Forensic Toxicology (2020) 38:30–41
https://doi.org/10.1007/s11419-019-00500-2

MINIREVIEW

Worldwide poisoning potential of *Brugmansia* and *Datura*

András Kerchner[1] · Ágnes Farkas[2]

Received: 20 June 2019 / Accepted: 23 August 2019 / Published online: 7 September 2019
© The Author(s) 2019

Abstract

Purpose The toxicological significance of human exposures to angel's trumpet plants (*Brugmansia* and *Datura* species) in their native American and non-native regions (Asia, Africa, and Europe) was highlighted, and the poisoning potential of various plant parts was discussed.

Methods Nearly 2500 cases of human plant exposures, reported to the Hungarian Toxicological Information Service between 2005 and 2017, were analyzed and compared to data of other toxicology centers in America, Asia and Europe, focusing on exposures to tropane alkaloid-containing plants.

Results In America, *Brugmansia* and *Datura* were not among the 15 most common plant ingestions, but were responsible for 20% of the fatal outcomes in a 26-year period. In Asia, the anticholinergic toxidrome, related to *Brugmansia* and *Datura*, was among the most frequent plant-related intoxications, which included accidental ingestion, improper use of herbal medicines and plant abuse. In Europe, *Brugmansia* and *Datura* were among the top four plant taxa causing intoxications with major outcomes, being the leading plants ingested for their hallucinogenic properties, and accounted for 60% of abuse cases in Hungary in a 13-year period. Use of *Brugmansia* and *Datura* for criminal purposes has been reported from America, Asia and Europe. The concentrations of tropane alkaloids vary with the species, seasons and plant parts. Ingestion of the seeds and flowers has the highest toxicological significance, but exposure to the leaves and floral nectar can also cause intoxication.

Conclusions Angel's trumpets have high toxicological significance both in their native and non-native regions, mainly due to their hallucinogenic property and accidental ingestion.

Keywords Abuse and accidental ingestion · Angel's trumpet · Atropine and scopolamine · Drug-facilitated robbery · Suicide · Tropane alkaloids

Introduction

Data of poison control centers from several countries reveal that a significant proportion of all poisonings is related to plant exposures [1–4]. The most common causes of plant-related toxicity are accidental ingestion of poisonous plant materials, misuse of herbal products, suicide attempts and abuse of hallucinogenic plants. The most frequently abused psychoactive plants include representatives of the Solanaceae family, such as *Brugmansia* and *Datura* species.

✉ Ágnes Farkas
agnes.farkas@aok.pte.hu

1 Institute of Biology, Faculty of Natural Sciences, University of Pécs, Ifjúság u. 6, Pécs 7624, Hungary

2 Department of Pharmacognosy, Faculty of Pharmacy, University of Pécs, Rókus u. 2, Pécs 7624, Hungary

Datura species, also called thornapple, devil's apple, angel's trumpet (in a broad sense) or devil's trumpet, have their main center of origin in Mexico and the south-west United States (US) [5, 6]. Today, representatives of the genus *Datura* are considered as cosmopolitan and naturalized in many regions with tropical and temperate climate conditions [7], being widespread also in Africa, Asia and Europe, comprising noxious weeds or ornamentals. The genus includes annual herbs and perennial shrubs with erect and branched stems, alternate simple basal leaves and opposite leaves on terminal branches. The actinomorphic flowers are bisexual and pentamerous, with tubular corolla. The fruit is a spiny capsule with reniform seeds [8].

The genus *Brugmansia* was treated earlier as a subgenus or section of *Datura*. Today, arborescent species with pendulous flowers, native to South America are separated at the genus level, comprising *B. arborea*, *B. aurea*, *B. candida*, *B. dolichocarpa*, *B. insignis*, *B. sanguinea*, *B. versicolor*, and

B. vulcanicola [9]. Most *Brugmansia* species had social and religious importance in ancient Andean cultures [10].

Both *Brugmansia* and *Datura* species are considered toxic, due to the presence of the tropane alkaloids atropine and scopolamine in each plant organ [11–19]. Atropine is known for its anticholinergic activity, causing mydriasis, blurred vision, suppressed salivation, vasodilation, tachycardia and delirium [20]. Scopolamine, also called hyoscine, is an antimuscarinic agent and a smooth muscle relaxant. Anticholinergic agents can be used in various fields of medicine, such as ophthalmology diagnostics, as antispasmodics, pre- and postoperative medications, analgesics, narcotics, sedatives, and also in treatments of asthma, Parkinson's disease and motion sickness [21–24].

Several cases of intoxication by ingestion of various parts of *Brugmansia* and *Datura* species have been reported [25–41]. Symptoms of intoxication include dilated pupils, confusion, hallucinations, dryness of skin and mucous membranes, increased blood pressure and heart rate, and increased body temperature [11, 36, 42–44]. Administration of physostigmine is the preferred treatment for severe cases of *Datura* poisoning, but due to controversies regarding potential adverse effects of physostigmine, it is not routinely applied in less severe cases, when supportive care and observation is satisfactory [45, 46].

Due to the fact that both *Brugmansia* and *Datura* taxa are becoming widespread worldwide—partly as a result of their successful reproductive strategies, and partly because being cultivated for ornamental purposes, their toxicological significance is increasing not only in tropical, but also in temperate regions of the world.

The objective of this article was to characterize human plant exposures that involve *Brugmansia* and *Datura* taxa in their native (America) and non-native regions (Asia, Africa, and Europe), and discuss the poisoning potential of various plant parts. To assess the worldwide toxicological significance of these tropane alkaloid-containing plants, a large number of cases were reviewed, based on toxicological center reports and case studies from several countries. To demonstrate the importance of plant-related anticholinergic intoxications in a European country, where *Brugmansia* and *Datura* are not native, data provided by the Hungarian Toxicological Information Service (HTIS) were analyzed in detail. In addition, we wanted to highlight differences in the poisoning potential of various plant parts, by analyzing data related to alkaloid concentrations in various plant parts and secretions, focusing on plant organs that have received less attention so far, such as the flowers and their secretory products.

Analysis of toxicology center reports

The 2005–2017 annual reports of the HTIS were reviewed to identify plant-related poisoning cases. Data were provided in a Microsoft Excel database by the HTIS. We analyzed a total of 2464 cases of human plant exposures and selected cases where the plant genera *Brugmansia* and *Datura* were involved. The data were analyzed to determine the frequency of poisonings, to identify the age and gender of those who were exposed, the reason for the exposure, and patient outcome. Descriptive statistics were used throughout the manuscript to characterize the data.

In addition, data of the HTIS were compared to similar data of other toxicology centers in the US [4], India [26], Taiwan [2], Switzerland [1] and Italy [3].

Brugmansia and *Datura* poisonings in America

From the native American region of *Brugmansia* and *Datura* species, we have toxicology reports from Canada, the US and Mexico.

