J Parasit Dis (July-Sept 2020) 44(3):559–573
https://doi.org/10.1007/s12639-020-01229-1

ORIGINAL ARTICLE

Prevalence of *Eimeria* species in sheep (*Ovis aries*) from Dakahlia governorate, Egypt

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Received: 8 January 2020 / Accepted: 6 May 2020 / Published online: 19 May 2020

Abstract Feces from 184 sheep from Dakahlia governorate, Egypt were tested for *Eimeria* species oocysts by using the standard floatation technique; oocysts were detected in 126 (68.4%). The prevalence was significantly higher in young sheep than adults. Eleven *Eimeria* species were identified: *Eimeria ahsata*, *Eimeria bakuensis*, *Eimeria crandallis*, *Eimeria faurei*, *Eimeria granulosa*, *Eimeria intricata*, *Eimeria marsica*, *Eimeria ovinoidalis*, *Eimeria pallida*, *Eimeria parva and Eimeria webybridgensis.* Oocysts of the most pathogenic ovine species, *E. ovinoidalis*, were detected in 27 (14.6%) sheep. This is the first report of *E. webybridgensis* in sheep from Egypt, possibly due to close similarity of their oocysts to those of *E. crandallis* which stated in the earlier reports. Worldwide reports on epidemiology of *Eimeria* spp. infections in sheep are tabulated.

Keywords *Eimeria* · *Eimeria ovinoidalis* · Coccidiosis · Prevalence · Sheep · Egypt

Introduction

Ovine coccidiosis can be a serious disease with economic consequences (Chartiera and Paraud 2012). Sheep are infected with 1 or more *Eimeria* spp; of them, *E. ovinoidalis* and *E. crandallis* are the most pathogenic species (Gregory et al. 1989). Until 3 decades ago, *Eimeria* spp. in sheep and goats were considered common. Cross transmission trials revealed that *Eimeria* in sheep and goats are species specific (McDougald 1979).

In Egypt, the estimated sheep population is 5.5 million (FAO 2015); 25% of them are reared in the Nile Delta region (Thomson et al. 2000). However, no reports on sheep coccidiosis from Dakahlia governorate, the largest agricultural governorate in the Delta region, are available. Additionally, Chartiera and Paraud (2012) reviewed different epidemiological, clinical and control aspects of small ruminants' coccidiosis; however, no data on the prevalence or the revealed *Eimeria* species worldwide were included.

Here, we aimed to determine the prevalence of different *Eimeria* spp. in sheep from Dakahlia governorate, Egypt, and to review reports concerned with the prevalence of this common parasite in sheep worldwide.

Materials and methods

Fresh feces collected from 184 sheep of various ages and genders during August 2015 to July 2016, were tested for oocysts of *Eimeria* spp. using the standard flotation technique (Duszynski and Wilber 1997). Sheep in this region are raised in small flocks (4–15 animals/flock) kept in households in rural areas of Dakahlia governorate (31° 50′ N, 31° 00′ E), Egypt. Flocks are reared in a nomadic

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Table 1 Prevalence of different *Eimeria* spp. in feces of 184 examined sheep from Dakahlia governorate, Egypt

Eimeria species	No. positive (%)	Single infection	Mixed infection
		No. positive (%)	No. positive (%)
E. ahsata	26 (14.1)	1 (0.8)	25 (19.8)
E. bakuensis	62 (33.7)	9 (7.1)	53 (42.1)
E. crandallis/E. webybridgensis	74 (40.2)	19 (15.1)	55 (43.6)
E. faurei	12 (6.5)	0.0	12 (9.5)
E. granulosa	27 (14.6)	3 (2.4)	24 (19.1)
E. ovinoidalis	27 (14.6)	1 (0.8)	26 (20.6)
E. intricata	17 (9.2)	0.0	17 (13.5)
E. marsica	5 (2.7)	0.0	5 (3.9)
E. pallida	14 (7.6)	1 (0.8)	13 (10.3)
E. parva	21 (11.4)	0.0	21 (16.6)
Total	126 (68.4)	34 (26.9)	92 (73.0)

pastoralism system where animals move within the agricultural lands and graze on residues of the harvested crops. Mixing of flocks from different households during grazing is common. Flocks are not treated with any anticoccidial. Sheep were divided into 3 age groups; young (< 1 year old), yearlings (1–2 years) and adults (> 2 years). *Eimeria* oocysts from positive samples were sporulated at room temperature using 2.5% potassium dichromate. Morphological observations and micrographs of sporulated and non-sporulated oocysts were performed using a binocular microscope coupled to Amscope® camera (Carl Zeiss, Oberkochen, Germany); oocysts' sizes were measured using a calibrated ocular micrometer. Different *Eimeria* spp. were identified per Eckert et al. (1995). Results were statistically analyzed using a chi-square test. The 95% confidence intervals of a proportion including continuity correction and odds ratios were calculated using www.vassarstats.net.

