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Review article

Promising medicinal plants for treatment of helminths of bison

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ABSTRACT. *Bison bonasus* (Linnaeus, 1758) and *B. bison* (Linnaeus, 1758) are mammals placed in the Red Book of the International Union for Conservation of Nature. Populations of those species of animals are under threat of extinction. Therefore, developing practical measures for their protection is of great significance. However, one way of improving the population of bisons is integrated control of their helminths. The article generalizes the data about the helminth fauna of *B. bonasus* and *B. bison*, as well as data on relatively medicinal plants with anthelmintic properties. The results of the analysis indicate the existence of more effective medicinal plants that could be used to develop novel anthelmintic drugs. Less effective anthelmintic plants may be consumed by animals in pastures or with hay in the conditions of stable maintenance. Helminths in bison populations should be controlled using plant-based anthelmintic drugs taking into account infections in animals in particular herds of bisons by more or less dangerous helminths.

Keywords: helminths, mammals, Trematoda, Cestoda, Nematoda, Bovidae, plant anthelmintic drugs

Introduction

Bisons are represented in the contemporary fauna by two species: *Bison bonasus* (Linnaeus, 1758) and *B. bison* (Linnaeus, 1758). These are large mammals included in the Red Book of the International Union for Conservation of Nature (Category IUCN 3.1 Near Threatened). These species are protected at the state level in all countries with their populations.

During the Holocene, the range of European bison *Bison bonasus* spanned from Britain and Spain to Mongolia and Lake Baikal. The range of this species has significantly decreased over the last two thousand years to parts of Western, Central and Eastern Europe, Ciscaucasia. According to the data of the staff of the Belovezhskaya Pushcha National Park, there were 8,461 European bison around the globe as of 2020, including 6,244 free, 479 half free and 1,738 individuals kept in captivity (mostly in Poland, Belarus, Russia and Germany – www.npbp.by).

The American bison *Bison bison* is very similar to the previous species, can freely mate with it, producing fertile offspring, and therefore those two species are often considered as one. For commercial purposes, around 500,000 individuals are reared at about 4,000 ranches in North America (the USA, Canada, and Mexico). According to the Recommendations of the IUCN Red Book, commercial herds are not included in the Red Book, and therefore the overall population of bison is estimated around 30,000 individuals (www.iucn.org).

Because bisons are constantly infected with helminths (more intensely during the warm period) by consuming food and water, scheduled deworming, conducted for large mammals on stock-raising farms, is less effective for bison. Scheduled deworming (for example, using albendazole or ivermectin) for wild animals is only effective for a short period of time, while sufficient concentration of the drug is present in the organism. The continuous daily influx of new eggs and larvae of helminths into the organism of bison in natural conditions gives no opportunity of using anthelmintic drugs that are used for farm ruminants or swine [1,2]. It is necessary to select new plant-based anthelmintic drugs depending

Table 1. Helminth fauna *Bison bonasus* (Linnaeus, 1758)

