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# Plants causing poisoning outbreaks of livestock in South America: A review

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ABSTRACT

This paper reviews toxic plants for livestock in South America. We included 219 plants in this review, considering only the plants that caused at least one demonstrated outbreak of poisoning. Plants reported as toxic in other regions and present in South America, but with no confirmed outbreaks of poisoning in this region, are not included. We report the main aspects of the epidemiology, clinical signs, pathology and economical importance of the poisonings. Initially, the toxic plants are described based on their toxic compounds, but because the toxic compound is unknown in 92 (42%) of the plants we also classify them according to the affected system. This review highlights the great diversity of toxic plants capable of affecting livestock in South America, and for this reason studies in this regard should be intensified.

## 1. Introduction

According to Tokarnia et al. (2012), "poisonous plants of livestock interest are those that, when ingested by farm animals under natural conditions, cause health problems or death." Following this definition, we include in this manuscript only toxic plants that have been proven to cause at least one outbreak of spontaneous poisoning in livestock in South America. In most of these plants, the toxicity was demonstrated by observing outbreaks and by the experimental reproduction of the disease. Also, we include as toxic plants for livestock those that contain a known toxic compound causing outbreaks of disease typical of this compound (e.g., fluoroacetate, nitrites, cyanogenic glycosides, pyrrolizidine alkaloids, swainsonine), and the diagnostic was based on clinical signs, pathology, and determination of the toxic compound in the plant. In this manuscript, we did not consider as toxic plants many species that occur in South America and have been reported as toxic in other regions, sometimes with a known toxic compound, but outbreaks in South America have not been demonstrated and published (e.g., *Taxus baccata*, *Datura stramonium*, *Nicotiana glauca*, and *Asclepias curassavica*). We also did not include those plants whose toxicity has been experimentally demonstrated in South America, but no spontaneous outbreaks of intoxication have been recorded.

Toxic plants cause severe economic losses, including direct losses due to the death of animals, reproductive losses, reduced production, subclinical diseases, and decreased immunity, and indirect losses due to the cost of control measures, loss of forage, the replacement of dead animals, reduced value of the farms, and costs of diagnosis and treatment. There is little data about South America's economic losses caused by toxic plants. In Brazil, based on data obtained from diagnostic laboratories from different Brazilian regions, annual losses due to animal deaths caused by plants are estimated as approximately 1,3 million cattle, 422,000 sheep, 58,000 goats, and 38,500 horses from a population of nearly 220 million cattle, 17,6 million sheep, 9,3 million goats, and 5,5 million horses (Pessoa et al., 2013a). It has also been estimated that in the Brazilian semiarid region, from a population of 7,6 million goats and 7,7 million sheep, 273,120 kids and 259,582 lambs died annually due to malformations caused by *Mimosa tenuiflora* and *Cesnotigma pyramidalis* (Pessoa et al., 2013a). Losses due to toxic plants had not been estimated in other South American countries.

In the last few years, mainly in Brazil, Argentina and Uruguay, research groups and diagnostic laboratories reported many plant poisonings. At present, there are 162 known toxic plants in Brazil, 68 in Argentina, and 45 in Uruguay. At all we include 219 toxic plants from different South American countries. These studies, most of them

*Abbreviations:* MFA, monofluoroacetate; PA, pyrrolizidine alkaloids.

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performed by diagnostic laboratories from the universities, refer mainly to the description of the epidemiology, clinical signs, and pathology of intoxications. Fewer studies include the identification of the toxic compounds of plants. Of the 219 toxic plants described, the toxic compound of 92 (42%) is unknown, highlighting the need for phytochemical research on these plants.

In this review, poisonous plants to livestock in South America will be presented, with emphasis on aspects related to the epidemiology of the intoxications, economic impact, toxic compounds, pathogenesis, characterization of clinicopathological features, and control and prevention techniques. The plants are grouped initially according to their toxic compound. After describing the poisoning by plants with a specific toxic compound, we include the plants with a similar effect but with an unknown toxic compound. In cases where the toxic compound is not known and the toxicity of the plant is not similar to that of known toxic compounds, the plants were classified by the affected organ system. Because we included 219 toxic plants in this review, it is not possible to include all references, so we chose the more important and\or the more recent references for each poisonous plant.

## 2. Poisonous plants in South America

### 2.1. Plants affecting the heart

#### 2.1.1. Plants that contain monofluoroacetate

In Brazil, 12 species from three plant families contain monofluoroacetate (MFA) and cause sudden death associated with exercise. This group comprises four species of the Rubiaceae family (*Palicourea marcgravii* (Fig. 1A and B), *Palicourea aeneofusca* (Fig. 1C), *Palicourea juruana* and *Palicourea grandiflora*); six species of the Malpighiaceae family (*Amorimia exotropica* (Fig. 1D), *Amorimia septentrionalis* (Fig. 1E), *Amorimia rigida*, *Amorimia pubiflora*, *Amorimia amazônica*, and *Niedenzuella stannea*), and two species of the Bignoniaceae family (*Tanaecium bilabiatum* (Fig. 1F) and *Fridericia elegans*) (Lee et al., 2012; Barbosa et al., 2017; Nascimento et al., 2018; ). It is estimated that plants containing MFA are responsible for nearly 50% of the deaths caused by toxic plants in Brazil (Pessoa et al., 2013a). Monofluoroacetate has been detected in other species such as *Palicourea amapaensis*, *Palicourea longiflora*, *Palicourea barraensis*, *Palicourea macarthurorum*, *Palicourea nigricans*, *Palicourea vacillans*, *Palicourea aff. juruana*, and *Amorimia camporum*. However, these species have not been associated with outbreaks (Lee et al., 2012; Cook et al., 2014). *Palicourea marcgravii* is probably the most important Brazilian toxic plant found in forests in all of Brazil except the southern region. After deforestation, large areas of

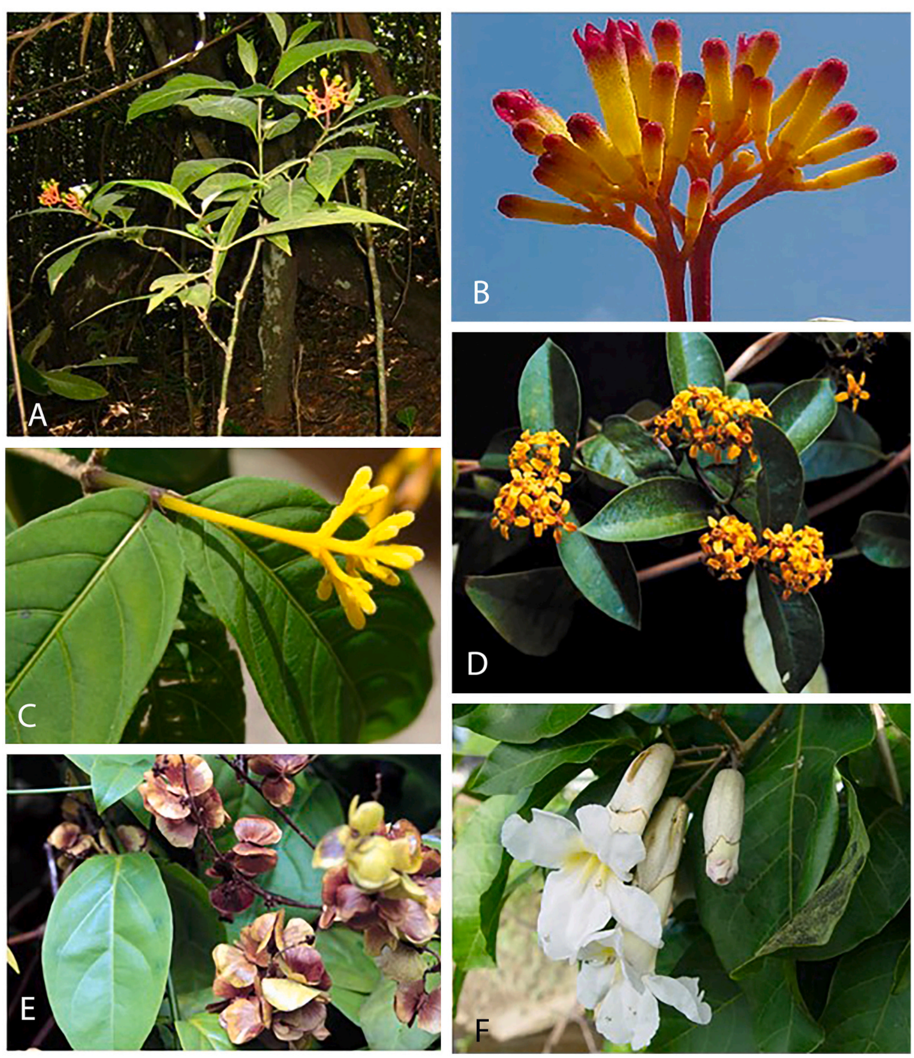


**Fig. 1.** Plants containing monofluoroacetate. A and B) *Palicourea marcgravii*; C) *Palicourea aeneofusca*; D) *Amorimia exotropica*; E) *Amorimia septentrionalis* (fruits); F) *Tanaecium bilabiatum*.

pasture created a favorable environment for *P. marcgravii* maintenance and growth (Ubiali et al., 2020).

Poisoning by MFA-containing plants mainly affects cattle, but sheep and goats can also be affected, mainly by *A. septentrionalis* and *A. rigida* found primarily in the Northeast region. Buffalos are nearly six times more resistant than cattle to *P. marcgravii* poisoning (Tokarnia et al., 2012) and there are also some differences in susceptibility between bovine breeds (Serodio et al., 2019). Clinical manifestations are peracute and characterized by collapse, tremors, difficulty breathing, limb paddling, and finally death due to acute heart failure within a few minutes (Cunha et al., 2022). Gross findings are nonspecific or absent. Hydropic vacuolar degeneration of distal convoluted tubule cells with nuclear pyknosis in the kidneys is observed in most cases (Tokarnia et al., 2002, 2012; Ubiali et al., 2020). Abortions, embryonic deaths, and neonatal mortality are observed in goats experimentally intoxicated by *A. septentrionalis* (Silva et al., 2017a; Lopes et al., 2019).

In Colombia, sudden death following exercise has been associated with *Amorimia concinna* (Gonzalez, 2010) and *Tanaecium exitiosum* (Mora, 1943), but no MFA has been determined in these species. *Tanaecium bilabiatum* causes sudden death in cattle in the region of the Orinoco River and its tributaries in Venezuela (Cortes, 1971).

Fencing off areas to prevent animals from accessing the plant is the most effective preventive measure, and animals that have consumed the plant should not be subjected to exercise. The use of bacteria that hydrolyze fluoroacetate to prevent poisoning has been experimentally proven but is not being used under field conditions (Silva et al., 2016; Pessoa et al., 2019).

#### 2.1.2. Plants that contain cardiotoxic glycosides

*Nerium oleander* (Apocynaceae) and *Kalanchoe blossfeldiana* (Crassulaceae) containing cardiotoxic glycosides have been reported in Brazil. Both plants are ingested when plants or their branches are cut and placed within reach of animals. Outbreaks of poisoning by *N. oleander* have been reported in distinct Brazilian regions, Argentina and Uruguay (Soto-Blanco et al., 2006; Fazzio et al., 2008; Rivero et al., 2011a); while *K. blossfeldiana* poisoning was reported in Northeastern Brazil (Mendonça et al., 2017).

#### 2.1.3. Plants that contain acetogenin

*Persea americana* (Lauraceae) poisoning was recently described in horses in Southeast Brazil. The disease presents a chronic clinical course associated with severe cardiac fibrosis. *P. americana* is cultivated in many areas of America, the poisoning rarely occurs (Freitas et al., 2022).

#### 2.1.4. Other plants with unknown toxic compound(s) causing cardiac lesions

Poisonings by *Ateleia glazioveana* (Leguminosae) in southern Brazil, *Niedenzuella acutifolia* (Malpighiaceae) in southeastern Brazil, and *Niedenzuella multiglandulosa* (Malpighiaceae) in southeastern and midwestern Brazil cause three clinically different diseases in domestic ruminants, which can occur singly or together: 1) cardiac form with fibrosis of the heart causing sudden death or congestive heart failure; 2) a perinatal form with abortion or neonatal death; and 3) a nervous form with spongiosis (*status spongiosus*) of the nervous system (Riet-Correa et al., 2009; Tokarnia et al., 2012; Gava et al., 2021). However, considerable overlap exists between the different forms of the disease. The observation of different clinical manifestations depends on the amount and duration of plant consumption. Aborted fetuses, and calves and lambs that died after parturition had cardiac and brain lesions similar to those observed in adult animals, indicating that the unknown toxin passed through the placental barrier (Riet-Correa et al., 2009a).