Results

Eimeria spp. oocysts were detected in 126 (68.4%) of 184 feces. The prevalence varied with age; the highest prevalence was in young sheep (59/63; 93.6%) followed by yearlings (37/53; 69.8%; OR = 6.38; $P = 0.00071$) and at least in adults (30/68; 44.1%; OR = 18.68; $P \leq 0.0001$). Prevalence was higher in females (97/135; 71.8%) than males (29/49; 59.1%; OR = 1.76; $P = 0.102$). The highest prevalence was in Autumn (26/33; 78.7%) followed by Spring (22/39; 56.4%; OR = 2.87; $P = 045$), Summer (23/34; 67.6%; OR = 1.78; $P = 0.303$), and Winter (55/78; 70.5%; OR = 1.55; $P = 0.37$).

Eleven *Eimeria* spp. were identified; of them, *E. crandallis/E. webybridgensis* (40.2%) and *E. bakuensis* (33.7%) were the most prevalent. *Eimeria ovinoidalis* were detected in 14.6% (27/184). The other identified species were *E. granulosa*, *E. ahsata*, *E. parva*, *E. intricata*, *E. pallida*, *E. faurei* and *E. marsica*. Mixed infections (73.0%: dual 31.7%, triple 30.1%, quadruple 10.3% and quintuple 0.8%) were common than single infections (26.9%), Table 1.

Morphological characteristics of different *Eimeria* spp. oocysts revealed in the present study (Fig. 1) were like the description of these species in literature (Norton et al. 1974; Eckert et al. 1995).

Discussion

The present study is the first report of different *Eimeria* spp. in sheep from Dakahlia governorate, Egypt; 126 (68.4%) of 184 were infected. Earlier reports from other Egyptian governorates together with the worldwide reports are summarized in Table 2.

Eleven *Eimeria* spp. were detected in the present study: *E. ahsata*, *E. bakuensis*, *E. crandallis*, *E. faurei*, *E. granulosa*, *E. intricata*, *E. marsica*, *E. ovinoidalis*, *E. pallida*, *E. parva and E. webybridgensis*. These species were previously reported in sheep from Egypt (Ghanem and Abd El-Raof 2005; Abou-El-Naga 2010; Mohamaden et al. 2018); however, this is the first report of *E. weybridgensis* in sheep from Egypt, probably due to close similarity of their oocysts to those of *E. crandallis* (Norton et al. 1974). Oocysts of both species are similar shape and size. Sporocysts morphology is variable (broad ovoid 10–12 × 7–8 µm in *E. crandallis* and elongate ovoid 14–15 × 7–8 µm in *E. weybridgensis*), but not enough to

