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SHORT COMMUNICATION

Ensiling fails to detoxify whole-plant maize contaminated with *Datura stramonium* plants

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Abstract
The objective of this study was to evaluate whether ensiling reduces tropane alkaloid concentrations in whole-plant maize contaminated with *Datura stramonium*, a concern for animal feed safety. Whole-plant maize silages were prepared with 10% dried and ground *D. stramonium* and analysed at 0, 30 and 90 days using liquid chromatography-tandem mass spectrometry. Atropine levels decreased by 21% over 90 days, while scopolamine increased by 17%, resulting in a non-significant overall reduction of total alkaloids. These results indicate that ensiling does not effectively detoxify whole-plant maize contaminated with *D. stramonium*. Consequently, contaminated silage may pose a risk to cattle health, underscoring the need for preventive measures to limit *D. stramonium* contamination in feed crops.

Keywords Maize silage · Feed contamination · *Datura stramonium* · Plant toxins · Tropane alkaloids

1 Introduction

Jimsonweed (*Datura stramonium* L.) is a plant of the *Solanaceae* family with a high spreading potential (Weber and Gut 2005). It has been shown that *D. stramonium* is well adapted to survive harsh climatic conditions (Chadha et al. 2020). Systematically collected empirical data and projections on the distribution and demography of *D. stramonium* are scarce (Weber and Gut 2005; Vaz-Jarnieu et al. 2026). The Global Biodiversity Information Facility (GBIF) data base collects global observations and they seemingly confirm that the frequency of *D. stramonium* occurrence is increasing in Europe and beyond (GBIF 2025). *Datura stramonium* is highly competitive in agricultural crops and often grows in the periphery of fields of cereal crops, which have large gaps in their populations for certain periods of time (Świder et al. 2026). These crops also include maize. The spread of *D. stramonium* is particularly relevant in organic farming systems (Alletsee et al. 2016). *Datura stramonium* plants produce tropane alkaloids, mainly (−)-hyoscyamine and (−)-scopolamine (Fig. 1), which are located in all parts of the plants (El Bazaoui et al. 2011; Lamp et al. 2021; Gravador et al. 2024; Piatti et al. 2025). It should be noted that analytically, atropine, the racemate of (−)-hyoscyamine and (+)-hyoscyamine, and scopolamine are usually determined and designated as such, as in this study. However, principally the (−)-enantiomers are naturally formed in plants (Thawabteh et al. 2025).

At harvest, not only the seeds of *Datura* spp., but the entire plant, parts of the plant or its sap can contaminate the harvested crop intended for feeding. Fresh plants of *Datura* spp. are usually avoided by animals due to their pungent odour and taste, which makes them unpalatable (Kara et al. 2009; EFSA 2013). Reports on feed contamination are scarce, however, some cases of tropane alkaloid poisoning are recurrently described in farm animals, including pigs, horses and cattle (Schulman and Bolton 1998; Naudé et al. 2005; Aboling et al. 2019; Schulte zu Sundern et al. 2025). A case of intoxication in fattening bulls, reported by Aboling et al. (2019), was due to spots of whole *D. stramonium* plants that were visible in the maize silos. These spots contained 11.5 mg/kg atropine and 4.7 mg/kg scopolamine on fresh weight basis (Aboling et al. 2019). The authors observed refusal of feed and tympany starting at 468 µg/kg body weight for the sum of atropine and scopolamine. Nelson et al. (1982) reported anorexia, rumen stasis, bloat, dry mucosal surfaces, miosis and constipation in calves following ingestion of *D. stramonium* seeds. Based on these

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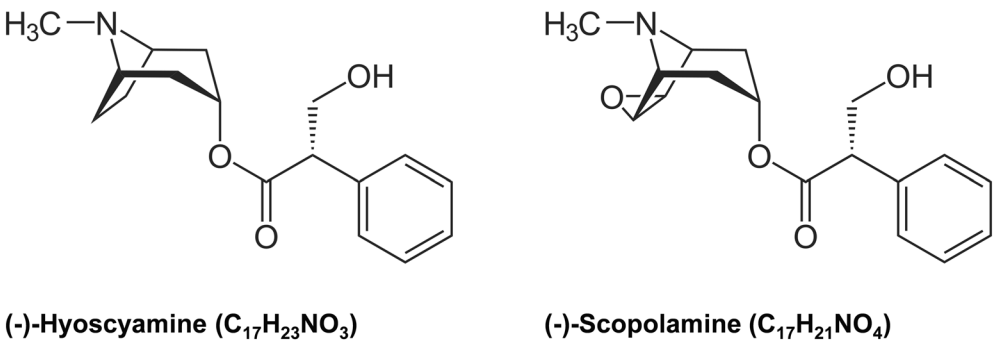