Based on the annual reports of the American Association of Poison Control Centers (AAPCC) published for the years 1983–2009, the number of plant exposures reflected as a percentage of all exposures reported to US poison centers decreased from 8.9% in 1983 to 2.4% in 2009 [4]. Although *Datura* species were not among the 15 most common plant ingestions, hundreds of *Datura* intoxications occurred each year in the US. For example, in 1993, 318 *Datura* exposures were reported to the AAPCC; however, we can suspect that the true number of cases was even higher [47]. From the 45 fatalities recorded for a 26-year time period 1983–2009, *Datura* species were responsible for 20% of the fatal outcomes, being the leading cause of death attributed to plant exposures [4]. For the time period 1997–2001, an average of 1044 cases of anticholinergic plant exposures, including *D. stramonium* (jimson weed), was reported yearly in the US. Almost half (46%) of the cases were due to abuse ingestion; 53% of patients had to be treated in health care facilities, and six deaths were reported. The majority (77%) of cases occurred in individuals below 19 years of age [48]. According to the annual reports of the AAPCC, in the period of 2012–2017, neither *Brugmansia* nor *Datura* species were among the top 25 plant species involved in plant intoxications in the US [49–54].

In the US and Canada, *Datura* poisoning has been reported primarily among adolescents who abuse the plant for its hallucinogenic effects (Table 1) [29, 32, 45, 48]. The most frequently reported *Datura* species is *D. stramonium*, which grows wildly throughout the US and the southern

Table 1 Case reports of *Brugmansia* and *Datura* intoxications from America, Asia, Africa and Europe

Study	Continent/country	Toxic plant/plant part	Category of intake	Symptom(s) + analytical result(s)	Gender (age in years)	Outcome
	America					
Chan (2002) [45]	United States	*D. stramonium*/flowers	Ab	Hallucinations, picking at nonexistent items	M (15)	FR
Soneral and Connor (2005) [48]	United States	*D. stramonium*/seeds	Ab	Disorientation, hallucinations, combativeness, unintelligible speech, blurry vision	M (15–17)	FR
Firestone and Sloane (2007) [43]	United States	*B. suaveolens*/flowers	Acc	Anisocoria, blurry vision	M (12)	FR
Wiebe et al. (2008) [32]	Canada	*D. stramonium*/seeds	Ab	Disorientation, hallucinations, combativeness	M (13–16), F (13)	FR
Goldfarb et al. (2019) [36]	Canada	*B. versicolor*	Acc	Anisocoria	F (69)	FR
	Asia					
Taha and Mahdi (1984) [56]	Saudi Arabia	*D. stramonium*/fruit	Acc	Dry mouth and skin, tachycardia, dilated pupils	Children (4–6)	FR
Chang et al. (1999) [57]	Taiwan	*B. suaveolens*/leaves	Acc	Dizziness, dry mouth, flushed skin, nausea, vomiting, tachycardia, blurred vision, mydriasis, hyperthermia, drowsiness, disorientation, agitation, delirium, urine retention, hypertension, coma	8 M (10–48) 6 F (6–48)	FR
Diker et al. (2007) [20]	Israel	Tea prepared from *D.* seeds	Ab	Unconsciousness, fever, mydriasis, dry oral mucosa and skin, tachycardia, coma	Case 1: M (21) Case 2: M (19)	FR; DE
Oshiro et al. (2008) [30]	Japan	Eggplant grafted on *D. metel*	Acc	Staggering, slurred speech, mydriasis, drowsiness	M (67), F (62)	FR
Phua et al. (2008) [31]	Singapore	*D. metel*	Wrongful use of traditional Chinese medicine	Stiffened upper limbs, non-purposeful movements, disorientation, mydriasis	F (42), M (59)	FR
Mohamad et al. (2009) [33]	Malaysia	*D. stramonium*/fruit	Acc	Dizziness, blurred vision, restlessness	M (48)	FR
Le Garff et al. (2016) [40]	Indonesia	*Datura*	Homicide (victim of robbery)	Stomach pain, unconsciousness, disordered heart rhythm, suspected heart attack	M (35)	DE

Table 1 (continued)

Study	Continent/country	Toxic plant/plant part	Category of intake	Symptom(s) + analytical result(s)	Gender (age in years)	Outcome
	Africa					
Onen et al. (2003) [58]	Botswana	Sorghum contaminated with *D. stramonium* seeds	Acc, sorghum porridge prepared from contaminated grains	Confusion, dry mouth, restlessness, dizziness, abdominal pain, uncontrolled talking, headache, vomiting, nausea, blurred vision	92 patients (<1–91) F: 55.4% M: 44.6%	FR
Steenkamp et al. (2004) [39]	South Africa	*D. ferox*/seeds	Poisoning (category not known)	Heart attack	M (middle-aged)	DE
Adegoke and Alo (2013) [62]	Nigeria	*D. stramonium* extract	Ab	Restlessness, incoherent talk, visual hallucinations, convulsions, increased body temperature, dry mouth, dilated pupils, tachycardia	M (12, 14)	FR
	Europe					
Osváth et al. (2000) [64]	Hungary	Tea prepared from *D. stramonium* seeds	Ab	Dizziness, blurry vision, incoherent talk, dry mouth, flushed skin, mydriasis, tachycardia, coma	M (29)	FR
Winckelmann et al. (2000) [65]	Germany	Tea prepared from *B. suaveolens* flowers	Ab	Dry skin and mucosa, mydriasis, hallucinations, incoherent speech, disorientation	M (14, 16)	FR
Boumba et al. (2004) [38]	Greece	*D. stramonium*/seeds	Ab	Blood concentrations of hyoscyamine and scopolamine: 1.1 and 0.2 µg/mL, respectively	M (19)	DE
Lazzarini et al. (2006) [66]	Italy	Meal prepared from *D. stramonium* flowers mistaken for edible pumpkin (*Cucurbita*) flowers	Acc	Loss of consciousness, agitation, confusion, hallucinations, combative behavior, mydriasis, disorientation, aphasia	F (53)	Discharged in good clinical condition, but with amnesia regarding the acute toxic episode
Marc et al. (2007) [28]	France	*D. stramonium*	Ab	Unconsciousness, agitation, delirium, visual and tactile hallucinations M: 1.7 ng/mL atropine in blood, F: 1.4 ng/mL scopolamine in blood; 114 ng/mL atropine in urine	M (17), F (17)	FR

Table 1 (continued)