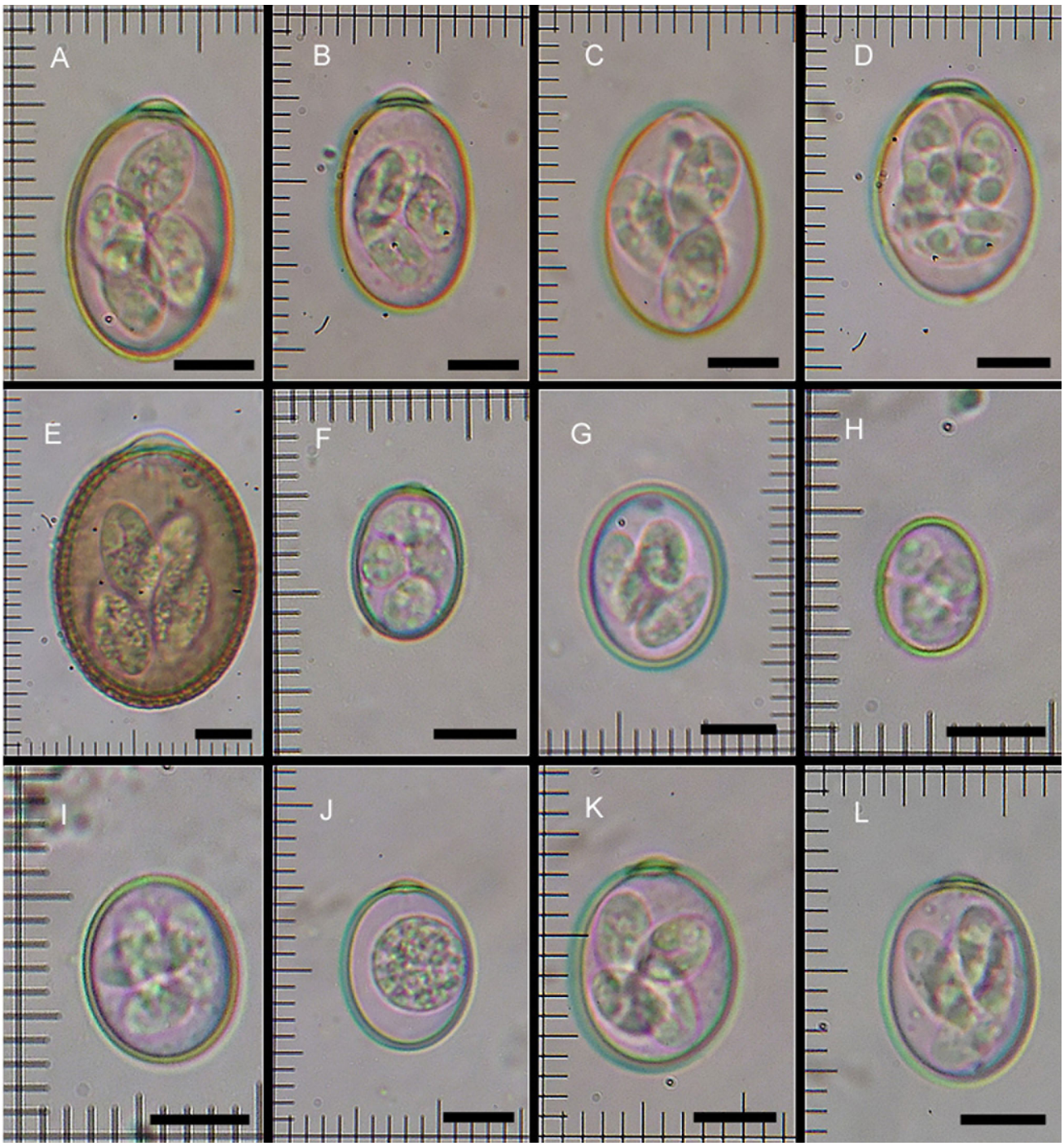

Fig. 1 Oocysts of *Eimeria* spp. in feces of sheep from Dakahlia governorate, Egypt. From **a** to **i**: Sporulated oocysts of *E. ahsata* (**a**), *E. bakuensis* (**b**), *E. faurei* (**c**), *E. granulosa* (**d**), *E. intricata* (**e**), *E. marsica* (**f**), *E. ovinoidalis* (**g**), *E. pallida* (**h**), *E. parva* (**i**). Non-sporulated oocyst of *E. crandallis/E. webybridgensis* (**j**). Sporulated oocyst of *E. crandallis* (**k**). Sporulated oocyst of *E. webybridgensis* (**l**). Unstained. Scale bars = 10 μm

easily distinguish both species (Fig. 1). Thus, both species were grouped together in our results.

In the present study, oocysts of the most pathogenic species in sheep (*E. ovinoidalis*) were detected in 14.6% (27/184) and all sheep were subclinical. Earlier in Egypt, subclinical *E. ovinoidalis* infections were also reported in 12.2% of 142 sheep from Suez governorate (Mohamaden et al. 2018). However, *E. ovinoidalis* and *E. crandallis* were detected in 13 lambs with bloody diarrhea in Kalubiya governorate (Ghanem and Abd El-Raof 2005), and

Table 2 Prevalence of *Eimeria* species in sheep worldwide

Country/region	Age range	No. examined	No. positive (%)	No. of *Eimeria* spp.	*Eimeria* species and remarks	References
Australia						
South regions	3–13 months	136	109 (80.0)	11	E. ahs 31%, E. bak 55%, E. cran/E, weyb 76%, E. fau 24%, E. intr 37%, E. gran 49%, E. ovin 54%, E. par/E, pal 44%, E. pun 1%	O'Callaghan et al. (1987)
Different	Variable	3412	616 (18.1)	5	118 positive samples were genotyped (PCR/Sequencing) E. ahs 28%, E. cran 48.3%, E. ovin 10.1%, E. weyb 10.1%, ***E. cylindrica*** 4.2% No mixed infection	Yang et al. (2014)
Austria						
Styria	Ewes, lambs	60, 126	NS	8	E. ahs 19.1%, E. bak 18.4%, E. cran/E. weyb 27.3%, E. fau 4.8%, E. gran 1.0%, E. ovin 28.3%, E. pal 10.9%, E. par 14.0% in adults Lambs were infected with same species except E. gran	Platzer et al. (2005)
Bangladesh						
Different region	NS	136	42 (30.8)	NS	NS	Islam and Taimur (2008)
Brazil						
Sao Paolo	2–32 weeks	25	NS	8	E. ahs, E. bak, E. cran, E. intr, E. ovin, E. pal, E. par, E. weyb	Amarante and Barbosa (1992)
Sobral, Ceara	Lambs, dams	30,10	NS	9	E. ahs, E. bak, ***E. caprovina***, E. cran, E. fau, E. gran, E. intr, E. ovin, E. par	Vieira et al. (1999)
Mostardas	NS	100	59 (59.0)	9	E. ahs 23.72%, E. bak 6.77%, E. cran 5.08%, E. fau 1.69%, E. gran 20.33%, E. ovin 11.86%, E. pal 1.69%, E. par 37.28%, E. pun 23.72%	da Silva et al. (2008)
Rio Grande do Norte	1–90 days	27	17–100%	8	E. ahs 43.3%, E. bak 43.3%, E. cran 65.7%, E. fau 29.0%, E. gran 53.7%, E. intr 3%, E. ovin 48.8%, E. par 54.7%	Silva et al. (2011)
Santa Ines	NS	100	63 (63.0)	6	***E. arloingi*** 6%, E. Fau 38%, E. intr 4%, ***E. ninakohlyakimovae*** 32%, E. pal 2%, E. par 12%,	Martins et al. (2011)
Lajes	4–8 months	64	36 (56.2)	NS	NS	Souza et al. (2012)
Colinas	Lambs, adults	255	50 (19,6)	8	E. ahs, E. bak, E. cran, E. fau, E. Intr, E. ovin, E. pal, E. par	Almeida (2013)

