



Supplementary Fig. 1. DNA sequence comparison of COI gene (A), ITS region (B) and beta-tubulin gene (C) between *H. schachtii* and *H. trifolii* and their primer positions. Primer positions for COI and ITS amplification of *H. schachtii* and *H. trifolii* are presented by blue and red arrow, respectively, while those for beta-tubulin amplification of the two species are indicated by green arrows. Genbank accession number of each gene is shown in blank. Detailed information of primers is available in Supplementary Table 1.

Supplementary Table 1. Information of primer set for molecular identification of *Heterodera* spp

Purpose	Gene	Species [Genbank Access no.]	Name of Primer	Sequence (5'→3')	bp	Tm (°C)	Product size
Species specific amplifica- tion	COI	<i>H. schachtii</i> [LC208708]	Hsch_COI_F	TCAGTATTGGTTTTATTGGTTGTTTAG	27	60.8	240 bp
			Hsch_COI_R	TGCGTACTGAGAATTAACCCTC	23	60.9	
	<i>H. trifolii</i> [KT163239]	Htrifol_COI_F	ATTAGAATTGGTTTTATTGGCTGTTTG	27	60.8	240 bp	
		Htrifol_COI_R	AGCGTACTAAGGATTAAGCCAC	23	60.9		
	ITS	<i>H. schachtii</i> [EU616693]	Hsch_ITS_F	GCTGCCCTGTTGGGCTAG	18	60.8	375 bp
			Hsch_ITS_R	ACGTACGACCGGAACGAAA	20	60.5	
<i>H. trifolii</i> [LC030416]	Htrifol_ITS_F	GCTGTCCTGTTGGGCGAG	18	60.8	374 bp		
	Htrifol_ITS_R	CGTAAGACTGGGAACGACAC	20	60.5			
Beta- tubulin	<i>H. schachtii</i> [AY689388]	Hetero_β-tubul_F	GACAATGTCCGGAGTGACGA	20	60.5	177 bp	
		<i>H. trifolii</i> [AY689379]	Hetero_β-tubul_R	GTCAGTTCTGCCACGGAACA	20	60.5	
Sequenc- ing	COI	<i>H. schachtii</i> [KY775592]	JB3	TTTTTTGGGCATCTGAGGTTTAT	24	57.6	448 bp
		<i>H. trifolii</i> [MG682348]	JB5	AGCACCTAAACTTAAACATAATGAAAATG	30	58.6	
	ITS	<i>H. schachtii</i> [MF043911]	TW81	GTTTCCGTAGGTGAACCTGC	20	59.3	1025 bp
		<i>H. trifolii</i> [MG682350]	AB28	ATATGCTTAAGTTCAGCGGGT	21	55.9	

bp = length of primers (base pairs), Tm = Melting temperature of primers.

Supplementary Table 2. Comparative morphometrics of *H. trifolii* infective juvenile populations from different countries

