THE USEFULNESS OF THE HONEY BEE (*APIS MELLIFERA* L.) AS AN AGENT IN THE POLLINATION OF *FRAGARIA ANANASSA* DUCH. CV. 'CARDINAL' STRAWBERRY

By

LOUIS EMANUEL PETERSEN, JR.

Bachelor of Science

Tuskegee Institute

Tuskegee, Alabama

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Thesis Approved:

Raymond E. Campbell
Thesis Adviser

Michael Smith

Ronald W. McNew

Joseph O. Moffett

Norman N. Durham
Dean of the Graduate College

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CHAPTER I

INTRODUCTION

The history of the strawberry, *Fragaria ananassa* Duch., family Rosaceae, goes back as far as the Romans and perhaps even as far as the Greeks, but because the fruit has never been a staple of agriculture it is difficult to find ancient references to it (3). By the 1300's the French were cultivating the strawberry in Europe. In the United States commercial strawberry production began around 1800.

Today strawberries are raised in all 50 states of the United States with an estimated acreage in 1980 of 35,650 and the crop was valued at $288,776,000 (33). California was the leading grower of strawberries with 11,000 acres followed by Oregon (5,200), Washington (2,900) and Michigan (2,700). Numerous other states produce more than 1,000 acres. In Oklahoma, the industry is confined mostly to Adair and Cherokee counties in the northeastern portion of the state with scattered acreage throughout the eastern and north-central counties. The total acreage is under 1,000 acres.

The strawberry is usually grown as a perennial herb, but in some southern states it is sometimes grown as an annual (3). The strawberry flower cluster is a series of double-branching parts bearing a flower in the crotch of each branch. The flower in the first crotch is termed the primary flower, the two in the next two crotches are termed secondary flowers. The next four are tertiary flowers, the next eight are the quartenary, and the next sixteen, if they develop, are the quinary flowers.

The leaves are trifoliate; the plant is stemless, low creeping, and has a crown from which the leaves and fruit originate. The leaves usually help protect the fruit from soil and sun damage. Runners occur after the fruiting season, which produce roots and inflorescence at the leaf base.

Two important climatic factors, that affect the strawberry plant, are those of temperature and of daily light period (3). In the winter and early spring, if the temperature inside the cultivated strawberry plant reaches -9° C, injury may occur, with the killing point at -12°C. When the temperature rises above 0° C, plant functions increase rapidly.

Different cultivars of all species of strawberry may be expected to react differently to diverse photoperiodic conditions. Fall-bearing types are long-day plants that form fruit buds under the long days of summer in northern regions (31). The more common types are short-day plants that form fruit buds when the days become short and the temperature mild. Photoperiods of 8 to 11 hours promote flower-bud formation; photoperiods of 17 to 20 hours have the opposite effect (28). Photoperiods of 14 hours are intermediate in their effects, the results with some cultivars being similar to those obtained at short photoperiods and with other cultivars to those obtained at long photoperiods.

The strawberry is not a true fruit, the botanical fruits being the small achenes disposed around it (10). The aggregate fruit of the strawberry is made up of the conical receptacle of the flower that supports numerous pistils, each with one carpel from which the true fruits or achenes are formed. When the achene contains a fertilized seed, it stimulates growth of that part of the receptacle. If several achenes do not set seed, that part of the receptacle may be noticeably deformed (25,29). Improperly shaped berries are termed nubbins.

Fragaria chiloensis Duch., which was selected by the Chilean Indians, represents the basis of modern cultivated strawberries (3). It had perfect flowers that produced very large fruits. Today all commercial cultivars of strawberries are hermaphroditic, but clones that are only staminate or only pistillate may appear in the wild or in some seedling populations (20). Imperfect, pistillate cultivars need cross-pollination in order to develop fruit. The stamens of such cultivars are either lacking or abortive. Cultivars with perfect or staminate flowers do not require cross-pollination. Free (8) stated that because the stigmas of the flowers are receptive long before the anthers dehisce, cross-pollination by insects is favored.

The honey bee (Apis mellifera L.) as a pollinating agent has been found to be useful in contributing to optimum fruit, quality, and yield in a wide range of horticultural crops. Honey bees are especially useful insects because unlike many insects, they can be managed by man, kept in confined areas in large numbers and transported. Horticultural crops that have benefited from honey bee activity include apples (Malus domestica Mill.), almonds (Amygdalus communis Batsch.), avocados (Persea americana Mill.), cranberries (Vaccinium macrocarpon Ait.), blueberries (Vaccinium spp.), peaches (Prunus persica L.), raspberries (Rubus idaeus L.)), blackcurrants (Ribes nigrum L.), pears (Pyrus communis L.), gooseberries (Ribes hirtellum Michx.), and citrus limon L. and citrus sinensis L. (2,10,14,13,7,21).

Crop producers are generally not aware of the pollination requirements of their crops, and therefore little is done to insure that adequate pollination takes place. Little or no consideration may be given to the local population of pollinating agents or to providing additional agents of pollination.

There is evidence that the strawberry plant can set fruit well almost without insects and that wind carries pollen to flowers. However, experiences continue to indicate that bees and other insects are important in contributing to maximum yields and fruit quality. Although many types of insects visit strawberry flowers, including flies, beetles, thrips, butterflies, and various other bees, only the honey bees have shown to be of real consequence in transferring pollen effectively without injuring the flower parts (20).

