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Myiopardalis pardalina in Afghanistan

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ABSTRACT: The Baluchistan melon fly, *Myiopardalis pardalina* (Bigot), is a serious and worsening problem in Central Asia. As it survives snowy and subzero temperatures as an overwintering pupa, it constitutes a quarantine risk to temperate countries where melons are grown, including in North America and Southern Europe. It is spreading rapidly in Turkmenistan and Uzbekistan as well as Afghanistan, and present from Turkey to India. Losses without control mount as high as 80%. In spite of this, the control of the fly has been little studied, and published recommendations are largely for cover applications of chemicals. It responds to no known lures, and reports of bait responses, though mixed, indicate poor responsivity. This study addressed these problems with a "crash program" of research in the melon season of 2006, in Mazar-i-Sharif, Afghanistan, with the following findings. (1) Although absence of proof of response is not proof of absence of response, adult flies responded to none of a wide suite of food baits in the field or laboratory. (2) Females laid viable eggs, with offspring completing their life cycle, having received no food as adults, adding suggestive support to a conclusion that adults may not be attracted to food baits. (3) When leaves were coated with sugar, however, flies which were on them were stimulated to remain, indicating that the addition of sugar to cover sprays (as opposed to spot sprays which might have attracted flies from a distance) may enhance their effectiveness and persistence. (4) Pupae experimentally buried to different depths led to teneral adult emergence from 50cm of soil, and thus fruit disposal by burial may need to be deeper than this. (5) Pupae in soil fully flooded for 48 hours suffered no reduction in survival, and thus field flooding for control may need to be longer than this. (6) A study of pupation found that (i) up to ten prepupal larvae may leave a melon through the same hole, (ii) unlike those of *Bactrocera*, larvae do not jump about and (iii), as a result, immediately around and below an exit-holed melon large numbers of pupae may be found in the soil. As infested melons are identified by exit-holes, if these are removed by the farmer a large number of potentially-reinfesting adults are still present in the field – but tightly grouped and thus easily located. (7) Postpupal adults emerging from the soil were killed by surface spot applications of carbaryl dust, even if applied days earlier: such applications, to the precise sites where infested melons were removed, may reduce the risk of adult reinfestation. As a result, recommendations were developed for in-field, in-season control by cover sprays with added sugar and the removal of infested melons with spot treatment of their resting places. A need remains, however, for research into attacking the life cycle at its putatively most vulnerable point – the overwintering pupae in melon fields which, in Afghanistan, are traditionally planted with winter wheat. Winter suppression, ideally cooperatively on an area-wide basis, seems to offer the best hope for sustainable control if the best way to do this can be discovered.

Key Words: Baluchistan melon fly, bait, cultural control, pupation

1. INTRODUCTION

The Baluchistan Melon Fly, *Myiopardalis pardalina* (Bigot), is a species relatively little studied. This paper reports the outputs of a "crash program" of research, undertaken in June and July 2006 in and immediately around Mazar-i-Sharif, Afghanistan, intended to find out as much as possible in a short time about its ecology, behavior and management, which might help to develop effective controls making minimum use of insecticides. Largely running concurrently, studies covered a wide range of topics; replication was not always optimal. This paper therefore comprises a series of "mini-papers", assembling a variety of small studies covering a wide range.

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2. BACKGROUND, BIOLOGY AND HOSTS

2.1. Distribution

The distribution of *Myiopardalis paradlina*, the only species in the *Myiopardalis* genus, was described in the late 1950s as from Cyprus, Lebanon, Turkey and Israel in the West through the Caucasus, Iraq and Iran to Afghanistan, Pakistan and India in the East (INKTO, 1957, CABI, 1961). Reported as a destructive pest in Western Afghanistan in the 1970s (Ullah, 1987), it has been observed to spread in an invasive "wave-front" from an epicenter tentatively identified in the far west, around Herat and the Iranian border, northwards and eastwards to Mazar-i-Sharif between 1995 and 2006. Similar progressions were apparent in Turkmenistan and Uzbekistan (pers. comms.). Why this is so, and the implications for the risk posed to other areas, are unclear. It is possible, in the light of the paucity of regional studies, that more than two or more species, with different characteristics, are going under the name of *Myiopardalis pardalina*.

2.2. Biology

Myiopardalis biology has been described in the Caucasus, Iran and Turkmenistan (respectively INKTO, 1957, Manukyan, 1974, García et al., 2002). Flies pass the winter as pupae in soil, and emergence begins in May/June, when the cucurbit flowers began to set fruit, until July. Oviposition begins in a week or less, and continues for about three weeks, each female laying up to 100 eggs or more, with a preference for small (<7cm) or newly-set fruit. Duration of the egg stage varies from 2-3 days in summer to a maximum of 7 days in autumn. The larval period lasts 8-18 days and the pupal stage 13-20 days or more. Pupation is in the soil and in fruit. Approximately three incomplete generations occur in a year, with considerable overlap. The life-cycle is completed in 30 days in summer. In this study, individual females in the laboratory were observed to mate with more than one male.

2.3. Hosts and Losses

Myiopardalis attacks watermelons, cucumber, muskmelon, snake melon, pumpkin, squirting cucumber and phoont (*Cucumis trigonus*) (INKTO, 1957). Unlike *B. cucurbitae*, however, which attacks gourds, cucumbers, pumpkins and other cucurbits with relish, it has a marked preference for musk/sweet melons over water melon and other cucurbits (Ullah, 1987). Losses have been reported as 85-90% of melons and 60% of watermelons in Israel (INKTO, 1957), 56.7% of melons, 2.8% of water melon, 1.1% of pumpkin and 0.1% of cucumber in Turkmenistan (García et al., 2002) and 6.7-34.5% of melons in Armenia (Manukyan, 1974). In Pakistan, if melons are bagged against attack 40,000 can be produced in an area where only 2,500 can be produced otherwise (INKTO, 1957), and the fly's arrival in Turkmenistan has been implicated in reductions in melon production of 80-90% (García et al., 2002). In this study, losses of unprotected melons in Northern Afghanistan were estimated by field counts and opinions of farmers and fieldworkers as 5-80%, with 30-40% being a typical value. Losses of cucumbers and watermelons were less than 5%.

2.4. Oviposition Size Preference

The preference of ovipositing females for young, small fruit was studied by allowing adult flies to roost, feed, mate and oviposit on a selection of melons, arranged in randomized order, of six different sizes, in six 2.5×0.5×0.5m laboratory cages for replication. Over a day, half-hourly counts were made of flies standing on each melon, and summed to obtain data as counts of "fly.half-hours". Means of these are given in Table 1. The distribution was highly "humped" with significant regression terms for both the ascending (slope t=6.6821[34]***) and descending (slope t=6.7412[33]***) components of a quadratic regression.

Table 1. Mean counts of adult fruit flies standing on melons of different sizes. N=6.

Fruit size (vernacular)	Nut	Apricot	Small mango	Large mango	Small melon	Large melon
Fruit length (cm)	2	5	10	15	20	40
Fly attention (fly.half-hours)	0.4	29.0	24.1	18.5	17.6	10.4

2.5. Oviposition "Clustering"

Observation in the laboratory indicated that some melons were more popular than others, females tending to group on a subset of "preferred" melons, even when these were already punctured by larval exit holes. Fresh and whole melons were preferred to older or damaged ones. A study was made of whether already-oviposited melons may be more or less likely to attract the attention of ovipositing females (in some tephritid species, ovipositing females leave kairomones to discourage others, "flattening" the distribution; in other cases, when melon skin is tough females may use the holes of earlier ovipositions to lay their own eggs, "clustering" the distribution). In a 2.5×0.5×0.5m laboratory cage, containing 25-30 young adult flies including laying females, were placed six melons which had been oviposited by other females and six melons which had not, in alternating pairs to minimize directional differences such as light. Half-hourly counts over three days were made of numbers of adults on each melon, and summed to totals of fly.half-hours on each melon. Means of these are given in Table 2. The difference between the two was not statistically significant ($t[11]=0.4444$ns).

Table 2. Mean counts of flies on melons which had or had not been previously oviposited. N=6.

Melon status	Oviposited	Unoviposited
Fly attention (fly.half-hours)	4.2	6.3

2.6. Control History

No natural enemies are reported as effective on *Myiopardalis*, either in general (Stibick, 2004) or in Afghanistan in particular (Ullah, 1987). There is potential for the breeding of resistant cultivars, though with strong cultural attachments to traditional varieties these cannot offer short-term help (Manukyan, 1974, García et al., 2002, Saparmamedova, 2004). Some suppressive effect has been reported by fruit pruning and thinning (Kashi & Abedi, 1998). Bagging, used in Pakistan, would be expensive in rural Afghanistan, which has virtually no supply of newspapers from which cheap bags might be made.

Recommendations for *Myiopardalis* management are at present, with a very few exceptions, based on cover applications of insecticide (Eghtedar, 1991, Prokudina & Shevchenko, 1983, pers. comms.). At present, no consistent differences between insecticides are apparent, and the current recommendation in Afghanistan is to use the safest and least environmentally damaging products available. Recommendations have emphasized the importance of timing, and particularly of early use, soon after or even before fruit set (during flowering) and indicated that three applications early in the season are effective (Prokudina & Shevchenko, 1983, Stride et al., 2002, pers. comms.).

Control recommendations are generally augmented by cultural methods, comprising some or all of the following (Prokudina & Shevchenko, 1983, Stride et al., 2002, García et al., 2002, pers. comms.)

- Resistant varieties
- Early or greenhouse planting
- Shallow or deep ploughing to expose or bury overwintering pupae
- Destruction of alternate hosts (wild cucurbits - largely absent in Afghanistan)
- Collection and destruction of infected fruit
- Destruction of plant residues
- Short and long term crop rotation

3. ADULT CONTROL - ATTRACTANTS, REPELLENTS AND INSECTICIDES

3.1. Attraction to Light and Color

Responses to color were assessed by placing in three farm melon fields a number of

70cm-diameter red, orange, yellow or blue plastic washing up bowls, adding up to a total of 21 trapxdays of each colour. No fruit flies were caught (though catches included bees, wasps, beetles, grasshoppers, dragonflies, mantids and non-tephritid flies). Responses to light traps were assessed with kerosene lamps, standing in blue washing up bowls of water, in two fields, adding to a total of nine trap.days. Traps caught no fruit flies (though over one hundred moths).

3.2. Repellence by Smoke

Smoke from fires to repel adults from crops has been recommended in Iran and Afghanistan (pers. comms.), including the use of the seeds of *espand* (*Perganum* sp.), which have a pungent smell and are often burnt to repel houseflies and other noxious creatures with their smoke. The effects of smoke on fly roosting were assessed in a 2.5×0.5×0.5m laboratory cage. Six melons were placed along the cage, and a small pot of burning material placed at one end. Flies were released into the cage, and half-hourly counts made, over half a day, of the time spent on each melon. The experiment was repeated four times for replication, with the end with the firepot alternating from left to right to balance out any background trends such as the effects of light. Fires were of wheat straw, alone or mixed with *espand*. When the fire was lit, the migration away from the smoke source was not immediate but took place over some two hours. Table 3 shows the distribution of flies at the final count of each run, after four hours. In each case the decline in numbers with increasing distance from the firepot was significant (for straw regression slope t=4.7538[22]***; for *espand* t=8.5239[22]***). The slope for the relationship was steeper for straw without *espand* than with it, providing no evidence that adding *espand* to the fire increased its effectiveness. It is not clear whether this positive result in the laboratory may be translated into effective field control.

Table 3. Mean distribution of flies on rows of melons in response to smoke. N=4.

Distance from source (cm)		**25**	**50**	**75**	**100**	**125**	**150**
Fly attention (fly.half-hours)	Straw	0	0	0	5	13	23
	Espand	0	0	0	3	2	20

3.3. Food Bait Olfactory Response - Attraction at a Distance

Food baits have indicated some attractive power against *Myiopardalis* in the past. In Herat, Afghanistan, control was obtained by spot sprays of a bait of boiled beef meat with crushed cucumber extract and urea (Stride et al., 2002) - the "Herat mix". Trap trials in Tejen, Turkmenistan, found adults in McPhail traps baited with beer waste, "Nu-Lure", ammonium acetate and ammonium carbonate (García et al., 2002).

First, baits were evaluated for olfactory responses, exerting stimulus at a distance. A wide and shifting range and mixture of candidate baits were assessed, to maximize chances of finding one satisfactorily attracting ingredient and representing all together a "best bet" chance of attracting flies if any such attraction were possible.

3.3.1. Field Attraction Study

Baits were applied to the undersides of leaves *in situ* on plants in the fields, with catchers to retain flies attracted and killed, placed 5-15cm below, in complete randomized blocks. Six treatments were used:

1. Simple sugar – 100 g of white refined sugar in 1 l of water
2. Complex sugars – 1 l of water containing 100 g of jaggery (unrefined cane sugar), 3 g dried melon, 4 g milk powder, 1 g citric acid, 4 g of mango drink powder and 1 dessertspoonful of honey
3. Fermented sugar – 100 g of jaggery in 1 l of water, fermented with one teaspoon. l^{-1} of active yeast for 24 hours
4. Commercial protein acid hydrolysate (International Pheromone Systems Ltd, www.internationalpheromones.co.uk) – 30 ml in 1 l of water
5. Animal protein – "Herat mix" comprising 250 g of beef boiled in 1 l of water for 20 minutes and skimmed of fat, with half a cucumber in 125 ml of water, liquidized, fermented for two days and sieved, and 5 g of urea in 125 ml of water
6. Untreated – water only

Assessment was in four sequential studies, in an increasingly intense attempt to obtain a response. The first three studies took place in an early-planted field, with 42.5% infestation (from visual inspection of a sample of 40 fruits); insecticide added to all six baits was malathion EC at 2%. The fourth study took place in a late-planted field, where no melons were mature, but in the evening adult flies were observed walking and mating on melon vegetation; insecticide added was deltamethrin EC at 0.5%.

Study 1. Application was of 10ml of bait to individual melon leaves, with a 5cm commercial paintbrush. Catchers were 28cm-diameter plastic washing-up bowls placed immediately below, with approximately 5cm of water. Checked over 72 hours; N=3.

Study 2. Application was of 100ml to $1m^2$ of melon vegetation, with a 5cm brush. Catchers were $1m^2$ squares of carpet, with a film of vegetable cooking oil applied with a paintbrush. Two blocks were in the melons themselves (close to the field edge) and one in trees and higher vegetation at the field margin. Checked over 72 hours; N=3.

Study 3. Application was as 40ml with handheld mist sprayers to $1m^2$ of dense arboreal foliage along the field margin, in cool, shaded and moist areas. Catchers were cotton bags stitched to rigid metal frames with a circular mouth 0.5m in diameter. Checked over 96 hours; N=2.

Study 4. Application was of 100ml to $1m^2$ of melon leaves, with hand sprayers. Catchers were $1m^2$ squares of carpet brushed with vegetable oil. Checked over 48 hours; N=3.

Baits caught muscid and other common flies, small wasps, small beetles, bees and crickets, but no tephritids.

3.3.2. Laboratory Attraction Study

In laboratory experiments each complete randomized block was a cage of mosquito netting stitched around a wire frame, a cube of approximately 1×1×1m. Candidate baits (except whole melon) were in Petri dishes held against the sides of the cages, but not in contact with them, so that olfactory (and visual) attraction would be unaffected but tactile attraction not possible. Flies standing on the cage walls opposite each dish were counted half-hourly for one day, to obtain data in fly.half-hours. Two sequential experiments were conducted (each N=2). Six baits were assessed, differing slightly between experiments:

1. Simple sugar – 100 g in 1 l of water
2. Complex sugars – 1 l of water with 25 g jaggery, 25 g honey, 25 g orange powder drink and 25 g mango powder drink

3. Protein hydrolysate – 30 ml in 1 l of water
4. Animal proteins – 1 l water with 250 ml boiled beef stock, 250 ml blood, 25 g urea and 25 g milk powder
5. Melon fruit – (Experiment 1) a 5 mm-deep disc of melon skin and flesh in a Petri dish; (Experiment 2) a small whole melon, skin unbroken, held against the cage in a cylinder
6. Dried melon – (Experiment 2 only) 1 l water with 100 g macerated dried melon
7. Control – water only

Mean numbers of fly.half-hours spent by flies opposite the various bait dishes are given in Table 4. Means, and analysis, are of data converted to logarithms. The four treatments common to both experiments were analysed statistically, by related *t*-tests of the three baits against the untreated control. Only melon fruit was significantly different from the untreated (t=3.823[3]*; for simple sugar t=0.775ns; for protein hydrolysate t=1.000ns). The exploitation for pest management of the attraction to adult flies of melon fruit remains an area for further study.

3.3.3. Adult Nutrition and Reproduction

Bait studies were complemented by observations on adult nutrition and reproduction. In the laboratory, emerged populations of adult melon flies were kept on a diet of water only. Young, small melons, suitable for oviposition, were placed in the cages, and emergence from these assessed by sieving sand from the bottom of the cages for pupae. Larvae emerged, and developed successfully into pupae and adults. This confirms that the life cycle can be completed without adult feeding. If adult *Myiopardalis* can produce viable offspring without feeding as adults, but relying on their larval food reserves, then this may explain why they are not attracted to food baits to adults.

It seems likely that *Myiopardalis* is not usefully olfactorily responsive to any bait. The list of possible candidate baits is not exhausted, however, and further trials are in development.

Table 4. Mean counts of adult flies standing opposite dishes of various baits. N=2 or 4.

Treatment	Melon fruit	Simple sugar	Complex sugars	Protein hydrolysate	Animal protein	Dried melon	Untreated
Fly attention (fly.half-hours)	5.3	0.7	0.0	0.4	0.0	0.4	0.2

3.4. Food Bait Tactile Response - Stimulus to Remain

Distinct from olfactory attraction, which allows baits to be used in isolated spots which may attract victims from a distance, is tactile stimulus to remain. While acting only on contact and thus unable to attract victims to spot sprays this may, if added to cover sprays, stimulate insects to remain, prolonging contact with deposits, and thus increase uptake and allow lower doses and longer reapplication intervals. Sugar has been successfully added to fruit fly cover sprays in other parts of South Asia (Verma & Sinha, 1977).

Assessment of stimulus to remain was by exposing flies to leaves coated with candidate baits. All treatments were applied with brushes to the undersides of melon leaves hung from ceilings of mesh cages. Flies standing on treated leaves were counted half-hourly, to obtain data as fly.half-hours. Each cage was a complete randomized block, locations of treatments in cages being independently randomized.

3.4.1. Comparison of Stimulant Effectiveness

Two successive experiments were carried out, each with four replications and run for one day, but with slightly differing treatment sets. Treatments were as follows:-

1. Simple sugar – 1 l water containing 100 g of white refined sugar
2. Complex sugars – (Experiment 1) 1 l water containing 100 g jaggery, 3 g dried melon, 4 g milk powder, 1 g citric acid, 4 g of mango drink powder and 1 dessertspoonful of honey; (Experiment 2) 1 l of water containing 25 g of jaggery, 25 g of honey, 25 g of orange drink powder and 25 g of mango drink powder
3. Fermented sugar – (Experiment 1 only) 1 l of water containing 100 ml of jaggery fermented with one teaspoon of active yeast for 24 hours
4. Protein hydrolysate – 30 ml in 1 l
5. Animal protein – 1 l of water containing 250 g of beef boiled in 1 l of water for 20 minutes and skimmed of fat, with (Experiment 1) half a cucumber in 125 ml of water, liquidized, fermented for 2 days and sieved and 5 g of urea in 125 ml of water (i.e. "Herat mix") or (Experiment 2) 250 ml of blood, 25 g of urea, 25 g of milk powder
6. Fresh melon – (Experiment 2 only) 1 l of water containing 100 g of macerated fresh melon
7. Untreated – Water only as a control

Totals of fly.half-hours were converted to logarithms before calculation of means and significance statistics. Table 5 shows results from the two experiments pooled. Each of the baits used in both studies was compared with untreated surfaces in planned related *t*-tests. The largest differences were not statistically significant (for simple sugar t=2.077[7] ns; for complex sugar t=1.441[7]ns; all other $t<1$) but the effect of sugar in stimulating adult resting was considered worthy of further study.

Table 5. Mean counts of flies on leaves brushed with various baits. N=4 or 8.

Treatment	Simple sugar	Complex sugars	Protein hydrolysate	Fermented sugar	Animal protein	Fresh melon	Untreated
Fly attention (fly.half-hours)	6.6	5.5	1.6	2.4	2.3	0.0	1.9

3.4.2. Strength of Sugar Coatings

To specify and quantify a suspected stimulus to remain exerted by sugar on leaves, sugar water was applied to individual pumpkin leaves at different concentrations, replicated in six laboratory cages, and the roosting of flies observed. Sugar solutions were 0, 1, 2, 5 and 10%, applied as approximately 0.25ml (two strokes of a 2.5 cm commercial paintbrush) per leaf. Table 6 gives means of fly.half-hours roosting on leaves treated with various strengths over 14 counts on one day. Regression of fly roosting to concentration obtained a significant result (regression F=5.0951[1,23]*).

Table 6. Mean counts of flies on leaves with sugar water of various strengths. N=6.

Sugar strength (%)	0	1	2.5	10
Fly attention (fly.half-hours)	0.3	1.3	1.8	3.7

3.5. Chemical Pest Management in the Field

Seven different chemical controls were assessed in a large irrigated farm field of melons. As the plot was irregularly-shaped a completely randomized design was chosen. Each treatment was replicated eight times, using 56 plots in all. All plots were 15×10m; sprays were of 1l per plot in the first half of the season, and 2l per plot in the latter. Treatments were as follows:-

1. Dipterex spray (2 ml.l^{-1})
2. Carbaryl spray (3 g.l^{-1})
3. Carbaryl dust (1:10 vol:vol in soil dust), at the same a.i./unit area as the carbaryl spray
4. Deltamethrin (1ml.l^{-1})
5. Deltamethrin (1 ml.l^{-1}) with added sugar (50 g.l^{-1})
6. Beef/cucumber/urea ("Herat mix") spot sprays (6 spots, each of 50 ml, per plot)
7. Unprotected control plot

Treatments were applied weekly throughout the growing season, for a total of seven weeks. Numbers of attacked and unattacked melons were counted weekly in all plots.

Table 7 shows the mean percentage infestation from the final count. The results may indicate that deltamethrin, particularly with the addition of sugar, is the most effective control, but this cannot be conclusively asserted as there were no significant differences (ANOVA F=1.5421[6,49]ns).

Table 7. Mean infestation of melons in field plots protected by chemical controls. N=8.

Treatment	Carbaryl dust	Carbaryl spray	Deltamethrin only	Deltamethrin + sugar	Herat mix	Dipterex spray	Untreated
Infestation (%)	10.9	12.8	5.4	5.1	10.3	13.8	15.5

4. PUPAL CONTROL - CULTURAL MANAGEMENT

The emphasis in cultural control has been on disruption of the life cycle by attacking the point where the fly is in, entering or leaving the pupal stage, both in the growing season by the removal of infested fruits and in the winter by ploughing or flooding.

There seems to be potential for the informed use of cultural controls, particularly in winter. If all flies overwinter as pupae, and these are only to be found immediately below the locations of infested melons, then the entire population must pass the winter in the soil in these fields. It is in any case rather surprising that these survive at all – after the final melon harvest fields are commonly irrigated, ploughed, sown with winter wheat and irrigated again, and flies putatively emerge, among the wheat plants, the following spring. The implication is either that pupae survive this gruelling regime in numbers adequately large to found the successor generation the following spring, or that this founding generation is composed of individuals from a few isolated sites such as field margins or piles of discarded fruit. Which of these is the case is a current area of study. Studies were made of where and how pupae may be controlled with the resources available to Afghan farmers.

4.1. Pupal Location in the Field

Infested melons are identified by exit-holes (the oviposition holes are hard to see) and so, by the time a fruit is identifiably infested, there will be pupae in the soil below which will thus escape control by fruit removal. A study of pupal numbers and location by digging and sieving soil around exit-holed melons in farm fields led to the following conclusions.

1. More than one larva may exit through the same hole – the soil below a melon may contain ten pupae for each hole in that melon.
2. *Myiopardalis* larvae emerging for pupation do not travel far. Unlike those of *Bactrocera* they were not observed to jump about. Pupae were found mostly at depths of 5-10cm, and within 30cm of the outer edge of the melon from which they emerged.
3. As a result, pupae in the soil are tightly clustered about the original melon, occupying an area approximately 0.7×0.7m, and thus the effectiveness of fruit removal may be enhanced by localized treatments of removed-fruit "footprints" to kill flies pupating in the soil immediately below.

4.2. Pupal Control

4.2.1. Pupal Control - Burial

In order to discover from what depths flies may emerge, pupae were buried in loose dry unsieved soil in lengths of clear plastic pipe, 3cm in internal diameter, at depths of 0, 1.25, 2.5, 5, 10, 20, 30, 40 and 50 cm. Each depth was replicated six times, in six separate pipes each containing one pupa. Emergence patterns are given in Table 8. Of the four emergents from the greatest depths (30 and 50 cm) none was observed to fly, and two (one from each depth) died with wings visibly unextended. It was concluded that flies may emerge from pupae buried to a depth of 50cm, and that to ensure 100% mortality burial should be deeper than this. Afghan farmers already plough after melons, with ox ploughs to a depth of 10-15 cm; deeper would not be practicable for farmers without tractors.

Table 8. Mean emergence of flies from pupae buried to different depths in soil. N=6.

Depth of burial (cm)	**0**	**1.25**	**2.5**	**5**	**10**	**20**	**30**	**40**	**50**
Emergence (%)	50	33	100	33	33	16	33	0	33

4.2.2. Pupal Control - Flooding

Pupae were placed in soil in the cut-off tops of 1.5l plastic drinks bottles (with the caps on) mounted upside down. Bottles were filled with about 5cm of soil, then six pupae placed on the soil and another 7.5cm of soil put on top, to mimic natural conditions. The bottles were then flooded with water for a specific period of time and then the caps removed so the water drained out again. The top of each tube was then covered with mosquito netting, and numbers of emerging adults counted. Each flooding was replicated in three bottles (18 pupae in all). Treatments were not flooded at all, flooded for one hour, and flooded for 48 hours. Table 9 shows the mean survival as percentages of pupae from which adults emerged. It was concluded that flooding of pupae is not a particularly effective source of mortality when applied for less than three days (few Afghan farmers have access to irrigation for longer than this).

Table 9. Mean emergence of flies from pupae in soil flooded for different periods. N=18.

Flood duration (hours)	**0**	**1**	**48**
Emergence (%)	56	56	61

4.2.3. Pupal Control - Insecticide

A study was made of the effects on pupal survival, and subsequent adult emergence, of insecticides applied to the soil surface. Treatments were untreated control and carbaryl wettable powder, applied either as a dust or a spray. Tests were in containers made of the cut-off bottom of a 1.5L fizzy drink bottle, into which 1cm of soil was placed, then two fly pupae and a further 5cm of soil to imitate natural conditions. Insecticide was then applied to the surface; this was with the intention of obtaining the same dosage of active ingredient per unit area, though this is notoriously difficult to make precise. Dust was made as 1:10 vol:vol of powder and sieved soil dust. A "light but even" cover was obtained by three shakes of a cotton dusting bag, which was 24.6g.m^{-2} of dust, and 0.7g.m^{-2} of carbaryl dust product; in liquid application the same dose was applied as 0.88l.m^{-2} of 0.8g.l^{-1} of WP suspension. Subsequently, each container was hung at the bottom of a tube of mosquito netting 70cm high, to create a column of well-ventilated space above the surface, so that emerged adults were not constrained close to the pesticide-treated surface. Live flies in each column were counted daily. Treatments were each replicated eight times in separate containers, each containing two pupae (16 in all for each treatment). To detect chronic as well as acute lethality, data were gathered as counts of flies alive in each container on each subsequent day, added up to obtain values of "fly.days" of life, and means of these are given in Table 10. Survival under dust treatment was significantly less than under liquid treatment or no treatment (for heteroscedastic data respectively t=5.2613[15]*** and t=2.6429[15]*; between liquid and untreated t=1.3029[15]ns).

Table 10. Survival of adults emerging from soil surface-treated with different insecticide applications while they were pupae below. N=16.

Soil treatment	None	Liquid	Dust
Survival (fly.days)	1	1.5	0

4.3. Cultural Pest Management in the Field

Cultural controls were assessed for their effects on fly infestation in a small irrigated farm melon field. Three controls were used, each applied weekly for four weeks, in two complete randomized blocks:

1. Collection-only – Infested melons collected weekly
2. Collection-and-dust – Infested melons collected and, as each melon was removed, sevin (carbaryl) dust dusted into the gap from which it was removed
3. No treatment

Treated plots were each 20×30m in size; untreated plots, limited in size at the request of the farmer and to the edge of the area (downwind), were triangles 7-20m long and 2-4m wide at the base. Melons were counted as infested or uninfested within the center of each plot, from an area approximately half that of the whole plot. Infested-fruit counts from the final count were divided into totals to obtain percentage infestation estimates, given as means in Table 11. Treatments were not statistically significantly different (ANOVA F=2.089[2,2]ns). It was concluded that fruit-collection-plus-dusting may provide superior control to collection-only and no-treatment, but this was not conclusively demonstrated.

Table 11. Mean infestation of melons in plots protected by cultural controls. N=2.

Treatment	Collection + dusting	Collection only	Untreated
Infestation (%)	24.0	34.5	36.5

5. SUMMARY AND CONCLUSIONS

1. Female adult flies were attracted to small, young, undamaged fruit as oviposition sites. There was no significant difference between melons on which flies had and had not previously oviposited.
2. Adult flies were not attracted to colour or light traps.
3. Neither food nor attractant baits were effective against adult flies. However, the list of possible candidate baits is not exhausted, and further trials are in development.
4. *Myiopardalis* was able to lay viable eggs without feeding during the adult stage.
5. Adult flies persisted on sugar deposits, but were not actively attracted to them from a distance. While acting only on contact and thus unable to attract victims to spot sprays this may, if added to cover sprays, stimulate insects to remain, prolonging contact with deposits, and thus increase uptake and allow lower doses and longer reapplication intervals.
6. Although no statistically significant reduction in infestation rates was achieved by cover spraying in the field, deltamethrin with sugar gave the best results and merits further study.
7. Smoke deterred adult flies in the laboratory, although the addition of *espand* seeds did not increase the effect of burning only straw. It is questionable whether this method offers a viable strategy in the field.
8. Emerging larvae pupated in the soil 5-10cm deep and in the immediate vicinity of the infested fruit. Damage to the fruit is not visible until at least some larvae have emerged, but the area beneath the fruit offers a target for control. Afghan farmers already plough after melons, with ox ploughs to a depth of 10-15cm; deeper would not be practicable for farmers without tractors.
9. Teneral adults are able to emerge through 50cm of soil. Damaged fruit therefore need to be buried deeper than this to ensure 100% mortality.
10. Pupae were able to survive 48 hours flooding of the soil. This calls into question the value of irrigation as a method of cultural control, since farmers are not usually able to irrigate for longer than this because of limitations on the supply of water. It also goes some way towards explaining how pupae are apparently able to survive the routine agricultural practices of ploughing and irrigation during the pupal period.
11. Dusting the soil surface with insecticide was clearly demonstrated in the laboratory to be an effective method of controlling emerging adults, although the field trial was not statistically conclusive.

The above studies led to the formulation of provisional control recommendations as follows:

1. Collection and destruction of infested fruit. As these are identified by exit-holes, the site of each fruit removed should be lightly dusted with insecticide. The emergence of adults from quite deeply buried pupae also indicates that shallow burial of collected fruits may not finish off the inhabitants, and collected fruit should be buried deeply (at least 75cm) and the surface treated with insecticide.
2. Cover application of insecticide when infestation risk is severe. Literature reports suggest that sprays need be no more often than every ten days and, as larger fruit are less prone to attack, focused early in the season. A crop should be considered at risk when a melon field within 500Mm was heavily infested the previous year, and should be treated when the first fruits reach “apricot” size. To increase effectiveness and persistence, sugar may be added to the spray mix at 30g per liter.

3. Coordinated control at neighborhood level. Controls of fruit flies are generally more effective when carried out in a co-ordinated way by neighbors in a locality (Stonehouse et al., in press), and neighbors should be encouraged to conduct controls to prevent reinvasion from nearby.
4. Winter destruction of pupae. It cannot be assumed that ploughing-in (up to 50cm) or short-period flooding (up to 48 hours) will destroy overwintering pupae, and longer-term flooding, of irrigated fields, is to be preferred. The effectiveness of winter control remains to be confirmed.

A need remains for further research into aspects of the management of *Myiopardalis*. One is the chemical basis of the attraction of adult flies to melon fruit, if an analogue may be made available as a field attractant. Another is the attack on the life cycle at its putatively most vulnerable point – the overwintering pupae in melon fields which, in Afghanistan, are traditionally planted with winter wheat. Winter suppression, ideally exercised cooperatively on an area-wide basis, seems to offer the best hope for sustainable control if the best way to do this can be discovered. Many aspects of the management of *Myiopardalis*, including exactly where and how it passes the winter, are still under study.

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