Editorial - Impact assessment, ecology and management of animal pests affecting field crop establishment: An introduction to the special issue

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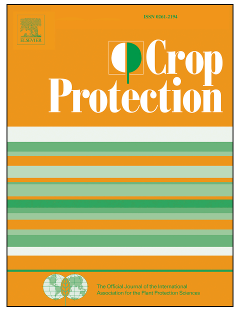

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PII: S0261-2194(21)00249-0

DOI: https://doi.org/10.1016/j.cropro.2021.105779

Reference: JCRP 105779

To appear in: *Crop Protection*

Received Date: 21 July 2021

Revised Date: 22 July 2021

Accepted Date: 23 July 2021

Please cite this article as: Lamichhane, J.R., Editorial - Impact assessment, ecology and management of animal pests affecting field crop establishment: An introduction to the special issue, *Crop Protection* (2021), doi: https://doi.org/10.1016/j.cropro.2021.105779.

Editorial - Impact assessment, ecology and management of animal pests affecting field crop establishment: An introduction to the special issue

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Keywords: bird damage, emergence failure, post-emergence damage, seed damage, seed predation, seedling damage, seedling losses

1. The crop establishment phase

Crop establishment is an early phase that consists of three sub-phases: sowing to seed germination, seed germination to seedling emergence, and seedling emergence to initial competition among young plants (Aubertot et al., 2020; **Figure 1)**. The initial seed and seedling vigor (i.e. the speed of seed germination and seedling emergence; Maguire, (1962)) are a key indicators that determine a rapid, uniform and robust crop establishment across diverse environmental conditions (Finch-Savage and Bassel, 2016; Maguire, 1962).

The quality of field crop establishment can be characterized by the rate of healthy looking young plants compared with the sowing density (Lamichhane et al., 2020b). This means that only a high percentage of final emergence is not sufficient for a crop to successfully establish as a non-optimal initial vigor will result in poor growth with stunted young plants. Resource use efficiency and crop yield depend on successful plant establishment in the field. This is especially true for crops that are not able to compensate pre- and post-emergence damage and/or losses due to several factors **(Table 1)**.

Several biotic (Firake et al., 2016; McKee et al., 2020; Rojas et al., 2016; You and Barbetti, 2017) and abiotic (Bybordi and Tabatabaei, 2009; Wijewardana et al., 2019) factors may lead to a poor quality of crop establishment **(Figure 2)**. This has several direct (e.g. yield losses, additional production costs due to seed purchase and resowing etc.) and indirect (e.g. weed development and increased seedbank that leads to heightened management costs) consequences for growers (Lamichhane et al., 2018).

Crop establishment is affected by five major groups of drivers and their interactions namely seed and seedling characteristics, seedbed components (physical, chemical and biological), weather, cropping systems (Lamichhane et al., 2018), and animal pests coming from outside the seedbed (Lamichhane et al., 2020b). The latter have been increasingly reported to cause post-emergence damage of field crops (Dimitri et al., 2012; Firake et al., 2016; Lamichhane, 2021; McKee et al., 2020; Nasu and Matsuda, 1976). A successful management of animal pests affecting crop establishment requires a systems-level approach that combines a range of disciplines including Agronomy, Biology and Ecology.

2. Key animal pests affecting the crop establishment phase

Vertebrate (e.g. birds, mammals, rodents etc.) and invertebrate (e.g. flea beetles, slugs, maggots, wireworms) pests cause damage to germinating seeds and emerging or emerged seedlings **(Figures 3-5)**. However, the type and extent of their damage depend on the characteristics related to the plot, field, or landscape. Characteristics related to the plot include the plot's size, crop species, sowing date, and tillage type; those related to the field include the extent of crop diversification and presence or absence of natural or semi-natural habitats; and those related to the landscape include residential areas, forests, and annual vegetations.