### 2.2. Plants affecting the liver

#### 2.2.1. Plants causing liver fibrosis

*2.2.1.1. Plants that contain pyrrolizidine alkaloids.* In South America, five plant genera from three families contain pyrrolizidine alkaloids (PA) and may cause three syndromes: 1) chronic liver fibrosis (cirrhosis); 2) hepatogenous photosensitization; and 3) centrilobular liver necrosis (with high doses of PA).

*Senecio* (Asteraceae) is the genus most often associated with outbreaks in cattle. In Brazil, it is the most important poisonous plant for cattle in the state of Rio Grande do Sul (Southern Brazil); species related to outbreaks include *Senecio brasiliensis*, *Senecio selloi*, *Senecio cisplatinus*, *Senecio heterotrichius*, *Senecio oxyphyllus*, *Senecio madagascariensis, and Senecio tweedei* (Panziera et al., 2018). In Uruguay, there are cases of poisoning by *S. brasiliensis*, *S. selloi*, *S. oxyphyllus*, *S. madagascariensis*, and *Senecio grisebachii* (Rivero et al., 2011a), and in Argentina by *S. tweediei*, *S. selloi*, *S. grisebachii*, *S. madagascariensis*, *Senecio pampeanus* (Odriozola, 2011), and *S. brasiliensis*. In Chile, several species of *Senecio* occurred, but only *Senecio erraticus* has been associated with poisoning (Araya, 2009). *S. brasiliensis* is the most important toxic species in southern Brazil and Uruguay, but *S. madagascariensis*, despite being less toxic, is a critical invasive weed introduced in the region in the 1990s with great dispersal capacity that allows it to remain throughout the year in pastures (Panziera et al., 2018).

The disease mainly affects cattle (Panziera et al., 2018) but also horses from southern Brazil (Panziera et al., 2017), Uruguay (Rivero et al., 2011a), Argentina (Micheloud et al., 2017a), and Chile (Araya, 2009). Significant outbreaks have been diagnosed in horses, with 20–25% mortality associated with the consumption of *S. rudbeckiaefolius*, *S. madagascariensis*, and *S. hieronymi* in Northwest Argentina (Micheloud et al., 2017a). Poisoning has also been described in sheep in Brazil (Giaretta et al., 2014) and Chile (Araya, 2009). However, sheep are more resistant to intoxication and are used to control the plant (Stigger et al., 2018). In the state of Rio Grande do Sul, southern Brazil, it has been demonstrated that a stocking rate of 0.5–3 sheep per hectare in continuous grazing, or a greater number of sheep (four or more sheep/hectare) in rotational grazing will control populations of *Senecio* spp. However, some species, such as *S. madagascariensis* that sprout throughout the year are more difficult to control (Stigger et al., 2018).

*Crotalaria retusa* (Leguminosae) is the most important poisonous plant for horses in the northeast region of Brazil causing hepatic fibrosis and hepatic encephalopathy (Nobre et al., 2004). In this same region, when seeds are consumed, *C. retusa* causes acute intoxication, with centrilobular necrosis, in sheep and goats. Experiments have shown that single doses of 205.2 and 273.6 mg of monocrotaline per kg live-weight from seeds cause acute intoxication with centrilobular necrosis. However, sheep can ingest daily doses of 136.8 mg/kg live weight for 70 or more days without showing clinical signs and creating resistance to intoxication (Anjos et al., 2010). These resistant animals (through daily administration of non-toxic doses) can control the plant, as they ingest it without showing signs. The only problem is that this resistance is lost in a short period (7–15 days) (Anjos et al., 2010). As outbreaks in animals ingesting growing *C. retusa* (without seeds) have never been observed, it is assumed that if sheep and possibly goats begin to consume the seedless plant, they ingest non-toxic doses and develop resistance. Sheep ingesting low, non-toxic amounts of *Senecio brasiliensis* also develop resistance, while high doses can cause acute poisoning (Grecco et al., 2012). In the last years, poisoning by *Crotalaria* spp. has increased in Brazil's Midwest region; the plant's dissemination has occurred through its increasing use as an agent of biological nitrogen fixation in agriculture. Intoxication by *Crotalaria spectabilis* causes fibrosis and centrilobular necrosis in horses that ingest oats contaminated by seeds (Lacerda et al., 2021), while *Crotalaria incana* causes hepatic fibrosis in cattle raised in pastures where the plant occurs (Leal et al., 2019).

Poisoning by seeds of *Crotalaria mucronata* in cattle and *Crotalaria juncea* in horses have been reported as the cause of respiratory signs and lung lesions in animals ingesting contaminated grains. Main microscopic lesions included thickening of the alveolar septa, interstitial fibrosis, alveolar, bronchiolar and perivascular edema, proliferation of type II pneumocytes, and proliferation of Clara cells (Pessoa et al., 2013b).

*Echium plantagineum* (Boraginaceae) is a common invasive weed in southern Brazil, Uruguay, and Argentina, but poisoning has rarely been diagnosed in cattle (Méndez et al., 1985; Rivero et al., 2011a). A single outbreak of intoxication by *Erechtites hieracifolia* (Asteraceae), containing 0.2% pyrrolizidine alkaloids, was reported in Uruguay, affecting cattle with hepatic fibrosis (Rivero et al., 2011a). An outbreak of hepatogenous photosensitization in cattle associated with the consumption of *Heliotropium elongatum* (Boraginaceae) was reported in Uruguay (Dutra, 2010a).

*2.2.1.2. Other plants with unknown toxic compounds causing liver fibrosis.* *Tephrosia cinerea* (Leguminosae) is a weed that causes marked ascites due to liver fibrosis in sheep in Northeast Brazil. Intoxication occurs due to prolonged consumption of *T. cinerea* that remains green during the dry season. Sheep of all ages are affected, and the leaves are the most toxic part of the plant. The clinical course is chronic and clinical and pathological features include ascites, periacinar hepatic fibrosis, portosystemic shunts, and hepatic encephalopathy (Riet-Correa et al., 2013b; Silveira et al., 2018).

### 2.2.2. Plants causing liver necrosis

*2.2.2.1. Plants that contain carboxyatractyloside or substances with similar action.* Plants that contain diterpene glycosides include *Xanthium strumarium* (Fig. 2A–C) (Asteraceae) (atractyloside and carboxyatractyloside), *Pascalia glauca* (Fig. 2D) (Asteraceae) (wedeloside), *Cestrum axillare* (Fig. 2E–G) and *Cestrum parqui* (Fig. 2H) (Solanaceae) (kaurene glycosides, parquin, and carboxyparquin). These substances with close structural similarity with carboxyatractyloside cause centrilobular or massive hepatic necrosis, with clinical signs of acute liver failure, including hepatic encephalopathy (Pearce et al., 1992; Machado et al., 2021; Ubiali et al., 2022).

*Xanthium strumarium* is a toxic plant, mainly for cattle in Uruguay (Rivero et al., 2011a; García y Santos and Capelli, 2016), Argentina (García et al., 2017), and southern Brazil (Méndez et al., 1998). However, it was diagnosed as causing high mortality in cattle in the State of Minas Gerais in Southeast Brazil. The plant has adapted to the areas flooded by the Araguari River due to several hydroelectric plants that create transient flood conditions similar to what happens in the southern

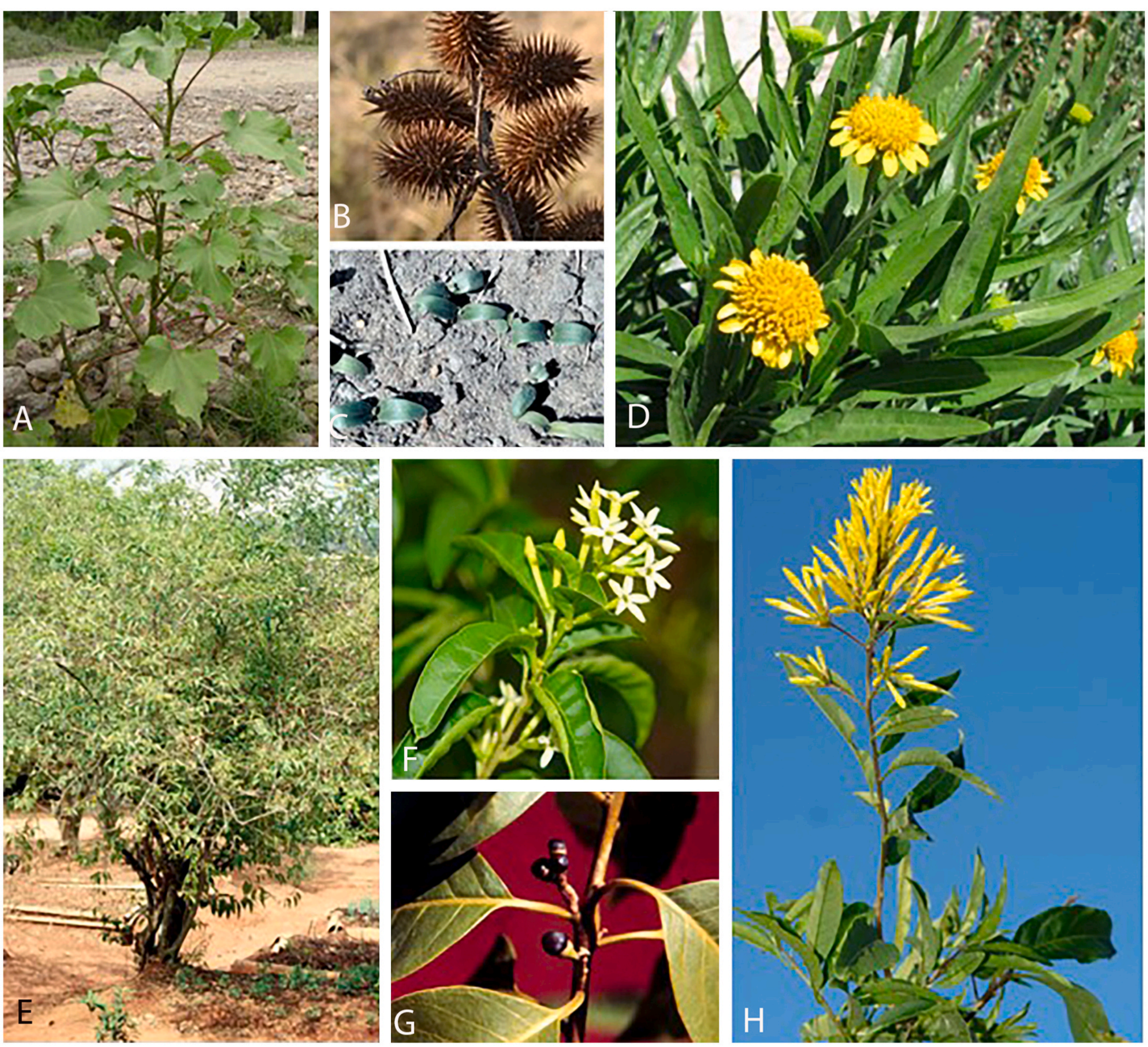


**Fig. 2.** Plants containing carboxyatractyloside or substances with similar action. A-C) *Xanthium strumarium,* green plant (A), burs (B) and cotyledons (C); D) *Pascalia glauca*; E-G) *Cestrum axillare,* tree (E): flowers (F) and fruits (G); H) *Cestrum parqui.*

region of Brazil (Pampa biome) (Machado et al., 2021). Intoxication occurs by ingestion of cotyledons or burs (mixed with silage or cereals) (Driemeier et al., 1999; García y Santos and Capelli, 2016; Machado et al., 2021). In Argentina, there have been cases of mortality due to the direct consumption of *Xanthium spinosum* fruits in the field (Costa et al., 2008).

*Pascalia glauca* is the main plant causing acute poisoning in cattle in Argentina, but it also affects sheep and goats in this country (Medina et al., 2022). The plant rarely causes poisoning in cattle in Uruguay (Rivero et al., 2010). Poisoning occurs by directly consuming the plant in areas invaded by it or by ingesting contaminated hay. Although *P. glauca* is perennial, the aerial part of the plant disappears after a frost, so the outbreaks that occur during the winter are usually the result of contaminated hay, causing significant mortality (Micheloud and Odriozola, 2012).

