New control methods against the cabbage stem flea beetle in oilseed rape crops

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Abstract

Cabbage stem flea beetle (CSFB) is one of the most damaging pests of oilseed rape (OSR) grown in the UK. An intensive research effort is underway in the UK and throughout OSR growing regions of continental Europe to develop new control methods for this pest. Here we review this research and consider approaches that may provide current/short, medium and long-term solutions to this pest problem. In the current/short-term, agronomic practices (sowing date, seed rate, crop defoliation, companion crops, etc) are being investigated and several of these approaches are already being used on farm. The use of physically acting biopesticides such as fatty acids, while not yet being used may also provide a short-term solution. In the medium-term, entomopathogenic fungi and nematodes, and botanical insecticides may be used. In the long-term, natural enemies such as parasitoids, and the development of resistant OSR varieties may be used. Each of these approaches has the potential to form part of future Integrated Pest Management (IPM) programmes but importantly none should be seen as simple replacements for conventional synthetic insecticides.

1. Introduction

The cabbage stem flea beetle (CSFB), *Psylliodes chrysocephala* Linnaeus (Coleoptera: Chrysomelidae) is one of the most important pests of winter OSR crops in central and northern European countries (Alford et al., 2003; Nicholls, 2016). The adult beetle causes 'shot holing' feeding damage (see Figure 1) on cotyledons and true leaves of young winter OSR plants in late summer-early autumn (Alford et al., 2003). The larvae feed inside petioles and stems of the plants (see Figure 2), causing additional damage (Williams, 2004).

The focus on making food production more environmentally friendly means reduced chemical inputs, protecting non-target species and the overall biodiversity (Benton et al., 2019). This led to the withdrawal of systemic synthetic neonicotinoid pesticide seed treatments in many crops (oilseed rape included) in 2013 (European Commission, 2013).

Since the withdrawal of neonicotinoid seed treatments, there has been a reliance on pyrethroid insecticides. This has been seen with a shift in the use of insecticides in oilseed rape, with CSFB the target for 28% of insecticide applications in 2012 (before neonicotinoid seed treatments were withdrawn) to 75% in 2020 (Garthwaite et al., 2021, 2013). The result of this shift has been the development of resistance to this group of insecticides in CSFB population (Højland et al., 2015). This situation has become so severe that some UK populations of CSFB are now 100% of resistant to the pyrethroid insecticide lambda-cyhalothrin (Willis et al., 2020). These changes have led to the area of oilseed rape grown in the UK being halved (755,717 hectares in 2012 versus 381,319 hectares in 2020) (Garthwaite et al., 2021, 2013), with growers citing CSFB as one of the main reasons for this decreased (Scott and Bilsborrow, 2019). At the same time, the number of insecticide spray rounds has increased from two to three between 2012 and 2020, with five of the most sprayed insecticides being pyrethroids. The most widely used pyrethroid insecticide, lambda-cyhalothrin, has also increased as a proportion of the insecticide-treated area from 32% in 2012 to 76% in 2020 (Garthwaite et al., 2021, 2013). Additional surveys by Fera using the CropMonitor information service between 2009 and 2020 show that the number of CSFB larvae per plant increased from an average of 0.5 larvae per plant in the years before the withdrawal of neonicotinoids, to more than 2 larvae per plant the following year in 2014 in East England, and almost 5 larvae per plant in 2019 in the Southwest of England (Fera, n.d.).

Here we present current/short, medium and long-term solutions that have been developed or that are under development and consider how these approaches could be used in Integrated Pest Management (IPM) programmes.

2. Proposed timescale to develop and make available new control methods

2.1. *Current and short-term control methods*

a. Agronomic practices

In Table 1, we summarise agronomic practices that are currently being used for CSFB management in the UK. These approaches have recently been reviewed by Blake et al., (2021), Ortega-Ramos et al. (2021) and White et al. (2020). Most of these approaches reduce feeding damage by adults and/or larval infestation and may lead to yield increases (see Table 1).

b. Fatty acids

Biopesticides are another potential short-term solution that could be considered for CSFB control. A biopesticide can be defined as a 'mass-produced agent manufactured from a living microorganism or a natural product and sold for the control of plant pests' (Chandler et al., 2011). Examples of physically acting biopesticides include formulations of fatty acids (contact insecticides). These carboxylic acids are widely occurring and natural organic compounds that can be obtained from various sources (Bayer, 2021). These products are already authorized for use against pests of horticultural crops and are considered safe for pollinators as they have no residual activity (Bayer, 2021). Products such as FLiPPER (Bayer/AlphaBio Control) or Neudosan (Certis/Progema) work by penetrating the insect cuticle and damage the cell structure, interfering with vital processes and disrupting feeding activity, leading to death (Bayer, 2021; Progema GmbH, n.d.).