The purpose of this study was to evaluate the effectiveness of the honey been as an agent of pollination in the 'Cardinal' strawberry. The 'Cardinal' cultivar was chosen for this study because of its popularity and widespread use among Oklahoma growers.

The objectives of this study were to evaluate the effectiveness of the honey bee as an agent of pollination on:

1. Total yield and total marketable yield.
2. Earliness of maturity of fruits.
3. Yield according to harvest dates.
4. Maintenance of berry size.
5. Percentage (by weight) of mis-shapen or deformed fruit.
6. Achene number.

CHAPTER II

LITERATURE REVIEW

Although the literature remains limited, a number of researchers have reported the effect of honey bee (*Apis mellifera L.*) activity on the pollination of the strawberry. The results of those studies have consistently shown that by providing honey bees as agents of pollination in addition to self pollination, wind, and other naturally occuring insects, maximum quality and yields of strawberries are more likely to result. To obtain well-formed fruits and maximum yields, it is necessary to assure proper pollination of the flowers (23). Honey bee activity has been shown to enhance the pollination of bisexual cultivars of strawberries and consequently have been beneficial in strawberry production (18).

Floral Morphology and Fruiting Habit

To understand how honey bee activity affects the yield and quality of the strawberry fruit, a knowledge of the flower cluster formation and fruiting habit of the plant is necessary. The flower cluster of the cultivated strawberry is made up of two main branches at the crotch of which is produced a single flower (35). This single flower is always the first of the cluster to bloom and is referred to as the primary flower. Each of the two branches is likewise made up of two other branches at the base of which are single flowers. These are the secondary flowers and are second of the cluster to bloom. Again each of these four branches divides and at these crotches are the tertiary flowers, the third group of flowers to bloom. This pattern repeats until there are quartenary and quinary flowers on very large clusters.

Thus, there is a very definite order of blooming in the strawberry cluster, and fruits resulting from primary flowers will be the largest, but only half as numerous as those from secondary flowers. The largest number of berries will be produced on the tertiary flowers and generally about twice as numerous as the secondary and four times as numerous as the berries produced on the primary flowers. Free (6) observed that there was a common experience of strawberry growers to observe a progressive decrease in berry size toward the end of the fruiting season. Along with this decrease in berry size, there is also an increase in the number of irregularly shaped berries or nubbins (35).

Most modern strawberry cultivars produce hermaphroditic flowers with stamens arranged in three whorls surrounding the pistils (34). A common characteristic of strawberry cultivars is that the primary flowers often lack well-developed stamens. As a result, the primary and sometimes the secondary flowers may not be well developed. The economic loss as a result of incomplete pollination of primary flowers may be considerable since the first flowers normally produce the largest berries and since complete pollination is necessary for maximum fruit size (23). In this situation, honey bees may be helpful as pollinating agents to transfer pollen from later flowers to complete the pollination of primary flowers since pistils remain receptive for several days (24).

Strawberry Pollination

In 1977, an experiment was conducted in Louisiana by Lackett and Burkhardt (19) using two cultivars of strawberries--'Dabreak' and 'Tangi'. They reported that both quality and yield were increased with the use of honey bees as pollinating agents. More U.S. No.1 grade strawberries were produced with the treatments utilizing bees than with either no-bees or open-plot treatments. Similarly, production of U.S. No.2 berries was greater in plots with bees over no bees. Fewer cull berries were harvested with the bees treatment versus the no-bees plot production, and total production, which included all categories of fruit, was greatest in the bee-treated plots.

Honey bee activity has been found useful in increasing berry set, berry weight, achene development and overall berry shape in cultivars with stamens shorter than the receptacles (1). Connor investigated the components of strawberry pollination and reported that stamen height was correlated with achene development in primary and secondary flowers in cages which excluded bees. He further reported that self-pollination was responsible for 53% achene development while the addition of wind motion and insect pollination resulted in 67% and 91% achene development respectively. Among the eleven cultivars used were 'Surecrop', 'Earlidawn', 'Guardian', 'Redchief', 'Sunrise', 'Midway' and 'Early Midway'.

In 1957, Skrebtsona, as cited by McGregor, discovered that fruit set, quality and berry weight increased with increased bee visitation (20). In a second experiment conducted in 1961, Hughes (14) discovered that extremely malformed and unmarketable quality berries were produced in plots screened to exclude bees. Similarly, in 1968, Free (6) observed that the exclusion of bee visitation to strawberry flowers resulted in lower fruit set, smaller fruits, and increased deformed strawberries.

Darrow (3), although he recognized and showed the need for insects, did not consider supplemental pollinating agents. Mommers, as reported by McGregor, recommended the use of honey bees on strawberries in greenhouses (20). Jaycox (15) in his report, recommended one strong colony per .8 hectare, with the bees in two or more groups on opposite sides of 4-20 hectare fields.

In her study at Efford, England, Hughes (14) caged individual strawberry plants to exclude bees at flowering time and thus see the effect on pollination and fruit setting under field conditions. In an experiment conducted in the Netherlands, Kronenberg (16) noted that even when honey bees were used, pollination was often insufficient in the center of his strawberry field. However, no mention was made of the size of the field. In a second study Kronenberg et al. (17) observed that cool, windy weather conditions increased the percentage of malformed fruits. Similarly, Hooper (12) reported that bees do not function well as pollinating agents in cool, wet or windy weather.

In an investigation of strawberry pollination, Moore observed that the exclusion of honey bees from strawberry plots resulted in significant yield reductions, and in a delay of fruit maturity (23). He further recognized a difference in cultivar responses to honey bee activity. The cultivars used were 'Blakemore', 'Earlibelle',and 'Tennessee Beauty'. Connor (1) observed similar differences in response to honey bee activity among eleven cultivars of strawberries as previously listed. He concluded that honey bee activity contributed most to pollination in cultivars with stamens shorter than the receptacles, and least in cultivars with tall stamens.

This observation was confirmed by Moeller and Koral (22). This may indicate that pollination requirements differ among strawberry cultivars. By using high and low populations of honey bees Moeller and Koval (22) further investigated the effect of honey bee populations on the yield of strawberries. Bee populations did not have a significant effect on yield. A low-bee population was equivalent to one colony per acre while a high-bee population was equivalent to 10 colonies per acre or 3 colonies per hectare. The three cultivars used were 'Badgerbelle', 'Sparkle' and 'Midway'. Honey bee activity did contribute significantly to the yield and size of strawberries, depending on the particular cultivar, even though the plants were apparently largely self-pollinated.

Nye and Anderson (27) also reported honey bee activity to have a great effect on berry size. In their study, yield reductions were accounted for by the decrease in berry size. They recommended for strawberry growers to provide honey bees specifically for the strawberry planting unless there are a significant number of colonies already located near their fields. The cultivars utilized were 'Fresno','Shasta' and 'Tioga'.

Timing of Hive Introduction

Timing appears to be another important factor in determining the efficiency of honey bee activity in the pollination of crops. In a cranberry experiment Moeller

(21) discovered that the timing of the placement of honey bee colonies in relation to the stage of bloom influenced the efficiency of pollination. When colonies were placed in cranberry bogs in full bloom bee visitation to flowers was greater than those placed in the bogs two weeks before the start of bloom. The influence of the timing of hive introduction on the production of highbush blueberries was also found to be significant (13). The early introduction of honey bees into caged blueberry bushes was associated with increased yield and fruit size. The suggestion was made that blueberry growers using honey bees for pollination should introduce the hives no later than 25% of full bloom. Support of these results for other crops have also been reported as Free (9) demonstrated with field beans. In peaches, apples and sweet cherry, honey bee visitation was increased by delaying the moving of their colonies into orchards after flowering had begun (10). In a report Jaycox (15) suggested that colonies of honey bees be moved to strawberry plantings when the first blooms are showing, not before.

CHAPTER III

MATERIALS AND METHODS

Preparation of Planting Site

A study to determine the effectiveness of honey bees (*Apis mellifera* L.) in the pollination of the 'Cardinal' strawberry (*Fragaria ananassa* Duch.) was conducted during the Spring and Summer of 1983 at the Oklahoma State University Research Farm located near Perkins, Oklahoma. The research plot was established on a Tellar loam soil.

In the Fall of 1981, the soil was disked, harrowed and subsoiled according to recommended practices. In the late Winter of 1982, prior to planting, the soil was again plowed and a mixed fertilizer containing 10% nitrogen, 9% phosphorus, and 8% potassium was applied at the rate of 675 kg/ha. Diazinon was incorporated into the soil at the rate of 4.5 kg/ha AI for the control of soil insects.

On March 11, 1982, 'Cardinal' strawberry plants were planted at a spacing of 1.2m between rows and 0.6m within rows. This spacing is equivalent to 13,500 plants per hectare. Immediately after planting, Devrinol was applied at the rate of 4.5 kg/ha AI for the control of weeds.

Irrigation was applied as needed, and in mid June of 1982 an additional application of nitrogen in the form of 33-0-0 was made at the rate of 112.5 kg/ha. General cultural practices such as hand weeding, and insect and disease control were performed as needed. A second mixed fertilizer application was made in the Fall of 1982 at the rate of 337.5 kg/ha to promote fruit bud formation. A second application of Devrinol was also made in February of 1983 at the rate of 4.5 kg/ha AI. A preventative disease control measure was provided by applying Benlate at the rate of 0.6 kg/ha AI. No spraying was done once the honey bees were introduced and care was used to make sure that sprays used prior to that time did not affect the bees.

The honey bee colonies were cared for and managed prior to being used in the experiment. Pollen cake was fed to the colonies once every two weeks. Terramycin was used as an antibiotic for disease prevention and control.

Experimental Design

Each of the fifteen plots used measured 7.32m in length and 3.66m in width. The cages used in this experiment measured 2.4m in height and were made of lumite Saran which reduced the light intensity by 20%. The cages were erected prior to flowering and the bees introduced at the onset of flowering. This procedure was completed by April 9, 1983. The honey bee hives were equalized before being utilized in the experimental plots. Equalizing the hives ensured that they were all of the same strength with respect to the quantity of bees and pollen and honey reserves. Each hive was also provided with one queen honey bee and equal amounts of brood or young bees. Five frames of honey bees and three frames of brood were used. The honey bees were provided with water and sugar syrup throughout the conducting of the experiment.

A completely randomized experimental design was used with three treatments and five replications. Treatments evaluated in the study included:

1. Caged bee plots which consisted of a five-frame hive of honey bees enclosed within a Saran screen cage to restrict the activity of the bees and to prevent other pollinators from entering.

2. Closed plots wherein Saran screen cages were placed over plots to prevent all insect pollinating activity. No outside pollinators were allowed to enter these plots. As a result, pollination in those plots was accomplished only by self-pollination and wind motion.

3. Open plots that were exposed to naturally-occuring pollinators of the area in addition to the influence of self-pollination and wind motion. Screen roofs were used to allow for a uniform shading effect throughout treatment plots.

The data was taken from four rows of plants within each plot that were 3m in length. The fruits were harvested a total of eight times and weighed. Only berries that were 75% or more ripe, by visual observation, were harvested. The degree of ripeness was determined by the extent to which the fruit was colored. Data collected and analyzed included total yield, marketable yield, % by weight of deformed fruit, berry size, earliness of fruit maturity, yield according to harvest dates and the number of achenes on an area of $7.85mm^2$ on ten berries randomly taken from each row.

Total weights represented the weight of all berries harvested from individual rows of plots while the weight of marketable fruits was obtained by separating the undersized and deformed berries from the total yield. The quantity of deformed fruit was expressed as a percentage by weight of the total yield. Berry size was obtained by calculating the average weight of 25 berries randomly selected from the total harvest from each row within each treatment plot. For achene count, a probe was inserted on a randomly chosen spot on each berry to define the area of observation.

All data collected was analyzed using the General Linear Models procedure, and the Duncan's multiple range test was used to identify pairs of means which were significantly different to each other at the .05 level.

CHAPTER IV

RESULTS

Total Yield

Table I shows the mean total yield of strawberry fruits as recorded in grams for each treatment. The mean total yield of strawberry fruits produced by the bee plots on the first harvest date was 1198.2g which was significantly higher than that produced by the no-bee and open-plot treatments. The no-bee and open-plots produced a mean total yield of 532.5g and 813.0g, respectively. The open-plot production was significantly higher than that of the no-bees.

On the second harvest the bee plots again produced the highest mean weight of 1025.5g. However, this weight was not significantly different to the open-plot mean weight of 880.8g. Both the bee plots and open plots produced significantly higher yields than did the no-bee plots which had a mean weight of 622.6g.

On the third harvest the all treatment plots indicated an increase in production of fruits although no significant difference was observed among treatment means. According to Table I, open plots yielded 1752.4g of fruit while the bee and no-bee treatment plots produced 1573.7g

TABLE I

TREATMENT MEANS OF TOTAL YIELD OF STRAWBERRY FRUITS

Perkins, Oklahoma 1983

	Total Yield (g)		
Harvest Date	Bee Plots	Open Plots	No Bees
1. 5/17/83	1198.2a	813.0b	532.5c
2. 5/20/83	1025.5a	880.0a	622.6b
3. 5/23/83	1573.7a	1752.4a	1167.7a
4. 5/25/83	1069.4a	1125.0a	1255.8a
5. 5.27/83	827.8a	869.1a	1021.5a
6. 5/31/83	986.6a	880.6a	929.7a
7. 6/3/83	497.7a	328.0a	507.4a
8. 6/6/83	446.2a	325.6a	424.8a
		Overall Means	
	959.3a	861.0a	821.1a

[a]Treatment means followed by the same letter within rows are not significantly different at the .05 level, according to Duncan's multiple range test.

TABLE II

TREATMENT MEANS OF MARKETABLE YIELD OF STRAWBERRY FRUITS

Perkins, Oklahoma 1983

	Marketable Yield (g)		
Harvest Date	Bee Plots	Open Plots	No Bees
1. 5/17/83	1081.4a	757.2b	418.7c
2. 5/20/83	958.47a	804.8a	533.1a
3. 5/23/83	1431.9ab	1585.5a	955.0b
4. 5/25/83	1006.2a	1040.2a	1033.5a
5. 5/27/83	775.9a	792.8a	811.4a
6. 5/31/83	886.1a	808.8a	798.8a
7. 6/3/83	408.4a	262.9a	382.1a
8. 6/6/83	360.2a	268.6a	333.9a
		Overall Means	
	869.1a	780.0ab	670.3b

[a]Treatment means followed by the same letter within rows are not significantly different at the .05 level, according to Duncan's multiple range test.

and 1167.7g, respectively. The no-bee plots gave the highest mean yield on the fourth, fifth, and seventh harvests although no significant difference was observed among treatment means. On the sixth and eighth harvests the bee plots produced the highest mean yield of strawberries. Again no significant difference among treatment means was observed.

Table I shows that there was no significant difference among overall treatment means with respect to total yield.

Marketable Yield

As Table II shows, a significant difference among treatment means was observed with respect to marketable yield on the first harvest date. The bee plots produced significantly higher yields than the no-bee and open-plot treatments with 1081.4g. Open plots produced a mean marketable yield of 757.2g which was significantly higher than the no-bee plots' production of 418.7g.

Both the bee plots and open plots produced significantly higher mean yields than the no-bee plots during the second harvest. Although the bee plots lead with a production of 958.47g, it was not significantly different from the open-plot production of 804.87g. No-bee plots gave the lowest mean weight of 533.19g.

As shown in Table II, open plots produced a significantly higher weight of marketable fruit over the no-bee plots on the third harvest. The open-plot mean of 1585.5g was not significantly higher than the bee plot production of 1431.9g. The no-bee plot production of 955.0g was not significantly lower than that of the bee plots.

On the fourth harvest, open plots gave the highest mean weight of marketable fruits. Bee plots gave the lowest yield while the no-bee plots were intermediate in production. The mean weights, however, were not significantly different from each other. Accordingly, no significant difference was observed among treatment means on the fifth harvest. On the sixth, seventh, and eighth harvests the bee plots gave the highest mean weight of marketable fruit, but these weights were not significantly higher than those of the open-plot or no-bee treatment plots.

The no-bee plots produced the lowest overall mean marketable yield of 670.34g. This weight was not significantly different from the overall mean production of 780.06g of the open plots. The bee-plot treatment yielded the highest overall mean of 869.12g. This weight was significantly higher than that of the no-bee treatment, but it was not significantly different to that of the open-plot treatment.

TABLE III

PERCENTAGES (BY WEIGHT) OF DEFORMED STRAWBERRY FRUIT

Perkins, Oklahoma 1983

Harvest Date	Deformed Fruit (%) Bee Plots	Open Plots	No Bees
1. 5/17/83	5.4a	7.3a	20.4b
2. 5/20/83	4.1a	5.6a	13.5b
3. 5/23/83	2.5a	2.8a	10.6b
4. 5/25/83	3.1a	3.6a	9.6b
5. 5/27/83	3.6a	5.5a	10.1b
6. 5/31/83	2.0a	3.7ab	5.8b
7. 6/3/83	3.0a	3.8ab	6.6b
8. 6/6/83	1.7a	5.2b	5.1b
		Overall Percentages	
	4.1a	3.8a	10.0b

[a]Percentages followed by the same letter within rows are not significantly different at the .05 level, according to Duncan's multiple range test.

TABLE IV

TREATMENT MEANS OF INDIVIDUAL STRAWBERRY FRUIT WEIGHT

Perkins, Oklahoma 1983

	Berry Size (g)		
Harvest Date	Bee Plots	Open Plots	No Bees
1. 5/17/83	16.7a	15.2a	12.2b
2. 5/20/83	14.2a	13.7a	13.0a
3. 5/23/83	15.4a	14.5a	14.0a
4. 5/25/83	13.5a	12.4a	12.4a
5. 5/27/83	10.5a	8.1a	8.6a
6. 5/31/83	6.6a	5.9a	5.6a
7. 6/3/83	5.1a	3.2b	3.0b
8. 6/6/83	3.6a	3.7a	3.7a
	Overall Means		
	11.5a	8.6b	8.3b

[a]Treatment means followed by the same letter within rows are not significantly different at the .05 level, according to Duncan's multiple range test.

Deformed Fruit

Table III shows that both the bee-plot and open-plot treatments produced significantly lower percentages of deformed fruit on the first harvest as compared to the no-bee plot production of 20.4%. The bee plot percentage of 5.4 was not significantly different to 7.3% of the open-plot production. This trend was observed through the fifth harvest. Until the fifth harvest, the bee-plot and open-plot treatments consistently produced significantly lower percentages of deformed fruit as compared to the no-bee plots.

On the sixth harvest, the bee-plots gave the lowest percentage of deformed fruit. The bee-plot production of 2.0% was not significantly different from 3.7% of the open plots. The no-bee plot production of 5.8% was, however, significantly higher than that of the bee plots. There was no significant difference between the percentages of deformed fruits from the open-plot and no-bee treatments. Table III shows that the results of the seventh harvest were the same as those of the sixth.

On the final harvest, the bee plots produced the lowest percentage of deformed fruits. The bee plot production of 1.7% was significantly lower than that produced by the open-plot and no-bee plot treatments. The open plots had a deformed fruit production of 5.2% which was not significantly different from the no-bee plot production of 5.1%.

As seen in Table III, both the open-plot and bee-plot treatments produced a significantly lower overall percentage of deformed fruit as compared to the no-bee plot production of 10.0%. The bee-plot treatment production of 4.1% was not significantly different from the open plot overall percentage of 3.8.

Fruit Size

A significant difference among treatment means was observed for berry weight on the first harvest. The bee plots and open plots yielded the larger berries with a mean weight of 16.7g and 15.2g, respectively. These weights were not significantly different from each other, but they both were significantly higher than the no-bee plot mean weight of 12.2g.

From the second harvest until the sixth, no significant difference was observed among treatment means. On the seventh harvest the bee plots had the highest mean berry weight of 5.1g which was significantly different to that of the open-plot and no-bee treatments. The open-plots and no-bee plots had mean weights of 3.2g and 3.0g, respectively. On the final harvest, no significant

TABLE V

MEAN NUMBER OF SEEDS ON $7.85mm^2$ ON STRAWBERRY FRUITS

Perkins, Oklahoma 1983

Harvest Date	No. of Seeds: Bee Plots	No. of Seeds: Open Plots	No. of Seeds: No Bees
1. 5/23/83	11.4[z]	11.0	10.7
2. 5/25/83	12.6	12.6	11.2
3. 5/27/83	13.0	13.2	12.6
4. 5/31/83	12.5	12.6	11.4
5. 6/3/83	10.8	12.4	10.8
6. 6/6/83	13.9	14.9	14.1
Overall Means	12.2	12.9	11.8

[z]No significant difference among treatment means was observed according to the Duncan's multiple range test.

difference among treatment means with respect to berry size was observed.

Table IV shows that the bee plot treatment had a significantly higher overall mean berry size as compared to both the open-plot and no-bee treatments. The berries produced by the bee plots had an overall mean weight of 11.5g while the berries produced by the open-plot and no-bee plot treatments had overall mean weights of 8.6g and 8.3g, respectively.

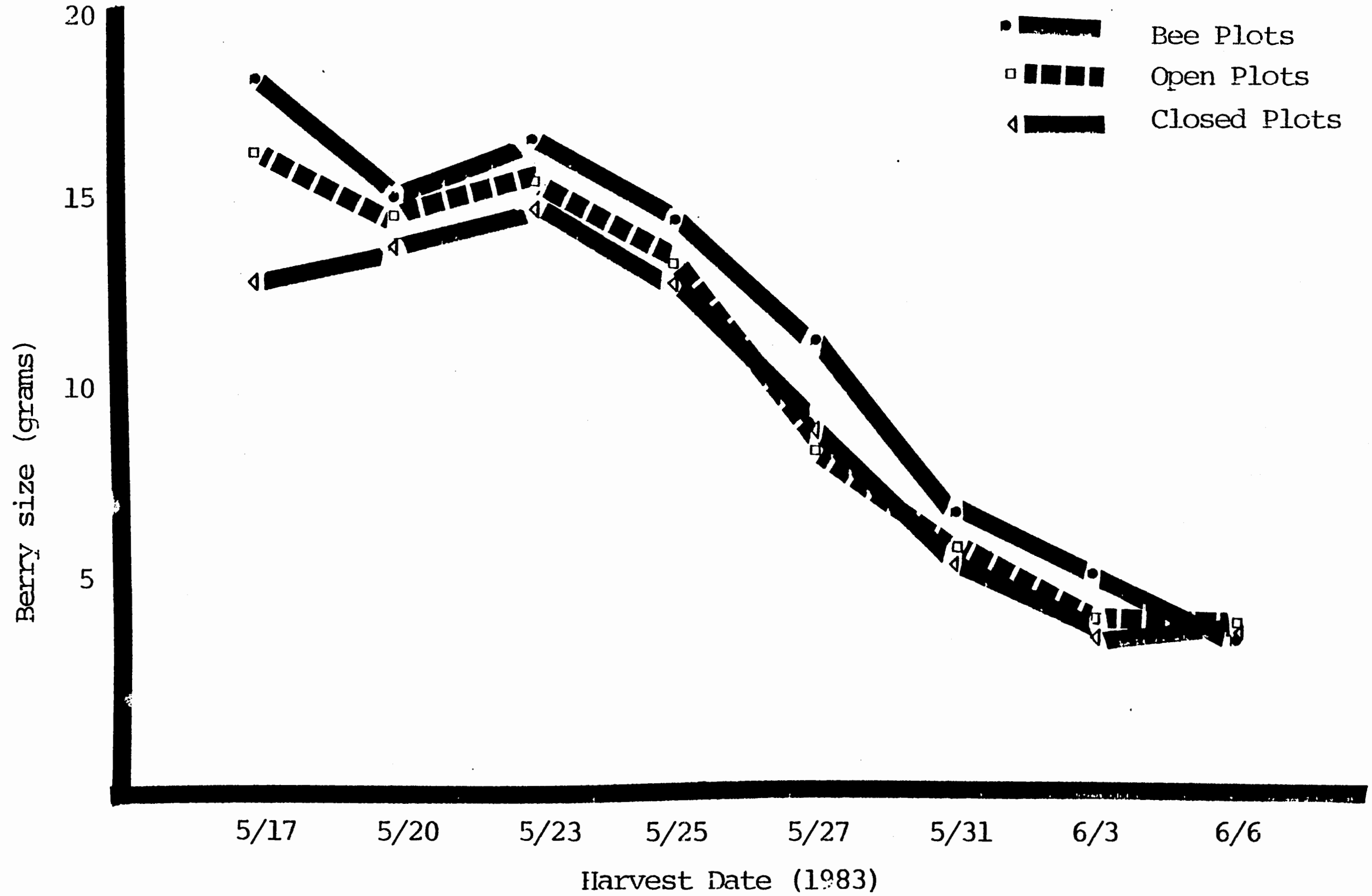
Achene Count

No significant difference among treatment means was observed with respect to achene count on any of the harvests. Achene count was not one of our initially-intended objectives, and thus commenced on the third harvest. According to Table V, there was no significant difference among overall treatment means with respect to seed count.

Earliness of Maturity

From visual observations, there was no evident difference among treatments with respect to the earliness of fruit maturity. However, the observation was made that a greater number of mature fruits was produced by the bee plots on the first harvest. This may indicate that a greater number of berries did mature earlier in the caged bee plots or that fruit set was greater in those plots.

FIGURE I. MAINTENANCE OF BERRY SIZE OVER EIGHT HARVESTS



Maintenance of Berry Size

From visual observations, the caged bee plots appeared to consistently produce the largest and most uniform fruits throughout the harvest period. Figure I shows that with the exception of the final harvest the bee plots did consistently produce the largest strawberries. However, only on the first and seventh harvests was this difference significant. On the first harvest the bee plots did not produce significantly larger berries than those of the open-plot treatment. Both of these plots yielded significantly larger berries than the no-bee plots.

CHAPTER V

DISCUSSION OF RESULTS

Yield Data

Table I shows a significant difference in total yield of strawberries on the first and second harvests. On the first harvest the bee plots significantly out-yielded both the open and no-bee plots. There was no significant difference among the overall treatment means for total yield. For the bee plots and open plots the highest total yields were obtained on the third harvest date. These results were consistent with Valleau's (35) report of peak yields with the third harvest. This was not true of the no-bee plots wherein the highest yield was observed on the fourth harvest, as seen in Table I. This may be indicative of a difference in the rates of fruit maturity among treatment plots.

In the evaluation of marketable yield, the US standards for grades of strawberry size were observed. Deformed or damaged fruits were not included. For strawberries to be classified as grade fruit, the diameter cannot be less than 5/8 inch (37). Significant differences were noted among mean marketable yields on the first, second and third harvests (Table II)as was observed with total yield, only on the first harvest did the bee plots produce significantly higher marketable yields than both the open and no-bee plots. This observation may suggest the importance of the initial harvest to the strawberry grower.

The highest marketable yields in the open and bee plots occured on the third harvest while the no-bee plots had their highest marketable yield on the fourth harvest date.

The overall mean marketable yields shown in Table II indicate a significantly higher yield in the bee plots when compared to the no-bee plots. This result was apparently due to a significant increase in berry size and significant decrease in the percentage of deformed berries in the bee plots. There was no significant difference between the mean marketable yield of the bee plots (869.12g) and the open plots (780.06g); however, the marketable yield from the bee plots was slightly higher.

Deformed Fruit Data

By the US standards (37) for strawberry grading, "deformed" means that the berry has not attained normal shape and development due to frost injury, lack of pollination, insect damage, or other causes. The percentage of deformed fruits produced by bee plots was consistently and significantly lower than that produced by the no-bee plots throughout the harvest period.

For all treatments, the highest percentage of deformed berries occured on the first harvest. This observation again indicates the importance of the first harvest, and suggests that measures should be taken early in the growing season to ensure that the highest possible level of pollination is achieved. The complete pollination of strawberry flowers is essential for the development of properly shaped fruits (25,29). Moore (23) reported that a common characteristic of many modern strawberry cultivars is that primary flowers often lack well developed stamens. This may have been the reason why the initial harvest of this experiment produced the highest percentage of deformed strawberries.

The fact that the no-bee plots produced the highest percentage of deformed berries on each harvest as well as on an overall basis suggests the importance of pollinating agents such as honey bees. Contrary to the findings of Valleau (35), the results of this research showed a general decrease in the number of deformed strawberries among all treatments toward the final harvest. Valleau reported that the number of nubbins or deformed fruits increased as the season continues.

Size, Maintenance and Achene Count

As seen in Table IV, the bee-plot treatment showed a significant contribution in increasing the overall weight of individual strawberries. The results of earlier researches support this finding (23,6,22). This observation again reinforces the usefulness of honey bees as agents of pollination. Only on two of the individual eight harvests was there significant treatment differences.

With respect to size, Valleau (35) further reported that the largest berries are produced on the first harvest and that subsequent harvests produce increasingly smaller fruits. This report was in agreement with the data taken from the open-plot and bee-plot treatments in this experiment. However, the data presented in Table IV for the no-bee treatment tends to disprove this generalization. The largest mean berry weight of 14.0g was observed on the third harvest date in the no-bee plot treatment. Figure I shows that the berries harvested from the bee plots maintained the largest size throughout the harvest period.

In the achene count evaluation (Table V), no significant difference among treatment means on any of the harvest dates was observed. Neither was there significant overall treatment differences. This observation did not appear to be consistent with the fact that there was an overall difference with respect to size since achene number has been shown to be an important factor in relation to size (35). Although the average berry size was highest on the first harvest, the highest mean achene count occured on the final harvest date.

It should be noted that the achene count evaluation included all achenes within the observational area on the berries and was not indicative of the number of seeds that were actually fertilized. Lackett and Burkhardt (18) reported no significant difference among treatment means with respect to the number of fertilized seeds, but there was a significant increase in the number of unfertilized seeds in cages where honey bees were excluded.

Earliness of Maturity

Visual observation of the experimental plots indicated that the rate of fruit maturity was not influenced by treatment differences. However, an analysis of the data indicated that the largest berry size was observed on the third harvest (Table IV) in the no-bee plots while open plots and bee plots produced their largest on the first harvest date. It should also be noted again that maximum yield was obtained on the fourth harvest in the no-bee plots while the other two treatment plots gave their highest yields on the third harvest date. It is very probable that these results indicate a delay in fruit maturity in the no-bee plots and that the causative factor was the absence of the honey bees as agents of pollination. Moore (23) noted a delay in fruit maturity due to the absence of bees in caged plots. In his study, the percentage of the total crop harvested in the first three pickings was used as an indicator of the rate of maturity.

Effects of Caging

Some differences did exist in the growing conditions within the caged plots when compared with those of the open plots. Light was reduced by 20% and apparently caused an increase in leaf area in plants grown completely under cages when compared with plants grown in the open plots. Although open plots were provided with roofs, the light which was allowed to enter from the sides seemed to have had an effect on plant growth. Microclimatic changes within caged plots could have possibly affected berry set, time of fruit maturation and utlimately yield.

In addition to light reduction, cages also reduced wind speed to some extent. Wind is an important component of strawberry pollination as was reported by Connor and Martin (1). They observed that the addition of wind-motion resulted in 67% seed development. However, in this study no quantitative data was taken in regard to the effects of wind and light reduction.

Caging has also been reported to adversely affect the activity of honey bees (23). When colonies of bees are confined in cages, they become increasingly inactive and forage less. At certain times during this experiment, large numbers of the bees were observed clinging to the roofs of the cages, presumably in attempt to get out.

Consequently, the efficiency of the bees as pollinating agents may not have been at its highest level even though they were enclosed.

CHAPTER VI

Summary and Conclusions

The purpose of this study was to evaluate the effectiveness of the honey bee as an agent in the pollination of 'Cardinal' strawberry. The objectives included the effect of honey bee pollination on:

1. Total yield and total marketable yield
2. Earliness of maturity
3. Yield according to harvest dates
4. Maintenance of berry size
5. Percent of mis-shapen or deformed fruit
6. Achene number

The following conclusions were drawn concerning the pollination of the 'Cardinal' strawberry by honey bees:

Honey bee pollination did not significantly affect the overall total yield of Cardinal strawberries, although the bee plot production exceeded that of the no-bee plots by 17%.

The confined-bee plots produced a significantly higher marketable yield of 30% when compared to that of the no-bee plots. The open plots produced an intermediate marketable yield which was not significantly different from that of the bee plots or the no-bee plots.

Harvest date was an important factor in the total yield and marketable yield harvested from the treatment plots. The first harvest date was most important. The bee plots produced a significantly higher total yield and marketable yield than both the open plots and no-bee plots on the first harvest date.

The strawberries produced in the open plots and bee plots showed a faster rate of maturity as compared to berries harvested from the no-bee plots.

The berries produced in the bee plots maintained the largest size throughout the harvest period when compared to berries from open and no-bee plots. The berries produced in the bee plots showed an overall increase in size of 39% when compared to those produced in the no-bee plots.

Both the bee plots and open plots produced a significantly lower percentage of deformed berries than the no-bee plots. The bee plots produced less than half as many deformed strawberries as did the no-bee plots.

The number of achenes produced on each strawberry was not significantly affected by treatment differences.

A statistical analysis of the data showed that the bee plots did not significantly out-perform the open plots except with regard to size. Based on the results of these findings, it cannot be recommended at this time that producers of Cardinal strawberries purchase or rent honey bee colonies for the purpose of enhancing the yield of this cultivar. However, honey bee colonies may be used to enhance the overall size of berries. It is very possible that this increase in berry size may lead to an increase in marketable yield. It should be noted that the population of naturally-occuring insects in any given area is subject to change. Insect populations may fluctuate depending upon climatic, disease, or parasitic conditions. Therefore, the decision to use honey bees in the pollination of 'Cardinal' should be based upon the population of insects that are present in the selected area at that time. In the case of this experiment, the population of naturally-occuring insects was apparently adequate for the purpose of pollinating the 'Cardinal' strawberry.

Future research with this cultivar should be considered. Since it is known that cultivars differ in their requirements for pollination and that stamen height is an important factor, it may be beneficial to study the morphology of the 'Cardinal' cultivar and determine the height of the stamen in relation to the receptacle. A second suggestion can be made with respect to achene count evaluation. It may also be worthwhile to differentiate between the seeds that are fertilized and those that are not since this factor determines the degree of fruit deformity. Such an observation should better indicate the effectiveness of pollinating agents.

Plant pollination is complex and influenced by many overlapping factors (plant morphology, weather conditions, timing of insect visitation, etc.). With all the research information that is available there is still much to be known about the phenomenon of pollination and how to use insects to achieve maximum efficiency in agricultural production.

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VITA

Louis Emanuel Petersen, Jr.

Candidate for the Degree of

Master of Science

Thesis: THE USEFULNESS OF THE HONEY BEE (*APIS MELLIFERA L.*) AS AN AGENT IN THE POLLINATION OF *FRAGARIA ANANASSA* DUCH. CV. 'CARDINAL' STRAWBERRY

Major Field: Horticulture

Biographical:

Personal Data: Born in Charlotte Amalie, St. Thomas, U.S. Virgin Islands, March 12, 1959, the son of Louis and Joyce L. Petersen.

Education: Graduated from Charlotte Amalie High School, Charlotee Amalie, St. Thomas in 1977; received the Bachelor of Science degree in Plant and Soil Sciences from Tuskegee Institute, Alabama in 1981; completed the requirements for the Master of Science degree in Horticulture at Oklahoma State University in December, 1983.

Professional Experience: Graduate Research Assistant, Department of Horticulture, Oklahoma State University, June, 1982 to December, 1983.