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OPIUM POPPY RESEARCH IN THE SOUTHWESTERN UNITED STATES, 1945-66

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ABSTRACT

Limited agronomic research on opium poppies was conducted in Arizona and California between 1945 and 1966. Poppies from many countries were planted under irrigation at Bard, Calif., and at Yuma and Mesa, Ariz., and screened for adaptability, desirable agronomic characteristics, and morphine content. Well-adapted lines were selected and seed increased under conditions of controlled pollination. A 36-acre planting of one line at Yuma yielded nearly one-half ton each of seed and straw (0.54 percent morphine) per acre. Lower yields occurred in a 40-acre planting at Brawley, Calif. More than 25 tons of seed were stockpiled, and the straw was used in morphine extraction experiments. Small quantities of seed of eight other lines were grown in isolation and stockpiled. A November planting of one line at Mesa yielded 1,247 pounds of seed and 1,218 pounds of straw (0.36 percent morphine) per acre. Later plantings gave successively lower yields, but the morphine level was not affected. In variety trials, one line at Yuma yielded 1,847 pounds of seed and 1,084 pounds of straw per acre. Capsule wounding did not affect morphine content significantly. The only severe disease was curly top caused by a virus spread by leafhoppers. Other troublesome insects included aphids and salt marsh caterpillars. Recommendations are given for growing poppies in the area.

KEYWORDS: Controlled pollination, cultural practices, curly top disease, aphids, leafhoppers, salt marsh caterpillars, morphine, opium, opium poppy, poppy, poppy seed, straw, temperature, wind damage.

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OPIMUM POPPY RESEARCH IN THE SOUTHWESTERN UNITED STATES, 1945-66

By Norris W. Gilbert¹

INTRODUCTION

The opium poppy (*Papaver somniferum* L.) has been known and cultivated throughout historical times as a source of opium and oil. Prior to World War II, opium poppy was grown to some extent in the United States, mainly for seed for the bakery trade but also for opium and its derivatives, used as analgesics in medicine. However, adequate supplies of opium for medicinal use could be produced more economically in other parts of the world where inexpensive labor for harvesting the opium was plentiful. The illicit drug trade also found it more profitable to smuggle opium into the United States than to attempt to produce it domestically even though at that time cultivation of the opium poppy in the United States was not illegal.

Upon the approach of World War II, the U.S. Government became concerned that hostilities could cut off imports of licit opium from India, Iran, and Turkey, the main sources of supply. Consequently, several years' supply was stockpiled, and an investigation was launched as to the feasibility of domestic production of the crop. Attention was focused on development of techniques for extraction of morphine from the mature, dry poppy straw (capsules or seed pods and stems) and the development of adapted varieties and production methods. Investigations were begun in 1939 by the Federal Bureau of Narcotics of the U.S. Treasury Department and the Bureau of Plant Industry of the U.S. Department of Agriculture (USDA) in collaboration with several large pharmaceutical companies.

The author did not become involved in experimental work on poppies until 1945 and has little knowledge of what transpired prior to that time. His involvement in poppy research from 1945 to 1966 was very light, partly due to the fact that no funds were made available to him specifically for poppy research. Thus, any poppy work undertaken had to be done at the expense of time and funds budgeted for research on other crops. The author left ARS employment for 8 years in 1966. Since then, reorganization of ARS and the attendant disposal of field records of defunct projects have left him with only his memory and annual station reports to draw upon. This paper is prepared in the hope that the information presented may be useful to any future research or production effort on opium poppy.

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At some time after the initiation of poppy investigations by the Federal Government in 1939, plantings of poppies were made on the U.S. Field Station of the Division of Western Irrigation Agriculture of the Bureau of Plant Industry at Bard, Calif., near Yuma, Ariz. (fig. 1). *P. somniferum* was only one of many species being grown under observation at Bard for a variety of uses, including condiment, food, fiber, rubber, and medicinal. The area is characterized by extremely low rainfall and relative humidity, nearly frost-free winters, and long, intensely hot summers.²

Due to the diversified nature of the experimental work in progress on the station and the acute shortage of personnel, little work could be accomplished. However, when the author began working at the Bard Station in January 1945, Edward G. Noble, Superintendent of the Station, had been planting poppies for several years. During the initial stages of the poppy investigation, plantings were made with seed that included two general types--the Scandinavian type and Indian White Poppy, No. 17. The Scandanavian type was obtained from Wisconsin or Minnesota where it was being grown clandestinely for seed. That type, adapted to the long days of the northern summer growing season, grew very tall at Bard and generally bloomed too late to mature seed regardless of planting date. The high temperatures and low relative humidity characteristic of late spring in that desert area caused the flowers to blast and plants to dry up prematurely.