Outbreaks of *Cestrum parqui* poisoning occur in Uruguay (Rivero et al., 2011a), Argentina (García et al., 2017), Chile (Araya, 2009), but rarely in southern Brazil (Riet-Correa et al., 1986). Most outbreaks are related to forage shortage conditions and mainly affect cattle and occasionally sheep (Dutra et al., 2012a,b). *Cestrum axillare* is one of the most important toxic plants in Southeastern Brazil and also occurs in the Northeastern region of this country. It affects mainly cattle, and occasionally buffalo and goats. Most outbreaks occur from April to September, during the dry season (Ubiali et al., 2022).

*2.2.2.2. Plants that contain cicasine.* *Cycas revoluta* (Cycadaceae) is an ornamental plant that causes hepatic necrosis in cattle. Poisoning occurs when animals consume it from gardens or when the plant is mixed with forage. Clinicopathological features of *C. revoluta* poisoning are similar to other plants that cause acute hepatotoxicity. Evidence of plant consumption is essential for diagnosis (Rivero et al., 2011a; Ferreira et al., 2015).

*2.2.2.3. Other plants with unknown toxic compounds causing liver necrosis.* Other plants causing hepatic necrosis in South America, but with unknown toxic compounds are shown in Table 1.

*2.2.3. Plants causing secondary (hepatogenous) photosensitization*

*2.2.3.1. Plants that contain lantadenes.* Lantadenes A and B are hepatotoxic pentacyclic triterpenoids identified in several *Lantana* species (Verbenaceae). Much of the available information deals with the toxicity of *Lantana camara*. In Brazil, natural cases have been identified with *L. camara* var. *aculeata*, *Lantana glutinosa*, *Lantana tiliaefolia* and *L. camara* var. *nivea* (Riet-Correa et al., 1984; Tokarnia et al., 1999a). Poisoning by L. *camara* has been reported in cattle in Argentina (Marín et al., 2005) and in cattle and sheep in Uruguay (Rivero et al., 2011b). Affected animals commonly present photosensitization, with weight loss, jaundice, and photophobia due to obstructive liver damage. The main gross lesions are severe jaundice and enlarged yellow to orange liver. The consumption of high doses of *L. camara* has been also associated with acute liver necrosis (Silva et al., 2021).

**Table 1**
Toxic plants without known toxic compounds that cause hepatic necrosis.

| Plants | Species affected | Region | Main references |
|---|---|---|---|
| *Cestrum corymbosum* | Cattle | Southern Brazil | Gava et al. (1991) |
| *Cestrum intermedium* | Cattle | Southern Brazil | Gava et al. (1996) |
| *Cestrum strigillatum* | Cattle | Argentina | Odriozola et al. (2002) |
| *Copernicia prunifera* | Cattle | Northeastern Brazil | Andrade et al. (2008) |
| *Dodonaea viscosa* | Cattle | Southern Brazil | Colodel et al. (2003) |
| *Pterodon emarginatus* | Cattle | Midwestern Brazil | Cruz et al. (2012); Sant'Ana et al. (2012) |
| *Sessea brasiliensis* | Cattle | Southeast Brazil | Canella et al. (1968) |
| *Sessea vestioides* | Cattle | Uruguay | Rivero et al. (2011a) |
| *Trema micrantha* | Goats, sheep and horses | Southern Brazil | Traverso et al. (2003); Bandarra et al. (2010); Wouters et al. (2013) |
| *Vernonia molissima* | Cattle | Midwestern Brazil | Döbereiner et al. (1976) |
| *Vernonia rubricaulis* | Cattle | Midwestern Brazil | Brum et al. (2002) |
| *Vernonia plantaginoides* | Sheep | Uruguay | Dutra et al. (2016) |

*2.2.3.2. Plants that contain furanosesquiterpenes.* *Myoporum laetum* (Myoporaceae) contains furanosesquiterpenes, the best known of which is ngaione. Poisoning mainly affects cattle and rarely sheep in Uruguay, Argentina, and southern Brazil (Odriozola et al., 1987; García y Santos et al., 2008). Cases of poisoning occur from the consumption of the leaves directly from the trees or from their branches that fall after storms. The clinical course is acute, and the animals show apathy, serous eye discharge, abdominal pain, constipation, jaundice, and photosensitization. The main gross lesions are severe jaundice and enlarged yellow to orange liver. In *Myoporum* poisoning, hepatic necrosis is periportal (García y Santos et al., 2008).

*2.2.3.3. Plants that contain lithogenic saponins.* In South America, three plant genera have been described as the cause of hepatogenous photosensitization caused by the presence of lithogenic saponins: *Urochloa* (syn. *Brachiaria*) spp, *Panicum* spp. (Poaceae) and *Tribulus terrestris* (Zygophyllaceae). Poisoning by *Urochloa* spp. in ruminants is frequent in different regions of Brazil (Riet-Correa et al., 2011a) and Colombia (Diaz and Boermans, 2011; Lozano et al., 2017). In Argentina, isolated cases of intoxication with a commercial hybrid of *U. brizantha* and *U. decumbens* (Mulato II) were reported in cattle and sheep (Raúl Marín, personal communication).

All *Urochloa* species are considered toxic, but the concentration of saponins differs between species. *Urochloa decumbens* contains high levels of lithogenic saponins (protodioscin), followed by *Urochloa brizantha* and *Urochloa ruziziensis* which contain lower amounts. The least toxic is *Urochloa humidicola.* Cattle, sheep, and goats are affected, but sheep are more susceptible than cattle, and young animals are more susceptible than adults. However, there is a difference in susceptibility between animals of the same breed. In animals raised on *Urochloa* pastures there is a natural selection of the most resistant ones since resistance/susceptibility is hereditary (Riet-Correa et al., 2011a). In Brazil, this natural selection has been associated with a decrease in the frequency of poisoning in sheep and cattle in regions where the plant is most used. It is also suggested that there is some degree of adaptation of the animals by gradual consumption or by the transfaunation of rumen microbiota (Castro et al., 2018). Another factor that has led to a lower frequency of intoxication is the replacement of *U. decumbens* (the most toxic) by less toxic species such as *U. brizantha.* Horses are susceptible to poisoning, but only *U. humidicola* has been reported to cause photosensitization in this species (Barbosa et al., 2006b), as they do not ingest other *Urochloa* species.

In Brazil, *Urochloa* spp. is the most frequently used forage, occupying about 85% of Brazil's cultivated pasture area (approximately 102 million hectares). Knowing the epidemiological characteristics mentioned above is essential for preventing and controlling intoxication. However, both the use of resistant animals and the utilization of *Urocloa* spp. with lower saponin content are the main ways of controlling the disease.

Other plants containing lithogenic saponins are *Panicum dicotomiflorum*, *Panicum miliaceum* and *Tribulus terrestris*. Poisoning by *Panicum dicotomiflorum* has been reported in sheep in northeastern Brazil

(Riet-Correa et al., 2009b). Similarly, in the central zone of Argentina, sporadic outbreaks of cattle intoxicated with *Panicum miliaceum* have been recorded (Odriozola, 2011). *Tribulus terrestris* is a perennial, flat-growing creeper with an underground root system adapted to dry environments. In Argentina, this species is found in the dry central region of the country and few outbreaks have been detected in sheep (Tapia et al., 1994). Although outbreaks are rare, when they occur the incidence is usually high and many animals are affected.

*Bassia* (*Kochia*) *scoparia* (Amaranthaceae) is a common weed, especially in the more arid regions of central-western Argentina, where outbreaks are sporadically observed in cattle and sheep (García et al., 2017). It has a variety of toxic and potentially toxic compounds in the plant. However, saponins and some alkaloids seem to be the toxic compounds involved in liver damage and photosensitization (Odriozola, 2011).

*2.2.3.4. Plants that cause photosensitization, abortions and/or digestive signs.* Poisonings by pods of *Enterolobium contortisiliquum*, *Enterolobium gummiferum*, *Stryphnodendron fissuratum*, and *Stryphnodendron obovatum* (Fabaceae) affect ruminants in the Midwest and Northeast of Brazil (Tokarnia et al., 2012; Bezerra et al., 2021; Guizelini et al., 2021). Poisoning by *Enterolobium cyclocarpum* also occurs in Colombia (Lozano et al., 2022). This group of plants causes three syndromes: 1) ruminal acidosis; 2) hepatogenous photosensitization; and 3) abortion. Animals consume the pods during drought season when they fall to the ground. Triterpene saponins isolated from *E. contortisiliquum* have been associated with liver lesions and photosensitization in cattle (Bezerra et al., 2021). It has been demonstrated that goats consuming non-toxic doses of pods of *E. contortisiliquum* developed resistance against the poisoning, and the pods may be used as forage (Pessoa et al., 2013a). Horses poisoned by *E. contortisiliquum* showed liver lesions without photosensitization or diarrhea (Machado et al., 2019).

### *2.3. Plants causing primary photosensitization*

#### *2.3.1. Plants that contain furocoumarins or anthraquinones*

*Ammi majus* (Apiaceae/Umbelliferae) (Fig. 3A) causes primary photosensitization due to the presence of furocoumarins. Poisonings have been reported in Brazil (Méndez et al., 1991), Uruguay (Rivero et al., 2011a), and Argentina (Dorsch et al., 2018). The plant is most toxic during seed production, when photodynamic compounds are concentrated. Although these species are well known for their toxicity and as a weed in crops, outbreaks are infrequent (Méndez et al., 1991; Dorsch et al., 2018).

*Heterophyllaea pustulata* (Rubiaceae) (Fig. 3B), which contains anthraquinones, causes significant economic losses due to primary photosensitization in northwestern Argentina (Micheloud et al., 2021).

#### *2.3.2. Other plants with unknown toxic compound causing primary photosensitization*

Other plants causing primary photosensitization but with unknown toxic compounds include *Froelichia humboldtiana* (Amaranthaceae) (Fig. 3C) and *Chamaecrista serpens* (Fabaceae, subfamily Caesalpinioideae) (Fig. 3D) affecting ruminants and equid (Pimentel et al., 2007a; ; Knupp et al., 2014; Silva-Filho et al., 2020; Mendonça et al., 2022), and *Malachra fasciata* (Malvaceae) (Fig. 3E) affecting sheep (Araújo et al., 2017). *F. humboldtiana* and *C. serpens* are widespread in northeastern Brazil, causing numerous poisoning outbreaks. Poisoning by *M. fasciata* was reported in the state of Paraiba, also in northeastern Brazil.

### *2.4. Plants affecting the nervous system*

#### *2.4.1. Plants that contain indolizidine alkaloids*

In South America, many plants from three families contain swainsonine and, in some cases, calystegines. Six toxic *Ipomoea* (Convolvulaceae) species are recognized in Brazil: *Ipomoea carnea* subsp. *Fistulosa* (Fig. 4A); *Ipomoea sericosepala; Ipomoea riedelli*; *Ipomoea sericophylla* (Fig. 4B); and *Ipomoea brasiliana* (Mendonça et al., 2018;

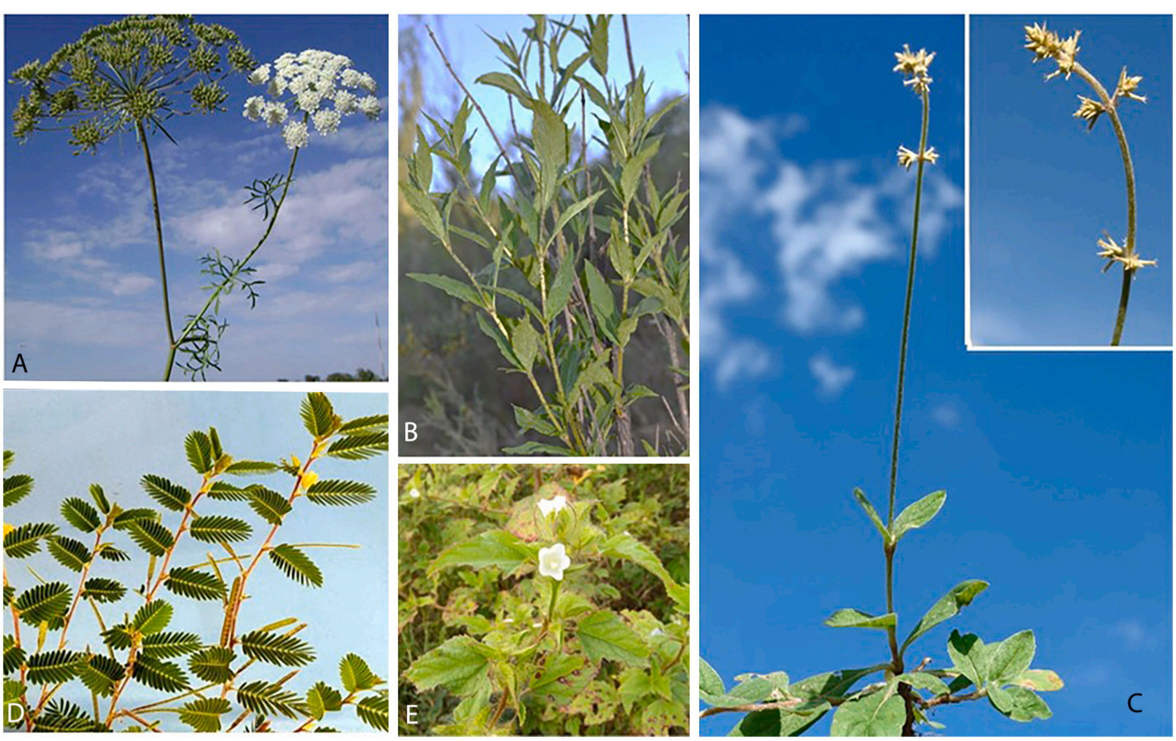


**Fig. 3.** Plants causing primary photosensitization. A) *Ammi majus*; B) *Heterophyllaea pustulata*; C) *Froelichia humboldtiana* D) *Chamaecrista serpens* (Cortesy of Dr. Múcio Mendonça); E) *Malachra fasciata* (Cortesy of Dr. Ricardo Lucena).


