	2.8 ± 0.1	406.8 ± 13.6	2.6 ± 0.2	410.6 ± 12.6	2.5 ± 0.3	415.6 ± 13.6	2.8 ± 0.3	421.3 ± 12.9	2.9 ± 0.2
Adhathoda vasica	425.5 ± 16.9	2.6 ± 0.3	427.9 ± 17.1	2.6 ± 0.2	439.6 ± 20.1	2.7 ± 0.6	447.1 ± 15.6	3.0 ± 0.8	398.5 ± 17.9	3.5 ± 0.3	408.6 ± 19.8	2.9 ± 0.4	439.5 ± 15.6	2.8 ± 0.3
Psidium guava	469.5 ± 20.4	2.1 ± 0.2	469.3 ± 19.8	1.9 ± 0.1	486.5 ± 21.8	2.2 ± 0.3	471.6 ± 20.5	1.9 ± 0.2	468.5 ± 18.1	2.1 ± 0.2	472.3 ± 18.9	2.1 ± 0.3	481.1 ± 22.5	1.8 ± 0.2
Solanum americanum	369.8 ± 18.5	3.8 ± 0.2	355.2 ± 17.9	3.9 ± 0.2	375.6 ± 16.5	4.1 ± 0.3	382.3 ± 18.6	3.8 ± 0.2	359.8 ± 12.5	4.2 ± 0.5	366.1 ± 11.6	4.3 ± 0.2	378.5 ± 15.9	3.8 ± 0.5
Gymnema sylvestre	471.5 ± 20.1	1.9 ± 0.2	462.3 ± 18.8	1.8 ± 0.2	480.6 ± 19.1	1.8 ± 0.2	465.9 ± 20.9	1.9 ± 0.1	472.6 ± 18.2	1.8 ± 0.1	464.9 ± 18.5	2.0 ± 0.1	478.9 ± 20.9	1.9 ± 0.1
Centella asiatica	502.3 ± 22.9	1.2 ± 0.1	519.6 ± 19.8	1.3 ± 0.1	528.9 ± 21.3	1.5 ± 0.1	520.6 ± 21.9	1.4 ± 0.2	531.9 ± 23.9	1.7 ± 0.2	503.6 ± 16.9	1.8 ± 0.3	506.9 ± 15.9	1.4 ± 0.2
Wattakaka volubilis	512.3 ± 19.6	1.2 ± 0.2	528.9 ± 21.9	1.2 ± 0.2	514.9 ± 19.6	1.3 ± 0.1	522.9 ± 20.1	1.3 ± 0.1	520.6 ± 22.1	1.6 ± 0.3	518.6 ± 15.6	1.7 ± 0.2	517.3 ± 14.9	1.3 ± 0.2
Ipomoea aquatica	487.6 ± 19.5	1.8 ± 0.1	486.5 ± 21.2	1.7 ± 0.2	489.2 ± 20.5	1.8 ± 0.1	479.5 ± 18.9	1.8 ± 0.2	480.6 ± 19.1	1.9 ± 0.1	476.2 ± 18.1	1.9 ± 0.2	477.1 ± 19.3	1.8 ± 0.2

Inhibition of starch hydrolases could be deemed as a more novel aspect when it comes to the properties of functional food. This inhibitory activity leads to a reduced breakdown of glucose, thereby controlling the amount of calories and insulin response in a physiological system. In this sense, inhibition of α-amylase is considered to be more important when it comes to reducing the breakdown of starch, since it triggers the production of the substrate for the subsequent action of α-glucosidase. Therefore, it is noteworthy that the edible plants used in this study were able to inhibit α-amylase better than α-glucosidase. Given this requirement, even many of the commercially available antidiabetic drugs to date, such as acarbose, primarily target the inhibition of α-amylase rather than α-glucosidase. Numerous analytical methods have been established for the assessment of starch hydrolase inhibitory activities, with only a few of them being able to be carried out in a high-throughput manner. Most of these established assay methods involve the usage of *p*-nitrophenyl-α-D-glucopyranoside (PNPG),[38] *p*-nitrophenyl-α-D-maltopentaoside (PNPG5)[39] or 3,5-dinitrosalicyclic acid (DNSA).[40] However, methods involving these chromophores are not suitable for the examination of the inhibitory activities of plant-based extracts since they contain compounds which interfere with quantification. The turbidity measurement established by Liu *et al.*[22] was able to overcome the typical drawbacks of these assay methods, allowing the use of natural substrates for inhibitory activity measurements.

CONCLUSIONS

This study was able to identify 18 edible plants as functional food products which can be consumed for the purposes of health, wellness and disease prevention. Although the parameters used in the study were not disease specific, quantification of properties such as antioxidant and starch hydrolase inhibitory potentials will be able to serve as a guide to the use of these plants for diseases associated with ROS. In this respect, *Coccinia grandis*, *Asparagus racemosus*, *Costus specious*, *Amaranthus viridis* and *Annona muricata* were identified as potent antioxidants and inhibitors of starch hydrolases. Nevertheless, for investigative purposes, the mechanisms of action of these plants require further study in order to provide a better understanding of their abilities to effectively cure and control diseases that have a significant impact on quality of life.

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