Fig. 1 Chemical structures of the toxins (−)-hyoscyamine and (−)-scopolamine, which are the most abundant tropane alkaloids in *Datura stramonium*. Note, atropine and scopolamine were determined, but only the shown (−)-enantiomers actually occur in the plants

Table 1 Exemplary concentrations of tropane alkaloids in aerial parts of *Datura stramonium* plants ($n=6$)

Plant part	DM (g/kg)	Atropine (mg/kg DM)	Scopolamine (mg/kg DM)	Sum (mg/kg DM)
Leaves/stems	118 ± 16.7	1629 ± 865.8 (703–2672)	739 ± 588 (237–1898)	2367 ± 771.0 (1190–3316)
Seed capsules/seeds	113 ± 35.4	1437 ± 303.1 (1052–1740)	460 ± 195 (224–622)	1897 ± 463.8 (1427–2358)

The whole plants ranged from 40 to 100 cm in height, had a dry weight of 13.0 ± 15.5 g (1.3–39.6 g), and 0–4 seed capsules. Seed capsules were present in 4 of the 6 plants. Values are arithmetic means and standard deviation; the minimum and maximum alkaloid concentrations are given in brackets. Abbreviations: DM = dry matter

clinical signs, the European Food Safety Authority (EFSA) proposed a No Observed Adverse Effect Level (NOAEL) of 300 µg/kg body weight for cattle (EFSA 2008).

The analysis of food products showed that *D. stramonium* seeds can contaminate cereal grains, which can result in tropane alkaloid levels up to a concentration of 650 µg/kg (Świder et al. 2026). Such concentrations exceed the maximum levels in food specified in Regulation (EU) 2023/915. In feed, the maximum content of *Datura* spp. seeds was set at 1000 mg/kg at 880 g/kg dry matter (DM) according to Directive 2002/32/EC. The basis for this regulation dates back to the early 1970s and was probably a compromise between protecting animal health and ensuring the marketability of animal feed. During ensiling of roughages, the aerial biomass of a crop is processed. In this case, contamination with tropane alkaloids from the other aerial plant parts add to the contamination with *D. stramonium* seeds. Such contamination is not covered by the regulation in Directive 2002/32/EC.

Given the anticipated increase in the distribution of *Datura* spp., whole-plant maize silage is a potential source of contamination of feed for cattle, and this study aimed to determine whether fermentation during ensiling affects the concentrations of the tropane alkaloids atropine and scopolamine.

2 Results and discussion

2.1 Tropane alkaloid concentrations

In this study, atropine and scopolamine were measured and the alkaloid concentrations are referred to as such. However, plants naturally produce only (−)-hyoscyamine and (−)-scopolamine. Regarding exposure to plant toxins, therefore, only the (−)-enantiomers are relevant for risk assessment.

In preparation for ensiling and analysis, *D. stramonium* plants were collected in the periphery of Berlin (Germany) on ruderal areas away from agriculturally used land. The plants were dried and ground, and in some of the plants the concentrations of the tropane alkaloids in the individual plant parts were determined. The results are summarized in Table 1. Based on this exemplary analysis, *D. stramonium* contained on average 0.14% atropine and 0.046% scopolamine in seed capsules including seeds and 0.16% atropine and 0.074% scopolamine in leaves and stems, respectively, on a DM basis.

The tropane alkaloid concentrations before and after ensiling are displayed in Fig. 2. Atropine and scopolamine were not detected in the control silages. At 0 h, whole-plant maize contaminated with 10% *D. stramonium* contained 107 ± 4.31 mg/kg DM atropine and 14.9 ± 0.949 mg/kg DM scopolamine. Atropine decreased to 92.4 ± 2.44 mg/kg DM after 30 days ($p<0.05$) and to 85.1 ± 9.45 mg/kg DM after 90 days ($p=0.083$). Scopolamine increased to 15.5 ± 1.72 mg/kg DM ($p=0.686$) and 17.5 ± 1.51 mg/kg DM ($p=0.131$) after 30 and 90 days, respectively. The sum