Table 2 continued

Country/region	Age range	No. examined	No. positive (%)	No. of *Eimeria* spp.	*Eimeria* species and remarks	References
Parana	1–8 months	210	147 (70.0)	9	E. ahs 8.1%, E. bak[a] 0.6%, E. cran 50%, E. fau 8.1%, E. gran 2.7%, E. intr 5.4%, **E. ovina**[a] 1.3%, E. ovin 2%, E. par 21.6%	Lopes et al. (2013)
Garanhuns	12 months	408	270 (66.1)	8	E. ahs 51.8%, E. bak 54.8%, E. cran 58.9%, E. fau 22.9%, E. gran 56.3%, E. ovin 72.6%, E. pal 14.4%, E. par 64.8%,	de Macedo et al. (2019)
Canada						
Alberta	NS	211	211 (100.0)	10	E. ahs 86%, ***E. arloingi*** 82%, E. cran 88%, E. fau 52%, E. gran 7%, E. intr 14%, ***E. ninakohlyakimovae*** 69%, E. pal 6%, E. par 53%, E. pun 4%	Mahrt (1969)
Western region	NS	510	461 (90.0)	8	E. ahs 33%, E. bak 56%, E. cran 34%, E. fau 6%, E. gran 1%, E intr 5%, **E. ninakohlyakimovae** 19%, E. par 35%	Uhazy et al. (1971)
Croatia						
North Dalmatia	Lambs	49	37 (75.5)	9	E. bak, E. cran, E. fau, E. gran, E. intr, E. mar, E. ovin, E. pal, E. par	Šarić et al. (2015)
China						Wang et al. (2010)
Heilongjiang	Adults, lambs	309	287 (92.9)	8	E. ahs 67.2%, E. bak 44.3%, E. cran 11.2%, E. fau 17.1%, E. gran 12.9%, E. intr 12.5%, E. pal 3.8%,E. par 59.9%	
Columbia						
Tennessee	15 months	23	9 (39.0)	5	E. ahs, E. bak, E. fau, E. gilruthi, E. ovin	Ammar et al. (2019)
Encino, Duitama, and Belen	< 12 to > 24 months	97	30 (30.9)	NS	NS	León et al. (2019)
Czech Republic						
Sokolov	Ewes	348	188 (54.0)	4	E. cran/weyb, E. intr, E. ovin, E. par	Kyriánová et al. (2017)
	Lambs	333	252 (75.7)		E. ovin was the most prevalent (84% in ewes and 85% in lambs)	
Egypt						
Kalubia	6–9 months	18	13 (72.2)	2	E. cran, E. ovin. 13 lambs had bloody diarrhea	Ghanem and Abd El-Raof (2005)
Sinai	Different	240	16 (6.7)	NS	NS	Abouzeid et al. (2010)
Matrouh	1–60 days	185	98 (52.9)	9	E. ahs 14.6%, E. bak 21.1%, E. cran 49.2%, E. fau 14.1%, E. gran 11.3%, E. intr 8.4%, E. mar 4.8%, E. ovin 36.7%, E. par 30.2%	Abou-El-Naga (2010)

Table 2 continued

Country/region	Age range	No. examined	No. positive (%)	No. of *Eimeria* spp.	*Eimeria* species and remarks	References
Kafrelsheikh	NS	224	37 (16.5)	NS	NS	Sultan et al. (2016)
Suez	> 6 months	142	82 (57.7)	10	E. ahs 30.5%, ***E. arloingi***, E. bak 26.8%, E. cran 30.5%, E. fau 18.3%, E. gran 14.6%, E. intr 7.3%, E. ovin 12.2%, E. pal 13.4%, E. par 18.3%	Mohamaden et al. (2018)
Dakahlia	Different	184	126 (68.4)	11	E. ahs 14.1%, E. bak 33.7%, E. cran/E. weyb 40.2%, E. fau 6.5%, E. gran 14.6%, E. intr 9.2%, E. mar 2.7%, E. ovin 14.6%, E. pal 7.6%, E. par 11.4%	Present study
Estonia						
Vormsi, Hiiumaa, and Saaremaa	NS	92 herds	87 (94.6)	11	E. ahs 23%, E. bak 50.6%, E. cran 14.9%, E. faur 28.7%, E. gran 26.4%, E. intr 4.6%, E. pal 31.0%, E. par 37.9%, E. mar 2.3%, E. ovin 93.1%, E. weyb 33.3%	Lassen et al. (2013)
Ethiopia						
Elfora export abattoir	< 1 to 2 years	262	175 (66.8)	12	The most prevalent species were E. cran 30%, E. pal 13.8%, E. par 30.8%,	Ayana et al. (2009)
Bishoftu (Oromia)	< 1 to > 1 years	157	78 (49.7)	NS	NS	Bersissa et al. (2011)
Gechi District	< 2 to > 2 years	255	31 (12.2)	NS	NS	Emiru et al. (2013)
Gemechis and Boke Districts	Different	384	121 (31.5)	NS	NS	Daniel et al. (2014)
Germany						
Northwest regions	Different	69	100% in < 10 wk	10	E. ahs, E. bak, E. cran /weyb, E. fau, E. gran, E. intr, E. ovin, E. pal, E. par	Barutzki et al. (1990)
All regions	NS	374	155 (41.4)	NS	NS	Raue et al. (2017)
Ghana						
Ayeduase	Different	110	57 (51.8)	NS	Lambs had higher prevalence (87.5%)	Owusu et al. (2016)
Coastal Savannah	Different	502	387 (77.1)	NS	Result from sheep and goats are combined together	Squire et al. (2019)
Iceland						
Fjárborgir	Lambs	NS	NS	10	E. ahs, E. bak, E. cran, E. fau, E. gran, E. intr, E. ovin, E. pal, E. par, E. weyb	Reginsson and Richter (1997)
Fossárdalur	Ewes and lambs	NS	NS	10	E. ahs 5.6%, E. bak 18.9%, E. cran 1.4%, E. fau 4.2%, E. gran 8.2%, E. intr 1.6%, E. ovin 40.7%, E. pal 1.6%, E. par 6.7%, E. weyb 11.1%	Skirnisson (2007)