3. Introduction to the special issue: Impact assessment, ecology and management of animal pests affecting field crop establishment

This special issue focuses on vertebrate and invertebrate pests affecting the crop establishment phase. These pests may cause partial or complete crop establishment failure with a huge economic impact for growers. Understanding the biology, ecology and population dynamics of these animal pests and their impact on the establishment quality of a given crop is a first step toward the development of sustainable crop protection measures that can be embedded into an integrated pest management (IPM) framework. The special issue includes seven research articles and one perspective paper, for a total of eight papers, which are grouped into three sections. The following are representative summaries of the articles gathered in this issue.

3.1. Damage assessment, identification and risk predictions of animal pests affecting crop establishment

Post-emergence seedling damage due to birds has become the most important economic problem for sunflower growers in France. Although severe losses of sunflower seedlings have been increasingly reported by growers across the country, no study attempted to date to quantify these losses. Sausse et al. (2021b), conducted a three-year observational study across 206 sunflower fields in two major sunflower production basins of France, and quantitfied the rate of post-emergence seedling damage. The authors found that 98% of the sunflower fields showed partial or total seedling damage symptoms attributable to birds. In particular, 10% of the surveyed fields were particularly affected with over 20% of seedlings completely destroyed. This damage results either in an increased production cost (in the case of resowing) or in significant production losses when no resowings are performed.

Wireworms represent one of the most important soil-dwelling pests from an economic point of view. These pests cause severe damage on crops, especially at the crop establishment phase. The severity of damage due to wireworms has been reported to increase under no-till systems although there is no consensus in the literature in this regard. Furlan et al. (2021b) investigated the effect of conventional versus no-tillage practices on the population dynamics of wireworms and the associated damage in the early growth stages of maize crops over a six-year study period (2011-2016). The authors did not find any significant effect of tillage versus no-till practices on the population density of these pests or the associated damage to maize crops at the crop establishment phase. These results are encourgaing for an increased adoption of no-till practices, which provide numerous environmental benefits including reduced soil erosion.

Mice cause significant damage to crops worldwide by digging up and consuming newly planted seeds, or by cutting seedlings and stems, and feeding on developing grains. Under favorable conditions, mice can rapidly increase in abundance to form mouse plagues. Forecasting mice population dynamics can assist management to keep this pest species at tolerable densities. This is important for preventative management of the pest that is sustainable in the long-term compared with reactive management, the latter being most often adopted to date. Wang et al. (2021) developed an iterative modeling approach, involving statistical inference and forecasting data, to predict the population dynamics of the striped field mouse (*Apodemus agrarius*), an indigenous rodent, in a cropland. This approach allowed to understand the effects of environmental variables (rain, temperature, and crop types) on the pest population dynamics, which, in turn, helped predict population outbreaks at the site level several months before their occurrence. The forecasting approach used by the authors can contribute to planning and deployment of *A. agrarius* management measures and to avoid crop damage.

3.2. Management of animal pests affecting crop establishment

Birds' damage to sunflower represents an important problem for growers as it often leads to severe economic losses. No effective management measures exist to date to reduce such damage. Werrell et al. (2021) propose a Sonic Net that broadcasts synthetic sounds at frequencies which purportedly mask or block birds' normal communications. In this way, birds are deprived of essential aural information; they vacate the impacted area for more secure locations beyond the reach of Sonic Net. By testing this device through basic small-plot field experiments, the authors demonstrated the effectiveness of the sonic net that reduced damage to sunflowers by 23% to 64% at maturity, depending on field locations. The authors predict that the effect of the Sonic Net treatment may be greater in other crop phases and types, such as in the establishment phase or ground cover crops. Indeed, a relative lack of tall, three-dimensional vegetational structure at the crop establishment phase may allow a more effective spread of the Sonic Net sound offering fewer physical refugia for birds to lower their perceived predation risk. Future studies should test the efficacy of this device on other crops and specifically at the crop establishment phase.