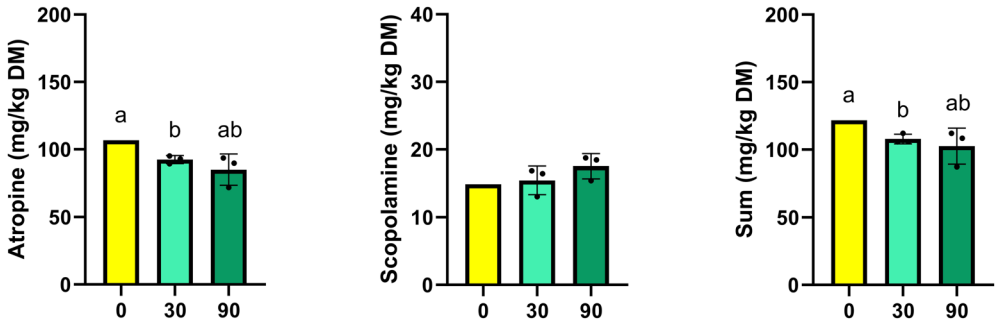


Fig. 2 Concentration of atropine (left), scopolamine (middle) as well as the sum of both (right) in whole-plant maize (day 0) and whole-plant maize silages (day 30 and day 90) contaminated with 10% *Datura stramonium* plants (proportion on DM basis). Three jars were opened per sampling time point, each jar was analysed three times, and each sample was measured at three dilution levels (1:100, 1:500, 1:1000). Each bar represents the arithmetic mean with standard deviation of the concentration. The indicated differences refer to the reference sample taken immediately before ensiling (0 h). ab Superscript letters indicate differences at $p<0.05$. Colour legend: yellow: whole-plant maize before ensiling (0 h), light green: whole-plant maize silage at 30 days, dark green: whole-plant maize silage at 90 days. Abbreviations: DM = dry matter

Table 2 Quality parameters of uncontaminated whole-plant maize and maize silages (control) and whole-plant maize and maize silages containing 10% *Datura stramonium* plants on dry matter basis

	Control						Maize plus *D. stramonium*					
Day	0	1	2	5	30	90	0	1	2	5	30	90
pH	5.4	5.0** ±0.027	4.7* ±0.15	4.4* ±0.38	3.9*** ±0.21	3.9*** ±0.01	5.1	5.0 ±0.22	4.8* ±0.067	4.6* ±0.20	3.9*** ±0.012	3.9*** ±0.012
Lactic acid	17.2	15.7*** ±1.51	18.4*** ±1.87	30.6** ±13.5	55.3*** ±2.28	54.9*** ±2.66	15.2	18.2*** ±3.56	22.9*** ±0.417	27.5*** ±5.92	59.1*** ±0.625	56.6*** ±2.49
Acetic acid	4.7	4.1*** ±0.31	4.9*** ±0.57	5.2*** ±0.97	6.5*** ±0.33	6.8*** ±0.29	4.3	4.8*** ±0.46	5.6*** ±0.26	5.3*** ±0.44	8.5*** ±0.21	8.4*** ±0.63
Ethanol	2.3	2.8*** ±0.16	3.8*** ±0.76	6.2* ±4.7	12.0* ±3.33	15.2* ±2.21	2.1	2.4*** ±0.91	2.7*** ±0.50	10.7* ±3.03	8.8** ±1.6	13.5* ±2.60
NH_3-N	2.8	2.1 ±0.31	1.8 ±0.00	1.6* ±0.46	2.9 ±0.31	3.9 ±0.52	1.5	1.7 ±0.44	1.5 ±0.81	1.9 ±0.76	3.0** ±0.12	3.9* ±0.51

Samples were taken at 0 h ($n=1$) and after 1, 2, 5, 30 and 90 days ($n=3$). The concentrations of organic acids and ethanol are given as g/kg dry matter. The concentration of NH_3–N is given as percent of total nitrogen. Values are arithmetic means and standard deviation. Level of significance (serial *t* tests): * $p<0.05$, ** $p<0.01$, *** $p<0.001$

of these alkaloids decreased from a mean of 122 ± 5.26 mg/kg DM (0 h) to 108 ± 2.93 mg/kg DM (30 days; $p<0.05$) to 103 ± 11.0 mg/kg DM (90 days; $p=0.132$). The raw data set analysed is given in Table S1 (Supplementary Material).

The concentrations and distribution of tropane alkaloids in different plant parts can vary considerably. The concentrations shown in Table 1 are within the range summarized by EFSA (2013) based on a literature review. It should be noted that tropane alkaloids can be found in all parts of the plant, based on the current study, sometimes in significant amounts up to 0.33% of DM.