Character	Korea (YS503)	Italy ¹	Sweden ²	Netherlands ³	Germany ⁴	USA ⁵	Canada ⁶
L	601.9 ± 20.6 (561.9-630.8)	583.9 ± 28.6 (525.1-671.6)	607 ± 19.6 (560-648)	547.1 ± 7.5 (493.2-628.4)	624 ± 21.9	497 (443-547)	510 (490-530)
Max body width	22.6 ± 0.9 (21.3-23.7)	22.2 ± 1.4 (16.9-24.2)			20.3 ± 0.6		
Anal body width	15.9 ± 0.7 (14.8-16.9)	14.8 ± 1.1 (13.3-16.9)		14.1 ± 0.2 (12.8-14.9)			
Stylet length (ST)	26.3 ± 1.0 (25.3-27.6)	29.6 ± 1.1 (25.5-30.9)	30.5 ± 0.9 (28.8-32.0)		30.2 ± 0.5	27.5 (25.5-29.5)	27 (25-29)
Stylet knob height	3.7 ± 0.4 (3.2-4.7)	3.6 ± 0.3 (3.0-4.8)	4.6 ± 0.38 (3.8-5.2)				
Stylet knob width	7.0 ± 0.5 (6.3-7.5)	6.9 ± 0.4 (6.1-7.3)	5.9 ± 0.27 (5.2-6.6)				
Lip height	4.7 ± 0.5 (4.0-5.4)	5.7 ± 0.6 (4.2-6.1)	5.7 ± 0.3 (5.2-6.4)				
Lip width	10.7 ± 0.5 (9.9-11.8)	10.9 ± 0.1 (10.3-10.9)	11.3 ± 0.4 (10.4-12.0)				
Anterior to median bulb valve	93.7 ± 5.0 (86.1-100.6)	90.8 ± 6.0 (76.2-102.9)	92.7 ± 4.5 (80.8-101.2)		91.3 ± 2.6		
Anterior to pharyngeal gland overlap	189.9 ± 10.4 (172.4-203.6)	192.4 ± 9.4 (171.8-205.8)					
Anterior to Excretory pore	132.6 ± 2.9 (127.9-136.5)	129.0 ± 4.8 (119.8-144.0)					
Tail length	69.2 ± 5.7 (63.6-75.9)	72.3 ± 4.3 (65.3-82.3)	74.2 ± 4.7 (64.4-82.0)	69.9 ± 0.7 (63.5-75.7)		60 (51-71)	59 (55-65)
Hyaline length	38.2 ± 2.1 (35.5-41.6)	40.6 ± 3.6 (35.1-47.2)	42.3 ± 2.6 (36.0-47.6)	37.9 ± 0.7 (33.8-47.3)	42.9 ± 2.1	30.7 (24.2-39.6)	36 (30-38)
a	26.7 ± 1.6 (24.2-29.6)	26.4 ± 2.1 (22.9-35.2)					
b	4.5 ± 0.2 (4.1-5.2)	5.2 ± 0.3 (4.8-6.2)					
b'	3.3 ± 0.2 (3.1-3.5)	3.0 ± 0.3 (2.3-3.9)					
c	8.8 ± 0.7 (7.9-9.9)	8.1 ± 0.4 (7.0-8.9)					
c'	4.4 ± 0.4 (3.8-4.9)	4.9 ± 0.3 (4.1-5.5)		5.0 ± 0.1 (4.3-5.5)			
L/Anterior to Median bulb valve	6.5 ± 0.4 (6.0-7.3)	6.4 ± 0.8 (4.5-8.2)					
H/ST	1.5 ± 0.1 (1.4-1.6)	1.4 ± 0.1 (1.2-1.6)					
Tail/H	1.8 ± 0.1 (1.6-2.1)	1.8 ± 0.2 (1.2-2.2)					

Data extracted from ¹Ambrogioni et al. (1999); ²Andersson (1984); ³Steele and Whitehand (1984); ⁴Schlang (1990); ^{5,6}Mulvey and Golden (1983). All measurements are in micrometers and in the form mean ± standard deviation (range). (L = total body length, a = body length/greatest body width, b = body length/distance from anterior end to junction of pharynx and intestine, b' = body length/distance from anterior end to posterior end of pharyngeal glands, c = body length/tail length, c' = tail length/body width at anus, H/ST = Hyaline length/ Stylet length, and T/H = Tail length/Hyaline length).

Supplementary Table 3. Comparative morphometrics of *H. trifolii* vulval cones from different countries

Character	Korea (YS 503)	Italy ¹	Sweden ²	Netherlands ³	Germany ⁴
Cyst Length	910.0 ± 160 (650.0-1100.0)	877.7 ± 117.6 (624.0-1080.0)	857 ± 162 (550-1105)	(568.3-1136.7)	873 ± 74.5
Cyst Width	500.0 ± 99.2 (350.0-601.0)	497.5 ± 112.8 (168.0-720.0)	518 ± 106 (293-702)	(310.0-671.7)	487 ± 56.3
Body length/body width	1.8 ± 0.2 (1.7-2.1)	1.8 ± 0.2 (1.3-2.2)			1.8 ± 0.1
Fenestral length	50.9 ± 4.9 (47.1-58.0)	44.3 ± 5.2 (30.3-54.5)	52 ± 6.0 (42-72.5)		
Fenestral width	36.0 ± 2.2 (33.4-38.3)	38.4 ± 3.9 (30.3-48.4)	38 ± 6.8 (29.5-49.5)		
Vulval bridge width	7.4 ± 0.7 (6.9-7.9)	6.4 ± 1.2 (3.6-8.5)	4.8 ± 1.3 (2.0-8.0)		
Vulval slit length	47.3 ± 2.8 (44.0-50.8)	47.9 ± 4.0 (39.9-56.9)	56.5 ± 4.3 (48.5-67)		
Under bridge length	112.7 ± 10.3 (105.2-127.8)	108.6 ± 11.2 (84.7-127.1)	127 ± 19.0 (97-170)		
Under bridge width	35.5 ± 5.6 (29.8-44.7)	25.9 ± 5.3 (15.7-33.9)	36 ± 4.2 (30-48)		