Feral or wild pigs represent one of the most important invasive species that cause severe economic crop losses worldwide. These animal pests may attack a large number of crop species and the crop establishment phase is particularly vulnerable to their attacks. More specifically to maize, feral pigs' damage to this crop mainly occurs immediately following planting as these pests consume the freshly planted and germinated seeds. Protecting the maize seeds or seedlings from feral pigs is important to ensure a good quality of maize establishment. Snow et al. (2021) propose an anthraquinone repellent seed treatment to limit seed and seedling damage due to feral pigs. The authors showed that the repellency rate was affected by the concentration of anthraquinone used and that treating the maize seed with 3% anthraquinone resulted in the greatest reduction in damage. Testing of this method under a wide range of field conditions and monitoring for the damage rate as well as the duration of protection offered by this seed treatment method may provide further insights into the usefulness of this method for growers to limit feral pig damage to maize. Nevertheless, unlike in the US, the use of this product is forbidden in many countries including those of the European Union.

Identification of the potential risk factors triggering animal pest damage to maize seedlings and an accurate assessment of seedling losses represent the first step towards integrated management of animal pests affecting the crop establishment phase. Furlan et al. (2021a) through a long-term field survey, identified plant-attacking bird species, agronomic characteristics, cultural practices, and landscape variables, such as the presence of roosting areas. The authors determined that corvids were the most important animal pests affecting maize crop establishment and that no-till practice increased the damage severity compared with minimum and conventional tillage systems. By using a multifactorial model, they highlighted that the presence of roosting areas around the field plots was the most important risk factor that increased damage risk up to five-fold. Seed coatings using chemical (methiocarb and ziram) and biological (ScudoSeed® and Eurodif®) bird repellents effectively reduced the risk of corvid damage to maize seedlings. Although the biological bird repellents were less effective than their chemical counterparts in reducing seedling damage due to corvids, the former kept the damage below the 15% threshold level. The authors conclude that integration of biological bird repellents into IPM principles may result a viable option for growers to limit corvids' damage to maize seedlings under high risk situations.

Vegetation management can be an important agronomic lever to reduce seedling damage due to animal pests. Damage to maize seedlings by rodents, birds and insects, such as stem-cutting termites, represents an important production constraint for growers in central Cameroon. Norgrove (2021) investigated the potential effect of different vegetation management techniques, namely chemical vs. manual weed management and mulching vs. removal of vegetation residues through burning, on maize seedling damage by these animal pests. The author showed that the presence or absence of vegetation cover influenced different types of animal pests affecting maize establishment. Seedling damage due to termites significantly increased in the absence of vegetation while the damage due to birds markedly decreased in the same situation. The removal of vegetation, which represents food sources for insects, via chemical weeding or burning, was the key reason triggering insect attacks to living plants. This emphasizes the importance of vegetation cover, including the presence of weed flora, in natural pest regulations via an improved food source provisioning.

3.3. Challenges and opportunities for the management of animal pests affecting crop establishment

Bird damage to crops in general and that at the crop establishment phase, in particular, has become an important problem for growers. While severe bird damage at the maturity phase occurs in North and South America, bird damage has become an emergeing problem at the establishment phase of spring-sown crops in France and other European countries. However, crop losses due to birds have drawn only little attention from the policy side resulting in poor research in these countries. As a consequence, limited bird management tools have been developed and tested to date. This has led to an impasse where the economic sustainability of growing spring crops has been increasingly challenged. Faced with this uncertainity, growers tend to partially or completly abandon crops such as sunflower from their cropping systems by replacing them with other crops that are less likey to suffer bird damage. Sausse et al. (2021a) discuss key contemporary challenges and opportunities for the management of bird damage to crops. The authors highlight the need to adopt data intensive and multiscale approaches to develop effective solutions for bird management and call for networking to tackle this issue.

4. Conclusions and perspectives

Damage by animal pests at the crop establishment phase represents an important problem for growers although the frequency and intensity of the damage may widely vary in space and time. More specifically to arable crops, seed and seedling damage due to animal pests has become an emerging problem for some crops such as sunflower, maize, and soybean. However, the solution to this problem, especially that due to birds, is increasingly difficult due to a number of issues as highlighted by Sausse et al. (2021a). In addition, because many bird species provide both ecosystem services and disservices, it is difficult to consider them only as « a pest », which further complicates their management. For example, vertebrate pests such as birds and bats act as natural predators of several crop pests (Sow et al., 2020).