Indian White Poppy, No. 17, was much shorter in stature and usually matured early enough to avoid unfavorable temperatures. Noble had increased the seed of that line and had broadcast planted a 0.1-acre plot of it along with wheat as a companion crop. This was harvested with a grain binder in early May 1945 with the recovery of a substantial amount of seed when threshed.

In December 1945, a poppy nursery was planted including the Scandanavian and Indian White types as well as a large number of newly acquired introductions from many areas, including India, Turkey, Afghanistan, and Australia. These introductions were evaluated as to growth behavior and adaptation to growing conditions of the region, yield of seed and capsule material, and morphine content (morphine determinations were made at the Plant Industry Station in Beltsville). Many buds in all lines were bagged to insure self-pollination. Seed was saved from the better adapted lines for later planting.

During the following season, seed from the bagged capsules was planted in a new nursery along with seed of a number of new acquisitions. Again, selfed seed from all adapted lines was saved and morphine determinations were made. In both the 1946 and 1947 spring seasons, no late-blooming lines were able to survive to maturity regardless of frequency of irrigation, when maximum air temperatures of 95° F (35° C) or above occurred for several days in succession. A heat wave on May 2, 3, and 4, 1947, with temperatures up to 115° F (46° C), eliminated all material not yet physiologically mature.

The author left USDA employment in July 1947, for 2-1/2 years, during which some work with poppies was done at Yuma, by other personnel. The best poppy introductions isolated at the Bard Station were inadvertently lost during the 1948-49 growing season. One well-adapted, white-flowered line, identified only

²Refer to climatic data in Appendix table 1.

Figure 1.--Opium poppy planting sites at Bard and Brawley, Calif., and at Mesa and Yuma, Ariz. during 1945-66.

as No. 40, survived, and the increased seed was planted the following season, 1949-50, at Yuma for a small experiment on bagging for self-pollination. Seed from that planting was stockpiled for future use. Also, in the same season, a nursery was planted with seed of Bard selections that had not been planted during the previous season. Selfed seed from selected lines from that nursery, along with a portion of the No. 40 seed, was turned over to the author after his return to USDA employment in January 1950.

THE 1951 POPPY PRODUCTION PROGRAM³

A poppy production program was carried out during the 1950-51 crop season at Yuma and at Brawley, Calif. The program was initiated by the War Munitions Board and executed by the USDA. The purpose of the program was to produce a supply of seed for possible emergency planting and capsule material for use in developing a commercial method for extracting morphine from the mature, dry capsule material. The author monitored the production of the crop at Yuma, bagged selected plants for self-pollination, and harvested the selfed seed. He also monitored commercial storage of the seed and semiannually sampled the stockpiled seed for germination testing.

A total of 76.5 acres was planted: 36.5 acres on a private farm near Yuma and 40 acres on the Southwestern Irrigation Field Station near Brawley. Seed of the white-flowered variety, No. 40, grown at Yuma in 1950, was planted at both locations. The seed was drilled in early December 1950 on standard-type vegetable beds spaced 40 inches from center to center with two rows 15 inches apart on each bed. Beds were separated by shallow irrigation furrows. Planet Jr. planters, equipped with special brass plates having 3/64-inch diameter holes, were used for planting both fields. Approximately 12 ounces of seed were planted per acre, resulting in a perfect stand of about 30 seedlings per foot of row. The field at Yuma was hand thinned on January 23, 1951, when leaves were 2 inches long, leaving plants spaced 8 to 12 inches apart. Thinning of the Yuma field cost \$30 per acre. The Brawley field was not thinned until February 15, 1951, and no cost data are available.

Both fields were cultivated at least twice before leaf spread of the plants precluded further tractor operation. Furrow irrigation was applied, but the quantity and frequency of irrigation is not on record. Both fields were mature in late May and ready for harvest. Table 1 gives crop data on both fields.

The striking difference between the yield at Yuma and that at Brawley can be attributed to several factors:

- (1) The crop at Yuma was grown under contract by a commercial vegetable producer while that at Brawley was grown by experiment station personnel perhaps not as experienced in the techniques of commercial vegetable production.
- (2) The soil at Brawley had high soil salinity in part of the field.
- (3) The Brawley planting was thinned very late after interplant competition was strong.