Study	Continent/country	Toxic plant/plant part	Category of intake	Symptom(s) + analytical result(s)	Gender (age in years)	Outcome
Sevketoglu et al. (2010) [44]	Turkey	*B. suaveolens*/flowers	Acc	Flaccid paralysis associated with respiratory symptoms; difficulty in speaking and swallowing, dry mouth, hypotonia and muscle weakness, anisocoria	M (5)	Recovery after ca. 2 months of hospitalization
Disel et al. (2015) [34]	Turkey	Meal “dolma” prepared from *D. stramonium* flowers mistaken for edible pumpkin (*Cucurbita*) flowers	Acc (cases 1 and 3: 1 piece of dolma each; case 2: 9 pieces of dolma)	Visual impairment, hallucinations, mydriasis, tachycardia, tachypnea, red and dry skin and mucous membranes; Case 2: in addition: left bundle branch block, rhabdomyolysis	Case 1: F (58); Case 2: M (60); Case 3: F (33)	FR for all cases
Trancă et al. (2017) [35]	Romania	*D. stramonium*/seeds	Ab	Fever, dry skin and mucosa, tachycardia, right bundle bunch block, urinary retention, rhabdomyolysis, coma	M (22)	FR
Lusthof et al. (2017) [41]	Netherlands	Scopolamine hidden in food and drink	Victims of robbery (without knowledge of scopolamine content)	Case 1: heart blood: 0.30 µg/mL scopolamine (4–5 days after death); case 2: hallucinations, scopolamine detected in urine; case 3: unconsciousness, nausea, scopolamine detected in serum (0.0035 µg/mL) and urine	Case 1: M (53); case 2: M; case 3: M	DE; FR; FR

Ab abuse, *Acc* accidental, *B Brugmansia*, *D Datura*, *DE* deceased, *F* female, *FR* full recovery, *M* male parts of Canada. Another common cause of intoxication can be gardening activity related to various *Brugmansia* taxa (angel's trumpets in a narrow sense), which are frequently grown as ornamentals [36]. In case of children, playing around *Brugmansia* plants and getting in contact with certain plant parts, e.g., the flowers, can also lead to symptoms of intoxication (Table 1) [43].

In Mexico, the most widely distributed *Datura* species are *D. discolor* and *D. stramonium*. Here, the most frequent causes of intoxication include the use of *Datura* in traditional shamanic medicine, accidental ingestion by children, and abuse in adolescents and adults [7].

Brugmansia and *Datura* poisonings in Asia and Africa

Poisoning cases with *Datura* have been frequently reported from Asia and Africa. In India, the total number of intoxication cases registered in a 3-year period (1999–2002) was 2720, out of which 1.5% was due to plant exposures. Children under the age of 18 years were involved in 15 cases related to toxic plants, out of which 10 cases (66%) were attributed to intoxication with various *Datura* species [26, 27]. Although the number of registered cases of plant intoxications seems to be very low for the country and population of this size—most probably due to underreporting—, the high ratio of *Datura* poisonings indicates by all means the significant poisoning potential of this plant genus in India. Accidental poisoning may occur when *Datura* seeds, resembling capsicum seeds, are mistakenly ingested. Consumption of wasp honey contaminated with *Datura* may also lead to poisoning [55]. Cases of accidental *D. stramonium* ingestion have been reported also from Saudi Arabia [56]. In Taiwan, 1414 plant-related poisoning cases were recorded in a 20-year period (1987–2006). Regarding the 389 cases of single-plant exposures, the most frequent type of intoxication, the anticholinergic toxidrome, was related to *Brugmansia* or *Datura* species. In adults, *B. suaveolens* (19%) and *D. metel* (16%) were the top two commonly ingested poisonous plants [2, 57]. *Datura* species may even cause intoxication when an otherwise edible plant is grafted on them, as in a case reported from Japan [30]. Mass poisoning was reported from Botswana, after consuming sorghum flour contaminated with *Datura* seeds [58] (Table 1).

In Ayurvedic medicine, in India, *D. stramonium* has been used to treat various health problems, such as inflammations, ulcers, wounds, rheumatism, gout, fever, asthma and bronchitis, and as a painkiller in headache or toothache. The external use, e.g., in the form of paste or solution to relieve local pain, may not have a deleterious effect; however, internal use may lead to severe anticholinergic symptoms [59]. In addition, some Chinese herbal medicines (CHM) contain anticholinergic agents. For example, "yangjinghua", the dried flower of *D. metel*, has been used for treatment of bronchial asthma, bronchitis, pains and flu symptoms [31, 60]. In Malaysia, "kecubung" (*Datura*) is eaten as a traditional medicine to treat allergic rhinitis. In Africa, *D. stramonium* and *D. ferox* are frequently used in traditional medicine, mainly to relieve asthma and to reduce pain [61]. Inaccurate doses, improper use of traditional herbal medicines or contamination of CHM with atropine-like substances may lead to severe or even fatal anticholinergic toxidrome [33, 60] (Table 1).

Besides accidental ingestion and wrongful use of traditional herbal medicines, intoxication with *Datura* extracts occurred most frequently when they were abused for hallucinogenic effects [20, 62], or due to crime-related poisoning [39, 40] (Table 1).

Brugmansia and *Datura* poisonings in Europe

From the *Datura* genus, three species, *D. ferox*, *D. innoxia* and *D. stramonium* are widely distributed and naturalized in several European countries [63]. From Europe, we had access to data of national poison control centers in three countries, Hungary, Italy and Switzerland.

In Hungary, 2464 cases of contact with or ingestion of toxic plant material were registered in the period 2005–2017. During this interval, there has been an increasing tendency in the number of plant exposures (Fig. 1), in contrast to the decreasing tendency observed in the US [4]. Unlike in the US, but similarly to India and Taiwan, *Brugmansia* and *Datura* were among the species involved in the largest number of plant-related poisonings in Hungary. The top four plant taxa that regularly caused intoxications in Hungary were *Brugmansia* and *Datura* species, *Convallaria majalis* and *Taxus baccata*, accounting for 1–7%, 1–16%, 6–20%, and 8–19% of all plant-related intoxications, respectively, in the period 2005–2017 (Fig. 2). As shown in Table 2, the number of *Brugmansia* and *Datura* poisoning cases in Hungary was fluctuating from year to year, with no clear-cut tendency for the proportion of anticholinergic exposures. However, in the last five years of the study, the number of such poisoning cases was on the decrease. This could be due to several reasons: (1) Hungarian people became better informed regarding the risks of ingesting *Brugmansia* or *Datura* plant parts or extracts, and thus avoided exposure to these plants; (2) adolescents and young adults started to use other natural or synthetic drugs for their hallucinogenic properties; (3) not all cases were reported to the toxicological center, probably due to milder symptoms of intoxication, when the affected individuals did not seek medical attention. In contrast to the US, where *Datura* intoxications were