Table 2 continued

Country/region	Age range	No. examined	No. positive (%)	No. of *Eimeria* spp.	*Eimeria* species and remarks	References
Iran						
Tabriz	< 6 months to > 1 years	240	40 (16.7)	6	E. ahs 8%, E. bak 18%, E. fau 18%, E. par 13%, E. pal 8%, E. intr 35%	Yakhchali and Zarei (2008)
Sanandaj	Different	240	46 (19.2)	6	E. ahs 10%, E. bak 10%, E. fau 29%, E. intr 10%, E. ovin 31%, E. par 10%	Yakhchali and Golami (2008)
Malayer	Different	250	40 (16.67)	7	E. ahs 6%, E. bak 16%, E. fau 16%, E. intr 39%, E. ovin 4%, E. pal 7%, E. par 12%	Yakhchali and Rezaei (2010)
Kabodan	NS	41	33 (80.4)	4	E. ahs 6.5%, E. fau 6.5%, E. ovin 9.7%, E. par 32.3%. wild sheep	Tavassoli and Khoshvaghti (2010)
Kermanshah and Ilam	Adult, lambs	410	375 (91.5)	10	E. ahs 81.8%, E. bak 56.2%, E. cran 33.06%, E. fau 24.8%, E. gran 2.93%, E. intr 15.2%, E. ovin 41.6%, E. pal 58.4%, E. par 67.4%, E. weyb 5.06%,	Hashemnia et al. (2014)
Rudsar	Different	270	170 (63.0)	5	E. ahs, E. bak, E. cran, E. ovin, E. par	Nourollahi-Fard et al. (2016)
Zabol	Different	420	84 (20.0)	6	E. ahs 8.3%, E. intr 0.9%, E.ovin 3.5%, E. pal 2.8%, E. par 7.3%, E. weyb 2.1%,	Mirzaei et al. (2016)
India						
Karnataka	NS	300	120 (40.0)	NS	NS	Mamatha and D'Souza (2007)
Mathura	Different	596	208 (34.9)	5	E. bak 27.6%, E. fau 11.24%, E. intr 0.11%, E. ovin 11.1%, E. par 15.4%,	Om et al. (2010)
Rajasthan	NS	3964	2010 (50.7)	NS	NS	Swarnkar et al. (2010)
Maharashtra	NS	2462	594 (24.1)	10	***E. ajantai 5.7%,*** E. ahs 9.2%, E. bak 6.9%, ***E. balloonii 4.3%, E. beedatus 3.7%,*** E. cran 18.2%, E. intr 10.2%, ***E. ninakohlyakimovae*** 12.6%, E. par 15.1%, E. weyb 13.8%	More et al. (2011)
Kashmir	12–89 months	500	49 (9.8)	NS	NS	Bhat et al. (2012)
Andhra Pradesh	NS	150	7 (4.6)	2	E. granulose, E. parva	Murthy and Rao (2014)
Omerga	NS	127	92 (72.4)	NS	NS	Sontakke et al. (2015)
Karnataka	6–9 months	47	42 (89.3)	8	E. ahs, ***E. arloingi***, E. bak, E. fau, E. gran, E. intr, E. ovin, E. par. Outbreak with bloody diarrhea and mortalities in lambs	Adeppa et al. (2016)
Jalpaiguri	< 1 to > 3 years	1350	431 (31.9)	NS	NS	Molla and Bandyopadhyay (2016)