In Table 2 we present two studies investigating the use of fatty acids against flea beetles, with encouraging results both in the field and in the laboratory. More research is however needed to evaluate the effect of these products in the field against CSFB.

2.2. Medium-term control methods

a. Entomopathogens

Entomopathogenic fungi (EPF) and entomopathogenic nematodes (EPN) are considered the organisms with the greatest potential to control CSFB (Hokkanen et al., 2003). Their successful application will however require the development of application techniques that overcome the negative impacts of environmental factors that may reduce persistence of these organisms in the field, such as temperature, humidity, and UV radiation (Chandler, 2017; Shapiro-Ilan et al., 2017). One approach to overcome these limitations is the use of a polymer gel to protect entomopathogens from UV and desiccation, which has been tested in several field studies (Antwi and Reddy, 2016; Briar et al., 2018; see Table 4). Timing of application, oil-based formulation, and the use of sunscreens can also be considered (Chandler, 2017; Shapiro-Ilan et al., 2017).

Table 3 lists the studies conducted with two EPF species, *Metarhizium anisopliae s.l. (brunneum)* (Metchnikov) Sorokin and *Beauveria bassiana* (Balsamo) Vuillemin, against CSFB and against the closely related crucifer flea beetle (*Phyllotreta cruciferae* Goeze) and striped flea beetle (*Phyllotreta striolata* Fabricius). Table 4 lists the studies conducted with various nematode species of the genera *Steinernema* and *Heterorhabditis* against CSFB, crucifer and striped flea beetles, and other *Phyllotreta* spp. species. CSFB mortality varies depending on the entomopathogen species, isolate used, insect species, life stage and study types (laboratory or field), but overall results are encouraging, and combinations of products appear to be more effective than individual products, showing increased adult mortality, reduced adult emergence, reduced feeding damage and increased yields.

b. Botanical biopesticides

Another medium-term control method is the use of botanical biopesticides, such as azadirachtin, extracted from the neem tree (*Azadirachta indica* A. Juss., Meliaceae) (Schmutterer, 1990). This is the most widely studied botanical biopesticide used against flea beetle pests. It can be combined with other biopesticides such as microbial organisms or fatty acids (see Table 5) and seems to be more effective when used in combination with other products than when used alone. Further work is required to identify the most effective combination for CSFB control.

2.3. Long-term control methods

a. Resistant varieties

Current research indicates that hybrid OSR varieties are more tolerant of CSFB presence as these crops develop faster in autumn and/or spring (Ortega-Ramos et al., 2021). There is also the possibility to identify resistant genotypes that can be crossed with high-yielding genotypes. While no differences in larval infestations between genotypes so far tested have been reported (White et al., 2020), CSFB larvae are known not to develop as well in white mustard compared to OSR (Ortega-Ramos et al., 2021).

b. Parasitoids

While parasitoids of CSFB have often been considered to have little impact on CSFB populations in the UK, Jordan et al. (2020) recorded more promising results with the parasitoid *Microctonus brassicae* (see Table 6). The successful use of parasitoids will, however, require more research on the biology, distribution, parasitism rates in the field, and whether conservation or augmentation approaches to biological control would be most effective/practical (Jordan et al., 2020).

3. Conclusion

Despite encouraging results, many of the control methods presented here have yet to be incorporated into IPM programmes for CSFB. There are several reasons for this, including a lack of underpinning research, financial constraints, legislation around approval of biopesticides and limited adoption to date of IPM in arable cropping systems. Reviews such as this should also be mindful of publication bias, where 'studies with significant or favourable results were more likely to be published, or were likely to be published earlier than those with non-significant or unimportant results' (Song et al., 2010). This is problematic, as the effect of publication bias is to give the impression that products are effective even though work is often only completed under laboratory conditions. As a result, these studies are published and encourage further work by researchers who are unaware that these same products were found not to be effective, often under field conditions, as these studies are often not published. Despite this, the diversity of approaches tested and positive results reported in multiple studies indicates the potential of many of the control methods/agents highlighted in this review.