The objective of this study was to test, whether ensiling reduces the concentration of tropane alkaloids in contaminated maize. In whole-plant maize silages contaminated with a 10% proportion of *D. stramonium* plants, atropine concentration decreased by about 21% within 90 days. Degradation of atropine could be induced by acid hydrolysis or enzymatic decomposition, breaking down the hyoscyamine molecule into tropine and tropic acid (Ballica et al. 1993). However, the actual pathways are still not known. While the concentration of atropine decreased, that of scopolamine seemed to have slightly increased. The increase in scopolamine was 17% within 90 days and thus less pronounced than the decrease in atropine. Therefore, transformation among hyoscyamine and scopolamine enantiomers seems to be unlikely. Other sources of scopolamine or *de novo* synthesis are also unlikely under anaerobic conditions (Cardillo et al. 2017). At the moment, it remains speculative why an increase in the scopolamine concentration was detected.

2.2 Silage quality parameters

Quality parameters of the control and contaminated whole-plant maize silages are summarized in Table 2. Rapid acidification (down to a pH of 3.9) was detected in both silage types. The silages were characterized by high lactic acid and low acetic acid and ethanol concentrations. The maximum proportion of NH_3-N was 3.9% of the total nitrogen and

thus did not indicate undesired fermentation or loss of quality. The concentrations of the following organic acids and alcohols were below the limit of detection given in brackets: propionic acid (0.34 g/kg DM), n-butyric acid (0.22 g/kg DM), iso-butyric acid (0.62 g/kg DM), n-valeric acid (0.24 g/kg DM), iso-valeric acid (0.12 g/kg DM), 1,2-propandiol (0.23 g/kg DM) and 1-propanol (0.91 g/kg DM). The raw data set of DM, nutrient concentrations and silage quality parameters is given in Table S2 (Supplementary Material).

From these accompanying analyses we can conclude that all silages were of sufficient quality and no undesired fermentation occurred. On this level of contamination, the silages' nutrient profile was not relevantly affected.

2.3 Implication on health effects for animals and humans

Whole-plant maize silages are a plausible and probably the primary route of exposure to *Datura* alkaloids for cattle. Due to the observed spots in the field and the silo, only a few individual animals are likely to be affected in the event of contamination. However, it cannot be completely ruled out that chopping the plant material could result in a wider spread of toxic plant parts. Even if the NOAEL is occasionally exceeded and exposure levels are reached that lead to acute adverse effects such as anorexia, this should generally result in a reduction of further intake of the toxins (Nelson et al. 1982).

Food monitoring has shown little evidence for relevant tropane alkaloid exposure to humans via milk consumption, as rates of contamination were low and where contamination was detected, the concentrations ranged only between 0.028 and 0.066 µg/L (Klein et al. 2024). These results could be explained by the fact that, although transfer rates of 0.037% and 0.007% were reported for atropine and scopolamine, respectively, the concentrations of tropane alkaloids in feed are very low (Lamp et al. 2021; Klein et al. 2024). Even if isolated spots of *D. stramonium* occur in feed and individual animals are exposed to higher levels of tropane alkaloids, this milk is significantly diluted via milk tanks. Furthermore, it can be assumed that intoxicated animals will exhibit recognizable symptoms that would render their milk unsuitable for human consumption in accordance with Regulation (EC) No 853/2004. Thus, it is unlikely that any risk for the consumers will arise.

3 Conclusions

In conclusion, no significant detoxification occurs in whole-plant maize silages in cases of tropane alkaloid contamination. Even if there is no widespread risk of exposure, the NOAEL set for cattle could be exceeded in individual cases. Serious poisonings are usually avoided, because cattle reduce feed intake when they ingest tropane alkaloids. This may lead to a drop in performance, at least temporarily. With regard to animal health, it must be noted that it is not primarily the seeds, but the entire plant that ends up in the silage, and all parts of the plant may contain tropane alkaloids. Even plants that have not yet developed seed capsules can therefore be toxic when the exposure is sufficiently high. To prevent the dissemination of *D. stramonium*, farmers should follow agronomic recommendations such as crop rotation, mulching or hand-pulling the plants before they develop seed capsules. Farmers should also pay attention to visible changes in the silage and sort out contaminated feed.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00003-026-01617-4.

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Data availability The data sets used and/or analysed during the current study are available as supplementary materials.

Declarations

Conflict of interests The authors declare to have no conflicts of interest.

Ethical approval The study did not involve animals or human subjects.

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