**Fig. 4.** Plants that contain indolizidine alkaloids. A) *Ipomoea carnea* var. *fistulosa*; B) *Ipomea sericophyla*; C) *Sida rodrigoi* Monteiro*;* D) *Sida carpinifolia*; and E) *Astragalus garbancillo* var. *garbancillo,* inset: flower.

Oliveira et al., 2021). All poisonings by the different species occur in goats in the Northeast region of Brazil, while intoxication by *I. carnea* subsp. *fistulosa* also occurs on Marajó Island (Amazonia). The latter was also diagnosed in cattle in the Brazilian Pantanal (central western Brazil), and *I. sericosepala* affects cattle and horses (Riet-Correa et al., 2017).

All these plants contain swainsonine, and some of them also contain calystegines. It has been proven that in *I. carnea* subsp. *fistulosa*, swainsonine is produced by an endosymbiotic ascomycete fungus of the order Chaetothyriales (Cook et al., 2013). The capacity of calystegines to induce neurological signs and lysosomal storage in goats experimentally intoxicated by *Ipomoea incarnata*, which contain only calystegines, has recently been demonstrated (Fábio Mendonça, personal communication).

In Brazil, in the southern and southeastern regions, poisoning by *Sida carpinifolia* (Malvaceae) (Fig. 4C and D) is frequent, affecting goats, cattle, and, less frequently, horses and sheep (Driemeier et al., 2000; Riet-Correa et al., 2017; Reis et al., 2018, 2019; Reis et al., 2019a,b). In the State of Santa Catarina, *S. carpinifolia* is the leading cause of neurological alterations caused by plants in cattle (Furlan et al., 2009). Reproductive failure mainly in goats with chronic clinical signs (Oliveira et al., 2011) and hydrallantois in cows (Reis et al., 2019a,b) are also reported following consumption of swainsonine containing plants.

In Argentina, swainsonine poisoning is caused by *Ipomoea carnea* var. *fistulosa*, *Sida rodrigoi, Ipomoea hieronymi* subsp. *calchaquina*, *Astragalus garbancillo* var. *garbancillo* (Fig. 4E), *Astragalus pehuenches*, and *Astragalus punae* in goats, sheep, cattle, and camelids (Cholich et al., 2021).

A characteristic of the intoxication by plants that contain swainsonine is that animals usually do not ingest these plants; however, when some animals, due to lack of forage availability, start to consume the plant, by social facilitation, the other animals of the herd acquire the habit to ingest it. Control of poisoning by plants that contain swainsonine in small ruminants by the technique of conditioned food aversion has been successfully used, using lithium chloride (LiCl) as an aversive. This technique allows the animals to be averted for at least two years (Oliveira-Júnior et al., 2014).

In the case of poisoning in goats by *I. carnea* subsp. *fistulosa* and *I. sericocepala*, and probably other *Ipomoea* species, the substitution of goats for sheep is an efficient control measure since, in field conditions, sheep do not ingest the plant. Another efficient control measure, especially in areas severely invaded by *Ipomoea* spp., is rotational grazing. Animals can be placed in areas invaded by the plant for 15–30 days or until the first clinical signs appear. After this time, the animals must be transferred to areas free of *Ipomoea* spp., and they must remain there for 30–40 days to eliminate swainsonine. After this period, they can return to ingest *Ipomoea* spp. (Cook et al., 2015).

*2.4.2. Plants that contain indole diterpene alkaloids*

Plants containing indole diterpene alkaloids are infected by endophytic fungi that produce this toxic substance. They include: *Cynodon dactylon* (Poaceae) (Fig. 5A) infected by *Claviceps cynodontes* (Uhlig et al., 2009); *Paspalum* spp. (Fig. 5B) (Poaceae) infected by *Claviceps paspali* (Riet-Correa et al., 2013a), *Ipomoea asarifolia* (Convolvulaceae) (Fig. 5C) infected by *Periglandula* sp. (Gardner et al., 2018), *Poa huecu* (Fig. 5D) and *Festuca argentina* (Fig. 5E) (Poaceae) infected by endophytes of the genus *Epichloe*, including *Epichloe tembladerae* (Martinez et al., 2020; Zabaleta et al., 2022), and *Lolium perenne* (Poaceae) infected by *Epichloe festucae* var. *lolii* (Odriozola et al., 1993). Indole diterpenoid alkaloids have also been identified in *Ipomoea pes caprae* (Convolvulaceae) (Stephen T. Lee, personal communication), which causes a disease similar to that caused by *I. asarifolia.*

The intoxications mentioned above affect goats, sheep, and cattle. The toxic compound can be eliminated in milk affecting offspring (Lopes et al., 2014). Typical signs of intoxication include generalized muscle tremors that are initially mild but increase when animals are moved, leading to falls. If the animals are left to rest, they recover and return to standing. The most characteristic clinical signs are intention tremors (cerebellar) with lateral movements of the head and neck that increase if


**Fig. 5.** Plants that contain diterpene alkaloids. A) *Cynodon dactylon* infected by *Claviceps cynodontes*; B) *Paspalum dilatatum* infected by *Claviceps paspali*; C) *Ipomoea asarifolia*; D) *Poa huecu* (Cortesy of Dr.Agustín Martinez); E) *Festuca argentina* (Cortesy of Dr. Agustín Martinez).

the animals are exercised, leading to loss of balance and fall. Affected animals fully recover within 7–15 days after being removed from infested areas. Only chronic cases can show permanent signs caused by degeneration and subsequent disappearance of Purkinje cells (Riet--Correa et al., 2013a; Lopes et al., 2014).

Other plants show very similar clinical signs. In northern Argentina, several outbreaks of a tremorgenic disease were observed in cattle grazing *Megathyrsus maximus* (Poaceae). However, indole diterpenoids were not found in the analyzed samples of *M. maximus* (Micheloud et al., 2017b).

### 2.4.3. Plants that contain piperidine alkaloids

Several *Prosopis* species produce many different alkaloids, including more complex molecules such as the piperidine alkaloids: 2-β-methyl-3-β-hydroxy-6-β-piperidinedodecanol, juliprosopine, and juliprosine (Pérez et al., 2014). These substances have demonstrated neurotoxic potential *in vitro* and are suggested to be the toxic compound of *Prosopis juliflora* (Fig. 6A and B) (Maioli et al., 2012). The main lesions responsible for the clinical signs is the degeneration and disappearance of motor neurons in the nuclei of cranial nerves, mainly in the trigeminal nerve. Animals poisoned by pods of *Prosopis* spp. exhibited dysphagia, masseter atrophy, tongue protrusion, mandible slackening, and progressive weight loss, leading to death (Tabosa et al., 2006).

*Prosopis* spp. intoxication occurs due to the continued consumption of large quantities of pods. In Brazil, outbreaks have been described in cattle, goats, and sheep consuming *P. juliflora* pods (Tabosa et al., 2006; Almeida et al., 2017). In Peru, *P. juliflora* poisoning occurs in goats (Bacca et al., 1963). In Argentina, natural cases of intoxication have been described in cattle and goats consuming *Prosopis nigra* (Fig. 6C, D and E) and *Prosopis alpataco* (Fig. 6F and G) pods (Micheloud et al., 2018a, 2018b, 2019). Sporadic cases of *Prosopis caldenia* intoxication have been diagnosed in the central region of Argentina (Odriozola, 2011).

In the semiarid region of Northeastern Brazil, *P. juliflora* pods are a good alternative for animal feed due to their high nutritional value (Medeiros et al., 2012; Riet-Correa et al., 2012). Breeding cattle can ingest up to 30% pods in their diet for up to six months. Cattle to be slaughtered can ingest up to 50% of pods for three months. Goats can ingest 30% of pods in the diet for up to one year and 50% for up to six months. Sheep can ingest the pods at 50% of the food for up to one year. In contrast, *P. juliflora* is an important invasive weed in the more humid pastures of the semi-arid region.

### 2.4.4. Plants that contain tryptamine alkaloids

Tryptamine alkaloids present in *Phalaris* spp. are direct agonists of serotonergic receptors, which induce the accumulation of α-synuclein and neuromelanin in the nervous system (Tayebi et al., 2021). Their toxicity is higher when the plants are young and growing. *Phalaris angusta* is a South American natural grass that produces poisoning in sheep and cattle in Argentina (Cantón et al., 2010; Odriozola, 2011), Uruguay (Riet-Correa et al., 1993), and Brazil (Gava et al., 1999).

*Phalaris* spp. toxicity can induce ''sudden death" (peracute) or "staggers" (acute or chronic neurologic manifestations) in ruminants (Tayebi et al., 2021). The sudden death syndrome does not occur in South America, and its pathogenesis is unclear. Only *Phalaris* staggers are reported in South America (Riet-Correa et al., 1993; Gava et al., 1999; Cantón et al., 2010; Odriozola, 2011).

The acute form is the most commonly diagnosed in cattle and sheep (Riet-Correa et al., 1993; Odriozola, 2011). Intoxicated animals initially show hyperexcitability, tremors, marked incoordination, recumbency, inability to stand, convulsions and death within 3–5 days. The chronic form occurs several weeks (up to 2 months) after the removal of cattle from *Phalaris* pastures. Affected animals have poor nutritional status, dullness, different degrees of incoordination, and paralysis of the tongue and lips. Because animals frequently fall on the chest they develop edema, bruising and skin lesions on the chest. In Argentina, this chronic form was only described in cattle, after outbreaks of the acute form (Cantón et al., 2010; Odriozola, 2011). A hallmark of *Phalaris* poisoning is the greenish discoloration in the thalamus, midbrain, spinal cord, and the intracytoplasmic brown pigment deposited in neurons, Recently, it was demonstrated the accumulation of neuromelanin and alpha-synuclein in the neurons (Tayebi et al., 2021).