Species of helminth	Prevalence %	Distribution	References
Trichostrongylidae sp.	94.5	North-Eastern Poland	[15]
	100.0	Borecka Forest, Poland	[17]
	27.8	Białowieża Primeval Forest, Poland	[9]
	78.3	Bialowieża National Park	[14]
	90.0–100.0	Ubiquitously	[5]
	53.6–82.5	Borecka Forest, Białowieża Forest, Knyszyn Forest, the West Pomeranian Voivodeship, as well as in enclosures located in Gołuchow, Pszczyna, Smardzewice, Niepołomice, Białowieża (Poland)	[16]
Cooperia oncophora (Railliet, 1898)	18.0	Belarus	[13]
	33.0	Forest of Białowieża and Borecka Forest	[12]
C. pectinata Ransom, 1907	8.0	Forest of Białowieża and Borecka Forest	[12]
C. punctata (Linstow, 1906)	8.0	Forest of Białowieża and Borecka Forest	[12]
Haemonchus contortus (Rudolphi, 1803)	4.0	Belarus	[13]
	–	German wildlife park	[18]
H. placei (Place, 1893)	11.0	Forest of Białowieża and Borecka Forest	[12]
Nematodirus helvetianus May, 1920	2.0	Belarus	[13]
	33.0	Forest of Białowieża and Borecka Forest	[12]
	7.0	Białowieża National Park	[19]
N. roscidus Railliet, 1911	61.0	Forest of Białowieża and Borecka Forest	[12]
	22.0	Białowieża National Park	[19]
N. europaeus Jansen, 1972	39.0	Forest of Białowieża and Borecka Forest	[12]
Nematodirus spp.	0.0–40.0	North-Eastern Poland	[15]
	25.0	Borecka Forest	[17]
	6.7	Bialowieża National Park	[14]
	3.5	Białowieża Primeval Forest, Poland	[9]
	4.8–18.1	Borecka Forest, Białowieża Forest, Knyszyn Forest, the West Pomeranian Voivodeship, as well as in enclosures located in Gołuchow, Pszczyna, Smardzewice, Niepołomice, Białowieża (Poland)	[16]
Nematodirella olcidis (Dikmans, 1935)	3.0	Forest of Białowieża and Borecka Forest	[12]
Ashworthius sidemi Schulz, 1933	–	Lutowiska Forestry District in the Bieszczady Mountains (Eastern Carpathians, Poland)	[20]
	–	Białowieża Forest	[21]
	14.0–44.0	Białowieża National Park	[19]
	89.0–100.0	Białowieża National Park	[4,7,8]
	–	Białowieża Forest (Poland)	[8]
Trichostrongylus axei (Cobbold, 1879)	53.0	Forest of Białowieża and Borecka Forest	[12]
T. capricola Ransom, 1907	19.0	Forest of Białowieża and Borecka Forest	[12]
Ostertagia ostertagi (Stiles, 1892)	13.0	Belarus	[13]
	100.0	Forest of Białowieża and Borecka Forest	[12]
O. lyrata Sjóberg, 1926	72.0	Forest of Białowieża and Borecka Forest	[12]
O. leptospicularis Assadov, 1953	86.0	Forest of Białowieża and Borecka Forest	[12]
O. kolchida Popova, 1937	83.0	Forest of Białowieża and Borecka Forest	[12]
Ostertagiinae sp.	81.5	Avesta Visentpark	[10]

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Species of helminth	Prevalence %	Distribution	References
Spiculopteragia boehmi Gebauer, 1932	86.0	Forest of Białowieża and Borecka Forest	[12]
S. matheuossiani Ruchliadev, 1948	19.0	Forest of Białowieża and Borecka Forest	[12]
Bunostomum trigonocephalum (Rudolphi, 1808)	2.0	Belarus	[13]
	22.0	Białowieża National Park	[19]
Trichuris globulosa (Linstow, 1901)	6.0	Belarus	[13]
Oesophagostomum venulosum (Rudolphi, 1809)	12.0	Belarus	[13]
	71.0–100.0	Białowieża National Park	[19]
Oe. radiatum (Rudolphi, 1803)	2.0	Belarus	[13]
	100.0	Forest of Białowieża and Borecka Forest	[12]
	14.0–100.0	Białowieża National Park	[19]
Chabertia ovina (Gmelin, 1790)	25.0	Forest of Białowieża and Borecka Forest	[12]
Aonchotheca bovis (Schnyder, 1906)	18.0	Belarus	[13]
A. bilobata (Bhalerao, 1933)	50.0	Borecka Forest	[17]
Aonchotheca sp.	40.8	North-Eastern Poland	[15]
	11.5	Białowieża Primeval Forest, Poland	[9]
	1.7	Bialowieża National Park	[14]
Dictyocaulus filaria (Rudolphi, 1809)	18.0	Belarus	[13]
D. viviparus (Bloch, 1782)	61.0	Forest of Białowieża and Borecka Forest	[12]
	27.7	North-Eastern Poland	[15]
	50.0	Borecka Forest	[17]
	12.5	Bialowieża National Park	[14]
D. viviparus subsp. *bisontis* Pyziel et al., 2020	–	Białowieża Primeval Forest and Borecka Forest (North-Eastern Poland)	[10]
Dictyocaulus sp.	–	Poland	[10]
Strongyloides spp.	0.0–16.6	North-Eastern Poland	[15]
Trichuris ovis (Abildgaard, 1795)	43.0–100.0	Białowieża National Park	[19]
	43.0–100.0	ubiquitously	[5,6]
	16.6	Borecka Forest	[17]
Trichuris spp.	25.0	Forest of Białowieża and Borecka Forest	[12]
	0.0–38.4	North-Eastern Poland	[15]
	4.9	Białowieża Primeval Forest, Poland	[9]
	1.7	Bialowieża National Park	[14]
	12.7	Borecka Forest, Białowieża Forest, Knyszyn Forest, the West Pomeranian Voivodeship, as well as in enclosures located in Gołuchow, Pszczyna, Smardzewice, Niepołomice, Białowieża (Poland)	[16]
Toxocara vitulorum (Goeze, 1782)	13.0	Belarus	[13]
	–	Animal park in Central Germany	[22]
Thelazia gulosa (Railliet et Henry, 1910)	28.0	Forest of Białowieża and Borecka Forest	[12]
Thelazia spp.	81.3	Poland	[11]
Onchocerca lienalis (Stiles, 1892)	60.0	Forest of Białowieża and Borecka Forest	[12]
O. gutturosa Neumann, 1910	36.0	Forest of Białowieża and Borecka Forest	[12]
Setaria labiatopapillosa (Alessandrini, 1838)	25.0	Forest of Białowieża and Borecka Forest	[12]
	71.0	Białowieża Forest	[23]

