Donovan Scientific Insect Research
Bees, Pollination, Wasps, Other Insects

POLLINATION OF BUTTERCUP SQUASH

Barry J Donovan

22 May 2002

A Report prepared for the New Zealand Buttercup Squash Council Inc.

Barry J Donovan MSc PhD
Canterbury Agriculture and Science Centre • Gerald Street • Lincoln
Private Bag 4704 • Christchurch
New Zealand
Telephone 64 3 325 6400 • Facsimile 64 3 325 2074 • After hours telephone 64 3 322 7029 • Email DonovanB@Crop.cri.nz

Executive summary

- Buttercup squash is wholly dependent upon bees for pollination.
- The specialist cucurbit pollinating bee *Peponapis pruinosa* was introduced to New Zealand in 1980, but apparently failed to establish.
- There are no reported studies of cucurbit pollination in New Zealand.
- Growers depend upon honey bees occurring in the vicinity for crop pollination.
- The honey bee mite *Varroa destructor* will kill feral bee colonies and many hobbyist hives, but good commercial beekeepers will control their mites.
- To be sure that sufficient honey bees are present, growers should hire in up to 3 beehives per hectare.
- Other enemies of honey bees could reach New Zealand and so disrupt the availability of beehives.
- Actual and potential problems with honey bee supply could be completely avoided by introducing the specialist cucurbit pollinating bee *Peponapis pruinosa.*
- Because of the absence of research on pollination and pollinators in New Zealand, it is suggested that crops be surveyed for insects visiting the flowers, and experiments be undertaken to determine the relative pollination efficacy of each insect species.
- The results of research should be firmer recommendations for use of honey bees, and so more certain and possibly higher fruit yields, and better quality with fewer misshapen fruits.

Introduction

Buttercup squash, *Cucurbita maxima* (Cucurbitae), in New Zealand is thought to be dependent upon pollination by honey bees for fruit set. With the discovery of the bee-killing parasitic mite, *Varroa destructor* (Acari: Varroidae), in South Auckland on 11 April 2000, and its rapid spread over about the upper two-thirds of the North Island, there is mounting concern as to the possible flow-on impact on pollination of buttercup squash.

Dependence of buttercup squash on pollination

Buttercup squash is thought to have originated in northern South America (Whitaker and Davis 1962), from whence it has been taken by mankind to many parts of the world. Plants are monoecious, in that they bear flowers that are either male or female. Numerous studies have shown that for a female flower to set a fruit and for the fruit to grow to full size, pollen must be transferred from the anthers of male flowers to the stigma of the female flower. Pollen grains are large and sticky, so the only significant agencies that can transfer sufficient grains to effect pollination are various species of bees.

Specialist bee species that pollinate **Cucurbita** *species*

Several dozen closely related species of *Cucurbita* originated in the area encompassing southern North America, Central America, and northern South America. Beginning about 40 years ago, entomologists discovered that females of 20 species of bees in two closely related genera, *Peponapis* and *Xenoglossa,* collected pollen only from species of *Cucurbita* (Hurd and Linsley 1970). Nectar was taken by both sexes of bees from both sexes of flowers, and sometimes from some other species of flowers. Male flower buds opened in the hours just before dawn, and closed again by late morning. It was found that female bees would leave their nests in the soil before dawn, and so would be collecting pollen well before any other species of bees were on the wing. The total dependence of female bees upon male flowers of *Cucurbita,* and their very early morning pollen and nectar collecting habits, suggested that these bees were excellent pollinators of *Cucurbita.*Over the last several hundred years, the range occupied by cultivated species of *Cucurbita* in the Americas has been extended by humans to most regions. Several species of *Peponapis* and *Xenoglossa* have taken advantage of this range extension of their host plants, and they too are now present over much greater areas.

Introduction of **Peponapis pruinosa** *to new areas*

The perceived excellence of these bees as pollinators, and their absence beyond the Americas, stimulated the suggestion that the introduction of one or more species of bees might increase the pollination and therefore the fruit yield of cultivated *Cucurbita* beyond the Americas (Michelbacher *et al.* 1968). Accordingly, in 1969, methods of transferring bees to new areas within California were successfully developed, and in 1970, probably more than 250 bees were released in Hawaii. As at 1971 it was not known whether the introduction was successful (Michelbacher *et al.* 1971), and there seems to be no further information since then (Dr R. Thorp, University of California, Davis, pers. comm. 14 April 2002).

Attempted introduction of **Peponapis pruinosa** *to New Zealand*

From 1966-69, I worked with Drs Michelbacher and Thorp on marking, transporting and releasing *P. pruinosa* in California. Between 1971 and 1978, I imported four shipments of overwintering prepupae (the resistant last larval stage) of *P. pruinosa* from California. The first three shipments were sent to me by Dr Michelbacher, and the fourth I collected at Gridley, about 100 km north of Sacramento. At DSIR Lincoln, 107 bees flew between 21 January – 6 March 1970 and a female was seen carrying pollen. However, no nests were discovered, and no bees have been seen since, so it appears that the species did not establish. Perhaps the number of bees released was too small, there may have been too few cucurbit flowers nearby, and/or nests may have been destroyed by cultivation during winter.

Comparative pollinating efficiency of **Peponapis pruinosa** *and honey bees*

Tependino (1981) measured the comparative efficiency of *P. pruinosa* and honey bees as pollinators of summer squash, *Cucurbita pepo,* in Utah, U.S.A. He found that there was little difference between the species, but that where *P. pruinosa* was plentiful, they accomplished most pollination during the early morning before honey bees appeared on the flowers. Where *P. pruinosa* was absent from a crop, honey bees would pollinate just as effectively later in the morning.

Recently, the proportion of pumpkins and squashes pollinated by honey bees in the United States has been each put at 10% (Morse and Calderone 2000). These authors state that this is because *Peponapis pruinosa* is the most important pollinator.

Pollination of Cucurbitaceae in New Zealand

There appear to be no studies of pollination and pollinators of any Cucurbitaceae in New Zealand. Hopping and Hawthorne (1979) used Ethrel to increase the number of female flowers on pumpkins, *C. maxima*, but the total number of fruits did not increase. Their paper has no mention of pollination, nor pollinators.

The booklet `Buttercup Squash Cultural Guidelines for Export Production' states the number of growing degree days to pollination and the length of the pollination period. However, there is no mention of insect pollinators (King and Wishart 1993). For insects in flowers of buttercup squash, the New Zealand flower thrips, *Thrips obscuratus,* was found during a survey for pests and diseases. It was not considered to be a serious pest (Herman 1995). As at 16 May 2002, the PPIN data base had 10 records of two species of insect larvae found in flowers, and one record of a species of thrips (Plant Pest Information Network, MAF, Lincoln).

According to Mr Ron Dunn and Mr Doug Grant, there have been seasons where fruit set was less than desired, and they think it possible that lack of pollination could have been responsible. If so, whether there may have been a lack of bees, and/or adverse weather limiting bee activity, is unknown. No growers are known to hire in beehives, as honey bees have generally always been present in an area to at least some degree. However, Mr Grant said that producers of pumpkin seed in Marlborough do hire in beehives.

At Lincoln, honey bees have been by far the most common insect in pumpkin flowers, but the short tongued bumble bee, *Bombus terrestris,* and the small native halictine bee, *Lasioglossum sordidum,* have also been present. Bumble bees appear to possess characteristics that might make them excellent pollinators. Their large size and hairy coat suggest that they can carry many pollen grains, and their ability to fly at low temperatures and early in the morning means they would be active when honey bees may be confined to their hives. The native bee is probably too small to act as effective pollinator, unless high numbers are present. The manageable lucerne leafcutting bee *Megachile rotundata,* which I introduced from North America 27 years ago, has not been recorded from cucurbit flowers.

Pollination requirements of buttercup squash in New Zealand

There appears to be no information as to whether pollen from a male flower can fertilize a female flower on the same plant, the number of pollen grains that must be deposited on a stigma, or the number of visits from an insect that might be needed to deposit sufficient pollen grains for full growth of a fruit. Indeed, the only study that looked at some of these types of factors seems to be that of Tepedino (1981) for *Cucurbita pepo* in Utah, U.S.A. It was found that honey bees deposited a mean 184.3 pollen grains per visit (range 0-616), and that most female flowers required at least 3 visits to be adequately pollinated. Data for *P. pruinosa* were similar.

Yields per plant in New Zealand

Only up to 7% of plants have two fruits, in spite of about 7-8 female flowers opening per plant. It is thought that abortion of flowers and/or fruits initiated at nodes succeeding those on which fruits developed to harvest, may be due to hormones produced by the developing fruit (King and Wishart 1993). However, perhaps plant competition for nutrients and light could be responsible (D. Grant pers. comm. 11 April 2002). Another possibility is that some female flowers may not be receiving sufficient pollen grains for fruit growth to proceed to maturity. Also, perhaps when bees are abundant, female flowers that are synchronously well pollinated may both be able to grow to maturity.

Misshapen fruits may be the result of lack of fertilization of all ovules due to insufficient pollination.

Estimation of the number of honey bees needed per hectare

From King and Wishart (1993) the number of fruits harvested per hectare can be up to about 23,000. However, 7-8 female flowers open per plant, and there can be up to 22,220 plants per hectare. The total number of female flowers that open can therefore be about 177,760. The number of male flowers can be about 5 times the number of female flowers, or about 888,000. The total number of flowers that open on a hectare may therefore be about 1,066,560.

Flowers are open for only one day, or even just part of a day, so in the absence of data from the field in New Zealand, perhaps it can be assumed that at peak flowering, up to 100,000 flowers may be open per hectare on one day, for say 4 hours of bee flying time. If a honey bee can visit a flower a minute, and say 5 visits to a female flower are needed to be sure of full pollination, plus 15 male flowers must be visited for pollen collection, then one honey bee requires 20 minutes to pollinate one female flower. One honey bee can therefore pollinate 3 flowers per hour, and 12 in a 4-hour day. To visit 100,000 flowers per hectare, and to pollinate 20,000 female flowers (most of which will abort), 8,333 honey bees would be needed on the crop throughout 4 hours. If flying time between flowers and between flowers and the hive, and time in the hive is considered, then this number could be doubled. One beehive of moderate forager strength during January should have 20-30,000 foragers, so if all the foragers from one beehive were to visit only buttercup squash flowers, they could pollinate up to about 1.2-2.0 hectares.

There are some experimental data quoted in McGregor (1976) and Free (1993) that suggest that these speculative calculations may be near the truth. Wolfenbarger (1962) found that the yield of squash (species or cultivar not specified) decreased with increasing distance from a group of 20 honey bee hives at one end of a field, and that there was a positive correlation between the number of honey bee hives per hectare and the number of baskets of fruit obtained, ie, an average of 0, 1.2, 2.5, 5 and 7.5 hives per hectare gave an average of 366, 383, 398, 415 and 427 baskets of fruit per hectare.

Possible impact of Varroa destructor

Following the discovery of varroa in hives in South Auckland on 11 April 2000, the mite is now known to be present almost everywhere north of a line from about East Cape to northern Taranaki, with a salient south towards Wanganui. Beehives cannot be moved south of this line, so for the present the southward movement of the mite has been slowed. However, based on the rapid spread of the mite in other countries, there is general agreement among the beekeeping fraternity that colonization of the remaining areas of New Zealand can be expected within the foreseeable future.

If hives are not treated to control varroa, hive death follows about 1-2 years after infection. If the impact of varroa in New Zealand is similar to that in other countries, feral bee colonies will be virtually eliminated a few years after varroa appears in an area. In California known wild colonies were all dead about three years after the mite became common in managed colonies. However, most commercial and many hobbyist beekeepers are able to control mites by using Apistan and/or Bayvarol miticide strips which are manufactured expressly for use in beehives. Other possible control treatments such as formic and oxalic acids have been recently approved by MAF. Beekeepers who fail to control mites will leave the industry, and their hives will be purchased by beekeepers who are controlling mites. A major decrease in the number of commercial hives is therefore unlikely, but many hobbyists will fail to buy in new bees to re-stock dead hives, and the hives will be left standing empty. The control of mites in managed hives will result in an increase in swarms, which will at least partly re-establish the number of feral colonies. However, mites will periodically reduce the number of feral colonies to a very low level.

The mite does not attack bumble bees, nor native bees (nor *Peponapis* or *Xylocopa*).

Growers should hire in beehives

The virtual elimination of feral colonies, and a marked decrease in the number of colonies managed by hobbyists, plus some decrease in numbers of commercial beehives, will mean that fewer bees will be available for pollination of buttercup squash. Because growers have relied on the presence of sufficient `naturally occurring' bees in their area, this decrease may be quite noticeable, and if the speculative calculations of the numbers of bees needed per hectare are approximately correct, could result in decreased pollination, and so lower yields. The decrease may be exacerbated if other nearby flowers prove to be more attractive to honey bees than buttercup squash flowers.

Growers of buttercup squash can assure their own supply of honey bees by hiring in beehives. The number of hives per hectare of crop is unknown, and could only be firmed up by research, but based on numbers suggested in McGregor (1976) for other Cucurbitae in the U.S.A., from 1-3 per hectare would probably be sufficient to ensure that all flowers were visited at least several times.

A point to consider is that with the advent of varroa, growers of other crops are likely to increase their demands for hives for pollination. Buttercup squash growers are therefore likely to find that pollination fees will rise in the near future.

The future of beekeeping and **Varroa destructor**

Overseas there are two contrasting situations which will prove momentous for beekeepers. One is that varroa is becoming increasingly resistant to both Apistan and Bayvarol, so that controlling mites with these user-friendly means is becoming more difficult. On the other hand, some programmes which are selecting bees for resistance to varroa are claiming increasing success. Some Russian bees imported into the United States are said to persist with no or minimal treatment for mites, and `Suppressed Mite Reproduction' bees (SMR) selected in the United States are being extensively tested (Spivak and Reuter 2001). However, there are questions as to the maintenance of resistance, the economics of breeding programmes to maintain resistance, bee temper, and honey production abilities. Other claims of mite resistance for bees raised in small cells, and bees treated with food grade mineral oil, are unproven. Nevertheless, it appears that much progress has been made towards selecting bee genotypes which may be able to survive mite attack indefinitely.

Some beekeepers are pushing for the introduction of purportedly varroa-resistant strains of honey bees into New Zealand, but to date there seems to be no move by the Varroa Research Advisory Group, nor MAF, or any other body, to move in this direction.

There are concerns that because mites can complete a generation in about 2 weeks, compared to 1-2 years for the reproductive caste of bees, the much faster generation time of varroa will allow the mites to quickly overcome any characteristics in bees that are selected for resistance. Whether bee resistance will break down is unknown.

Possible future threats to honey bees

New Zealand honey bees are free of most of the pests which attack honey bees in other countries. If pests such as the acarine mite, European foul brood, the small hive beetle, and several species of mites such as *Tropilaelaps clarae,* were to reach New Zealand, the disruption to beekeeping could be as severe as or even more disastrous than that caused by the varroa mite.

Establishment of* Peponapis pruinosa *would safeguard buttercup squash pollination.

As stated by Morse and Calderone (2000), *Peponapis pruinosa* is responsible for 90% of the pollination of pumpkins and squashes in the United States. The pollination service provided by this bee is completely free, as no management is needed apart from protecting ground nesting sites from flooding, the prevention of disturbances such as trampling and camping by animals, and the use of only bee-friendly chemicals on flowering cucurbits. Further, because this species of bee is immune to all the enemies that attack honey bees, the advent of any of these new enemies in New Zealand will have no effect on the pollination of buttercup squash. Consideration could be given to introducing this bee to New Zealand.

Suggested research

Because nothing is known about pollination and pollinators of buttercup squash in New Zealand, two research projects are suggested.

1. The first step would be to discover what insects are found in flowers, and based on their biology, which of these are likely to be the main pollinators. To this end, during the main flowering period when female flowers are being pollinated, insects should be collected from crops in the main growing regions, and their behaviour observed. Other data to be obtained are the numbers of the various insect species that are present at different times of the day, and their numbers in relation to the numbers of flowers of each sex. After harvest, the data would be examined for correlations with fruit yield and quality.

2. A second step is to determine the efficacy of each species of insect as a pollinator. This can be achieved by the classic experimental procedure whereby a flower bud is bagged with mesh cloth, the bag is removed after the flower has opened, and the flower is observed until one insect has completed one visit. The bag is then replaced, and the resultant fruit is assessed at harvest. Variations on this theme can determine the numbers of visits of a particular insect species that are necessary, on average, to effect full pollination.

These two research projects will provide a sound basis of information upon which, for example, recommendations could be made for the numbers of honey bee hives per hectare that should be employed for maximum pollination and subsequent fruit yield. The recommendations would have to take into account the restrictions on bee activity caused by adverse weather, and the possible competition for the attention of bees of more attractive crops within the foraging range of about 5 km. The overall result should be greater yields per hectare, fewer shape defects, and more certainty of good yields when weather for the field activity of pollinating bees is poor.

References

Free, J. B. 1993: *Insect Pollination of Crops Second Edition.* Academic Press Ltd., London. 684 pp.

Herman, T. J. B. 1995: A pest and disease survey of buttercup squash: towards the development of an IPM programme. *Crop and Food Research, CropSeed Confidential Report No. 214*: 32 pp.

Hopping, M. E. and Hawthorne, B. T. 1979: Effect of Ethrel 48 on sex expression and yield in pumpkins. *N. Z. Journal of Experimental Agriculture 7*: 399-403.

Hurd, P. D. and Linsley, E. G. 1970: A classification of the squash and gourd bees *Peponapis* and *Xenoglossa* (Hymenoptera: Apoidea). *University of California Publications in Entomology 62*: 39 pp.

King, D, and Wishart, G. 1993: *Buttercup Squash Cultural Guidelines for Export Production Second Edition.* New Zealand Buttercup Squash Council, Wellington, New Zealand: 94 pp.

McGregor, S. E. 1976: *Insect Pollination of Cultivated Crop Plants.* USDA Agriculture Handbook No. 496, Washington, D.C. 411 pp.

Michelbacher, A. E., Hurd, P. D. and Linsley, E. G. 1968: The feasibility of introducing squash bees (*Peponapis* and *Xenoglossa*) into the Old World. *Bee World 49,* 4: 159-167.

--1971: Experimental introduction of squash bees (*Peponapis*) to improve yields of squashes, gourds and pumpkins. *Bee World 52, 4*: 156-166.

Morse, R. A. and Calderone, N. W. 2000: *The Value of Honey Bees as Pollinators of U.S. Crops in 2000.* Cornell University, Ithaca – New York. 15 pp.

Spivak, M. and Reuter, G. 2001: Comparison of hygienic, SMR, Russian and Italian honey bees in a commercial apiary. *American Bee Journal 144, 12*: 894 (abstract of paper presented at the American Bee research Conference).

Tepedino, V. J. 1981: The pollination efficiency of the squash bee (*Peponapis pruinosa*) and the honey bee (*Apis mellifera*) on summer squash (*Cucurbita pepo*). *Journal of the Kansas Entomological Society 54, 2*: 359-377.

Whitaker, T. W. and Davis, G. N. 1962: *The cucurbits – botany, cultivation and utilization.* World Crop Books, London. Leonard Hill (Books) Ltd. 249 pp.

Wolfenbarger, D. O. 1962: Honey bees increase squash yields. *Florida Agriculture Experiment Station Sunshine State Agricultural Research Report 7, 1*: 15, 19.

Donovan Scientific Insect Research

Bees, Pollination, Wasps, Other Insects

Tax Invoice

GST No. 60-531-447

Date: 23/05/02

New Zealand Buttercup Squash
Council Inc.
P.O. Box 8351
Symonds Street
AUCKLAND.

To: Preparation of a report on pollination of buttercup squash		$ 950.00
	Plus GST	118.75
	Total	$1068.75

PAID

28/5/02
2014 $1068.75

6505 950 =
118.75
1068.75

B J Donovan

B.J. DONOVAN

Director.

Barry J Donovan MSc PhD
Canterbury Agriculture and Science Centre Gerald Street Lincoln
Private Bag 4704 Christchurch
New Zealand
Telephone 64 3 325 ~~2511~~ 6400 Facsimile 64 3 325 2074 After hours telephone 64 3 322 7029