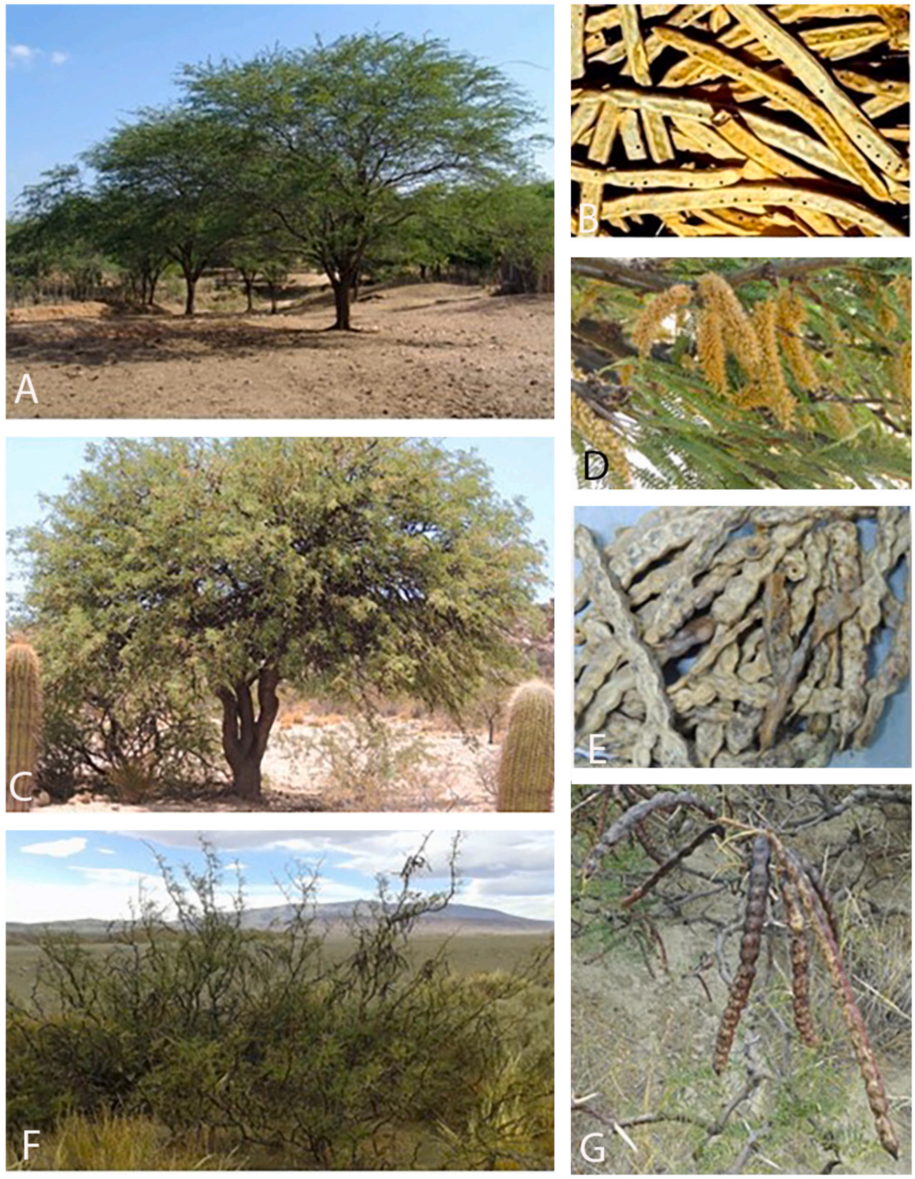


**Fig. 6.** A) *Prosopis juliflora*; B) pods of *P. juliflora*; C) *Prosopis nigra*; D) flowers of *P. nigra*; E) pods of *P. nigra*; F) *Prosopis alpataco* (Cortesy of Dr. Agustín Martinez); G) pods of *P. alpataco* (Cortesy of Dr. Agustín Martinez).

### *2.4.5. Plants that contain indospicine*

*Indigofera lespedezioides* (Leguminosae) which contains indospicine causes chronic neurological disease in horses in the state of Roraima, Brazil (Lima et al., 2012). The plant is mainly found in native vegetation known as "lavrado" on the edges of forests. Most poisoning cases occur at the end of the drought when *I. lespedezioides* is practically the only green vegetation available. Morbidity is usually up to 10% but occasionally may reach 100%. Histologically, a PAS positive pigment with the characteristics of lipofuscins is observed in neurons and Wallerian-like degeneration is present in some mesencephalic tracts (Lima et al., 2012).

### *2.4.6. Other toxic compounds affecting the central nervous system*

Other toxic compounds found in South America poisonous plants include tetrahydrocannabinol in *Cannabis sativa*, which caused an outbreak in cattle (Driemeier, 1997), caffeine in *Coffea arabica* and *Coffea canephora* husks affecting horses (Delfiol et al., 2012; Benezoli et al., 2019) and ethanol produced by fermented pseudo fruits of *Anacardium occidentale* affecting cattle (Soto-Blanco and Ribeiro Filho, 2007).

### *2.4.7. Other plants with unknown toxic compounds affecting the nervous system*

Other plants affecting the nervous system, in which toxic compounds are unknown are mentioned in Table 2.

## *2.5. Plants causing mainly nephrosis*

### *2.5.1. Plants that contain oxalates*

Oxalate is a common component of plants and it occurs in two forms: soluble and insoluble. Soluble oxalates are one of a number of antinutrients in forage plants and block calcium (Ca), magnesium (Mg) and some trace minerals such as iron (Fe) absorption. High oxalate blood concentration may result in severe hypocalcaemia and hypomagnesaemia. High oxalate salts concentrations in the blood are filtered by the kidney, and form insoluble oxalate crystals that may cause kidney failure. In cattle, nephrosis was reported to be associated with the consumption of *Setaria anceps* (Schenk et al., 1982) in Brazil, and *Setaria*

**Table 2**
Toxic plants without known toxic compounds that affect the nervous system.

| Plants | Species affected | Region | Main references |
|---|---|---|---|
| *Aeschynomene indica* | Pigs | Southern Brazil | Riet-Correa et al. (2003); Oliveira et al. (2004) |
| *Bambusa vulgaris* | Horses | Northern Brazil | Barbosa et al. (2006a) |
| *Casearia commersoniana* | Goats | Northeastern Brazil | Bezerra et al. (2012) |
| *Centaurea solstitialis* | Horses | Argentina and Uruguay | Perdomo and Freitas (1978); Giannitti and Margineda (2014) |
| *Condalia microphylla* | Cattle and pigs | La Pampa province, Argentina | Bedotti et al. (2006); Delgado et al. (2011) |
| *Equisetum* spp. | Horses | Southeastern Brazil | Alvim (1948) |
| *Erythroxylum argentinum* | Sheep | Southern Brazil | Barros et al. (2004) |
| *Erythroxylum deciduum* | Sheep | Southern Brazil | Borelli et al. (2011) |
| *Halimium brasiliense* | Sheep | Southern Brazil and Uruguay | Riet-Correa et al. (2009) |
| *Hovenia dulcis* | Goats and cattle | Southern Brazil | Colodel et al. (1998); Bernardi et al. (2016) |
| *Hybanthus calceolaria* | Cattle, sheep, and goats | Northeastern Brazil | Carvalho et al. (2014) |
| *Hypochaeris radicata* | Horses | Southern Brazil and Southern Chile | Araya et al. (1998); Araújo et al. (2008); Rodrigues et al. (2008) |
| *Marsdenia megalantha* | Cattle, sheep, goats and horses | Northeastern Brazil | Pessoa et al. (2011); Geraldo-Neto et al. (2013) |
| *Marsdenia hilariana* | Sheep and cattle | Northeastern Brazil | Pessoa et al. (2011) |
| *Poiretia punctata* | Cattle | Northeastern Brazil | Nascimento et al. (2014) |
| *Solanum bonariense* | Cattle | Southern Brazil and Uruguay | Riet-Correa et al. (1983) |
| *Solanum paniculatum* | Cattle | Northeastern Brazil | Guarana et al. (2011) |
| *Solanum subinerme* | Cattle | Northern Brazil | Lima et al. (2014) |
| *Talisia esculenta* | Sheep and cattle | Northeastern Brazil | Riet-Correa et al. (2014); Almeida et al. (2021) |

*sphacelata* (Sala et al., 2021) and *Setaria italica* (Perusia and Rodríguez Armest, 2004) in Argentina.

In contrast to soluble oxalates that cause nephrosis, insoluble oxalates are not absorbed causing gastrointestinal tract irritation. In Brazil, cases of intoxication have been described in cattle and goats that consumed *Dieffenbachia picta* and *Dieffenbachia seguine* (Dantas et al., 2011) with the presence of calcium oxalates in the form of needles. After chewing the leaves of these plants, animals develop swelling (edema) and protrusion of the tongue, and edema of the lips, face and glottis. There is salivation, difficulty apprehending food, hyperthermia, tachycardia, tachypnea and diarrhea.

The high concentration of oxalates in some tropical pastures, including *Urochloa humidicola* and *Megathyrsus* (*Panicum*) *maximum* is also responsible for fibrous osteodystrophy in horses. The high concentrations of oxalates in these grasses form complexes with Ca preventing its absorption. This results in a negative Ca/P ratio leading to hyperphosphatemia and secondary hyperthyroidism, which causes fibrous osteodystrophy. The bones of the face are enlarged and there is a generalized bone fragility (Tokarnia et al., 2012).

### 2.5.2. Plants that contain tannins

Tannins are naturally occurring plant polyphenols. Their main characteristic is that they bind and precipitate proteins. They can have a large influence on the nutritive value of many foods eaten by humans and animals. In cases of intoxication, the animals present gastrointestinal lesions and severe nephrosis. In South America, tannin containing plants toxic to cattle include *Quercus robur* and *Combretum* (*Thiloa*) *glaucocarpa*. Spontaneous poisoning by *Q. robur* has been reported in cattle in Argentina (Costa et al., 2021), Uruguay (Dutra et al., 2014), and Chile (Araya, 2009). The poisoning usually occurs in late summer or autumn when forage is scarce and the availability of green acorns is very high, or in early spring when shoots and young oak leaves are widely available. The first signs are observed several weeks after the animals enter the grazing area with *Q. robur*. Intoxicated animals show weakness, progressive weight loss, poor body condition, pale mucous membranes, tachycardia, ruminal impaction, and constipation with dry feces covered with mucus.

*Combretum glaucocarpa* is the most important nephrotoxic plant in Brazil and as *Q. robur*, its toxicity is associated with tannins (Tokarnia et al., 1981; Miranda-Neto et al., 2009). The leaves are ingested by cattle, causing a subacute disease, with evolution between 5 and 20 days. The affected animals show subcutaneous edema, especially in the thigh, perineum, and scrotum, extending to the ventral abdomen, thorax, and submandibular region. Usually, the lethality is high. The outbreaks occur annually, always at the start of the rainy season when *C. glaucocarpa* is sprouting (Tokarnia et al., 1981).

### 2.5.3. Other nephrotoxic plants with unknown toxic compounds

Other nephrotoxic plants of South America include *Lysimachia* (*Anagallis*) *arvensis* (Primulaceae), *Metternichia princeps* (Solanaceae), and *Amaranthus* spp. (Amaranthaceae). Poisoning by L. *arvensis* has only been diagnosed in cattle and sheep in Uruguay in cultivated pastures invaded by this plant (Rivero et al., 2001, 2011a). *M. princeps* is a tree distributed in a vast region from Bahia to Rio de Janeiro, predominantly in the Atlantic Forest and spontaneous poisoning by this plant has been reported in goats in the state of Rio de Janeiro (Prado et al., 2012).

Different species of *Amaranthus* have been reported as nephrotoxic in Brazil, including *Amaranthus hybridus, Amaranthus quitensis, Amaranthus blitum* and *Amaranthus retroflexus* for cattle (Ferreira et al., 1991; Lemos et al., 1993); *A. retroflexus, A. quitensis* and Amaranthus *viridis*, for swine (Salles et al., 1991; Kommers et al., 1996); and *Amaranthus spinosus* for sheep (Peixoto et al., 2003; Melo et al., 2014). The intoxication occurs when the animals are introduced into paddocks severely invaded by the plant, mainly in harvested fields of corn, soybean, sorghum and watermelon, where large amounts of the plants remain in the paddock. In Argentina and Uruguay, the only species associated with kidney failure in cattle was *Amaranthus quitensis* (Rodriguez et al., 1989; García y Santos and Capelli, 2016). The poisoning occurs in autumn when *Amaranthus* spp. is in seeding stage (Ferreira et al., 1991; Lemos et al., 1993). Clinical signs and pathology of these nephrotoxic plants are similar to other plants causing nephrosis.

## 2.6. Plants affecting mainly the skin

### 2.6.1. Plants that contain mimosine

*Leucaena leucocephala* (Leg. Mimosoideae) is a forage plant characterized by high leaf concentrations of mimosine, and toxicity associated with its consumption in livestock is relatively frequent. Mimosine is a toxic non-protein amino acid chemically similar to tyrosine. Leucaena toxicity occurs due to the incorporation of mimosine into biologically vital proteins in place of tyrosine. Spontaneous poisoning cases have been described in Brazil and Argentina in cattle, sheep, goats, and horses. The main clinical signs are loss of hair or wool (alopecia) and, in horses, hair loss of the tail and mane. Lethargy and decreased appetite, and excessive salivation is also observed. The animals recover after being removed from access to this toxic plant (Riet-Correa et al., 2004; Peixoto et al., 2008; Radrizzani and Nasca, 2014; Porto et al., 2017).

### 2.6.2. Plants that contain ergot alkaloids

The ergot alkaloids are mycotoxins that have a significant impact on livestock health and productivity around the world. They are secondary metabolites of the *Claviceps* spp. and *Epichloë* spp. fungi. Ergotamine and ergovaline are the main ergot alkaloids, which account for approximately 80%–97% of total alkaloids produced by *Claviceps purpurea* and *Epichloë coenophialum*, respectively. In South America ergotism has been reported to be caused by *Claviceps purpurea* (not included in this review), and by *tall fescue* (*Schedonorus arundinaceus*; previously *Festuca arundinacea*) infected by *Epichloë coenophialum*.