Data extracted from ¹Ambrogioni et al. (1999); ²Anderson (1984); ³Steele and whitehead (1984); ⁴Schlang (1990). All measurements are in micrometers and in the form mean ± standard deviation (range).

Supplementary Table 4. Comparative morphometrics of *H. schachtii* infective juvenile populations from different countries

Character	Korea (GC147)	Italy ¹	Jordan ²	USA ³	Turkey ⁴	Syria ⁵
Body length (L)	484.2 ± 11.1 (473-504.2)	444.5 ± 14.2 (418.7-471.9)	488.3 ± 55.6 (412-600)	452 ± 49.7	479.0 ± 11.7 (455-489)	481.92 ± 4.88 (458.16-519.53)
Max body width	20.3 ± 0.9 (19.1-21.8)	20.2 ± 0.9 (18.2-21.8)	20.1 ± 1.0 (18-22)		21.4 ± 0.5 (21-22)	
Lip height	4.4 ± 0.3 (3.9-4.9)	4.7 ± 0.3 (3.6-4.8)	4.8 ± 0.3 (3.9-4.9)			
Lip width	9.5 ± 0.2 (9.1-9.9)	9.6 ± 0.3 (8.5-9.7)	10.0 ± 0.4 (9.8-10.9)			
Stylet length (ST)	22.1 ± 0.9 (21.3-24.3)	26.0 ± 0.8 (24.2-27.8)	24.3 ± 2.0 (19.6-26.5)	25.6 ± 0.1	24.7 ± 0.4 (24-25)	25.31 ± 0.86 (24.69-26.12)
DGO to stylet base	4.0 ± 0.3 (3.5-4.4)	4.0 ± 0.7 (2.4-4.8)	5.5 ± 1.2 (4-7)	3.4		
Anterior to median bulb valve	76.4 ± 0.4 (75.8-77)	73.6 ± 5.9 (60.5-85.9)				
Anterior to pharyngeal intestine junction	126.2 ± 1.0 (124.8-131.1)	90.6 ± 5.7 (76.2-98.0)	102.9 ± 16.2 (88.2-125.4)			
Anterior to pharyngeal gland overlap	169.3 ± 15.2 (138.4-184.4)	158.5 ± 16.5 (124.6-182.7)	164.3 ± 15.8 (137.2-186.2)			
Anterior to median bulb base	82.9 ± 1.0 (81.3-84.3)		80.0 ± 6.1 (68.6-90.2)			
Anterior to Excretory pore	105.6 ± 1.9 (104.2-110.2)	98.4 ± 1.2 (84.7-108.9)	107.9 ± 7.6 (98-121.5)			
Tail length	49.9 ± 1.8 (48.2-53.2)	47.3 ± 4.3 (42.4-55.7)	64.1 ± 7.1 (52.9-72.5)	48.5 ± 0.7	47.6 ± 1.0 (47-49)	42.84 ± 0.77 (41.69-43.87)
Anal body width	14.4 ± 0.7 (14.2-15.8)	13.2 ± 0.9 (10.9-14.5)	14.6 ± 2.0 (11.8-16.7)			
Hyaline length	29.2 ± 2.1 (26.7-34.3)	25.4 ± 2.2 (20.6-29.0)	33.8 ± 5.8 (27.4-49)	27.1 ± 0.6	24.6 ± 1.1 (23-26)	25.63 ± 1.11 (24.79-26.87)
a	23.8 ± 0.9 (22.9-25.1)	22.0 ± 0.9 (20.2-23.7)				
b	4.2 ± 0.1 (3.7-4.6)	4.9 ± 0.2 (4.6-5.5)				
b'	2.9 ± 0.3 (2.6-3.4)	2.8 ± 0.3 (2.4-3.4)				
L/Anterior to median bulb valve	6.3 ± 0.1 (6.2-6.5)	6.1 ± 0.4 (5.5-6.9)				
c	9.6 ± 0.4 (9.4-10.0)	9.5 ± 0.8 (7.7-10.6)	7.5 ± 0.5 (6.5-8.4)			11.2
c'	3.5 ± 0.2 (3.2-3.8)	3.6 ± 0.4 (3.2-4.6)	4.3 ± 0.4 (3.5-4.7)			
H/ST	1.3 ± 0.1 (1.2-1.6)	1.0 ± 0.1 (0.8-1.1)	1.6 ± 0.2 (1.3-1.8)		0.99 ± 0.04 (0.92-1.04)	1.0
Tail/H	1.7 ± 0.1 (1.6-1.9)	1.9 ± 0.1 (1.7-2.5)			1.94 ± 0.08 (1.85-2.08)	1.7