Table 1. Helminth fauna *Bison bonasus* (Linnaeus, 1758))

Species of helminth	Prevalence %	Distribution	References
Capillaria bilobata Bhalerao, 1933	22.0	Forest of Białowieża and Borecka Forest	[12]
Capillaria spp.	3.6–13.9	Borecka Forest (Poland), Białowieża Forest, Knyszyn Forest, the West Pomeranian Voivodeship, as well as in enclosures located in Gołuchow, Pszczyna, Smardzewice, Niepołomice, Białowieża (Poland)	[16]
Moniezia spp.	1.7	Bialowieża National Park	[14]
	3.7–17.6	North-Eastern Poland	[15]
	3.1	Białowieża Primeval Forest, Poland	[9]
	3.0–5.4	Borecka Forest, Białowieża Forest, Knyszyn Forest, the West Pomeranian Voivodeship, as well as in enclosures located in Gołuchow, Pszczyna, Smardzewice, Niepołomice, Białowieża (Poland)	[16]
M. benedeni (Moniez, 1879)	8.0	Belarus	[13]
	–	Forest of Białowieża and Borecka Forest	[12]
Fasciola hepatica Linnaeus, 1758	64.1	North-Eastern Poland	[15]
	23.0	Belarus	[13]
	44.0	Forest of Białowieża and Borecka Forest	[12]
	100.0	Białowieża Forest	[23]
	37.5	Borecka Forest	[17]
	50.8	Bialowieża National Park	[14]
	35.3	Poland	[24]
	43.0–100.0	ubiquitously	[5,6]
Dicrocoelium dendriticum (Rudolphi, 1819)	11.0	Belarus	[13]
	41.0	Forest of Białowieża and Borecka Forest	[12]
Paramphistomum cervi (Zeder, 1790)	5.0	Belarus	[12]
	50.0	Borecka Forest	[17]
	5.0	Forest of Białowieża and Borecka Forest	[12]
Parafasciolopsis fasciolaemorpha Ejsmont, 1932	6.0	Forest of Białowieża and Borecka Forest	[12]

Explanations: "–" in cell of prevalence means absence of data in original source

on the species of helminth dominant in a particular herd of bisons.

More effective plants (that kill helminths in low concentration of decoction, tincture or plant extract) are usually bitter or have strong smell and therefore are poorly consumed by animals. Nonetheless, extracting active substances and developing novel drugs based on them is promising. Less effective plants (that kill helminths only in high concentrations of their extracts or aqueous tinctures) usually have weaker smell and taste, and therefore are better consumed by mammals. It would be promising to use these species of plants as bases of fodder mixtures, adding them in dry form into hay for feeding animals [3].

Helminths, as natural focal parasites, are locally distributed in relatively small territories, and therefore usually no more than 10 species of helminths (usually less) are found in one bison herd. Therefore, it would be more promising to conduct development of the most effective plant diets and phytopreparations for treatment of these helminthoses with an orientation towards local parasites faunas. The objective of this literature review was to demonstrate the possibility and perspectives of controlling helminths in bison populations using plant-based anthelmintic preparations.

Morbidity of ruminants of *Bison* genus with helminths

Among the commonest species of helminths of ruminants of the Bovidae family are representatives

Table 2. Helminth fauna of *Bison bison* (Linnaeus, 1758)

Species of helminth	Prevalence %	Distribution	References
Strongyle-type spp.	95.2	Central Nebraska	[25]
Dictyocaulus hadweni Chapin (1925)	–	Canada	[26]
Ostertagia bisonis (Chapin, 1925) Lichtenfels, 1991	–	Canada	[26]
Trichostrongylus sp.	–	Prioksko-Terrasny Nature Reserve	[27]
Nematodirus spp.	30.0	Steppe zone of Ukraine	[28]
	21.5	Central Nebraska	[25]
Bunostomum sp.	40.0	Steppe zone of Ukraine	[28]
Oesophagostomum sp.	100.0	Steppe zone of Ukraine	[28]
Strongyloides papillosus (Wedl, 1856)	–	Prioksko-Terrasny Nature Reserve	[27]
Strongyloides sp.	30.0	Steppe zone of Ukraine	[28]
Trichuris spp.	30.7	Central Nebraska	[25]
Moniezia spp.	41.6	Central Nebraska	[25]