In cattle, tall fescue poisoning includes three clinical syndromes: 1) dysthermic syndrome; 2) gangrenous syndrome; and 3) bovine fat necrosis. It is an important forage species in some South American countries, particularly Argentina's central region. In this country dysthermic syndrome is a common problem observed during summer, causing economic losses. Gangrenous ergotism or fescue foot syndrome appears sporadically in cattle during the autumn-winter when temperatures are low and in flooded fields in Argentina (Odriozola et al., 2002), Uruguay (Riet-Correa et al., 1993) and Chile (Sepulveda et al., 1996). Bovine fat necrosis syndrome, characterized by abnormal accumulation of masses of hard fat in the abdominal cavities of cattle, has not been reported in the region. In horses, the consumption of ergot alkaloid in *S. arundinaceus* is associated with agalactia, abortions, and stillbirth foals in mares in the central-southern region of Chile (Cruz et al., 1997).

### 2.6.3. Other plants with unknown toxic compounds affecting the skin

*Tephrosia noctiflora* (Leguminosae) causes dermatopathy and, in severe cases, emaciation and death of cattle in Northeastern Brazil. The plant is found invading pasture areas of *Urochloa decumbens*. Clinical and pathological features include alopecia, exudative dermatitis, lichenification, limb and dewlap edema, and weight loss. The animals recover within two weeks of being removed from the areas invaded by the plant (Barbosa et al., 2022).

## 2.7. Plants affecting mainly the reproductive system

### 2.7.1. Plants that contain quinolizidine and piperidine alkaloids

Quinolizidine and piperidine alkaloids contained in several plants induce birth defects. The mechanism of action of quinolizidine and piperidine alkaloid-induced teratogenesis is similar, however, there are differences in incidence, susceptible gestational periods, and severity between livestock species. In South America, the species linked to this type of disorder are *Mimosa tenuiflora* (Fabaceae) (Fig. 8A, B and C) and *Conium maculatum* (Apiaceae). *M. tenuiflora is* a shrub endemic to northeastern Brazil, especially in the Caatinga biome. The toxicity of this species is attributed to the presence of N-methyl and N,N-dimethyltryptamine (Gardner et al., 2014). *Mimosa tenuiflora* poisoning causes malformations in goats, sheep, and cattle that naturally consume the plant, mainly during drought (Pimentel et al., 2007b). Newborn kids and lambs have various types of malformations, including congenital contractures affecting the legs (arthrogryposis), spine (scoliosis and lordosis), neck (kyphosis), and rib cage. Malformations of the bones of the head and face, including micrognathia, primary cleft lip due to unilateral or bilateral hypoplasia or aplasia of the incisive bone, and secondary cleft palate (palatoschisis), are also observed. Some animals are born blind, with varying degrees of opacity of the cornea and microphthalmia, and others with ocular dermoids.

Similar malformations have been described in goats and sheep consuming *Cenostigma pyramidale* (Fabaceae) (Fig. 8D, E and F) (syn. *Poincianella pyramidalis, Caesalpinia pyramidalis*) in the same region of Brazil. In this case it is estimated that the toxic principles are the same or similar to *M. tenuiflora* (Reis et al., 2016, 2020). Both plants also produce embryonic mortality and abortion (Lopes et al., 2017; Santos et al., 2018).

*Conium maculatum* (hemlock) is a common annual or biennial herb commonly distributed in temperate regions of South America. Although cases of acute intoxication with this plant have been described, they are very infrequent. Eventually, when females consume the plant during the first third of pregnancy, the offspring can be born with scoliosis, palatoschisis, arthrogryposis, hydrocephalus and/or torticollis. The toxicity of *C. maculatum* is likely due to the presence of several piperidine alkaloids, although coniine and gamma-coniceine are considered the most important (López et al., 1999). Natural cases of poisoning with hemlock have been described in the central region of Argentina (García et al., 2017).

### 2.7.2. Plants that contain labdane acids

An abortion outbreak in cattle was associated with consumption of *Hesperocyparis* (*Cupressus*) *macrocarpa* and *Cupressus arizonica* needles. There were no significant macroscopic or histological findings in the fetuses. Abortifacient labdane acids were detected in the needles of *H. macrocarpa* (1.68%, D.W.) and *C. arizonica* (0.36%, D.W.) (Buroni et al., 2020). In Argentina, abortion in cattle was associated with the consumption of *Pinus ponderosa* (Pinaceae) needles with concentrations of isocupressic acid greater than 0.5% (Martinez et al., 2018).

### 2.7.3. Plants that contain estrogenic isoflavones

*Trifolium subterraneum* (Leguminosae) contains phytoestrogens that cause reduced fertility rates in cattle and sheep. Formononetin levels greater than 0.3% can cause reproductive losses. Phytoestrogen poisoning is uncommon in South America. Only one outbreak affecting Holstein heifers grazing on pastures predominantly of *Trifolium subterraneum* var. Yarloop for four months has been reported from the state of Rio Grande do Sul, Brazil. The heifers showed development of the mammary gland and vulva, dilatation of the cervical canal, and production of vaginal secretions (Pimentel et al., 1977). Similar problems have been detected in Argentina with *Trifolium subterraneum* and *Medicago sativa* pastures (López and Odriozola, 1988).

### 2.7.4. Other plants with unknown toxic compounds causing reproductive losses

*Aspidosperma pyrifolium* (Apocynaceae) (Fig. 8G, H, and I) causes abortion, premature birth, and embryonic death in goats and probably in sheep and cattle in Northeast Brazil. Poisoning occurs when the plant is consumed during the dry period or when it re-sprouts shortly after the rains. In goats, embryonic death occurs mainly in the first 34 days of pregnancy, and abortion can occur at any stage of pregnancy (Riet-Correa et al., 2011b).

## 2.8. Plants affecting mainly the digestive system

### 2.8.1. Plants that contain ricin and ricinine

Ricin and ricinine are the toxins of *Ricinus communis* (Euphorbiaceae). Ricinine is an alkaloid present in the leaves and pericarps, that causes neurotoxic effects probably due to increased release of glutamate and inhibition of the postsynaptic receptors, but without gross and microscopic lesions in nervous tissue. Ricin is a lectin in seeds, primarily affecting the alimentary tract causing necrotic gastroenteritis, hypersalivation, diarrhea, dehydration, teeth grinding, hypothermia, colic, ruminal stasis, and recumbency. Simultaneous manifestations (neurological and gastroenteritis) occur in cases of consumption of the whole plant. Ricinine can be detected in the liver and rumen fluids (Machado et al., 2022b). Poisoning occurs in conditions of forage shortage or when the plant is cut and offered to animals. In Brazil, the poisoning has been reported in cattle (Albuquerque et al., 2014), sheep (Bianchi et al., 2018), horses (Montão et al., 2018), and goats (Machado et al., 2022b). In Argentina, the poisoning is less frequent (Marín et al., 2018).

### 2.8.2. Plants that contain macrocyclic trichothecenes

Macrocyclic trichothecenes cause severe digestive signs in ruminants and horses. In South America, the first known toxic plant poisoning reported since the 17th century, was *Baccharis coridifolia* (Asteraceae). It contains roridin A and E, miotoxin A, B, C and D, miophytocen A and B, and verrucarol, produced by the fungi *Myrothecium roridum* and

*Myrothecium verrucaria* (Habermehl et al., 1985). Roridins and verrucarins were also produced by endophytic fungus isolated from *B. coridifolia* (Rizzo et al., 1997).

The intoxication has been diagnosed in Uruguay, Argentina, and southern Brazil (García et al., 2017; Schild et al., 2020). Poisoning usually occurs in naïve animals (raised in areas without *B. coridifolia*) introduced into paddocks with the plant. The plant causes conditioned food aversion when naïve cattle consume small amounts or are exposed to the plant via low doses by oral gavage before being introduced into infested paddocks (Almeida et al., 2013). The poisoning caused acute clinical digestive signs; most affected animals died in 12–96 h.

Other plants containing macrocyclic trichothecenes and causing similar clinical signs to *B. coridifolia* are *Baccharis artemisioides* in Argentina (Rizzo et al., 1997) and *Bacharis megapotamica* var. *weirii* and *Baccharis megapotamica* var. *megapotamica* in southern Brazil in cattle, sheep and buffalo (Pedroso et al., 2010; Oliveira-Filho et al., 2011; Panziera et al., 2015). *Baccharis vulneraria* (Costa et al., 2022) and *Eupatorium tremulum* (Lucioli et al., 2004) in Brazil cause a disease similar to that caused by *B. coridifolia*, however, macrocyclic trichothecenes have not been identified in these species.

### *2.8.3. Plants that contain phorbol esters*

Phorbol esters are the main toxic compound of *Jatropha* spp. (Euphorbiaceae**)**. Poisoning by *Jatropha curcas* in livestock occurs mainly by the ingestion of by-products of oil extraction (press cake), seeds, or seed hulls. However, such poisonings have only been reported experimentally in Brazil. In contrast, spontaneous outbreaks of goat poisoning by the ingestion of *Jatropha ribifolia* are reported in the semiarid region of Northeastern Brazil. The first cases of poisoning occurred when the goats started to consume the plant due to the severe shortage of forage during the dry season. Later, social facilitation influenced other goats to start eating the plant, which caused outbreaks in successive years. Affected goats presented apathy, anorexia, soft feces, weight loss, severe dehydration, and a reddish pigment in the skin, lips, horns, and teeth. This pigment is present on *J. ribifolia* and animals acquire it by feeding on the plant. Emaciation was the main lesion observed on necropsies (Pimentel et al., 2012).

### *2.8.4. Other plants with unknown toxic compound affecting the digestive system*

Plants that affect the digestive system in which toxic compounds are unknown are presented in Table 3.

Of the plants mentioned in Table 3 it is important to highlight *Megathyrsus* (*Panicum*) *maximum*. This species was introduced as a forage in Brazil in the 1980′s and since that time three main cultivars have been developed in the country: Tanzânia, Mombaça and Massai. Presently there are nearly 20 million hectares of *M. maximum* planted in Brazil (Souza et al., 2017). However, since the introduction of *M. maximum* in the northern (Amazonic) region of Brazil this plant was identified as an important cause of severe intestinal bloat, colic and deaths in horses and mules ingesting sprouting pastures during the raining season (Cerqueira et al., 2009; Souza et al., 2017). The disease was reproduced experimentally in penned horses ingesting growing *P. maximum* (Cerqueira et al., 2009; Souza et al., 2017). Colic in Equidae is due to bloat caused probably by rapid hydrolysis and fermentation of carbohydrates, which are in high content during the growing stage of the plant (Cerqueira et al., 2009; Souza et al., 2017). Pastures that induce colic contain significantly higher starch concentration than pastures that do not cause the disease (Souza et al., 2017).

*M. maximum* var. Tanzania was also identified in Northeastern Brazil as a cause of severe cecal dilatation, tenesmus and abdominal bilateral distention in cattle. The disease did not cause deaths and occurred in a rotational system where the paddocks were grazed with high stocking rate for one day and the animals returned to the same paddock after 28 days. After each grazing period the pastures were fertilized with urea (Riet-Correa et al., 2011b). In Northern Brazil a similar disease has been associate with the ingestion of *M. maximum* var. Mombaça and var. Tanzania in pastures with high starch concentration after fertilization with urea and/or poultry litter (unpublished data).

**Table 3**
Toxic plants without known toxic compounds that affect the digestive system.

| Plants | Species affected | Region | Main references |
|---|---|---|---|
| *Arrabidaea corallina* | Goats | Northeastern Brazil | Pessoa et al. (2010) |
| *Asclepias mellodora* | Cattle | Argentina | García et al. (2017) |
| *Centratherum brachylepis* | Goats and cattle | Northeastern Brazil | Medeiros et al. (2009) |
| *Cichorium intybus* | Cattle | Uruguay | Riet-Correa et al. (1993) |
| *Luetzelburgia auriculata* | Goats | Northeastern Brazil | Mello et al. (2010) |
| *Medicago sativa*, *Trifolium repens*, and *Trifolium pratense* | Cattle | Uruguay, Argentina, and Southern Brazil | Riet-Correa et al. (1993);Rivero et al. (2011a)Riet-Correa et al. (1993);Rivero et al., 2011a |
| *Megathyrsus* (*Panicum*) *maximum* | Horses and cattle | Brazil | Cerqueira et al. (2009); Riet-Correa et al. (2011c); Souza et al. (2017) |
| *Merremia macrocalyx* | Cattle | Northeastern Brazil | Brito et al. (2019) |
| *Nierembergia hippomanica* | Cattle and sheep | Uruguay | Odini et al. (1995) |
| *Nierembergia linariifolia* var. *linariifolia* | Goats and cattle | Northwestern Argentina | Torino et al. (2017) |
| *Phytolacca decandra* | Sheep | Southern Brazil | Peixoto et al. (1997) |
| *Phytolacca dioica* | Sheep | Uruguay | García y Santos and Capelli, 2016 |
| *Plumbago scandens* | Goats and cattle | Northeastern Brazil | Medeiros et al. (2001) |
| *Portulaca elatior* | Cattle and goats | Northeastern Brazil | Galiza et al. (2011); Oliveira-Neto et al. (2017) |
| *Simarouba versicolor* | Cattle | Midwestern Brazil | Carvalho et al. (2013) |
| *Sisyrinchium platense* | Cattle and sheep | Southern Brazil | Méndez et al. (1993) |
| *Stryphnodendron coriaceum* | Cattle and goats | Northeastern Brazil | Brito et al. (1995) |

## *2.9. Plants causing mainly hemolytic anemia*

### *2.9.1. Plants that contain n-propyl disulfide*

The only Brazilian toxic plant that contains n-propyl-disulfide is *Allium cepa* (*Amaryllidaceae*) (onion) which causes hemolytic anemia and hemoglobinuria in carnivores, horses, and ruminants. In Brazil, poisoning has been reported in buffalo consuming the onion bulb in the state of Santa Catarina (Borelli et al., 2009).

### *2.9.2. Other plants with unknown toxic compound causing hemolytic anemia*

Other plants causing hemolytic anemia in Brazil are *Urochloa arrecta* (syn. *Brachiaria radicans*) (Poaceae) (tanner-grass), *Ditaxis desertorum* (Euphorbiaceae), and *Indigofera suffruticosa* (Fabaceae). The poisoning by *U. arrecta* has been reported in cattle in the southern, southeastern, and northeastern regions in cattle grazing in pastures formed exclusively by this grass, especially when green and lush (Gava et al., 2010). *Ditaxis desertorum* rarely causes hemolytic anemia in cattle in northeastern Brazil (Tokarnia et al., 1997). The poisoning by *Indigofera suffruticosa* also affects cattle in northeastern Brazil (Barbosa-Neto et al., 2001).

These plants cause anemia, hemoglobinuria, and progressive weight loss. Additionally, *I. suffruticosa* poisoning causes a blue discoloration of the urine, and sometimes of the liver, due to the presence of aniline in the plant (Barbosa-Neto et al., 2001). The pigment is probably the toxic compound of *I. suffruticosa* (Salvador et al., 2011).

### *2.10. Plants that contain β-aminopropionitrilo*

Several outbreaks of osteolathyrism caused by *Lathyrus hirsutus* (Fabaceae) were diagnosed in cattle in Uruguay from 2004 to 2008. Affected cattle, mainly calves, were recumbent or had difficulties for moving and showed progressive weight losses. They recovered within days after being removed from the pastures. The poisoning was reproduced experimentally by the administration of *L. hirsutus* pods. No macroscopic or histologic lesions were observed (García y Santos et al., 2011).

### *2.11. Plants that contain tetranortriterpenoids*

*Melia azedarach* (Meliaceae) is a plant native to Asia that can be found in some regions of South America. Tetranortriterpenes such as meliatoxin A1, A2, B1, and B2 are the most relevant toxic compounds identified in the fruits of this plant (Oelrichs et al., 1983). Poisoning by *M. azedarach* mainly affects pigs due to the ingestion of the fruits (Méndez et al., 2006), and the poisoning is rarely reported in cattle (Fazzio et al., 2015). Intoxication occurs by ingesting ripe fruits when they fall on the ground or when branches are within reach of animals. Affected animals virtually show two syndromes: 1) characterized by nausea, vomiting, constipation, or diarrhea, often bloody; 2) characterized by excitement or depression and dyspnea, followed by death. The histopathological study showed necrosis in various tissues and different degrees of segmental degeneration and fragmentation of skeletal muscle (Méndez et al., 2002).

### *2.12. Plants that contain cyanogenic glycosides*

Cyanide poisoning is frequently reported in Brazil, Uruguay, and Argentina (Tokarnia et al., 1999b; García y Santos and Capelli, 2016; García et al., 2017). Poisoning by *Sorghum halepense* (Poaceae) (Johnson grass) frequently occurs in Uruguay, where this plant behaves as a weed (García y Santos and Capelli, 2016), and in Northeastern Brazil where the plant is cultivated as a forage in the border of some dams (Nóbrega et al., 2006). In Argentina, it is relatively frequent in the country's central region during dry years.

Poisonings by other *Sorghum* species are rare (Juffo et al., 2012); however, some external factors, such as drought or early frost, can increase the risk of poisoning. Additionally, atypical cases of ataxia and urinary incontinence have been reported in horses and cows grazing forage *Sorghum* (Odriozola, 2011). More recently, abortions and calf births with arthrogryposis have been observed in cows grazing grain and forage *Sorghum* in Brazil and Argentina (F. Sofía and Márcio B. Castro, personal communication).

Several native species of *Manihot* (Euphorbiaceae) found in the northeastern region of Brazil cause cyanide poisoning when accessed by animals for direct consumption or when eaten after being cut (Amorim et al., 2005). *Manihot esculenta* (Euphorbiaceae) is also a frequent cause of cyanide poisoning when animals are fed with the tubers or their by-products (cassava wastewater or cassava husks) (Silva et al., 2017b).

In Brazil, other cyanogenic plants such as *Anadenanthera macrocarpa* and *Piptadenia viridiflora* (Fabaceae) (Tokarnia et al., 1999b, 2012), *Cnidoscolus phyllacanthus* (Euphorbiaceae) (Oliveira et al., 2008), and *Passiflora foetida* (Passifloraceae) (Carvalho et al., 2011) cause poisoning in the Northeast region; while *Prunus sellowii* (Rosaceae), *Cynodon* spp. (Poaceae), and *Sorghum sudanense* cause poisoning in the southern region (Gava et al., 1992; Juffo et al., 2012; Molossi et al., 2019; Gris et al., 2021).

### *2.13. Plants that contain nitrates and nitrites*

Nitrate and nitrite poisoning occur in Uruguay, Argentina and Brazil in grass pastures, mainly of *Lolium multiflorum* or *Avena sativa* (Poaceae), fertilized with nitrogen or after severe drought followed by abundant rainfall (Rivero et al., 2011a; Jönck et al., 2013; García et al., 2017). In Argentina, it has been caused by the consumption of sorghum and maize forage during dry years (Odriozola, 2011). *Chenopodium album* (Amaranthaceae) has been linked with poisoning in cattle in the central region of Argentina (García et al., 2017). In southern Brazil, poisoning was reported in a stubble reed invaded by *Amaranthus* spp., while in the Northeast region, intoxication occurs in *Echinochloa polystachya*, *Pennisetum purpureum*, and *Urochloabrizantha* (Poaceae) pastures irrigated by wastewater from cities or on the border of dams that had been covered by water for long periods (Simões et al., 2022). In this system, as the water goes down during the drought, the producers sow grasses, which accumulate nitrates because they grow in soils with high organic matter (Simões et al., 2022).

*Portulaca oleracea* (Portulacaceae) is a plant that usually accumulates nitrates and causes outbreaks of intoxication in the Northeast region of Brazil in pastures invaded by it or when it is cut and administered in feed troughs (Simões et al., 2018). In Chile, poisoning by nitrates and nitrites has been described in cattle by the ingestion of *Silybum marianum* (Asteraceae) (Freire and Araya, 1988).

### *2.14. Plants that contain calcitriol or glycosides derivatives*

In South America, four native calcinogenic plants of the Solanaceae family cause enzootic calcinosis characterized by systemic calcification, hypoparathyroidism, hypercalcitoninism, hypercalcemia, hyperphosphatemia, thyroid C-cell hyperplasia, parathyroid atrophy, osteonecrosis, and osteopetrosis (Machado et al., 2020b). The pathogenesis of enzootic calcinosis is complex but studies demonstrated a similarity with the bone-forming process. Recently, it was demonstrated that extracellular vesicles produced by vascular smooth muscle cells are crucial for developing vascular mineralization (Machado et al., 2022a).

Poisoning by *Solanum glaucophyllum* (Fig. 7A and B), which contains 1,25(OH)$_2$D$_3$ (calcitriol), is endemic and causes severe economic losses in low-flooded areas of the Rio Salado in Buenos Aires Province (Gimeno, 2000) but also occurs in the Brazilian Pantanal (Döbereiner et al., 1971) and Uruguay (Riet-Correa et al., 1975). The disease mainly affects cattle and rarely sheep, buffaloes, horses and pigs by consumption of the fallen leaves mixed with the pasture (Machado et al., 2020b). Additionally, poisoning caused by contaminated hay was reported (Micheloud et al., 2012).

Two species of *Nierembergia* cause enzootic calcinosis in sheep and less frequent in cattle (Riet-Correa et al., 1987; Machado et al., 2020a; Schild et al., 2021). *Nierembergia veitchii* (Fig. 7C) occur in the State of Rio Grande do Sul in Brazil, in hilly areas, and *Nierembergia rivularis* (Fig. 7D) in Uruguay in humid areas mainly in the borders of the lakes and streams (Machado et al., 2020a; Schild et al., 2021). In the case of *Nierembergia veitchii*, an action similar to 1,25(OH)$_2$D$_3$ was demonstrated in chickens (Riet-Correa et al., 1987). *Solanum stuckertii* (Fig. 7E) poisoning has been reported in goats in the province of San Luis in Argentina (Rossanigo et al., 2020).

### *2.15. Plants that contain ptaquiloside*

The ptaquiloside is a norsesquiterpenoid glycoside present in several fern species. The ferns most frequently linked to toxicity in South America are species of the *Pteridium* complex, mainly *Pteridium arachnoideum* and *Pteridium caudatum* (Furlan et al., 2014a; Rocha et al., 2022). However, recent reports demonstrated that other fern species, such as *Pteris deflexa*, *Pteris plumula* and *Adiantopsis chlorophylla* induce toxicity similar to that of *Pteridium* spp. in cattle (Micheloud et al., 2017c; Oliveira et al., 2020).

**Fig. 7).** Calcinogenic plants. A e B) *Solanum glaucophylum*; C) *Nierembergia veitchii*; D) *Nierembergia rivularis*; E) *Solanum stuckertii*, inset: fruits, (Cortesy of Dr. Carlos E. Rossanigo).

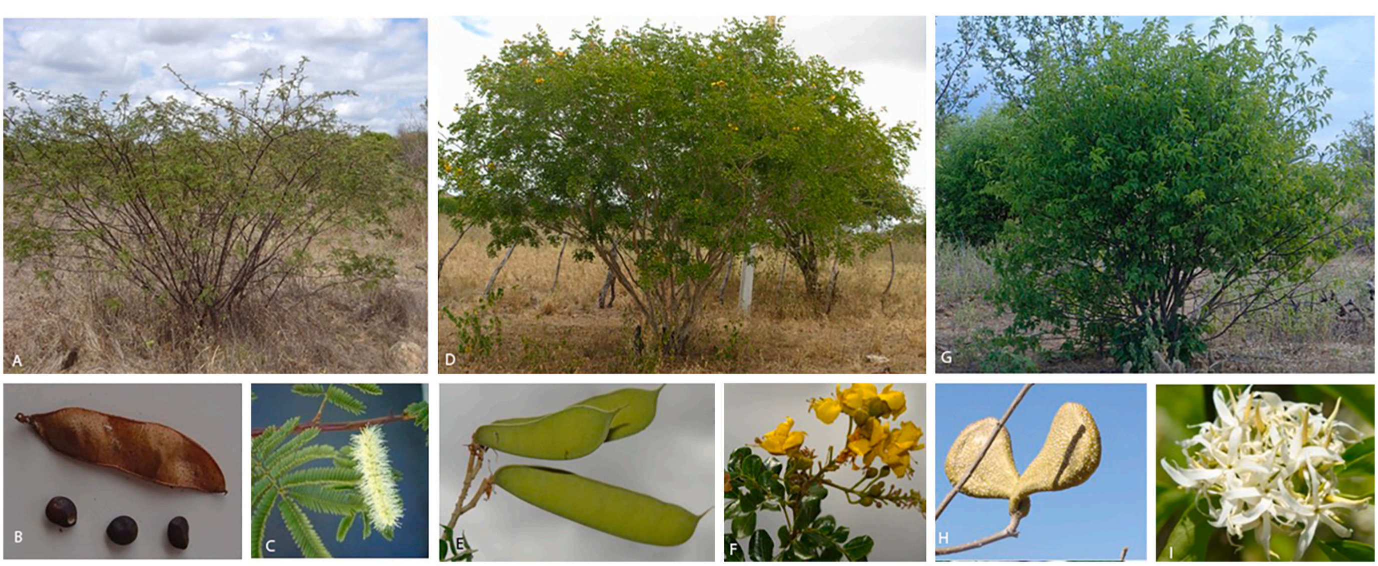

**Fig. 8.** Plants causing malformation abortion and embryonic deaths. A-C) *Mimosa tenuiflora*; D-F) *Cenostigma pyramidale*; G-I) *Aspidosperma pyrifolium.*