A lack of fundamental knowledge of how products may interact is apparent in studies that have sought to combine control methods where the selection of control methods often appears arbitrary. Despite this, studies presented in this review have demonstrated positive results when combining control agents, such as two species of entomopathogens (Antwi and Reddy, 2016; Reddy et al., 2014), entomopathogenic nematodes with a conventional insecticide (Antwi and Reddy, 2016), azadirachtin with entomopathogenic nematodes (Yan et al., 2013), azadirachtin with fatty acids (Reddy et al., 2014). More research in this area would enable the intelligent selection of combinations of control methods that work additively or synergistically within an IPM programme.

The high cost of currently available biopesticides, which have to date, been used primarily in horticultural crops is often seen as a barrier to uptake. Indeed, based on current prices, a single application of a fatty acid is likely to cost up to 20 times more than an application of a pyrethroid insecticide. While the cost of biopesticides is likely to decrease if widely used in arable crops, such as OSR, the current requirement for the use of multiple applications of a biopesticide must also be addressed. Despite this, direct comparisons between the costs of biopesticides and conventional synthetic insecticides is unhelpful in that this implies that one is simply a direct replacement for the other. Instead, biopesticides should be seen as a component of IPM programmes, where the value of the biopesticides is its effectiveness and compatibility with other management tools that may also include synthetic insecticides.

IPM is often visualised as a pyramid, with the base consisting of preventative measures, and the top consisting of chemical control methods. In the case of CSFB in OSR, an IPM pyramid (see Figure 3) could be based on the agronomic practices listed in section 2.1.a, as well as resistant varieties listed in 2.3.a, followed by monitoring CSFB migration, crop damage and number of individuals (adults and larvae) in relation to existing thresholds, which were developed by Green (2008). Where monitoring activities (Ortega-Ramos et al., 2021) indicate a pest pressure that exceeds existing thresholds, then biological control methods such as entomopathogens, natural enemies or biopesticides may be used. Only when biological control methods have not provided adequate control should conventional synthetic insecticides be used as a last resort, either on their own or combined with biopesticides to increase their efficacy and reduce the quantities required.

Despite having this model for IPM of CSFB in OSR, more research is required to develop and demonstrate the reliability, practicality and cost effectiveness of this approach. In this respect, development of improved monitoring tools and thresholds are likely to be as important as demonstrating the efficacy of biopesticides and other IPM compatible control methods in encouraging uptake by farmers. Importantly, future research should seek to identify the positive interactions between each of the constituent parts to unlock the true potential of IPM.

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Figure 1. Adult cabbage stem flea beetle feeding damage, called ‘shot-holing’, on oilseed rape leaves.

<u>Figure 2. Cabbage stem flea beetle larvae (mainly third instars) feeding in the petiole of an oilseed rape plant.</u>