Research and policy should come together with an increasing effort on networking at local, regional, national and international levels. This will help in developing sustainable management solutions that can limit animal pests' damage at the crop establishment phase. More specifically to research, three key priorities can be identified for future: i) an economic estimation of yield losses in monetary terms due to animal pests' damage at the crop establishment phase; ii) an increased effort on the development and testing of methods and/or tools and their robust economic analysis in terms of cost-effectiveness; and iii) a larger scale testing of the effectiveness of newly developed tools and/or methods, especially when they are used in combination with other management strategies, as part of IPM.

Acknowledgements

I thank the reviewers of this special issue, who collaborated with me to ensure timely publication of the issue, and Stephen N. Wegulo for his feedback on this editorial. JRL is partly supported by the Ecophyto Dephy Expe FAST, PSPC Naturellement Pop-corn, and UMT PACTOLE.

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Table 1. Ability of field crops to compensate pre- and post-emergence losses and potential correlation between the quality of field crop establishment and yield

Crop type	Crop	Pre- & post-emergence losses compensation ability#	Compensation method	Potential correlation between crop establishment quality and yield*	References
Straw cereals	Barley	Yes	Tillering	No	del Moral and del Moral (1995)
	Oat	Yes	Tillering	No	Peltonen-Sainio and Järvinen (1995)
	Wheat	Yes	Tillering	No	Abati et al. (2017)
	Sorghum	Yes	Tillering	No	Maranville and Clegg (1977)
	Maize	No	Nil	Often positive¶	Liu et al. (2004)
	Rice	Yes	Tillering	No	Fageria (2007)
Pulse crops	Common bean	Yes	SDG, IG, B	No	De Ron et al. (2016); Raveneau et al. (2011)
	Pea	Yes	SDG, IG, B	No	Gan et al. (2002); Raveneau et al. (2011)
	Lentil	Yes	SDG, IG, B	No	Siddique et al. (1998)
	Chickpea	Yes	SDG, IG, B	No	(Gan et al., 2002)
	Faba bean	Yes	SDG, IG, B	No	López-Bellido et al. (2005)
Oleaginuous crops	Sunflower	No	Nil	Often positive¶	McMaster et al. (2012)
	Oilseed rape	Yes	Branching	No	Hossain et al. (2019)
	Soybean	Yes	SDG, IG, B	No	Lamichhane et al. (2020a)
Root and tuber crops	Sugar beet	No	Nil	Often positive¶	Boiffin et al. (1992); Souty and Rode (1993)
	Potato	Yes	Branching	No	Vander Zaag et al. (1990)
Cover crops	Asteraceae, Brassicaceae, Fabaceae, Hydrophylaceae, Poaceae, Polygonaceae	Most of them yes	SDG, IG, B	NA	Baligar and Fageria (2007); Huang et al. (2021); Marshall and Lewis (2004); Tridevi et al. (2015)

SDG: Semi-determinate growth; IG: indeterminate growth; B: branching; NA: not applicable; #Dependent on crop species and growth conditions

*The correlation depends on several factors including water availability, soil fertility, maturity rating, planting date and row spacing. A high heterogeneity in emergence date is detrimental to yield for certain crops as plants emerging late relative to neighboring plants provided reduced yield.