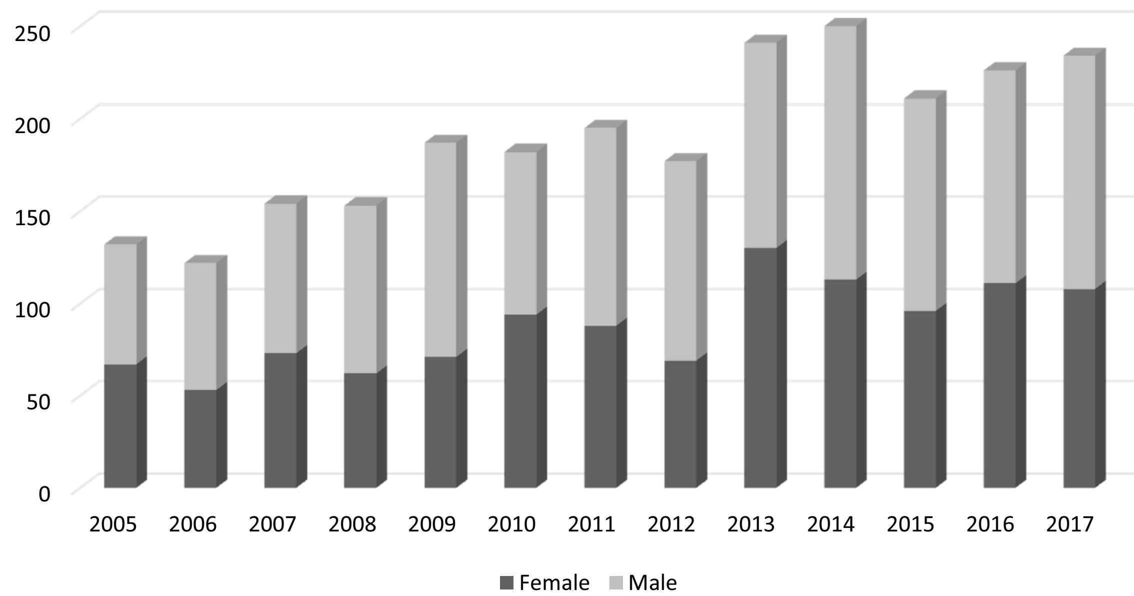

Fig. 1 Total annual numbers of all types of toxic herbal exposures in Hungary 2005–2017

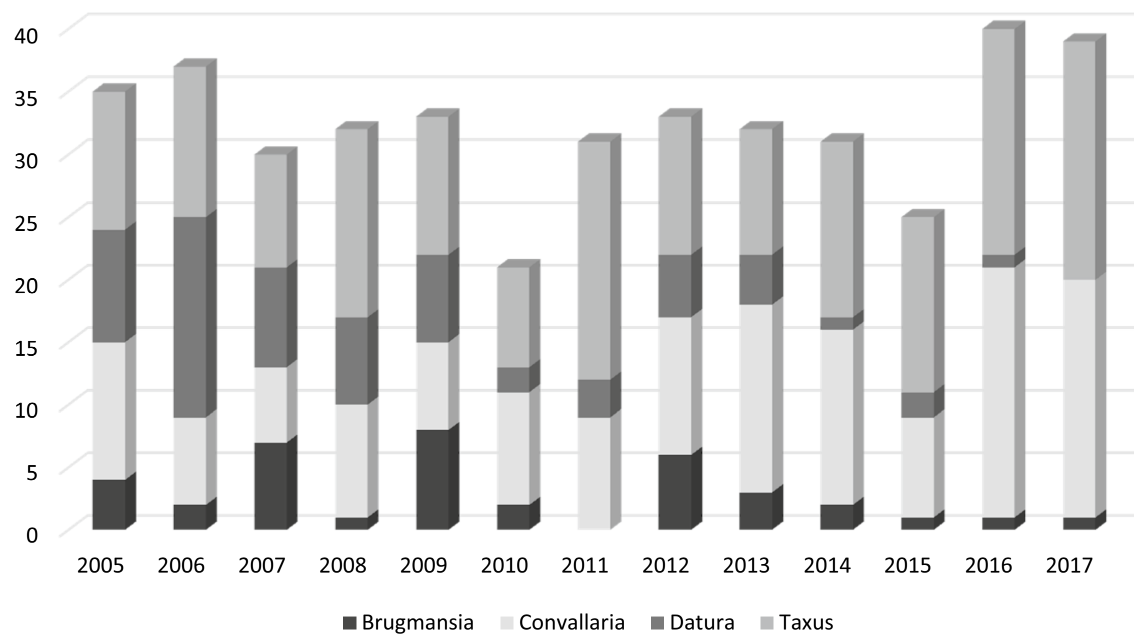

Fig. 2 Ratios (%) of intoxications caused by the top four poisonous plants in Hungary 2005–2017

responsible for one-fifth of plant-related fatalities, in Hungary there were no fatal intoxications related to *Brugmansia* or *Datura* for a 13-year time period, even though 12% of major outcomes were related to these species.

Between 2005 and 2017 in Hungary, *Brugmansia* and *Datura* taxa were responsible for 60% of all plant abuse cases, being the leading plants ingested for their hallucinogenic properties [64] (Tables 1, 2), while they accounted for a much lower proportion (18%) of suicide attempts. Considering all *Brugmansia* and *Datura* poisonings (167 cases), the percentage of abuse cases (60%) was double of accidental ingestions (30%), and only 10% was due to suicide attempts (Table 2). Intoxication with *Brugmansia* and *Datura* occurred mainly in the months August–October, which suggests that in most cases the fruits, and particularly the seeds are ingested. At this time of the year in temperate

Table 2 Summary of *Brugmansia* and *Datura* poisonings that took place in Hungary in 2005–2017, reported to HTIS

Year of study	Number of cases/plant part		Co-ingestion	Category of intake	Age group	Gender	Outcome
	Brugmansia	*Datura*					
2005	5/flowers	12/seeds	(1) *D* + alc; (2) *B* + alc; (3) *B* + benzodiazepines	6 Acc; 9 Ab; 2 Sui	11 Ado; 6 Adu	2 F; 15 M	13 FR; 4 H
2006	2/flowers	19	(1) *D. stramonium* + alc + white powder + benzodiazepines	3 Acc; 17 Ab; 1 Sui	2 Ch; 16 Ado; 3 Adu	4 F; 17 M	20 FR; 1 H
2007	11/flowers	14/fruit, seeds	(1) *D* + alc; (2) *D* + benzodiazepines	4 Acc; 19 Ab; 2 Sui	3 Ch; 18 Ado; 4 Adu	10 F; 15 M	25 FR
2008	2	10/seeds	(1) *D* + alc; (2) *B* + benzodiazepines	5 Acc; 5 Ab; 2 Sui	3 Ch; 6 Ado; 3 Adu	1 F; 11 M	10 FR; 2 H
2009	14	13/seeds	(1) *D. stramonium* + alc	8 Acc; 18 Ab; 1 Sui	5 Ch; 14 Ado; 8 Adu	6 F; 21 M	22 FR; 5 H
2010	3	3	–	2 Acc; 3 Ab; 1 Sui	2 Ch; 2 Ado; 2 Adu	1 F; 5 M	5 FR; 1 H
2011	0	5/seeds	–	5 Ab	3 Ado; 2 Adu	2 F; 3 M	4 FR; 1 H
2012	11/sap, stem, flower	8	–	4 Acc; 11 Ab; 4 Sui	2 Ch; 5 Ado; 12 Adu	3 F; 16 M	17 FR; 2 H
2013	6/flower, sap	9/seeds	(1) *B* + zopiclone	4 Acc; 10 Ab; 1 Sui	3 Ch; 4 Ado; 8 Adu	5 F; 10 M	13 FR; 2 H
2014	4	3	–	5 Acc; 2 Ab	2 Ch; 1 Ado; 4 Adu	3 F; 4 M	7 FR
2015	2	4	–	4 Acc; 1 Ab; 1 Sui	3 Ch; 3 Adu	2 F; 4 M	4 FR, 2 H
2016	3	2	(1) *D. stramonium* + cannabis	3 Acc; 1 Ab; 1 Sui	3 Ch; 2 Adu	2 F; 3 M	3 FR; 2 H
2017	2	0	–	2 Acc	2 Ch	2 M	2 FR
Total	65	102		50 Acc; 101 Ab; 16 Sui	30 Ch; 80 Ado; 57 Adu	41 F; 126 M	145 FR; 22 H