Table 2 continued

Country/region	Age range	No. examined	No. positive (%)	No. of *Eimeria* spp.	*Eimeria* species and remarks	References
Iraq						
Baghdad	NS	306	230 (75.1)	9	E. bak, E.cran, E.fau, E. gran, E. mar, E. ovin, E. pal, E. par, E. weyb	Fadl et al. (2011)
Mosul	Different	500	318 (63.6)	9	E. ahs 65.4%, E. bak 86.7%, E. cran 30.5%, E. fau 19.8%, E. gran10%, E. intr 11%, E. ovin 73.5%, E. pal 38.9%, E. par 56.6%	Hasan and Abed (2012)
Baghdad	NS	280	195 (69.6)	NS	E. bak (18.4%) was the highest and the lowest was ***E. arloingi*** (1.5%)	Kalef et al. (2013)
Diyala	Different	143	124 (86.7)	8	E. ahs 22.6%, E. cran 18.8%, E. fau 3.77%, E. gran 16.1%, E. intr 8.5%, E. ovin 6.6%, E. pal 10.3%, E. par 13.2%	Minnat (2014)
Sulaimaniya	Different	150	108 (72.0)	11	E. ahs 23.1%, E. bak 33.3%, E. cran 25%, E. fau 23.1%, E. gran 14.81%, E. intr 32.4%, E. mar 25.9%, E. ovin 35.2%, E. pal 50.9%, E. par 53.7%, E. weyb 26.8%,	Kareem and Yücel (2015)
Wasite	NS	120	69 (57.5)	10	E. ahs 22.5%, E. bak 20%, E. cran 11.6%, E. fau 12.5%, E. gran 3.3%, E. intr 21.6%, E. ovin 15%, E.pal 7.5%, E.par 18.3%. E.weyb 2.5%	Al-Rubaie and Al-Saadoon (2018)
Wasite	0–36 months	120	60 (50.0)	7	E. ahs 7.5%, E.bak 24.1%, E. cran 9.1%, E. intr 0.8%, E. ovin 18.3%, E.par 20.8%, E. weyb 5.8%	Al-Saadoon and Al-Rubaie (2018)
Kirkuk	< 1 to > 2 years	160	23 (27)	8	E. bak 26%, E. cran 21.7%, E. fau 39%, E. gran 56.5%, E. intr 56.5%, E. ovin 60.8%, E.pal 73.9%, E. par 47.8%	Al-Robaiee et al. (2019)
Italy						
Rome	–	20	–	5	E. ahs, E. bak, E. intr, E. ovin, E. parva	Battelli and Poglayen (1980)
Jordan						
Sekhra	Ewes	61	39 (63.4)	NS	NS	Jawasreh et al. (2013)
Kenya						
Different districts	< 1 to > 1 years	50	NS	10	E. ahs, E. bak 43%, E. cran, E. fau, E. gran, E. intr, E. ovin 16.5%, E. pal, E. par	Kanyari (1993)
Nyandarua	Different	575	253 (44.0)	8	E. ahs 15.2%, E. bak 43.6%, E. fau 2.8%, E. gran 4.8%, E. intr 8.27%, E. ovin 23.6%, E. pal 0.67%, E. par 1.06%	Maingi and Munyua (1994)
Kuwait	Different	17	3 (17.5)	3	E. bak, E. cran, E. ovin	Majeed et al. (2015)

Table 2 continued

Country/region	Age range	No. examined	No. positive (%)	No. of *Eimeria* spp.	*Eimeria* species and remarks	References
Malaysia						
Perak	NS	175	162 (92.5)	NS	NS. 175 animals were examined including 150 goats and 25 sheep	Zainalabidin et al. (2015)
Mexico						
Huixquilucan	Ewes, lambs	62	NS	9	E. ahs, E. bak, E. cran, E. fau, E. gran, E. intr, E. ovin, E. pal, E. par	Gonzalez et al. (1990)
Southeast region I	2 months to 2 years	412	NS	11	E. ahs, E. bak, E. cran, E. fau, E. gran, E. intr, E. mar, E. ovin, E. pal, E. par, E. weyb	Trejo-Huitrón et al. (2020)
Nigeria						
Ibadan	NS	1040	832 (80.0)	7	***E. arloingi*** 10%, E. fau 31%, E. gran 3%, E. intr 6%, ***E. Ninakohlyakimovae 22%,*** E. pal 19%, E. par 8%	Majaro and Dipeolu (1981)
Gwagwalada	Adult, young	44	1 (2.3)	1	E. fau	Jegede et al. (2015)
Sri Lanka						
Jaffna	Adults, lambs	100	76 (76.0)	4	E. bak, E. intr, E. ovin, E. par	Kandasamy et al. (2011)
Sudan						
Khartoum	Adult, lambs	NS	58.8%	11	E. ahs 42%, E. bak 60%, E. cran 33%, E. fau 28.9%, E. gran 7.7%, E. intr 9.7%, E. mar 12.7%, E. ovin 47%, E. pal 11%, E. par 27%, E. pun 0.9%	Elamin et al. (2004)
Pakistan						
Punjab	More or less than 6 months	486	209 (43.0)	5	E. ahs 45.4%, E. fau 19.1%, E. intr 28.7%, E. ovin 48.3%, E. par 24.4%	Khan et al. (2011)
Papua New Guinea						
University farms	< 1 to > 3 years	75	67 (89.0)	8	E. ahs 45%, E. bak 72%, E. cran 39%, E. fau 28%, E. intr 24%, E. gran 4%, E. ovin 48%, E. par 58%	Varghese and Yayabu (1985)
Different regions	NS	110	19 (17.3)	NS	NS	Koinari et al. (2013)
Poland						
Various regions	Adult	400	136 (34.1)	NS	NS	Gorski et al. (2004)
Western Pomerania	NS	20	20 (100)	NS	NS	Juszczak et al. (2019)
Saudi Arabia						
Jeddah	Different	100	41 (41.0)	4	**E. arloingi 22%**, E. bak 17.1%, E. intr 26.8%, E. par 31.7%	Toulah (2007)
Al-Baha	Different	487	227 (46.6)	8	E. ahs 12.3%, E. bak 27.9%, E. cran 29.8%, E. fau 7.6%, E. intr 9.9%, E. pal 2.9%, E. par 4.7%, E. weyb 23.4%,	Ibrahim and Afsa (2013)

Table 2 continued

Country/region	Age range	No. examined	No. positive (%)	No. of *Eimeria* spp.	*Eimeria* species and remarks	References
Scotland						
Hirta, St Kilda	Lambs, adults	Different	Different	11	E. ahs 27. 5%, E. bak 33.7%, E. cran 22.1%, E. fau 24%, E. gran 13.3%, E. intr 28.2%, E. mar 19.8%, E. ovin 19.8%, E. pal 9.5%, E. par 27.1%, E. weyb 18.7%	Craig et al. (2007)
Senegal						
Sahelian zone	6 months-4 years	2234	2204 (94.0)	8	E. ahs 28%, E. bak 69.6%, E. cran 62%, E. fau 23%, E. intr 15%, E. ovin 75.6%, E. pal 18%, E. par 25%	Vercruysse (1982)
Slovakia						
Various regions	Adults, lambs	445	445 (100.0)	5	E. par (in lambs 42%, in adults 37%), E. bak, E. cran, E. fau, E. ovin 2% of oocysts in lambs and 5% in adults could not be identified	Vasilková et al. (2004)
South Africa						
North-West	< 1 year	NS	NS	6	E. ahs 40%, E. bak 100%, E. cran 100%, E. intr 20%, E. ovin 20%, E. weyb 60%	Bakunzi et al. (2010)
Spain						
Galicia	Different	1882	1393 (74.0)	9	E. ahs 71%, E. bak 59%, E. cran/E. weyb 64%, E. fau 59%, %, E. gran 18%, E. intr 15%, E. mar 3%, E. ovin 74%, E. par 36%	Díaz et al. (2010)
Cartagena	< 1 to > 1 year	396	396 (100.0)	11	E. ahs 75.8%, E. bak 48.5%, E. cran 89.4%, E. fau 62.1%, E. gran 74.2%, E. intr 18.2%, E. mar 43.9%, E. ovin 97%, E. par/E.pal 97%, E. weyb 90.9%	Carrau et al. (2018)
Tanzania						
Vingunguti	< 2 years	43	40 (93.0)	7	E. ahs 21%, E. bak 29%, E. cran 96%, E. fau 29%, E. gran 8%, E. ovin 29%, E. par 92%	Kusiluka et al. (1996)
Morogoro	> 1 year	121	118 (97.5)	NS	NS	Kambarage et al. (1996)
Turkey						
Elaziğ	2–4 months	155	147 (94.8)	9	E. ahs, E. bak, E. cran, ***E. ninakohlyakimovae***, E. fau, E. gran, E. intr, E. pal, E. par,	Güler et al. (1990)
Different regions	NS	444	434 (97.7)	9	E. ahs, 29.9%, E. bak 39.4%., E. cran 3.9%, E. fau 1.1%, E. gran 41.9%, E. intr 19.3, ***E. ninakohlyakimovae*** 16.3%, E. pal 0.4%, E. par 6.6%	Demir (1995)

Table 2 continued

Country/region	Age range	No. examined	No. positive (%)	No. of *Eimeria* spp.	*Eimeria* species and remarks	References
Kars	Different	592	556 (93.9)	10	E. ahs 23.4%, E. bak 46.6%, E. cran 13.7%, E. fau 15.1%, E. gran 27.7%, E. intr 13.9%, E. ovin 47.7%, E. pal 23.2%, E. par 37.1%, E. pun 2.3%	Arslan et al. (1999)
Van	NS	350	349 (99.9)	9	E. ahs 39.4%, E. bak 39.1%, E. cran 38.8%, E. fau 15.4%, E. gran 16.5%, E. intr 11.4%, E. ovin 43.1%, E. pal 33.1%, E. par 46.5%	Gül and Değer (2002)
Antakya	Lambs	248	248 (100.0)	10	E. ahs 11.3%, E. bak 38.7%, E. cran 64.9%, E. fau 11.3%, E. intr 9.3%, E. mar 16.9%, E. ovin 55.2%, E. pal 3.6%, E. par 13.3%, E. weyb 30.2%	Kaya (2004)
Bitlis	NS	241	215 (89.2)	9	E. ahs 46.1%, E. bak 49.4%, E. cran 35.2%, E. fau 10.7%, E. gran 12.8%, E. intr 8.7%, E. ovin 43.5%, E. pal 30.3%, E. par 45.6%,	Gül (2007)
Van	1–60 days	132	80 (60.6)	NS	NS	Ozdal et al. (2009)
USA						
Alabama	Lambs	NS	NS	2	E. ahs, E. cran	Smith and Davis (1961)
Illinois	NS	153	105 (69.0)	10	***E. arloingi 53%,*** E. ahs 24%, E. cran 24%, E. fau 6%, E. gran 4%, E. intr 7%, ***E. ninakohlyakimovae*** 1%, E. pal 6%, E. par 5%, E. pun 1%	Shah (1963)
Louisiana	ewes	109	94 (86.2)	10	E. ahs 41.3%, E. bak 48.6%, E. cran 36.7%, E. fau 43.1%, E. gran 28.4%, E. intr 17.4%, E. ovin 59.6%, E. pal 4.6%, E. par 45.9%, E. pun 1.8%	da Silva and Miller (1991)
Wales	NS	60	57 (95.0)	9	E. ahs, ***E. arloingi***, ***E. ninaekohlyakimovae***, E. cran were the most common	Michael and Probert (1970)
England and Wales	NS	639	NS	11	E ahs 42.1%, E bak 81.7%, E cran 71.4%, E fau 57.7%, E gran 1.7%, E intr 14.9%, E mar 14.2%,E ovin 64.8%, E pal 13.9%, E par 59.5%, E weyb 43.8%,	Macrelli et al. (2019)

Table 2 continued

Country/region	Age range	No. examined	No. positive (%)	No. of *Eimeria* spp.	*Eimeria* species and remarks	References
Zimbabwe						
Harare	–	497	414 (83.3)	11	E. ahs 91%, E. bak 95%, ***E. caprovina*** 26.2%, ***E. christenseni*** 12.3%, E. cran 69.7%, E. fau 61.4%, E. gran 53.2%, E. intr 23.8%, E. ovin 100%, E. pal 24.6%, E. par 98.3%	Chhabra and Pandey (1992)

E. ahs, *E. ahsata*; E. bak, *E. bakuensis*; E. cran, *E. crandallis*; E. fau, *E. faurei*; E. gran, *E. granulosa*; E. intr, *E. intricata*; E. mar, *E. marsica*; E. ovin, *E. ovinoidalis*; E. pal, *E. pallida*; E. par, *E. parva*; E. pun, *E. punctata*; E. weyb, *E. weybridgensis*; NS, not stated. All *E. ovina* recorded in the table as *E. bakuensis*

Bold species are considered invalid

[a]Both are same species but recorded with different infection rates

respectively in 68 and 91 of 185 lambs suffered from diarrhea in Matrouh governorate (Abou-El-Naga 2010).

There is a debate concerning the validity of species of *Eimeria* in sheep because the endogenous stages are known only in a few of them. Some authors consider 15 *Eimeria* species in sheep as valid (Kaufmann 1996). Of them, 13 were reported worldwide: *E. ahsata*, *E. bakuensis*, *E. crandallis*, *E. faurei*, *Eimeria gilruthi*, *E. granulosa*, *E. intricata*, *E. marsica*, *E. ovinoidalis*, *E. pallida*, *E. parva*, *Eimeria punctata* and *E. weybridgensis*. In addition to *Eimeria gonzalezi* (Bazalar and Guerrero 1970) in sheep from South America and *Eimeria dalli* in Dall sheep (*Ovis dalli*) from Alaska, USA (Clark and Colwell 1974). Other species are considered invalid because of inadequate description or lack of archived specimens, for example *Eimeria ajantai*, *Eimeria balloonii* and *Eimeria beedatus* in sheep from India (More et al. 2011). *Eimeria macusaniensis* (camelid species) was reported in 2 sheep herds from Argentina grazed with guanaco (a closely related species to lama) on the same pasture (Vázquez et al. 2014), notable in this report, the oocyst per gram (OPG) in sheep was low (1420) in one herd; however, it exceeds 29,000 OPG in the other herd. Enteric developmental stages of *E. macusaniensis* were not investigated in intestinal samples of sheep. Furthermore, *E. cylindrica* (bovine species) infection was molecularly identified in sheep from Australia (Yang et al. 2014).

Global reports on *Eimeria* species infecting sheep indicating high parasite diversity in small or large scale surveys even at the level of small size populations, which revolutionize our understanding of this parasite. Subsequently, more studies are needed to clarify the transmission dynamics depending on the multilocus genetic analysis of different *Eimeria* species infecting sheep and other ruminant animals.

Acknowledgements This study was conducted as a part of the master of the first author, and did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. We thank Dr. Ragab Fereig (South Valley University) for helping in statistical analysis.

Author's contribution IA, YA, MA and SA designed and coordinated the study and shared in parasite identification. EE collected and examined samples. JPD, IA and EE collected and analyzed the data, wrote and revised the manuscript.

Data availability All data generated or analyzed during this study are included in this manuscript.

Compliance with ethical standards

Conflict of interest The authors declare that there is no conflict of interest.

Ethical statement All applicable international, national, and/or institutional guidelines for the care and use of animals were followed. Written informed consents were taken from owners of the sheep involved in this study prior to collection of samples.

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