³This section of the report is based on Line Project Report No. a-8-1-2 of the Division of Tobacco, Medicinal and Special Crops, Bureau of Plant Industry, USDA, April 15, 1952, and the author's Annual Report for 1951.

(4) At Brawley, insects and diseases caused injury to plants and loss of stand.

(5) At Yuma, as indicated in table 1, fertilizer was applied at planting and supplemental nitrogen was added in March. No fertilizer was applied at Brawley where the plants were light green late in the season and were somewhat retarded in growth. At Yuma, the plants retained their healthy, deep-green color until ripe and were fully 12 inches taller than at Brawley.

(6) Considerable seed was lost in the harvest operation at Brawley where a 5-foot Allis-Chalmers All-Crop Harvester was used. At Yuma, a 12-foot John Deere combine was used with very little seed loss, but a lower grade of straw was recovered, which included a much larger component of stem material (fig. 2). Obviously, existing machinery will have to be modified for efficient poppy harvesting.

TABLE 1.--Summarized data on 1951 poppy production

Item	Moody Ranch Yuma, Ariz.	S. W. Irrigation Field Station Brawley, Calif.
Acres planted	36.5	40.0
Acres harvested	36.5	35.0
Date planted	12/1-3/50	12/4-5/50
Date thinned	1/23/51	2/15/51
Date of peak bloom	4/15/51	4/15/51
Date of harvest	5/25-30/51	6/5-10/51
Fertilizer at planting at 225 lb/acre	13-39-0	None
Fertilizer in March at 30 lb/acre	NH ₃ in irrigation water	None
Yield of seed (total), pounds	36,336	15,187
Seed yield per acre, pounds	995.5	380
Yield of capsules and straw (total), pounds	31,205	23,000
Capsule and straw yield per acre, pounds	855	657
Morphine content, ¹ percent	0.54	0.51

¹Reported by Northern Regional Research Laboratory, Peoria, Ill.

Seed harvested at Brawley was stored in a commercial seed warehouse in Brawley while that harvested at Yuma was stored in two seed warehouses in Yuma. The author drew samples of seed from the stockpile semiannually for germination tests, which were performed by the National Seed Storage Laboratory at Fort Collins, Colo. By 1960, viability of the seed had dropped below the minimum level for use as planting seed. In January 1961, it was sold to an oilseed processor for crushing.

Most of the straw from the two fields, totaling 25 tons, was shipped to the Northern Regional Research Laboratory at Peoria, Ill. The straw was used at the Laboratory in developing processes for the recovery of alkaloids from poppy capsules.

Figure 2.--Combine harvesting 38-acre field of No. 40 poppy at Yuma, Ariz., in May 1951. Both seed and capsule material were obtained.

EXPERIMENTAL PLANTINGS, 1950-66

The principal location of poppy investigations in Arizona was changed from Yuma to Mesa in 1950 for the following reasons: (1) George Abel and John Lindsay, who worked with poppies at Yuma in 1948 and 1949, were transferred from Yuma. (2) The USDA was interested in the Salt River Valley of Arizona as a potential poppy production area. (3) The author, with some experience with poppies already, returned to USDA employment in 1950 and was stationed at Mesa, with headquarters at the University of Arizona Agricultural Experiment Station there, to work mainly on research with other crops.

Since no funds were specifically allocated for poppy research in Arizona, the work had to be limited to what could be done along with the principal projects of the Mesa Station, research on safflower and canaigre. Objectives of poppy research at Mesa were to develop information on cultural practices, to screen available germplasm and isolate varieties adapted to the Southwestern desert region, and to increase seed of adapted varieties for possible use in commercial poppy production.

Planting material consisted of (a) seed lots from the previously described work at Yuma; (b) seed selections harvested by the author from the Poppy Production Program at Yuma in 1951; and (c) new introductions, mostly from foreign sources. The following three types of plantings were made: (1) Cultural experiments, mainly time of planting and variety comparison. (2) Nursery plantings of selected material for observation, screening, and selection of desirable types. (3) Seed propagation in isolation of the most desirable selections.