(1) Case 1, (2) case 2, (3) case 3

Ab abuse, *Acc* accidental, *Ado* adolescent (13–18 years of age), *Adu* adult (older than 18 years), *Alc* alcohol, *B Brugmansia*, *Ch* children (younger than 13 years), *D Datura*, *F* female, *FR* full recovery, *H* further treated in hospital, *HTIS* Hungarian Toxicological Information Service, *M* male, *Sui* suicide

climate, the plants are still in bloom, but at the same time several fruits have already developed on these plants. In most cases, *Brugmansia* and *Datura* were taken without any co-ingestants, but in a number of cases, they were ingested together with alcohol and/or psychoactive drugs, such as benzodiazepines (Table 2).

With regard to gender, 75% of all *Brugmansia* and *Datura* ingestions in Hungary occurred in males and only 25% in females in the period of 2005–2017 (Table 2). This indicates that males are three times more likely to suffer anticholinergic intoxication by plant origin than females, in most cases by taking the risk of ingesting various plant parts or extracts of *Brugmansia* or *Datura* for their hallucinogenic properties.

Data on the types, frequency and severity of plant poisonings are available from Switzerland for a 29-year period (1966–1994). From a total of 24,950 registered cases of intoxication with plant material, severe plant poisonings were reported in 152 cases. Out of these, 17 cases (11%) were related to the ingestion of *D. stramonium* [1]. The Poison Control Center of Milan, the leading toxicological center in Italy, registered 4432 plant exposures for the time period 2001–2005. In the age group of 15–90 years, the second most frequent cause of plant-related intoxications was the recreational use of hallucinogenic species (41 cases, 7%), including *D. stramonium* (26 cases, 63%) [3].

In addition, we have several reports from other European countries about consuming *Brugmansia* or *Datura* for their hallucinogenic effect [28, 35, 38, 65]. Similarly, in Spain, *Datura* species are mainly used as recreational drugs, but recently the use for criminal purposes is increasing [7]. From the Netherlands, a series of scopolamine-facilitated robberies were reported, including some fatal cases [41] (Table 1).

Cases of accidental intoxication were reported from Italy and Turkey, when *D. stramonium* flowers were mistaken for the similarly trumpet-shaped pumpkin (*Cucurbita* sp.) flowers [34, 66], or *B. suaveolens* flowers were unintentionally ingested [44] (Table 1).

Poisoning potential of various plant parts of *Brugmansia* and *Datura* species

The concentrations of tropane alkaloids vary depending on the *Brugmansia* or *Datura* species, seasons of the year and the plant parts involved in the exposure [16, 17, 19, 46]. The ratio of scopolamine and atropine in various plant organs was found to be species dependent, e.g., in *D. innoxia*, scopolamine was found to be predominant in all plant organs, while atropine levels were found to be higher as compared to scopolamine in leaf samples of *D. metel* [17]. Alkaloid levels may even differ in two varieties of the same species, the purple-flowered variety of *D. stramonium* (var. *tatula*) contained significantly higher alkaloid concentrations in all plant parts, except the stem, as compared to the white-flowered variety (var. *stramonium*) [17].

The alkaloid content is influenced also by whether the plant is in the juvenile or the reproductive stage, being the highest when the plant is flowering [46]. A study on four *Datura* taxa revealed that the alkaloid content of the stem and the leaf significantly decreased with plant aging, i.e., during transition from summer to autumn [17].

The alkaloid content is generally the greatest in the flowers and the seeds of various *Datura* species (e.g., up to 0.61 and 0.66% in *D. stramonium* [67]; 0.1–0.8 and 0.2–0.5% in the flowers and seeds of *D. metel*, respectively) [68], but in the case of *D. metel* similarly high alkaloid concentrations were reported for the leaves, as well (0.5%) [67, 68].

The atropine and scopolamine concentration of *D. stramonium* seeds was determined as 1283 and 678 µg/g, respectively [69]. The seeds of *D. metel* were reported to contain 2788 and 2020 µg/g; *D. metel* leaves 69.87 and 840.4 µg/g; while *B. pittieri* leaves contained 64.67 and 448.2 µg/g of atropine and scopolamine, respectively [70]. Calculating with average alkaloid content data, 1 g *Datura* seed would contain 2.9 mg atropine and 0.5 mg scopolamine, which is already in the toxic range. Bioavailability depends on whether the seeds were chewed, ground or swallowed as a whole, and also whether some kind of extract was prepared from various plant parts or dried plant parts were smoked [46].

Scopolamine and atropine were detected also in the floral nectar of *Brugmansia* and *Datura* species. From five *Datura* species studied, only *D. tatula* was characterized by the dominance of atropine, while the nectar of *D. innoxia*, *D. metel*, *D. meteloides* and *D. stramonium*, and also that of *B. suaveolens* contained higher ratio of scopolamine than atropine [16, 71]. Nectar alkaloid concentrations in *D. innoxia*, *D. metel* and *D. meteloides* ranged from 58 to 400, 85–132 and 120–190 µg/mL scopolamine, and 2–37, 3–4 and 0.19–0.42 µg/mL atropine, respectively [16]. Consumption of *Brugmansia* or *Datura* flowers [34, 44, 65, 66] and/or their secretory product, the nectar, may also cause severe anticholinergic symptoms. Nectar volumes in small-flowered species, such as *D. quercifolia* and *D. stramonium* are typically around 25 µL/flower, whereas large-flowered species, e.g., *B. suaveolens, D. innoxia* and *D. metel* can produce substantial amounts, up to 150 µL nectar per flower [71, 72]. Knowing that the toxic doses of atropine and scopolamine range between 2.0 and 6.5 mg in case of oral administration [20], the ingestion of the nectar of 50–100 flowers can induce severe anticholinergic intoxication, if we calculate with an average nectar volume of 100 µL/flower in large-flowered species [72] and an average nectar alkaloid concentration of 215 µg/mL [16]. Nectars containing tropane alkaloids may also be processed into toxic honeys, which may cause intoxication when ingested [73, 74].