Explanations: see Table 1

of the Strongylata suborder (Nematoda) – one of the largest suborders of nematodes (Tab. 1, 2). Most often, species of the Bovidae family were found to host nematodes of the Trichostrongylidae family. The level of infection with these helminths in some natural zones reaches 100% [4–10].

In the literature, the largest amount of data has been generated for parasites of the European bison (*Bison bonasus*) [5,6]. Prevalence of representatives of the *Oesophagostomum* genus in European bison is high. *Trichuris ovis* (Abildgaard, 1795) (Trichurata suborder, Nematoda class) and *Fasciola hepatica* Linnaeus, 1758 (Fasciolata suborder, Trematoda class) are found to be ubiquitous in European bison. At the same time, prevalence of trichocephalosis and fasciolosis in various natural zones may reach 100%. In the territory of Poland, the most commonly found parasite is *Thelazia* spp. (Spirurata suborder, Nematoda class) [11].

Among the representatives of Cestoda class, the *Bison* (Bovidae) genus is most often observed to host helminths of the *Moniezia* genus [9,12–16].

At the same time, according to Treboganova [29], 17 helminth species were found in the bisons of Prioksko-Terrasny Nature Biosphere Reserve. Three species belonged to Trematoda: *Fasciola hepatica* Linnaeus, 1758; *Dicrocoelium lanceatum* (Stiles et Kassall, 1898), and *Paramphistomum cervi* (Zeder, 1790); 2 species to Cestoda: *Moniezia benedeni* (Moniez, 1879), *M. autumnalia* (Kuznetsov, 1967) and 12 representatives to Nematoda: *Dictyocaulus viviparus* (Bloch, 1782), *Ostertagia ostertagi* (Stiles, 1892), *O. lirata* (Sjoberg, 1926), *Cooperia oncophora* (Railliet, 1898), *C. zurnabada* Antipin, 1931; *Haemonchus contortus* (Rudolphi, 1803), *Nematodirus helvetlanus* (May, 1920), *Oesophagostomum radiatum* (Rudolphi, 1803), *Trichocephalus ovis* (Abildgaard, 1795), *Capillaria bovis* (Sehnyder, 1906), *Setaria labiatopapillosa* (Alessandrini, 1838)). Until 1992, bison were also observed as a host of *Bunostomum trigonocephalum* (Rudolphi, 1808).

Other than the species indicated in tables 1 and 2, according to the data of Kuzmina et al. [30], European bison was also observed to have such representatives of Trematoda class as *Paramphistomum ichikawai* Fukui, 1929 and *Liorchis scotiae* (Wilmott, 1950) Velichko, 1966. Bison of this species are also parasitized by *Moniezia expansa* (Rudolphi, 1810) and larval stage of *Taenia hydatigena* (Pallas, 1766) – representatives of Cestoda class. Nematoda class is also represented by *Bunostomum phlebotomum* (Railliet, 1900), *Cooperia mcmasteri* Gordon, 1932; *C. zurnabada* Antipin, 1931; *Gongylonema pulchrum* Molin, 1857; *Mazamastrongylus dagestanicus* (Altaev, 1953), *Nematodirella longissimespiculata* (Romanovich, 1915), *Nematodirus abnormalis* May, 1920; *N. europaeus* Jansen, 1972; *N. filicollis* (Rudolphi, 1802), *N. iratianus* Rajevskaja, 1929; *N. roscidus* Railliet, 1911; *N. spathiger* (Railliet, 1896), *Ostertagia antipini* Matschulsky, 1950; *O. bacuriani* Schischkin, 1937;

Table 3. Data about effects of plants as alternative means of combating helminths of ruminants