¶When the number of individuals per area is increased beyond the optimum plant density, there is a series of consequences that are detrimental to yield

Table 2. A visual disgnostic key describing major causes affecting crop establishment and descriptions of their symptoms/ characteristics

Sub-phase	Symptoms or characteristics			Causes of no crop establishment	References
Sowing - seed germination	Seeds fail to germinate (pre-germination)	Absence of the intact seed or presence of seed parts	No presence of seed or seed parts	Technical problem of sowing or predation of seeds by pests*	Carabajal-Capitán et al. (2021); Tschumi et al. (2018)
			Outer seed coat altered, presence of empty seed coat	Damage caused by granivores (e.g. slugs, earthworms or rodents)	Carabajal-Capitán et al. (2021); Tschumi et al. (2018)
		Presence of non-germinated and germinated seeds	Intact seed content but no germination	Abiotic stress (heat water or mechanical) or dormancy problem or seed death	Lamichhane and Aubertot (2021)
Seed germination - seedling emergence	Seedlings fail to emerge (pre-emergence)		Rotten seed content and no germination	Pre-emergence damping-off (seed- and soil-borne pathogens)	You and Barbetti (2017)
			Presence of holes or larvae in or around seeds	Soil-borne pests (e.g. seed maggots, wireworms, symphylans, millipedes)	Ebregt et al. (2005)
			Occurrence of germination but no emergence, twisted seedlings, abnormal radicle growth, absence of necrosis and/or rot, presence of crust and/or soil compaction in the seedbed	Mechanical stress such as soil compaction, soil crust formation	Gallardo-Carrera et al. (2007); Lamichhane et al. (2020); Lamichhane and Aubertot (2021)

			Occurrence of germination but no emergence, twisted seedlings, absence of necrosis and/or rot or crusting, presence of clods, crop residues or stones above the seedling in the seedbed	Mechanical stress such as soil clods, crop residues and stones (depending on the type of (no)tillage	Dürr and Aubertot (2000); Lamichhane et al. (2020)
			Occurrence of germination but no emergence, normal seedlings, absence of necrosis and/or rot or crusting, no clods in the seedbed	Too high sowing depth (technical problem of sowing that leads to a poor soil-seed contact in no-till systems)	Blunk et al. (2021); Kirby (1993); Mahdi et al. (1998)
			Occurrence of germination but no emergence, dried or desiccated seedlings, absence of necrosis and/or rot, no soil crust, neither compaction or large clods in the seedbed.	Post-germination drought stress	Boureima et al. (2011)
Seedling emergence – initial competition among young plants	Seedlings have well-emerged (post-emergence)	Seedling falls down due to the damaged stem at the ground level and remains on the seedbed	Seedling wilting, reddish root necrosis, hypocotyl and seedling collar rot, absence or few secondary roots	Post-emergence damping-off (seed- and soil-borne pathogens)	Rojas et al. (2016); Serrano and Robertson (2018); You et al. (2017)
			Holes and presence of larvae in cotyledons, stem and/or roots; swelling of seedling collar; shrinking and gradual disappearance or entangled seedlings; accumulation of filamentous brown debris	Soil-borne animal pests (e.g. seed maggots, wireworms, symphylans)	Douglas et al. (2017); Furlan et al. (2021b); Vea and Eckenrode (1976)
		Partial or total damage of leaves, damaged stem, uprooted seedlings	Damaged cotyledons and/or part of the hypocotyl/epicotyl at or just after seedling emergence; uprooting of seedlings and their spread in or complete disappearance from the seedbed; pitting and shot-holing; leaf perforation; stunting and poor plant vigour; chewed leaves or	Herbivory related to animal pests (e.g. flea beetles, slugs, birds, rodents, mammals)	Douglas et al. (2017); Douglas and Tooker (2012); Furlan et al. (2021a, 2021b); Lamichhane (2021); Sausse et al. (2021b)

			entire seedlings		
		Seedling falls down and die	Leaf scorching, sudden wilting of the entire plant, pale brown patches in the plot	Frost damage	Brandsæter et al. (2000); Chen et al. (2005); Pescador et al. (2018)
		Seedlings do not fall down on the seedbed	Modification of seedling colors, deformations, abnormal chlorotic or necrotic symptoms but different than those caused by soil-borne pathogens	Problem related to chemical stress (phytotoxicity) or water logging and subsequent root asphyxia	Lamhamdi et al. (2013); Loose et al. (2017); Yasumoto et al. (2011); Zaman et al. (2018)

*An absence of the intact seed could be also related to a rapid seed rotting, especially for small-seeded plant species, under high moisture conditions in the seedbed or when the field diagnosis is performed too late.