Data extracted from ¹Ambrogioni et al. (1999); ²Lafi et al. (2015); ³Mulvey and Golden (1983); ⁴Cui et al. (2016); ⁵Haidar et al (2015). All measurements are in micrometers and in the form mean ± standard deviation (range). (L = total body length, a = body length/greatest body width, b = body length/distance from anterior end to junction of pharynx and intestine, b' = body length/distance from anterior end to posterior end of pharyngeal glands, c = body length/tail length, c' = tail length/body width at anus, H/ST = Hyaline length/Stylet length, and T/H = Tail length/Hyaline length.)

Supplementary Table 5. Comparative morphometrics of *H. schachtii* vulval cones from different countries

Character	Korea (GC147)	Italy ¹	Jordan ²	USA ³	Turkey ⁴	Syria ⁵
Cyst Length	795.8 ± 97.1 (639.5-882.6)	815.4 ± 85.9 (684.0-960.0)		626-890	703 ± 61.5 (628-765)	
Cyst Width	510.8 ± 75.1 (378.5-600.4)	512.4 ± 63.0 (444.0-648.0)		361-494	473.2 ± 49.6 (410-530)	
Body length/body width	1.6 ± 0.1 (1.5-1.6)	1.6 ± 0.1 (1.3-1.8)			1.49 ± 0.04 (1.44-1.53)	
Fenestral length	42.2 ± 3.6 (36.1-45.3)	38.7 ± 6.2 (27.8-48.4)	57.6 ± 3.4 (55.2-60.0)			71.28 ± 4.98 (57.61-95.32)
Fenestral width	28.2 ± 4.0 (24.3-33.8)	31.1 ± 3.6 (26.6-39.9)	18.4 ± 1.4 (16.8-19.2)			40.71 ± 2.11 (26.62-49.65)
Vulval bridge width	4.5 ± 1.2 (3.1-5.9)	6.6 ± 1.2 (4.8-8.5)				14.12 ± 1.06 (12.38-15.83)
Vulval slit length	37.4 ± 5.2 (30.3-42.2)	44.1 ± 4.6 (36.3-54.5)	43.9 ± 1.1 (42.7-45.0)		44.6 ± 0.2 (44.5-44.9)	52.25 ± 3.82 (49.49-55.09)
Under bridge length	102.3 ± 10.8 (93.7-120.8)	109.9 ± 10.4 (84.7-124.1)	104.0 ± 13.9 (96-120)		115.5 ± 4.79 (110-120)	
Under bridge width	16.6 ± 2.4 (12.4-18.4)		12			

Data extracted from ¹Ambrogioni et al. (1999); ²Lafi et al. (2015); ³Mulvey and Golden (1983); ⁴Cui et al. (2016); ⁵Haidar et al (2015). All measurements are in micrometers and in the form mean ± standard deviation (range).