The toxic effects of bracken ingestion are diverse, depending on the animal involved and the consumed doses. In bovine, ferns poisoning includes three clinical syndromes: 1) the most common syndrome is bovine enzootic haematuria, which results from neoplastic urinary bladder damage and is induced by chronic ingestion of bracken. It is reported in several South American countries such as: Peru (Herencia et al., 2013), Colombia (Lozano and Diaz, 2013), Bolivia (Marrero-Faz et al., 1999), Venezuela (Sánchez-Villalobos et al., 2008), Brazil (Tokarnia et al., 2012; Furlan et al., 2014a), Uruguay (Dutra, 2010b) and Argentina (Marín, 2011); 2) upper alimentary squamous cell carcinoma. This presentation is relatively common in Southern Brazil and has been associated with chronic bracken fern consumption (Faccin et al., 2018). However, bovine papillomavirus type 4 (BPV-4) is considered a cofactor in developing these neoplasms (Medeiros-Fonseca et al., 2021); 3) acute hemorrhagic syndrome or hemorrhagic diathesis. Such cases occur when a large amount of bracken is ingested by cattle and results in acute depression of hematopoietic activity of the bone marrow inducing anemia, leucopenia, thrombocytopenia and haematuria. Outbreaks of this syndrome have been described in Brazil (Tokarnia et al., 2012; Boabaid et al., 2018) and Uruguay (Oliveira et al., 2020).

### 2.16. Plants that contain coumarins

*Melilotus alba* and *Melilotus officinalis* are common legumes used in Argentina. When these plants are used for hay making and silage with high levels of humidity, some species of fungi colonize the material and the coumarins in sweet clover are converted to dicumarol. Dicumarol is a potent vitamin K antagonist and anticoagulant. When hay or toxic silage is consumed for several weeks, changes in the proenzymes necessary for prothrombin synthesis result in a bleeding syndrome. Furthermore, dicumarol can cross the placenta in pregnant animals and the newborn can be affected at birth. Outbreaks of dicumarol poisoning have been sporadically recorded in cattle consuming sweet clover hay in Argentina (Colque-Caro et al., 2017).

### 2.17. Plants that cause systemic granulomatous disease

The genus *Vicia* comprises more than 150 species, including *Vicia villosa* and *Vicia sativa* (Barros et al., 2001; Aguirre et al., 2021), which have been reported to be toxic in South America. The toxic compound that causes hairy vetch poisoning is unknown. Intoxication causes a type IV hypersensitivity reaction, suggesting that some plant constituents act as antigens that sensitize lymphocytes causing multisystem granulomatous inflammation through a mechanism not yet described (Sonne et al., 2011).

The poisoning is characterized by dermatitis, conjunctivitis, fever, diarrhea, and lesions of extensive granulomatous infiltration of various organs. The disease mainly affects adult cattle of different breeds (Sonne et al., 2011). Although the incidence is usually low, the lethality is high, and many animals die even after being removed from the problem paddock.

### 2.18. Plants that cause muscular damage

Spontaneous cases of poisoning by *Senna occidentalis* have been reported in cattle in Brazil (Carmo et al., 2011) and Argentina (Mussart et al., 2013), and in swine (Martins et al., 1986) and wild boar (Sant'Ana et al., 2011) in Brazil. The toxic compound of *S. occidentalis* responsible for myodegeneration has not been definitively identified. However, dianthrone, an anthraquinone in *S. occidentalis* has been shown to cause mitochondrial damage associated with myopathy (Chileski et al., 2021). Poisoning by *Senna obtusifolia* has been reported in cattle (Furlan et al., 2014b) and sheep (Campos et al., 2018) in Brazil.

Usually, poisoning by *S. occidentalis* occurs through the consumption of feed contaminated by seeds. However, intoxication by *S. obtusifolia* and sometimes by *S. occidentalis* can result from the consumption of plants in the field, generally associated with low availability of good quality forage, high infestation rate and/or high stocking rate. Seeds can also be eaten mixed with chopped green forage (Mussart et al., 2013; Furlan et al., 2014b).

*Petiveria alliacea* is a perennial herb that can reach 1 m in height, native to the Amazon and other tropical areas of South America. The toxicity of *P. alliacea* seems to be common in cattle in some areas of Colombia (Torres-Gámez, 2018). Affected animals have incoordination and progressive cachexia with persistent flexion of one or both hocks. Main gross lesions are characterized by diffuse yellow flaccid muscles and yellow discoloration of the kidneys. Main histologic lesions are degeneration, necrosis and atrophy with proliferation of fibrous tissue of skeletal and cardiac muscles, and chronic nephrosis (Ruiz, 1971). Many compounds have been identified in the plant, but it is not clear which is the cause of the clinical signs.

### 2.19. Plants that cause necrosis of the lymphatic tissue

Two toxic plants were reported to cause lymphatic tissue necrosis as the main alteration: *Polygala klotzschii* (Polygalaceae) (Tokarnia et al., 1976), and *Riedeliella graciliflora* (Fabaceae) (Riet Correa et al., 2001). Clinical signs are acute and death occurs after 10–38 h of clinical manifestation. The most characteristic histological lesion is necrosis of lymphatic tissue affecting the spleen, lymph nodes, Peyer's patches, and peribronchial lymphoid tissue. There is diffuse necrosis in the germinal center of lymphoid follicles. Enteritis is observed in both small and large intestines (Tokarnia et al., 1976; Riet Correa et al., 2001). The toxic compound of *P. klotzschii* is suggested to be 5-methoxy-podophyllotoxin, which belongs to the podophyllin group. The toxic compound of *R. graciliflora* is unknown. Other plants causing necrosis of the lymphatic tissue, including *Baccharis* spp. and *Simarouba versicolor* are mentioned in the plants containing macrocyclic trichothecenes and plants causing digestive disorders, respectively.

### 2.20. Plants that cause pigmentation of the tissues

In La Hulla and Tolima departments of Colombia, the consumption of *Bunchosia pseudonitida* and *Bunchosia armeniaca* causes pigmentation of different tissues in cattle, sheep, and goats. The poisoning is characterized by bluish-purple or pink pigment in mucous membranes, teeth, elastic tissues, subcutaneous tissue, muscles, bones, and hair. Microscopically, no changes are observed, and the pigment disappears after processing the tissues for histologic examination (Gámez et al., 1983). Most of the animals remain without other clinical signs, but some show gait disturbances, emaciation, prostration, recumbency, and death. A similar pigmentation of the viscera and carcasses have been reported in sheep in the Brazilian northeastern region, but the plant responsible for the disease was not identified (Pimentel et al., 2013).

### 2.21. Chronic phytogenic copper poisoning in sheep

This intoxication occurs in sheep in Uruguay in pastures of *Trifolium repens* and/or *Trifolium pratense*, which contain normal concentrations of copper, but also low levels of molybdenum. First cases are often seen after at least three months grazing in such pastures. The intoxication is observed throughout the year but is more frequent in spring. Morbidity varies between 1% and 12% and lethality is nearly 100%. The poisoning is characterized by a haemolytic crisis, with jaundice and hemoglobinuria. The death occurs in 24–96 h. The main gross lesions are jaundice, subcutaneous yellow edema, serous liquid in cavities, swollen friable ochre-coloured liver with distended and edematous gallbladder, dark kidneys and dark urine (haemoglobinuria). Microscopically the main lesions are degenerative and necrotic lesions of the liver and nephrosis. Chronic phytogen copper intoxication occurs in pastures with low molybdenum, less than 0.36 ppm, and normal copper concentration. The diagnosis is based on the epidemiological data, clinical signs, macroscopic and histologic lesions, and the determination of Cu concentrations in the liver (over 500 ppm) and kidneys (over 80 ppm). For the prevention of intoxication, grazing periods of no more than three months in pastures with a predominance of *T. repens* or *T. pratense* are recommended (Rivero et al., 2011a).

## 3. Final considerations

In this review, we report 219 species of toxic plants for livestock.

Most of these poisoning have been reported in Argentina, Brazil, and Uruguay, where many diagnostic laboratories and Universities are researching toxic plants for livestock. This research expands the number of known toxic plants reported in the last 40 years; for example, in Brazil, there were 90 known toxic species and 52 genera in 1980, 112 species and 64 genera in 2004, 135 species and 72 genera in 2010, 139 species and 80 genera in 2012, and 162 species and 96 genera in 2022. This significant increase in the knowledge of poisonous plants in Brazil in the last 40 years was due to the increase in the number of federal and state universities and diagnostic laboratories in different states with veterinary and animal science education, improving the recognition and diagnosis of livestock diseases. In Northeastern (e.g., Caatinga), Central-Western (e.g., Cerrado), and Northern Brazil (e.g., Amazonia) regions, the knowledge of livestock diseases was very rudimentary 40 years ago. As research continues, and as livestock producers become better informed, it is expected that the list of toxic species will continue to increase in the coming years. In general, the study of toxic plants has been related to their epidemiology, clinical signs, and pathology. In contrast, the determination of toxic compounds (i.e., natural product chemistry) has been insufficient since in 92 (42%) of the 219 plant species, the toxic compound is unknown. Despite this, several toxic compounds have been identified with the collaboration of researchers from the USA, Brazil, Denmark, and Germany. At this point, it is worth highlighting the collaboration of the USDA Poisonous Plant Research Laboratory at Logan, Utah through which the toxic compounds of various plants were determined, including fluoroacetate, pyrrolizidine alkaloids, diterpene glycosides, lithogenic saponins, indolizidine alkaloids, indole diterpene alkaloids, quinolizidine and piperidine alkaloids, and labdane acids. However, to advance on this issue, it is necessary to create more research groups in Latin America to identify toxic compounds with government funding. Some plants, such as *Xanthium* spp., *Crotalaria* spp., *Senecio* spp. *Mimosa* spp., *Prosopis* spp. and *Pteridium* spp., adapt and spread easily in different environments as a result of different agricultural practices and are difficult to control, causing significant economic losses. Research and investments in the creation of biological and chemical control methods are necessary to mitigate these losses.

Some of the most important toxic plants reported in South America include: *Pteridium* spp., affecting cattle in many countries of the region; *Senecio* spp. affecting cattle but occasionally horses and sheep in Southern Brazil, Uruguay, Argentina and Chile; plants containing fluoroacetate, including *Palicourea* spp. and *Amorimia* spp. which are very important in Brazil where approximately one million cattle die annually due to toxic plants and half of these deaths are caused by plants containing fluoroacetate (Pessoa et al., 2013a); *Urochloa* spp. in Brazil and Colombia as a cause of secondary photosensitization mainly in cattle and sheep; *Solanum glaucophyllum* causing enzootic calcinosis in cattle in some regions of Argentina and also in Brazil and Uruguay; and *Mimosa tenuiflora* and *Cesnotigma pyramidalis* causing malformations in sheep, goats and cattle in Northeastern Brazil. Bloat caused mainly by *Trifolium* spp. and other leguminous plants is a very important poisoning in cattle mainly in Argentina and Uruguay. Swainsonine-containing plants (*Ipomoea* spp., *Sida* spp. and *Astragalus* spp.) are important mainly for goats in Brazil (Pessoa et al., 2013a) and also occur in Argentina. An important toxic plant for horses mainly in northeastern Brazil is *Crotalaria retusa* as a cause of liver fibrosis and hepatic encephalopathy; this plant also causes liver necrosis in sheep and goats (Anjos et al., 2010). Also, in horses and mules, the use of *Megathyrsus maximus* as the main forage for these species in northern Brazil resulted in great economic losses due to the high number of deaths and the difficulties of using other grasses for Equidae in the region (Cerqueira et al., 2009; Souza et al., 2017).

Despite recent advances in the research of toxic plants for livestock in South America, it is important to increase the number of research groups working on plant poisonings and emphasizing the determination of toxic compounds. It is also necessary to study the chronic and/or subclinical effects that some toxic plants may cause to livestock and humans.

## Credit author statement

**Franklin Riet-Correa, Mizael Machado,** and **Juan F. Micheloud** prepared the review and reviewed the manuscript.

## Ethical statement

Not applicable.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

No data was used for the research described in the article.

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