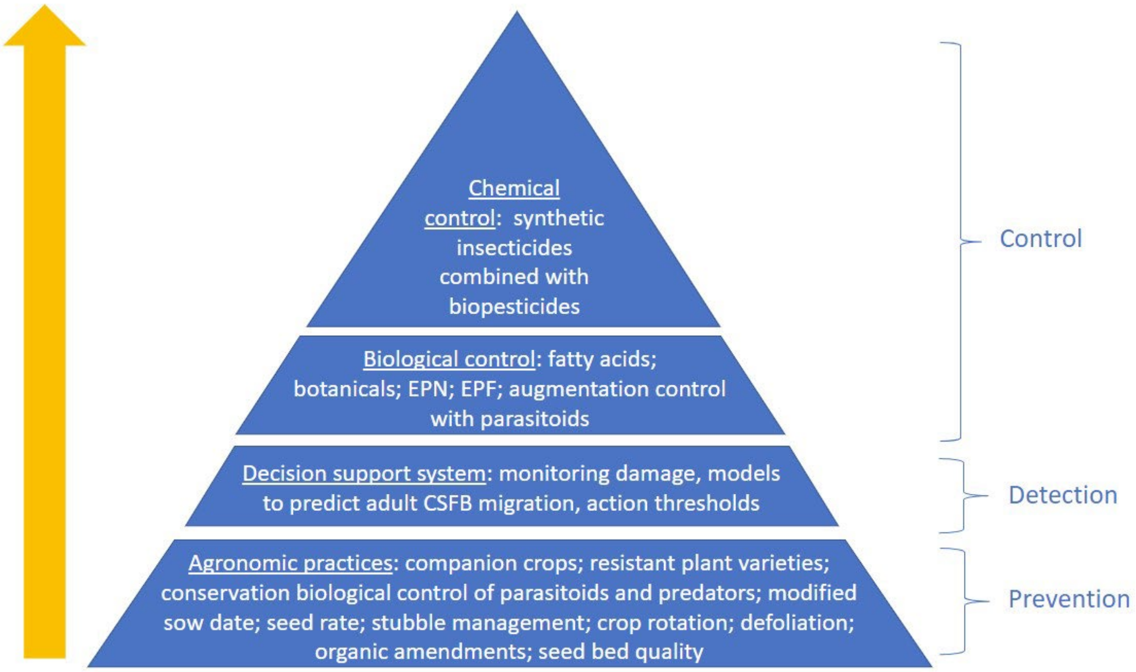

Figure 3. Integrated Pest Management (IPM) pyramid for the control of cabbage stem flea beetle (CSFB) in oilseed rape (adapted from Hoarau et al., 2022)

Table 1. Agronomic practices to control the cabbage stem flea beetle (CSFB) in oilseed rape.

Practice	Take-home message	Reference
Crop rotation	Unlikely to disrupt CSFB as they are highly mobile unless rotations between farms of the same area are synchronized.	Ortega-Ramos et al. (2021)
Tillage and stubble management	CSFB numbers reduced when using minimum or zero tillage compared with ploughing. Reduced tillage increases soil-dwelling predator numbers. Conflicting results on the effect of long stubble from the previous crop on adult CSFB infestation.	Blake et al. (2021) Ortega-Ramos et al. (2021) White et al. (2020)
Mowing/sheep grazing (defoliation)	Removing infested leaves improve yields by reducing numbers of larvae entering the main stem in spring. Oilseed rape can compensate for defoliation before stem elongation. Further work is required to optimize timing and grazing intensity to overcome these negative impacts. In winter, defoliation helps reduce larval numbers by up to 75%.	Blake et al. (2021) Ortega-Ramos et al. (2021)

Seed rate	Conflicting results on the effect of high versus low seed rate, with some studies finding that it is best to increase the seed rate to reduce CSFB infestation, while others reported that low seed rates were more effective.	Blake et al. (2021) Ortega-Ramos et al. (2021) White et al. (2020)
Companion planting	Two approaches: nurse crop (protect and hide oilseed rape) and trap crop (attract pest away from oilseed rape). Berseem clover as a nurse crop reduced CSFB adult damage and/or larval infestation. Trap crops reduce CSFB adult and larval infestation and damage, such as turnip rape or volunteer oilseed rape.	Blake et al. (2021) Ortega-Ramos et al. (2021) White et al. (2020)
Sowing date	Early drilling (before mid-August) because plants are more robust once the CSFB migrate to the crop, but also means increased infestation by larvae as plants are exposed to oviposition for longer than late-sown crop (from mid-September). Late sowing also means that the crop emerges after peak CSFB migration.	Blake et al. (2021) Ortega-Ramos et al. (2021) White et al. (2020)
		Blake et al. (2021)

Seed bed quality	Moist soils led to lower levels of damage compared to dry soils, due to faster emergence and vigorous growth.	Ortega-Ramos et al. (2021) White et al. (2020)
Organic amendments	Some reports of reduced adult CSFB damage, due to the smell potentially deterring or preventing the pest from finding the crop or improving crop growth.	White et al. (2020)
Varieties	Some varieties better able to tolerate CSFB feeding damage	White et al. (2020)

Table 2. Results of laboratory and field studies using fatty acids against flea beetle species.

Targeted pest	Study type	Treatment	Main results	Reference
Adult crucifer flea beetle	Canola field, USA	M-Pede	Significantly reduced leaf damage when combined with azadirachtin and increased yields	Reddy et al. (2014)
Adult CSFB	Laboratory, UK	FLiPPER and Neudosan	After 24h: With FLiPPER, > 85% mortality; With Neudosan: >60% mortality.	Hoarau et al. unpublished

Table 3. Results of laboratory and field studies using entomopathogenic fungi (EPF) species *Metarhizium anisopliae* and *Beauveria bassiana* against flea beetle species.

Targeted pest	**Study type**	**Treatment**	**Main results**	**Reference**
Adult CSFB	Laboratory, UK	*M. anisopliae*	100% mortality after 14 days with isolate V90 (ARSEF 819).	Butt et al. (1992)
Adult CSFB	Laboratory, UK	*M. anisopliae, B. bassiana*	V208 and V245 of *M. anisopliae* led respectively to 88% and 73% mortality.	Butt et al. (1994)
Adult crucifer flea beetle	Laboratory, Canada	*B. bassiana*	50-90% mortality within 7 days of inoculation.	Miranpuri and Khachatourians (1995)
Adult *Phyllotreta* spp.	Turnip rape field, Finland	*M. anisopliae* (strain/isolate unidentified)	Reduced flea beetle emergence after a spray application (41% reduction) and soil incorporation (34% reduction).	Menzler-Hokkanen et al. unpublished (cited in Hokkanen et al. (2003)
Adult crucifer flea beetle	Laboratory and field, USA	Botanigard ES (*B. bassiana* GHA*)*	Low flea beetle mortality in the laboratory, high leaf damage in the field.	Antwi et al., 2007a,b)
Adult crucifer flea beetle	Canola field, USA	Botanigard 22WP (*B. bassiana)* +	Applying each EPF twice reduced feeding damage and led to similar	Reddy et al. (2014)

		Met52 (*M. anisopliae* F52), applied successively, once or twice	or higher yields compared to neonicotinoid seed treatment.	
Adult CSFB	Laboratory, UK	Botanigard WP (*B. bassiana* GHA)	>50% CSFB mortality after two weeks when applied at double the field rate.	Hoarau et al. unpublished

Table 4. Results of laboratory and field studies using entomopathogenic nematodes (EPN) species of *Steinernema* and *Heterorhabditis* genera against flea beetle species.

Targeted pest	**Study type**	**Treatment**	**Main results**	**Reference**
Adult crucifer flea beetles	Caged canola micro plots, Canada	*S. feltiae*	No difference compared to water control.	Morris (1987)
Larvae of striped flea beetle	Laboratory and field, China	*S. feltiae*	Between 87 and 100% of larvae parasitized in the lab, and between 77 and 94% in the field.	Li and Wang (1990)
Larvae of striped flea beetle	Vegetable field, China	*S. carpocapsae*	Reduced larval populations from 38 to 84%.	Wei and Wang (1993)
Larvae of striped flea beetle	Field, China	*S. carpocapsae*	71% of larvae infected by EPN.	Hou et al. (2001)
Larvae of striped flea beetle	Japanese radish field	*S. carpocapsae*	Damage to roots was 3-5 times lower than in controls.	Kakizaki (2004)
Adult CSFB	Oilseed rape field, Finland	*S. feltiae*	Reduced flea beetle emergence by 56%.	Hokkanen et al. unpublished (mentioned in

				Hokkanen et al., 2003)
Adult *Phyllotreta* spp.	Oilseed rape fields, Finland	*S. feltiae*	Reduction (41.5%) in the recorded numbers of flea beetle	Hokkanen et al. (2006)
Adult *Phyllotreta* spp.	Oilseed rape fields, Finland	*S. feltiae*	Reduction of 50.1% in numbers of flea beetle.	Menzler-Hokkanen and Hokkanen (2005), mentioned in Hokkanen (2008)
Various adult *Phyllotreta* spp.	Laboratory, Slovenia	Commercial formulations of *S. feltiae*, *S. carpocapsae*, *H. bacteriophora*, and *H. megidis*	For all nematode treatments, flea beetle mortality was greater than in the control treatment. *S. feltiae* and *H. bacteriophora* were the most effective species.	Trdan et al. (2008)
Larvae and pupae of striped flea beetle	Laboratory, China	*S. carpocapsae, S. pakistanense* and *H. indica*	Flea beetle mortality above 80% for all four isolates reached at 25°C.	Xu et al. (2010)
			Both EPN species reduced soil-dwelling flea beetle larval	

Larvae and adults of striped flea beetle	Cabbage field, China	*S. carpocapsae* and *Heterorhabditis indica*	populations in the field, decreased leaf damage and increased yields.	Yan et al. (2013)
Adult crucifer flea beetle	Canola field, USA	Millenium (*S. carpocapsae*), applied twice or four times	Both treatments significantly reduced adult feeding damage compared to untreated plots.	Reddy et al. (2014)
Adult crucifer flea beetle	Canola field, USA	Scanmask (*S. feltiae)* and Ecomask (*S. carpocapsae*), each applied alone or combined, or with a polymer gel Barricade	EPN applied as a single species or combined with a second species, without Barricade, were not effective. *S. feltiae* + 1% Barricade resulted in significantly higher yields.	Antwi and Reddy (2016)
Adult crucifer flea beetle	Canola field, USA	Steinernema-System (*S. feltiae)* + 1% Barricade	Level of control comparable to neonicotinoid seed treatment.	Briar et al. (2018)
Larvae and adults of	*Brassica campestris*	*S. carpocapsae,*	For *B. campestris*, no effect on larvae, while for *B. juncea,* lower	

striped flea beetle	and *B. juncea* field, China	*S. pakistanense* and *H. indica*	numbers of larvae with EPN. No effect on adult numbers and yield.	Yan et al. (2018)
Larvae and adults of striped flea beetle	Laboratory and Chinese radish field, Thailand	*S. siamkayai, S. carpocapsae* and *H. indica*, Range of concentrations	In the laboratory EPN treatments killed all stages of the pest. In the field, no effect on adult numbers. EPN significantly reduced damage on radish roots.	Noosidum et al., (2021)
Adult CSFB	Laboratory, UK	*S. feltiae, S. carpocapsae*, *S. kraussei* and *H. bacteriophora*	*H. bacteriophora* most effective (>75% mortality after 8 days), *S. feltiae* second best (85% mortality after just two days), *S. carpocapsae* slower to act (maximum 30% mortality after 2 days), *S. kraussei* least effective (maximum of 50% mortality)	Hoarau et al. unpublished

Table 5. Results of laboratory and field studies using the botanical insecticide azadirachtin, alone or combined with other products, against flea beetle species.

Targeted pest	**Study type**	**Treatment**	**Main results**	**Reference**
Adult striped flea beetle	Cabbage field, China	Azadirachtin + *S. carpocapsae* and *H. indica*	Azadirachtin significantly decreased emergence when combined with EPN.	Yan et al. (2013)
Adult crucifer flea beetle	Canola field, USA	Aza-Direct (azadirachtin) combined with M-Pede (fatty acids) or petroleum spray oil	Both combinations decreased leaf damage and partly increased yields.	Reddy et al. (2014)
Adult CSFB	Laboratory, UK	Azatin (azadirachtin)	Less than 40% mortality after two weeks when sprayed at field rate.	Hoarau et al. unpublished

Table 6. Parasitoid and predator species used as biocontrol agents against various stages of cabbage stem flea beetle (CSFB).

Targeted pest	**Study type**	**Treatment**	**Main results**	**Reference**
CSFB larvae	Field, France	*Tersilochus tripartitus* (Brischke, Ichneumonidae)	61% parasitism	Alford (2000)
CSFB larvae	Field, Europe	*Tersilochus microgaster* (Szépligeti, Ichneumonidae)	0-57% parasitism in Germany, 11% in the UK	Ulber et al. (2010)
CSFB larvae	Field, France	*Aneuclis melanaria* (Holmgren, Ichneumonidae)	0.2-1.5% parasitism	Jourdheuil (1960)
CSFB adult	Laboratory, UK	*Microctonus brassicae* (Haeselbarth, Braconidae)	44% parasitism	Jordan et al. (2020)
Crucifer and striped				

flea beetle adults	Field, USA	*Microctonus vittatae* (Muesebeck, Braconidae)	3-15% parasitism (crucifer) and 15-53% (striped)	Wylie (1982)
Crucifer and striped flea beetle adults	Field, Europe	*Townselitus bicolor* (Wesmael, Braconidae)	50% parasitism	Sommer (1981) (in Dosdall and Mason, 2010)