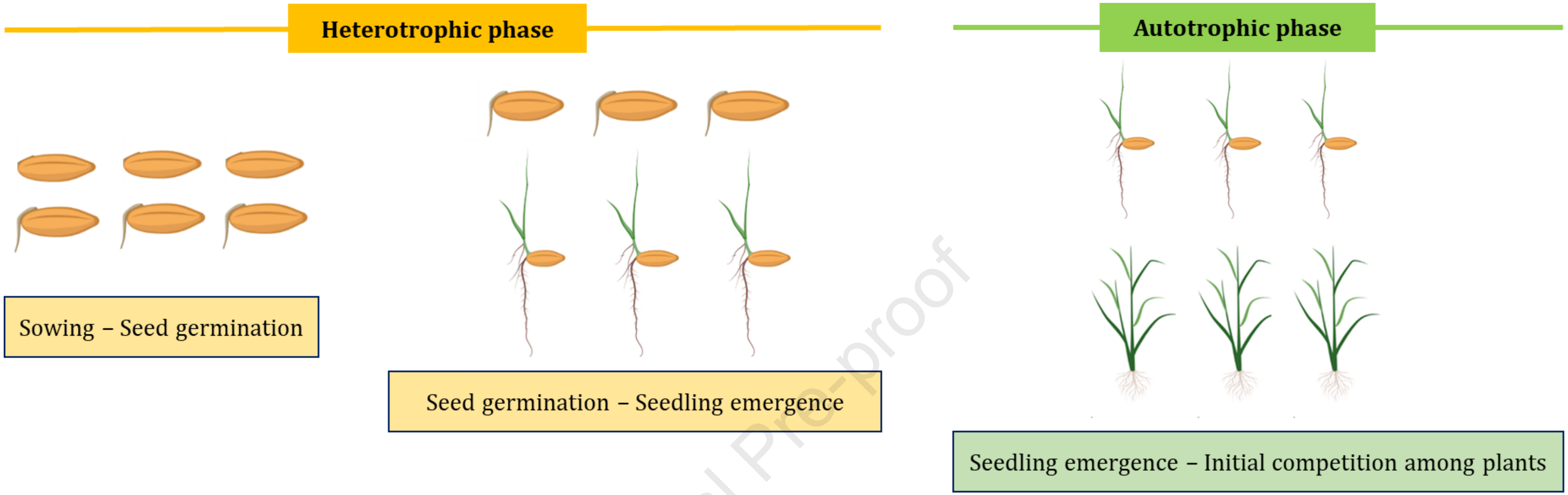

Figure 1. Crop establishment is a phase that consists of three sub-phases viz. sowing to seed germination; seed germination to seedling emergence; and seedling emergence to initial competition among young plants. The former two sub-phases are heterotrophic (i.e. the radicle and seedling development relies on the seed reserves) while the last sub-phase is autotrophic (i.e. the seedling has already developed true leaves that are capable to perform photosynthesis and, thus, do not depend anymore on seed reserves that are already exhausted at this stage).

Figure 2. Poor field emergence of faba bean (a) and brown mustard (b) due to unknown reasons. Identification of the causes leading to non-emergence is a first step to better manage biotic and abiotic factors affecting seed germination and seedling emergence via best cropping practices.

Figure 3. Seed predation due to slugs under directly sown soybean in a relay cropping system. These pests can cause partial (a) or total (b) seed predation when the sowing quality is not optimal (superficial sowing depth, poor soil-seed contact etc.).

Figure 4. Characteristic symptoms of post-emergence seedling damage due to animal pests. Slug feeding (a), and cutting and uprooting by common wood pigeon (b) of soybean seedlings.

Figure 5. Characteristic symptoms of post-emergence seedling damage due to animal pests. Chewed cotyledons or the entire young leaves of soybean by European hare (a), and shot-holing of radish leaves by flea beetle (b).

This is an editorial so there are no highlights.

Declaration of interests

☒ 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.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: