SHORT COMMUNICATION

Germination of kiwifruit, *Actinidia chinensis*, after passage through Silvereyes, *Zosterops lateralis*

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Abstract: Silvereyes, *Zosterops lateralis* Latham, commonly feed on kiwifruit rejected for export and either stored in open bins at packhouses or in piles ready to be fed to livestock, and may play a role in the spread of wild kiwifruit in native and exotic forest in the Bay of Plenty, New Zealand. We determined the germination rate and percentage germination of *Actinidia chinensis* Planch. seed sown (1) after gut passage through silvereyes, (ingested seed), (2) after a standard laboratory fruit pulp removal method (enzyme-extracted seed), (3) as entire fruit and (4) as fruit sections. Ingested and enzyme-extracted seed sown in trays in a glasshouse had nearly identical percentage germination (63.7% and 64.7% respectively) after 71 days. No seed germinated from intact fruit or fruit slices during the experiment. Gut-passage accelerated the germination rate compared with enzyme-extracted seed. This study supports the view that *Z. lateralis* is involved in dispersing kiwifruit seed into native and exotic forest.

Keywords: *Actinidia*, germination, wild kiwifruit, *Zosterops lateralis*

Introduction

Birds that feed on fruit may play an important role in the population dynamics of plants by dispersing viable seed (Snow, 1971). Germination of seed eaten and passed by birds can be enhanced or inhibited (Traveset, 1998; Paulsen and Hogstedt, 2002). The effect of gut passage on seeds varies with different bird and plant species possibly due to differences in gut retention time and the subsequent level of abrasion on the seed coat (Traveset *et al*., 2001). Silvereyes, *Zosterops lateralis* Latham, are common frugivores and feed on and disperse the seed of many native and exotic plants in Australia and New Zealand (French *et al*., 1992; Williams and Karl, 1996; Stansbury, 2001; Stanley and Lill, 2002). In the Bay of Plenty, *Z. lateralis* are readily observed to feed on the pulp of kiwifruit left on vines and in bins and may be contributing to the naturalisation of kiwifruit in neighbouring native and exotic forest (Webb *et al*., 1988; Sullivan and Williams, 2002).

Three species of kiwifruit have been commercialised in New Zealand: *Actinidia arguta* (Sieb. *et* Zucc.) Planch. ex Miq. 'Hortgem Tahi', 'Hortgem Rua', 'Hortgem Toru', 'Hortgem Wha' and several public domain cultivars without standardised names; *A. chinensis* Planch. 'Hort16A' marketed under the brand name 'Zespri™ Gold'; and *A. deliciosa* (A. Chev.) C.F. Liang *et* A.R. Ferguson 'Hayward' marketed as 'Zespri™ Green'. All *Actinidia* species are perennial vines that fruit annually. Most naturalised or wild vines are *A. deliciosa*, but recently, wild *A. chinensis* and *A. arguta*, and the non-commercial species *A. eriantha* Benth. and *A. polygama* (Sieb. *et* Zucc.) Maxim., have been found growing wild. The mix of wild species is probably related to the history of cultivation and to planted area: *A. deliciosa* 'Hayward' was extensively planted in the 1970s and 1980s and is now grown on approximately 9000 ha (Ferguson and Bollard, 1990; Kerr *et al*., 2004); *A. chinensis* 'Hort16A' was commercialised in 2000 and is now established on approximately 1500 ha (Kerr *et al*., 2004), and *A. arguta* has been commercially produced since 2004 and is planted on 24 ha (R. Lowe, HortResearch, Te Puke, pers. comm.). Kiwifruit are thought to have become naturalised after dumping of vines, vine prunings and reject fruit and by dispersal of kiwifruit seed by birds and other frugivores (Sullivan and Williams, 2002). Isolated wild kiwifruit have been reported from Europe,

and may have originated from seed in discarded fruit leftovers as little kiwifruit is cultivated there (Kasperek, 2003). Dumping reject fruit and prunings in bush in the Bay of Plenty is probably now rare but dispersal of seed is likely to remain an on-going source of new plants. Potential seed sources are fruit rejected for export and either stored in open bins at packhouses or in piles ready to be fed to livestock, and fruit left on vines. As many kiwifruit orchards in the Bay of Plenty border gullies that contain native and exotic forest, the risk of dispersal by birds may be high.

Here we report on the germination rate and percentage germination of *A. chinensis* seed sown (1) after gut passage through *Z. lateralis*, (2) after a standard laboratory fruit pulp removal method, (3) as entire fruit and (4) as fruit sections. Our objective was to determine whether gut passage through silvereyes influenced germination of kiwifruit seed. Seed from laboratory fruit pulp removal were included as a comparison to determine whether any effect on germination was due to mechanical and chemical scarification of seed by the gut. Intact fruit and sections were included to test whether any effect on germination was due to the removal of pulp containing germination inhibitors from around the seed (Samuels and Levey, 2005). *A. chinensis* is closely related to *A. deliciosa* and until 1984 formed one taxon (Ferguson, 1990), and bird passage may have similar effects on the seed of both species.

Methods

Seed of *A. chinensis* was collected after gut passage through *Z. lateralis* by the following method. Plastic sheets were placed on the ground under a kowhai tree, *Sophora microphylla*, used as a roost by *Z. lateralis*. The tree was within 3 m of an 800-L bin used for reject fruit at the HortResearch kiwifruit orchard, Te Puke, Bay of Plenty. Fruit at the top of the pile in the bin were part of a selection programme for improved lines of tetraploid *A. chinensis* and had been stored at 1.5 °C for 12 weeks. Plastic sheets were exposed between 11 a.m. and 3 p.m. on each of two consecutive sunny days (18, 19 August 2005). Passage for seed of *Coprosma quadrifida* and *Rhagodia parabolica* eaten by *Z. lateralis* was 6–28 min (French, 1996) and 13–57 min (Stanley and Lill, 2002) respectively, and may be at least as rapid for *A. chinensis*. Thus, seed on plastic sheets was assumed to be from reject fruit added to the bin during the same day. Approximately 320 seeds were collected from plastic sheets after they were left to dry in the laboratory for five days and are referred to below as 'ingested seed'.

Twelve entire fruit and slices of *A. chinensis* fruit were collected from the bin on the same two days that ingested seed were collected. Seed were extracted from six fruit using an enzyme solution at a concentration of 1 mL of pectinase (Rohm Rohapect D5L) to 200 mL of water. Fruit, with skin removed, were soaked in the enzyme solution for 48 h and the seed collected and air-dried after the fruit pulp was washed through a sieve. These seed are referred to below as 'enzyme-extracted seed'. Six remaining entire fruit, six slices of fruit with seed, enzyme-extracted seed and ingested seed were sown in six trays of seed-raising mix (Yates Black Magic, Orica New Zealand Limited) on 30 August 2005. Before sowing, seed were submerged for 10 min in 0.5% sodium hypochlorite (Janola®) to remove any seed surface pathogens. Each tray was sown with 50 enzyme-extracted and 50 ingested seed in five rows of ten seed, each seed 10 mm apart from the nearest seed, giving a total of 300 seeds for each of these two treatments. One entire fruit and one fruit slice, each with an unknown number of seeds, were placed on the surface of seed-raising mix in each tray. After sowing, seed-raising mix in trays was soaked in Terrazole 35WP (active ingredient 350 g/kg etridiazole) at a concentration of 75 g/100 L to limit any death of seedlings from damping off. Fruit and fruit sections were covered with wire mesh to deter any predation by rodents or birds. Trays were kept on a bench in a glasshouse and the surface temperature of one tray was logged every half hour during the experiment.

Germination was recorded on days 1, 2, 3, 7 and 9 after sowing and thereafter on week days from 12 September (day 13). The experiment was terminated on 9 November 2005 (day 71) after negligible germination for three weeks. The number of ingested and enzyme-extracted seed remaining to germinate on each recording day was subject to a Kaplan-Meier survival analysis (Fox, 2001). The Kaplan-Meier method is a maximum-likelihood estimate of the survival function. The log-rank test was used to determine the equality of survival curves with $P < 0.05$. The analyses were completed in Genstat 8.1.

Results and Discussion

Ingested and enzyme-extracted seed had nearly identical percentage germination (63.7% and 64.7%, respectively) after 71 days. However, no seed germinated from entire fruit or fruit slices during the experiment. The pulp of entire and sliced fruit was consumed by the larvae of drosophilid flies, and only seed and the leathery epidermis remained at the end of the experiment. Thus removal of pulp from around seed of *A. chinensis* was necessary for their germination, and this was achieved equally effectively by passage through the gut of *Z. lateralis* or by enzyme extraction. The germination rate for ingested and enzyme-extracted seed differed (log-rank statistic = 4.96, $P = 0.02$). Gut
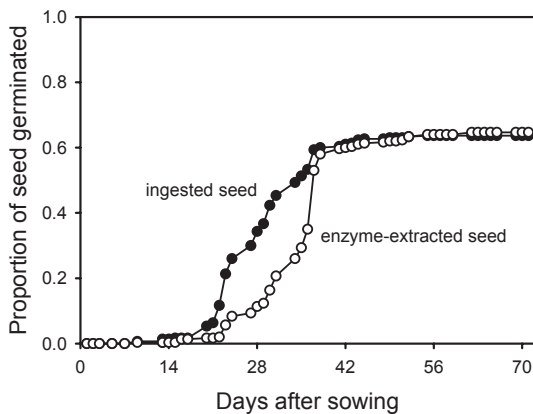
Figure 1. Germination of kiwifruit seed (*Actinidia chinensis*) ingested and passed by silvereyes, *Zosterops lateralis*, (ingested seed) or extracted from fruit using a pectinase solution (enzyme-extracted seed). No germination was measured from two additional treatments: seed sown as entire fruit and as fruit sections.

passage accelerated germination rate compared with enzyme-extracted seed (Fig. 1); the number of days taken to reach the median germination of ingested seed, calculated from the Kaplan-Meier survival analysis was 37 d (95% CI = 35–41 d) compared with 41 d (95% CI = 41–42 d) for enzyme-extracted seed. This difference may be the result of greater chemical and mechanical abrasion of the seed coat during gut passage than during extraction by pectinase.

Our analysis was based on censored data and assumed that all remaining seed retain the potential to germinate. The experiment was stopped after germination rate had significantly slowed and the objective of measuring an effect of ingestion on seed was met. The fate of remaining seed sown singly or as fruit was unknown. It is possible that seed remaining after drosophilids consumed fruit pulp may have germinated later in spring and summer. Further, the remaining ungerminated seed sown singly or as fruit may have remained dormant until the following year when winter chilling and spring temperatures initiated germination. There is some evidence that kiwifruit seed can remain dormant and germinate several years after development (Sullivan and Williams, 2002; Kasperek, 2003), but this needs to be confirmed by studies of the relative size and longevity of kiwifruit seedbanks. Seed left after drosophilid-consumption of fruit pulp may not be a significant source of wild kiwifruit compared with bird-dispersed seed. This is because no or very few fruit from commercial crops are currently dumped in native and exotic forest. Nearly all fruit is harvested and sent to packhouses where fruit not suitable for export is sold locally or fed to livestock (P. Allison, Trevelyan's Pack and Cool Ltd, Te Puke, pers. comm.).

Dormancy occurs in seed of *A. deliciosa* extracted from fruit at harvest or stored at a constant 21 °C before sowing (Smith and Toy, 1967; Lawes and Anderson, 1980). Chilling followed by a regime of daily alternating temperatures is known to break dormancy in seed of *A. deliciosa* and *A. chinensis* (Smith and Toy, 1967; Lawes and Anderson, 1980; Hofstee and Grant, unpubl.). Smith and Toy (1967) found that chilling seed at 4.4 °C for 2–12 weeks followed by daily alternating temperatures of 10 and 21 °C could result in close to 100% germination of *A. deliciosa*. In our experiment, nearly two-thirds of *A. chinensis* seed germinated after being chilled at 1.5 °C for 12 weeks (during fruit storage) and then experiencing alternating temperatures between a mean daily minimum and maximum of 10.7 °C and 24.3 °C after sowing. The level of germination we achieved is relatively high for *A. chinensis* which is more difficult to germinate than *A. deliciosa* (B. Hofstee, HortResearch, Te Puke, pers. comm.). Treatment of seed and seed-raising mix with anti-fungal agents is likely to have contributed to the relatively high germination rate. For this reason, and because of variable temperature and moisture regimes in natural environments, caution is necessary when considering the implications of our results for germination of kiwifruit seed in native and exotic forest.

This study supports the view that *Z. lateralis* is involved in dispersing kiwifruit seed into native and exotic forest. *Z. lateralis* was the most common species observed feeding on kiwifruit in bins and remaining on vines at the HortResearch kiwifruit orchard, Te Puke during winter and spring 2005. House sparrows, *Passer domesticus* Linnaeus, were also observed to feed on reject fruit in bins but were less common than *Z. lateralis*. Other passerines in orchards such as blackbirds, *Turdus merula* Linnaeus, and starlings, *Sturnus vulgaris* Linnaeus, may also feed on fruit but were not observed to do so. Seed dispersal by *Z. lateralis* has not been directly measured. Mark-recapture experiments indicate that about 70% of movement by *Z. lateralis* is less than 1 km and about 20% is in the range 1 to 10 km (Stansbury, 2001). Based on a flight velocity of 56 km h^{-1} and a mean gut passage time of 12.5 min, Stansbury (2001) estimated that the maximum dispersal distance for seed spread by *Z. lateralis* is approximately 12 km. This implies that most dispersal of kiwifruit seed by *Z. lateralis* will occur relatively close to feeding sites, given that there are suitable perches. In many areas of the Bay of Plenty, kiwifruit orchards are immediately adjacent to native and exotic forest and the risk of seed dispersal by *Z. lateralis* is thus probably relatively high. Germination after gut-passage depends on a suitable microenvironment. Young kiwifruit plants typically grow in moist, shady conditions and not in exposed, dry

areas. In the Bay of Plenty, wild *A. deliciosa* has often been found growing near streams and tree-fall gaps in native and exotic forests (Sullivan and Williams, 2002; J. Mather, Environment Bay of Plenty, Mt. Maunganui, pers. comm.). In China, wild kiwifruit generally grow in relatively damp conditions, often at the edge of clearings and streams, but are increasingly restricted to remote locations and national and provincial nature reserves because of harvesting by local people (Huang and Ferguson, 2001).

In conclusion, our study confirmed that ingestion by *Z. lateralis* and the subsequent removal of pulp with gut passage allows germination of *A. chinensis* seed. We suspect that ingestion and dispersal of kiwifruit seed by *Z. lateralis* contributes significantly to the spread of wild kiwifruit in the Bay of Plenty, New Zealand. Germination was similar for ingestion and enzyme treatments and it may be possible to estimate germination rates of *Actinidia* spp. in native and exotic forest using enzyme-extracted seed. As *A. deliciosa* 'Hayward' is the most widely planted kiwifruit species and the most common wild species, a comparison of germination with *A. chinensis* and other *Actinidia* species would be informative. Further study is also necessary to define the number of dispersed seed that will germinate and produce wild vines in New Zealand.

Acknowledgments

References

Ferguson, A.R. 1990. Botanical nomenclature: *Actinidia chinensis*, *Actinidia deliciosa*, and *Actinidia setosa*. *In:* Warrington I.J., Weston G.C. (editors), *Kiwifruit: Science and Management*, pp: 36-57. Ray Richards Publisher, New Zealand Society for Horticultural Science.

Ferguson, A.R.; Bollard, E.G. 1990. Domestication of the kiwifruit. *In:* Warrington I.J., Weston G.C. (editors), *Kiwifruit: Science and Management*, pp: 165-246. Ray Richards Publisher, New Zealand Society for Horticultural Science.

French, K. 1996. The gut passage rate of silvereyes and its effect on seed viability. *Corella 20:* 16-19.

French, K.; O'Dowd, D.J.; Lill, A. 1992. Fruit removal of *Coprosma quadrifida* (Rubiaceae) by birds in

south-eastern Australia. *Australian Journal of Ecology 17:* 35-42.

Fox, G.A. 2001. Failure-time analysis: Studying times to events and rates at which events occur. *In:* Scheiner S.M., Gurevitch J. (editors), *Design and Analysis of Ecological Experiments*, pp: 235-266. Oxford University Press, New York.

Huang, H.; Ferguson, A.R. 2001. Kiwifruit in China. *New Zealand Journal of Crop and Horticultural Science 29:* 1-14.

Kasperek, G. 2003. Kiwifruit (*Actinidia deliciosa* Liang & Ferguson) occurring in the wild in western Germany. *Floristische Rundbriefe 37:* 11-18.

Kerr, J.P.; Hewett, E.W.; Aitken, A.G. 2004. *New Zealand Horticulture, Facts and Figures*. HortResearch, Auckland.

Lawes, G.S.; Anderson, D.R. 1980. Influence of temperature and gibberellic acid on kiwifruit (*Actinidia chinensis*) seed germination. *New Zealand Journal of Experimental Agriculture 8:* 277-280.

Paulsen, T.R.; Hogstedt, G. 2002. Passage through bird guts increases germination rate and seedling growth in *Sorbus aucuparia*. *Functional Ecology 16:* 608-616.

Samuels, I.A.; Levey, D.J. 2005. Effects of gut passage on seed germination: do experiments answer the questions they ask? *Functional Ecology 19:* 365-368.

Smith, R.L.; Toy, S.J. 1967. Effects of stratification and alternating temperatures on seed germination of the Chinese gooseberry, *Actinidia chinensis* Planch. *Proceedings of the American Society for Horticultural Science 90:* 409-412.

Stanley, M.C.; Lill, A. 2002. Avian fruit consumption and seed dispersal in a temperate Australian woodland. *Austral Ecology 27:* 137-148.

Stansbury, C.D. 2001. Dispersal of the environmental weed Bridal Creeper, *Asparagus asparagoides*, by Silvereyes, *Zosterops lateralis*, in south-western Australia. *Emu 101:* 39-45.

Snow, D.W. 1971. Evolutionary aspects of fruit-eating in birds. *Ibis 113:* 194-202.

Sullivan, J.J.; Williams, P.A. 2002. *The ecology, distribution, and environmental weed potential of wild kiwifruit (*Actinidia *species) in the Bay of Plenty, New Zealand*. Contract Report LC 0102/166, Landcare Research, Auckland, New Zealand.

Traveset, A. 1998. Effect of seed passage through vertebrate frugivores' guts on germination: a review. *Perspectives in Plant Ecology, Evolution and Systematics 1/2:* 151-190.

Traveset, A.; Riera, N.; Mas, R.E. 2001. Passage through bird guts causes interspecific differences in seed germination characteristics. *Functional Ecology*

15: 669-675.

Webb, C.J.; Sykes W.R.; Garnock-Jones, P.J. 1988. *Flora of New Zealand. Volume IV, Naturalised pteridophytes, gymnosperms, dicotyledons.* Botany Division, DSIR, Christchurch, New Zealand.

Williams, P.A.; Karl, B.J. 1996. Fleshy fruits of indigenous and adventive plants in the diet of birds in forest remnants, Nelson, New Zealand. *New Zealand Journal of Ecology 20:* 127-145.

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