Conclusions

Data of poison information centers from all over the world indicate that most exposures to *Brugmansia* and *Datura* are related to abuse, in connection with their hallucinogenic property, mostly in the age group of adolescents. Accidental ingestion is less frequent, but has been reported in small children, and also in adults who have mistaken various plant parts of the toxic species for their edible counterparts. Anticholinergic intoxication may also result from the improper use of traditional herbal medicines containing *Datura*. More recently, the use of *Brugmansia* and *Datura* as incapacitating drug in sexual crimes and robberies has caught the attention of authorities. The highest toxicological significance can be attributed to the flowers and seeds of *Brugmansia* and *Datura*, but exposure to the leaves and floral nectar can also cause intoxication.

Acknowledgements Open access funding provided by University of Pécs (PTE) is acknowledged. The authors are grateful to the Hungarian Toxicological Information Service for providing data on plant exposures in the period 2005–2017; and to the Doctoral Program in Biology and Sport Biology, University of Pécs, Hungary, for supporting our floral biological and nectar chemistry studies.

Compliance with ethical standards

Conflict of interest There are no financial or other relations that could lead to a conflict of interest.

Ethical approval No ethical approval was required for the preparation of this type of article.

Open Access This article is distributed under the terms of the Creative Commons Attribution 4.0 International License (http://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made.

References

1. Jaspersen-Schib R, Theus L, Guirguis-Oeschger M, Gossweiler B, Meier-Abt PJ (1996) Serious plant poisonings in Switzerland 1966–1994. Case analysis from the Swiss Toxicology Information Center. Schweiz Med Wochenschr 126:1085–1098 **(PMID: 8711457) (in German with English abstract)**
2. Lin TJ, Nelson LS, Tsai JL, Hung DZ, Hu SC, Chan HM, Deng JF (2009) Common toxidromes of plant poisonings in Taiwan. Clin Toxicol 47:161–168. https://doi.org/10.1080/15563650802077924
3. Moro PA, Assisi F, Cassetti F, Bissoli M, Borghini R, Davanzo F, Della Puppa T, Dimasi V, Ferruzzi M, Giarratana T, Travaglia A (2009) Toxicological hazards of natural environments: clinical reports from Poison Control Centre of Milan. Urban For Urban Green 8:179–186. https://doi.org/10.1016/j.ufug.2009.02.007
4. Krenzelok EP, Mrvos R (2011) Friends and foes in the plant world: a profile of plant ingestions and fatalities. Clin Toxicol 49:142–149. https://doi.org/10.3109/15563650.2011.568945
5. Symon DE, Haegi L (1991) *Datura* (Solanaceae) is a new world genus. In: Hawkes JG, Lester RN, Nee M, Estrada N (eds) Solanaceae III: taxonomy, chemistry, evolution. Royal Botanic Gardens Kew, London, pp 197–210
6. Luna-Cavazos M, Bye R, Jiao M (2009) The origin of *Datura metel* (Solanaceae): genetic and phylogenetic evidence. Genet Resour Crop Evol 56:263–275. https://doi.org/10.1007/s10722-008-9363-5
7. Benítez G, March-Salas M, Villa-Kamel A, Cháves-Jiménez U, Hernández J, Montes-Osuna N, Moreno-Chocano J, Cariñanos P (2018) The genus *Datura* L. (Solanaceae) in Mexico and Spain—ethnobotanical perspective at the interface of medical and illicit uses. J Ethnopharmacol 219:133–151. https://doi.org/10.1016/j.jep.2018.03.007
8. Gallego MJ (2012) *Datura* L. In: Castroviejo S, Aedo C, Laínz M, Muñoz Garmendia F, Nieto Feliner G, Paiva J, Benedí C (eds) Flora iberica, vol. 11. CSIC, Madrid, pp 216–224 **(in Spanish)**
9. Schultes RE, Plowman T (1979) The ethnobotany of *Brugmansia*: Tommie Earl Lockwood. J Ethnopharmacol 1:147–164. https://doi.org/10.1016/0378-8741(79)90004-7
10. Schultes RE, Farnsworth NR (1980) Ethnomedical, botanical and phytochemical aspects of natural hallucinogens. Bot Mus Leafl Harv Univ 28:123–214. https://www.jstor.org/stable/41762829
11. Griffin WJ, Lin GD (2000) Chemotaxonomy and geographical distribution of tropane alkaloids. Phytochemistry 53:623–637. https://doi.org/10.1016/S0031-9422(99)00475-6
12. Evans WC, Lampard JF (1972) Alkaloids of *Datura suaveolens*. Phytochemistry 11:3293–3298. https://doi.org/10.1016/S0031-9422(00)86392-X
13. Miklós EJ, Botz L, Horváth G, Farkas Á, Dezső G, Szabó LG (2001) Atropine and scopolamine in leaf and flower of *Datura arborea* L. Int J Hortic Sci 7:61–64. https://doi.org/10.31421/IJHS/7/2/268
14. Miraldi E, Masti A, Ferri S, Comparini IB (2001) Distribution of hyoscyamine and scopolamine in *Datura stramonium*. Fitoterapia 72:644–648. https://doi.org/10.1016/S0367-326X(01)00291-X
15. Berkov S, Zayed R (2004) Comparison of the tropane alkaloid spectra between *Datura innoxia* growth in Egypt and Bulgaria. Z Naturforsch C 59:184–186. https://doi.org/10.1515/ZNC-2004-3-409
16. Boros B, Farkas Á, Jakabová S, Bacskay I, Kilár F, Felinger A (2010) LC–MS quantitative determination of atropine and scopolamine in the floral nectar of *Datura* species. Chromatographia (Suppl 1) 71:43–49. https://doi.org/10.1365/s10337-010-1524-y
17. Jakabová S, Vincze L, Farkas Á, Kilár F, Felinger A, Boros B (2012) Determination of tropane alkaloids atropine and scopolamine by liquid chromatography–mass spectrometry in plant organs of *Datura* species. J Chromatogr A 1232:295–301. https://doi.org/10.1016/j.chroma.2012.02.036
18. Kerchner A, Darók J, Bacskay I, Felinger A, Jakab G, Farkas Á (2015) Protein and alkaloid patterns of the floral nectar in some solanaceous species. Acta Biol Hung 66:304–315. https://doi.org/10.1556/018.66.2015.3.6
19. Romera-Torres A, Romero-González R, Vidal JLM, Frenich AG (2018) Analytical methods, occurrence and trends of tropane alkaloids and calystegines: an update. J Chromatogr A 1564:1–15. https://doi.org/10.1016/j.chroma.2018.06.004
20. Diker D, Markovitz D, Rothman M, Sendovski U (2007) Coma as a presenting sign of *Datura stramonium* seed tea poisoning. Eur J Intern Med 18:336–338. https://doi.org/10.1016/j.ejim.2006.09.035
21. Bo T, Li KA, Liu HW (2003) Investigation of the effect of space environment on the contents of atropine and scopolamine in *Datura metel* by capillary zone electrophoresis. J Pharm Biomed Anal 31:885–891. https://doi.org/10.1016/S0731-7085(02)00670-2
22. Hamilton MG, Lundy PM (2007) Medical countermeasures to WMDs: defence research for civilian and military use. Toxicology 233:8–12. https://doi.org/10.1016/j.tox.2006.08.034
23. Lukasewycz S, Holman M, Kozlowski P, Porter CR, Odom E, Bernards C, Neil N, Corman JM (2010) Does a perioperative belladonna and opium suppository improve postoperative pain following robotic assisted laparoscopic radical prostatectomy? Results of a single institution randomized study. Can J Urol 17:5377–5382 **(PMID: 20974030)**
24. Rapoport A (2010) Sublingual atropine drops for the treatment of pediatric sialorrhea. J Pain Symptom Manag 40:783–788. https://doi.org/10.1016/j.jpainsymman.2010.02.007
25. Birmes P, Chounet V, Mazerolles M, Cathala B, Schmitt L, Lauque D (2002) Self-poisoning with *Datura stramonium*. 3 Case reports. Presse Med 31:69–72 **(PMID: 11850988) (in French with English abstract)**
26. Gupta SK, Peshin SS, Srivastara A, Kaleekal T (2003) A study of childhood poisoning at National Poisons Information Centre, All India Institute of Medical Sciences, New Delhi. J Occup Health 45:191–196. https://doi.org/10.1539/joh.45.191
27. Srivastava A, Peshin SS, Kaleekal T, Gupta SK (2005) An epidemiological study of poisoning cases reported to the National Poisons Information Centre, All India Institute of Medical Sciences, New Delhi. Hum Exp Toxicol 24:279–285. https://doi.org/10.1191/0960327105ht527oa
28. Marc B, Martis A, Moreau C, Arlie G, Kintz P, Leclerc J (2007) Acute *Datura stramonium* poisoning in an emergency department. Presse Med 36:1399–1403. https://doi.org/10.1016/j.lpm.2007.04.017 **(in French with English abstract)**