Species of helminth	Preparations	Dosage	References
Fasciola hepatica Linnaeus, 1758	crude ethanol extracts of Brazilian *Artemisia annua* L.	with 70% ethanol, extract concentration 2.0 mg/ml, 23 h exposure to mature individuals	[40]
	crude ethanol extracts of Chinese *Artemisia annua* L.	with 70% ethanol, extract concentration 2.0 mg/ml, 16 h exposure to mature individuals	[40]
Paramphistomum sp.	methanolic extract of leaves *Hypericum japonicum* Thunb.	LC_{50} for mature individuals – 0.21 mg/ml	[41]
	methanolic extract of *Hydrocotyle sibthorpioides* Lam.	LC_{50} for mature individuals – 5.36 mg/ml	[41]
Strongyloides spp.	aqueous extract of shoots *Lawsonia inermis* L.	10 mg/ml for females with 24 h exposure	[42]
Strongyloides papillosus (Wedl, 1856)	aqueous extract of shoots *Fumaria parviflora* Lam.	LC_{50} for larvae – 16.60 mg/ml	[43]
	powder of ginger rhizome *Zingiber officinale* Roscoe, given with concentrated food	with 28 days exposure in the concentration of 5–20 g/kg of body weight	[44]
	aqueous tinctures of leaves *Salvia sclarea* L.	LD_{50} for non-invasive larvae equals 327 ± 186 mg of dry plant/l; LD_{50} for invasive larvae equals 464 ± 192 mg of dry plant/l of water	[45]
	extract of *Punica granatum* L. peel	mortality 100% of larvae was caused by exposure to 20% of ethanol extract	[46]
	aqueous tinctures of roots *Taraxacum officinale* (L.) Weber ex F.H. Wigg.	LD_{50} for invasive larvae equals 0.760 ± 0.420%; LD_{50} for non-invasive larvae equals 0.386 ± 0.227%	[47]
	aqueous tinctures of roots *Sanguisorba officinalis* L.	LD_{50} for invasive larvae equals 0.814 ± 0.263%; LD_{50} for non-invasive larvae equals 0.074 ± 0.019%	[47]
	aqueous tinctures of leaves *Ambrosia artemisiifolia* L.	LD_{50} for invasive larvae equals 0.448 ± 0.203%; LD_{50} for non-invasive larvae equals 0.110 ± 0.086%	[47]
	aqueous tinctures of leaves *Aristolochia manshuriensis* Kom.	LD_{50} for non-invasive larvae equals 0.24%	[48]
	aqueous tinctures of leaves *Celastrus scandens* L.	LD_{50} for non-invasive larvae equals 0.23%	[48]
	aqueous tinctures of leaves *Colchicum autumnale* L.	LD_{50} for non-invasive larvae equals 0.80%	[48]
	aqueous tinctures of shoots *Juniperus sabina* L.	0.22% for LD_{50} non-invasive larvae	[48]
	aqueous tinctures of leaves *Laburnum anagyroides* Medik.	LD_{50} for non-invasive larvae equals 0.19%	[48]
	aqueous tinctures of leaves *Securigera varia* (L.) Lassen	LD_{50} for non-invasive larvae equals 0.48%	[48]
	aqueous tinctures of leaves *Wisteria sinensis* (Sims) DC.	LD_{50} for non-invasive larvae equals 0.31%	[48]
	aqueous tinctures of leaves *Quercus petraea* subsp. *iberica* (Steven ex M.Bieb.) Krassiln.	LD_{50} for non-invasive larvae equals 0.84%	[48]
	aqueous tinctures of leaves *Ginkgo biloba* L.	LD_{50} for non-invasive larvae equals 0.79%	[48]

Table 3. Data about effects of plants as alternative means of combating helminths of ruminants

Species of helminth	Preparations	Dosage	References
Strongylida sp.	aqueous tinctures of leaves *Magnolia kobus* DC.	LD_{50} for non-invasive larvae equals 0.26%	[48]
	aqueous tinctures of leaves *Ailanthus altissima* (Mill.) Swingle	LD_{50} for non-invasive larvae equals 0.75%	[48]
	aqueous tincture of *Teucrium polium* L.	LD_{50} for non-invasive larvae equals 0.060%	[49]
	aqueous tincture of *Achillea millefolium* L.	LD_{50} for non-invasive larvae equals 0.082%	[49]
	aqueous tincture of *Genista tinctoria* L.	LD_{50} for non-invasive larvae equals 0.067%	[49]
	aqueous extract from *Spondias mombin*	LC_{50} for invasive larvae equals 0.907 mg/ml	[50]
	ethanol extract *Spondias mombin* L.	LC_{50} for invasive larvae equals 0.456 mg/ml	[50]
	hydro-alcoholic extract *Phytolacca dodecandra* L'Hér.	Inhibits egg hatching in 5.0 mg/ml concentrations	[51]
	hydro-alcoholic extract *Albizia gummifera* (J.F. Gmel.) C.A. Sm.	Inhibits egg hatching in 10.0 mg/ml concentrations	[51]
	hydro-alcoholic extract *Vernonia amygdalina* Delile	Inhibits egg hatching in 10.0 mg/ml concentrations	[51]
Trichostrongylus colubriformis (Giles, 1892)	acetone extract *Limoniastrum monopetalum* (L.) Boiss.	IC_{50} for invasive larvae equals 47.9 (37.1–60.4) μg/ml	[52]
	acetone extracts *Cladium mariscus* (L.) Pohl	LC_{50} for invasive larvae equals 77.8 (60.6–100.0) μg/ml	[52]
	acetone extract *Helichrysum italicum* subsp. *picardi* (Boiss. & Reut.) Franco	IC_{50} for invasive larvae equals 132.5 (112.0–157.1) μg/ml	[52]
	acetone extract *Pistacia lentiscus* L.	IC_{50} for invasive larvae equals 29.7 (22.2–39.7) μg/ml	[52]
	ethanol extract *Valeriana officinalis* L.	inhibited larval (L_3) migration (LMI) in 2,000 μg/ml concentration – 87.50 ± 29.32 %	[53]
	ethanol extract *Satureja hortensis* L.	inhibited larval (L_3) migration inhibition (LMI) in 2,000 μg/ml concentration – 60.00 ± 26.90%	[53]
	ethanol extract *Juglans regia* L.	inhibited larval (L_3) migration inhibition (LMI) in 2,000 μg/ml concentration – 58.97 ± 20.36%	[53]
	ethanol extract *Inula helenium* L.	inhibited larval (L_3) migration inhibition (LMI) in 2,000 μg/ml concentration – 68.75 ± 2.81%	[53]
	ethanol extract *Consolida regalis* Gray	inhibited larval (L_3) migration inhibition (LMI) in 2,000 μg/ml concentration – 51.67 ± 3.21%	[53]
	ethanol extract *Artemisia absinthium* L.	inhibited larval (L_3) migration inhibition (LMI) in 2,000 μg/ml concentration – 76.92 ± 2.64%	[53]
	ethanol extract *Allium sativum* L.	inhibited larval (L_3) migration inhibition (LMI) in 2,000 μg/ml concentration – 66.67 ± 12.94%	[53]
Haemonchus spp.	aqueous extract from *Agave sisalana* Perrine	EC_{50} for inhibition of egg hatching equals 0.1 mg/ml; the percent efficacies that were observed for the larval migration equaled 50.3% (concentration 100.0 mg/ml)	[54]

Table 3. Data about effects of plants as alternative means of combating helminths of ruminants

Species of helminth	Preparations	Dosage	References
Haemonchus contortus (Rudolphi, 1803)	Ethyl-acetate extract of *Agave sisalana* Perrine	EC_{50} for inhibition of egg hatching equals 4.7 mg/ml; the percent efficacies that were observed for the larval migration equal 33.2% (concentration 100.0 mg/ml)	[54]
	flavonoid fractions of *Agave sisalana* Perrine	EC_{50} for inhibition of egg hatching equals 0.05 mg/ml	[54]
	saponin fractions of *Agave sisalana* Perrine	the percent efficacies that were observed for the larval migration equal 64.1% (concentration 2.5 mg/ml)	[54]
	aqueous extract of *Hedera helix* L.	ED_{50} for inhibition of egg hatching equals 0.12 mg/ml	[55]
	hydro-alcoholic extract of *Hedera helix* L.	ED_{50} for inhibition of egg hatching 0.17 mg/ml	[55]
	onion powder (*Allium cepa* L.) and coconut powder (*Cocos nucifera* L.)	once daily for 8 days in amount of 60 g of onion powder and 60 g of coconut powder plus dry milk powder spread on their normal food caused 100% death of parasites	[56]
	aqueous fraction *Elephantorrhiza elephantina* (Burch.) Skeels	the total faecal egg count reduction of 81.7%, 96.8% and 98.6% at doses of 25, 50 and 75 mg/kg, respectively, on day 56.	[57]
	hydroalcoholic extract of leaves of *Acacia cochliacantha* Willd.	LC_{50} for infective larvae (L_3) equaled 129.39 mg/ml; LC_{90} for infective larvae (L_3) equaled 177.88 mg/ml	[58]
	crude aqueous extracts of leaves of *Corymbia citriodora* (Hook.) K.D. Hill & L.A.S. Johnson	ED_{50} = 0.997 and ED_{99} = 105.03 mg/ml for egg hatch; 100% inhibition of egg hatching in 50 mg/ml; ED_{50} = 5.31 and ED_{99} = 157.33 mg/ml for larval paralysis	[59]
	crude methanolic extracts of leaves of *Corymbia citriodora* (Hook.) K.D. Hill & L.A.S. Johnson	ED_{50} = 1.82 and ED_{99} = 52.18 mg/ml for egg hatching; 100% inhibition of egg hatching in 100 mg/ml; ED_{50} = 5.50 and ED_{99} = 165.45 mg/ml for larval paralysis	[59]
	aqueous extract of *Iris kashmiriana* Baker	LC_{50} for adult worms equals 18.50 mg/ml	[60]
	methanolic extract of *Iris kashmiriana* Baker	LC_{50} for adult worms equals 16.66 mg/ml	[60]
	aqueous solution of *Taraxacum officinale* (L.) Weber ex F.H.Wigg.	LD_{50} for invasive larvae equals 1.78 ± 0.10%	[47]
	Powder of *Mitragyna inermis* (Willd.) Kuntze	3.2 g/kg of body weight	[61]
	hydroalcoholic extract from the fruit of *Piper cubeba* L.f.	EC_{50} for the egg hatching equals 200 µm/ml; EC_{50} for larval development equals 83.00 µm/ml; 100% L_3 migration inhibition in 95 µg/ml	[62]
	hydroalcoholic extract of leaves of *Psidium cattleianum* Sabine	IC_{50} equaled 0.55 mg/ml for egg hatching inhibition; IC_{50} 0.20 mg/ml for larval development inhibition; IC_{50} < 0.19 mg/ml for inhibition of larval migration	[63]
	acetone extracts of *Limoniastrum monopetalum* (L.) Boiss.	IC_{50} for invasive larvae equals 39.4 (33.2–46.4) µg/ml	[52]

Table 3. Data about effects of plants as alternative means of combating helminths of ruminants

Species of helminth	Preparations	Dosage	References
	acetone extract of *Cladium mariscus* (L.) Pohl	IC_{50} for invasive larvae equals 88.9 (66.3–118.7) μg/ml	[52]
	acetone extract of *Helichrysum italicum* subsp. *picardi* (Boiss. & Reut.) Franco	IC_{50} for invasive larvae equals 92.8 (78.9–107.4) μg/ml	[52]
	acetone extract of *Pistacia lentiscus* L.	IC_{50} for invasive larvae equals 27.8 (21.3–36.8) μg/ml	[52]
	fed on hay of *Medicago sativa* L.	34.1 gDM/Kg BW/d	[64]
	fed on hay of *Sulla coronaria* (L.) Medik.	34.7 gDM/Kg BW/d	[64]
	fed on hay of *Onobrychis viciifolia* Scop.	36.2 gDM/Kg BW/d	[64]
	fed on hay of *Artemisia absinthium* L.	37.0 gDM/Kg BW/d	[64]
	infusion of *Artemisia frigida* Willd.	number of EPG was reduced by 22.0%, in 5 days post infusion	[65]
	infusion of *Tanacetum vulgare* L.	number of EPG was reduced by 20.5%, in 5 days post infusion	[65]
	infusion of *Allium sativum* L.	number of EPG was reduced by 17.8%, in 5 days post infusion	[65]
	Aqueous extract of *Cichorium intybus* L.	mortality index for mature individuals: 12.5 mg/ml – 0.5; 25 mg/ml – 1.0; 50 mg/ml – 1.0	[66]
	methanol (95%) extract from *Artemisia absinthium* L.	mortality index for mature individuals: 12.5 mg/ml – 0.4; 25 mg/ml – 1.0; 50 mg/ml – 1.0	[66]
	ethanol extract from leaves of *Moringa oleifera* Lam.	LC_{50} against egg development equals 0.985 mg/mL over 48 h; LC_{50} against egg hatching equals1.7 mg/ml over 6 h; LC_{50} against L_1 larvae equals 1.89 mg/mL over 24 h; LC_{50} against L_2 larvae equals 1.5 mg/ml over 24 h	[67]
	ethanolic extract of *Fumaria parviflora* Lam.	ED_{50} against eggs equals 9.12 mg/ml; LC_{50} aghainst larvae equals 10.23 mg/ml	[43]
H. placei	hydroalcoholic extract of leaves of *Acacia cochliacantha* Willd.	LC_{50} against infective larvae (L_3) equals 126.53 mg/ml; LC_{90} for infective larvae (L_3) equals 172.59 mg/ml	[58]
Chabertia ovina (Gmelin, 1790)	ethanol extract from *Allium sativum* L.	IC_{50} for mature individuals equals 0.30 ± 0.04 mg/ml, 24 h	[68]
	ethanol extract from *Daucus carota* L.	IC_{50} for mature individuals equals 0.62 ± 0.11 mg/ml, 24 h	[68]
	ethanol extract from *Valeriana officinalis* L.	IC_{50} for mature individuals equals 0.63 ± 0.11 mg/ml, 24 h	[68]
	ethanol extract from *Tanacetum vulgare* L.	IC_{50} for mature individuals equals 0.65 ± 0.09 mg/ml, 24 h	[68]
	aqueous extract of *Fumaria parviflora* Lam.	ED_{50} for eggs equals 14.45 mg/ml	[43]
Cooperia punctata (Linstow, 1906)	hydroalcoholic extract of leaves of *Acacia cochliacantha* Willd.	LC_{50} for infective larvae (L_3) equals 136.90 mg/ml; LC_{90} for infective larvae (L_3) equals 174.7 mg/ml	[58]

O. gruehneri Skrjabin, 1929; *O. circumcincta* (Stadelmann, 1894), *O. trifurcata* Ransom, 1907; *Setaria cervi* (Rudolphi, 1819), *Spiculopteragia asymmetrica* (Ware, 1925), *S. boehmi* Gebauer, 1932; *S. mathevossiani* Ruchljadev, 1948; *Thelazia skrjabini* Erschov, 1928; *Th. rhodesi* (Desmarest, 1822), *Trichostrongylus axei* (Cobbold, 1879), *T. askivali* Dunn, 1964; *T. capricola* (Ransom, 1907), *T. vitrinus* Looss, 1905; *Trichuris globulosa* (Linstow, 1901), *T. skrjabini* (Baskakov, 1924) and *T. gazellae* (Gebauer, 1933). Therefore, European and American bison are parasitized by 67 species of Nematoda, three species of Cestoda, and also 6 representatives of Trematoda.

Medicinal plants to use against helminths of bison

Currently, a number of authors are studying alternative methods of combating parasites of agricultural and wild animals to decrease the toxic pressure on natural ecosystems, and also improving the quality of livestock products (Tab. 3). Studies of such methods quite often contain data about substances used in the food industry [31–33]. Our previous studies demonstrated strong effects of cinnamaldehyde, benzaldehyde, formic acid and benzoic acid [34–36], and also some other food supplements [37,38] on nematode larvae – parasites of the digestive tract of ruminants. Some studies were focused on nematocidal properties of plant essential oils [39].

The most interesting methods of combating parasites are those utilizing medicinal plants and plant-based drugs (Tab. 3). Currently, there are many data about effects of medicinal plants on representatives of the Nematoda, especially representatives of the Trichostrongylidae family of the Strongylida order. As one of the ways of combating helminths of this family, authors of numerous articles propose aqueous or alcohol extracts of plants (most often, there ethanol or methanol extracts are used). Studies are conducted both *in vitro* and *in vivo*.

The best results were exerted by ethanol extract from *Spondias mombin* against larvae of third-stage nematodes of the Strongylida [50], hydro-alcoholic extract of *Hedera helix* inhibited hatching of eggs of *Haemonchus contortus* (Rudolphi, 1803) [55], methanolic extracts of *Eucalypyus citriodora* inhibited egg hatching and paralyzed larvae of nematodes [59], hydroalcoholic extract of *Psidium cattleianum* inhibited egg hatching and larval development and larval migration of nematodes [63]. Also, one of the most successful was ethanolic extract from leaves of *Moringa oleifera* which inhibited development of eggs of *H. contortus* in 48 h, egg hatching of this species in 6 h, and L_1 larvae in 24 h [67].

According to Urban et al. [68], ethanol extracts from *Allium sativum*, *Daucus carota*, *Valeriana officinalis*, *Tanacetum vulgare* displayed significant anthelminthic action toward mature individuals of *Chabertia ovina*. Methanolic extract of *Hypericum japonicum* has notable antiparasitic properties against mature individuals of *Paramphistomum* sp. [41].

In conclusion, using plants that have helminthocidal properties to treat bison is promising for limiting some species of helminths and to a lower degree – other species of parasites. However, supplementing diets of large mammals with plant fodders that may inhibit even some commonest nematodes may be promising to improve the health of bison populations using non-chemical means. To treat bison, it is promising to develop novel forms of anthelminthic drugs based on plants that have not been used to treat large mammals before.

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