29. Spina SP, Taddei A (2007) Teenagers with Jimson weed (*Datura stramonium*) poisoning. Can J Emerg Med 9:467–469. https://doi.org/10.1017/S1481803500015530
30. Oshiro N, Kuniyoshi K, Nakamura A, Araki Y, Tamanaha K, Inafuku K (2008) A case of food poisoning due to ingestion of eggplant, *Solanum melongena*, grafted on Devil's trumpet, *Datura metel*. J Food Hyg Soc Jpn 49:376–379. https://doi.org/10.3358/shokueishi.49.376**(in Japanese with English abstract)**
31. Phua DH, Cham G, Seow E (2008) Two instances of Chinese herbal medicine poisoning in Singapore. Singap Med J 49:e131–e133 **(PMID: 18465037)**
32. Wiebe TH, Sigurdson ES, Katz LY (2008) Angel's trumpet (*Datura stramonium*) poisoning and delirium in adolescents in Winnipeg, Manitoba: summer 2006. Paediatr Child Health 13:193–196 **(PMID: 19252697)**
33. Mohamad N, Baharuddin KA, Ahmad R (2009) A traditional Malay myth leading to unintentional self intoxication with kecubung fruit. Southeast Asian J Trop Med Public Health 40:1331–1334 **(PMID: 20578469)**
34. Disel NR, Yilmaz M, Kekec Z, Karanlik M (2015) Poisoned after dinner: dolma with *Datura stramonium*. Turk J Emerg Med 15:51–55. https://doi.org/10.5505/1304.7361.2015.70894
35. Trancă SD, Szabo R, Cociş M (2017) Acute poisoning due to ingestion of *Datura stramonium*—a case report. Rom J Anaesth Intensive Care 24:65–68. https://doi.org/10.21454/rjaic.7518.241.szb
36. Goldfarb J, Pesin N, Margolin E (2019) Gardening and dilated pupils: an interesting case of anisocoria from *Brugmansia versicolor*. Can J Ophthalmol 54:e59–e61. https://doi.org/10.1016/j.jcjo.2018.05.004
37. Urich RW, Bowerman DL, Levisky JA, Pflug JL (1982) *Datura stramonium*: a fatal poisoning. J Forensic Sci 27:948–954. https://doi.org/10.1520/JFS12217J
38. Boumba VA, Mitselou A, Vougiouklakis T (2004) Fatal poisoning from ingestion of *Datura stramonium* seeds. Vet Hum Toxicol 46:81–82 **(PMID: 15080209)**
39. Steenkamp PA, Harding NM, van Heerden FR, van Wyk BE (2004) Fatal *Datura* poisoning: identification of atropine and scopolamine by high performance liquid chromatography/photodiode array/mass spectrometry. Forensic Sci Int 145:31–39. https://doi.org/10.1016/j.forsciint.2004.03.011
40. Le Garff E, Delannoy Y, Mesli V, Hédouin V, Tournel G (2016) Forensic features of a fatal *Datura* poisoning case during a robbery. Forensic Sci Int 261:e17–e21. https://doi.org/10.1016/j.forsciint.2016.02.028
41. Lusthof KJ, Bosman IJ, Kubat B, Vincenten-van Maanen MJ (2017) Toxicological results in a fatal and two non-fatal cases of scopolamine-facilitated robberies. Forensic Sci Int 274:79–82. https://doi.org/10.1016/j.forsciint.2017.01.024
42. Isbister GK, Oakley P, Dawson AH, Whyte IM (2003) Presumed Angel's trumpet (*Brugmansia*) poisoning: clinical effects and epidemiology. Emerg Med 15:376–382. https://doi.org/10.1046/j.1442-2026.2003.00477.X
43. Firestone D, Sloane C (2007) Not your everyday anisocoria: angel's trumpet ocular toxicity. J Emerg Med 33:21–24. https://doi.org/10.1016/j.jemermed.2007.02.046
44. Sevketoglu E, Tatli B, Tuğcu B, Demirelli Y, Hatipoglu S (2010) An unusual cause of fulminant Guillain–Barré syndrome: angel's trumpet. Pediatr Neurol 43:368–370. https://doi.org/10.1016/j.pediatrneurol.2010.05.019
45. Chan K (2002) Jimson weed poisoning—a case report. Perm J 6(4):28–30 **(PMC: 6220643)**
46. Krenzelok EP (2010) Aspects of *Datura* poisoning and treatment. Clin Toxicol 48:104–110. https://doi.org/10.3109/15563651003630672
47. Centers for Disease Control and Prevention (CDC) (1995) Jimson weed poisoning—Texas, New York, and California, 1994. MMWR Morb Mortal Wkly Rep 44:41–44 **(PMID: 7823893)**
48. Soneral SN, Connor NP (2005) Jimson weed intoxication in five adolescents. Wisconsin Med J 104:70–72 **(PMID: 16294604)**
49. Mowry JB, Spyker DA, Cantilena LR Jr, Bailey JE, Ford M (2013) 2012 Annual report of the American Association of Poison Control Centers' National Poison Data System (NPDS): 30th Annual Report. Clin Toxicol 51:949–1229. https://doi.org/10.3109/15563650.2013.863906
50. Mowry JB, Spyker DA, Cantilena LR Jr, McMillan M, Ford M (2014) 2013 Annual report of the American Association of Poison Control Centers' National Poison Data System (NPDS): 31st Annual Report. Clin Toxicol 52:1032–1283. https://doi.org/10.3109/15563650.2014.987397
51. Mowry JB, Spyker DA, Brooks DE, McMillan N, Schauben JL (2015) 2014 Annual report of the American Association of Poison Control Centers' National Poison Data System (NPDS): 32nd Annual Report. Clin Toxicol 53:962–1147. https://doi.org/10.3109/15563650.2015.1102927
52. Mowry JB, Spyker DA, Brooks DE, Zimmerman A, Schauben JL (2016) 2015 Annual report of the American Association of Poison Control Centers' National Poison Data System (NPDS): 33rd Annual Report. Clin Toxicol 54:924–1109. https://doi.org/10.1080/15563650.2016.1245421
53. Gummin DD, Mowry JB, Spyker DA, Brooks DE, Fraser MO, Banner W et al. (2017) 2016 Annual report of the American Association of Poison Control Centers' National Poison Data System (NPDS): 34th Annual Report. Clin Toxicol 55:1072–1252. https://doi.org/10.1080/15563650.2017.1388087
54. Gummin DD, Mowry JB, Spyker DA, Brooks DE, Osterthaler KM et al. (2018) 2017 Annual report of the American Association of Poison Control Centers' National Poison Data System (NPDS): 35th Annual Report. Clin Toxicol 56:1213–1415. https://doi.org/10.1080/15563650.2018.1533727
55. Kanchan T, Atreya A (2016) Datura: the roadside poison. Wilderness Environ Med 27:442–443. https://doi.org/10.1016/j.wem.2016.04.007
56. Taha SA, Mahdi AH (1984) *Datura* intoxication in Riyadh. Trans R Soc Trop Med Hyg 78:134–135. https://doi.org/10.1016/0035-9203(84)90196-2
57. Chang SS, Wu ML, Deng JF, Lee CC, Chin TF, Liao SJ (1999) Poisoning by *Datura* leaves used as edible wild vegetables. Vet Hum Toxicol 41:242–245 **(PMID: 10434380)**
58. Onen CL, Othol D, Mbwana SK, Manuel IL (2003) *Datura stramonium* mass poisoning in Botswana. S Afr Med J 92:213–214 **(PMID: 12040948)**
59. Gaire BP, Subedi L (2013) A review on the pharmacological and toxicological aspects of *Datura stramonium* L. J Integr Med 11:73–79. https://doi.org/10.3736/jintegrmed2013016
60. Chan TY (1995) Anticholinergic poisoning due to Chinese herbal medicines. Vet Hum Toxicol 37:156–157 **(PMID: 7631497)**
61. van Wyk B-E, Oudtshoorn B, Gericke N (2002) Medicinal plants of South Africa, 2nd edn. Briza Publications, Pretoria
62. Adegoke SA, Alo LA (2013) *Datura stramonium* poisoning in children. Niger J Clin Pract 16:116–118. https://doi.org/10.4103/1119-3077.106783
63. Moore DM (1972) *Datura* L. In: Tutin TG, Heywood VH, Burges NA, Moore DM, Valentine DH, Walters SM, Webb DA (eds) Flora Europaea, vol. 3. Cambridge University Press, Cambridge, pp 200–201
64. Osváth P, Nagy A, Fekete S, Tényi T, Trixler M (2000) A case of *Datura stramonium* poisoning—general problems of differential diagnosis. Orv Hetil 141:133–136 **(PMID: 10693336) (in Hungarian with English abstract)**

65. Winckelmann U, Lübke G, Brockstedt M, Schanz I, Dechent J, Weber J, Albani M (2000) Anticholinerges Syndrom nach Ingestion von Tee aus Engelstrompetenblüten. Monatsschr Kinderheilkd 148:18–22. https://doi.org/10.1007/s001120050004
66. Lazzarini D, Baffoni MT, Cangiotti C, Di Fronzo G, Gerboni S, Micheli R, Morelli S, Morolli L, Ioli G (2006) Food poisoning by *Datura stramonium*: an unusual case report. Intern Emerg Med 1:88–90. https://doi.org/10.1007/BF02934733
67. Rätsch C (1998) The encyclopedia of psychoactive plants: ethnopharmacology and its applications. Park Street Press, Rochester
68. Lindequist U (1992) *Datura*. In: Blaschek W, Hänsel R, Keller K, Reichling J, Rimpler H, Schneider G (eds) Hagers Handbuch der Pharmazeutischen Praxis, 5th edn. Springer, Berlin, pp 1138–1154
69. Caligiani A, Palla G, Bonzanini F, Bianchi A, Bruni R (2011) A validated GC–MS method for the detection of tropane alkaloids in buckwheat (*Fagopyron esculentum* L.) fruits, flours and commercial foods. Food Chem 127:204–209. https://doi.org/10.1016/j.foodchem.2010.11.141
70. Ciechomska M, Woźniakiewicz M, Nowak J, Świadek K, Bazylewicz B, Kościelniak P (2016) Development of a microwave-assisted extraction of atropine and scopolamine from Solanaceae family plants followed by a QuEChERS clean-up procedure. J Liq Chromatogr Relat Technol 39:538–548. https://doi.org/10.1080/10826076.2016.1196215
71. Kerchner A (2019) Néhány Solanaceae faj nektárkémiai és virágbiológiai vizsgálata. PhD dissertation. University of Pécs, Pécs, Hungary **(in Hungarian with English summary)**
72. Farkas Á, Kerchner A, Déri H, Boros B, Darók J (2011) Nectary structure and nectar production of various *Datura* species. Int J Plant Reprod Biol 3:31–35
73. Marciniak J, Sikorski M (1972) Poisoning by alkaloids of *Datura stramonium* and *D. inoxia* after ingestion of honey. Pol Tyg Lek 27:1002–1003 **(PMID: 5068984) (in Polish)**
74. Ramirez M, Rivera E, Ereu C (1999) Fifteen cases of atropine poisoning after honey ingestion. Vet Hum Toxicol 41:19–20 **(PMID: 9949478)**

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.