From 1950 through 1957, poppy work in Arizona was under direction of the Tobacco, Medicinal and Special Crops Research Branch, USDA, in cooperation with the University of Arizona. As a result of reorganization of ARS in 1957,

responsibility for poppy work was turned over to New Crops Research Branch. Thereafter, no further variety improvement work was done. No plantings were made in Arizona during the 1957-58 crop season. In December 1958, the author was directed to increase seed of as many good selections as practical in anticipation of the need for replacing the stockpile of No. 40 seed grown in 1951. By that time, the germination level of the No. 40 seed was approaching the minimum allowable for use as planting seed. From 1959 to 1966, seed increase plantings resulted in the stockpiling of seed of eight poppy lines.

Cultural Experiments

Experience with poppies in the Yuma area indicated that December plantings gave satisfactory results in regard to seed germination and stand establishment, vegetative growth, and the maturity of those types requiring a medium to short growing season. (I had thought that earlier plantings might subject emerging seedlings to unfavorable temperatures and that later plantings might not allow sufficient time for plants to mature before the onset of hot weather.) Strains adapted to higher latitudes were blasted by the heat at Yuma before maturity, some even during the blooming stage.

Due to the normally mild, relatively frost-free winters in the Yuma Valley, plants were never subjected to the test of their frost hardiness. Thus, some concern was felt regarding the best planting date for Mesa, which is 1,087 feet in elevation higher than Yuma and has killing frosts at times during the winter months.⁴ The normal dates of first and last occurrences of certain critical minimum temperatures are as follows:

<u>Temperature (° F)</u>	<u>Fall</u>	<u>Spring</u>
32	Nov. 17	Mar. 13
28	28	Feb. 2

At Mesa, 10 plantings were made at weekly intervals from November 6, 1950, to January 9, 1951, using seed of the white-flowered, white-seeded No. 40 line that had been increased at Yuma during the previous season. The same cultural methods used successfully at Bard, Brawley, and Yuma in former years were employed at Mesa. Seed was drilled in dry soil 1/8- to 1/4-inch deep in two rows 15 inches apart on standard raised vegetable beds adjacent to shallow irrigation furrows. Two irrigations, one week apart, were required to effect emergence of seedlings and establishment of a satisfactory stand. Plants were thinned to a spacing of 9 inches when in the fourth or fifth true leaf stage and kept free of weeds throughout the life of the crop. The soil moisture level was maintained well above the wilting range. Ammonium phosphate (16-20-0) at 250 lb/acre was side dressed in late January. Aphid infestation was controlled with parathion. No disease problems were noted in the date of planting trial although in an adjacent nursery planting disease did appear as discussed later in this report.

Capsules were harvested by hand when completely dry, then crushed to permit separation of the seed from capsule material. Morphine assays of capsule samples from the 1951 crop and those of subsequent years were conducted by technicians of the Tobacco, Medicinal and Special Crops Research Branch at Beltsville, Md. Plant behavior and harvest data are presented in table 2.

⁴Refer to Appendix table 2.

TABLE 2.---Behavior and yields of No. 40 poppy on 10 dates of planting at Mesa, Ariz., in 1951

Planting date	Date of peak bloom ¹	Mature height	Average Number of capsules per plant	Color index number of capsule material ²	Calculated yields ³		Capsule-to-seed ratio
					Seed	Capsules	
		Inches			Pounds per acre		
11/6	4/8	57	6.1	110	1,247	1,218	0.98
11/13	4/10	58	5.7	100	1,156	1,234	1.16
11/20	4/11	54	4.5	100	1,030	1,119	1.09
11/27	4/12	51	3.6	100	881	1,032	1.17
12/5	4/15	50	3.9	110	841	909	1.08
12/11	4/15	49	3.6	110	613	719	1.17
12/18	4/17	45	3.6	100	614	756	1.23
12/26	4/18	41	3.9	100	385	632	1.64
1/2	4/23	39	2.8	90	239	481	2.01
1/9	4/26	38	2.6	100	217	370	1.71

¹Data are means of 3 replicates.

²Color index numbers shown indicate a range of 0.30 to 0.36 percent in morphine content (colorimetric method used by M. S. Lowman, Plant Industry Station, Beltsville, Md.).

³4-row plots, harvested area of plots: 2 rows 20 feet long or 0.00149 acres.

Although plantings were spread over a 9-week period, peak bloom occurred within an 18-day period. The spread in maturity dates was even narrower although no data are available to support that observation. Thus, the fruiting behavior of the No. 40 poppy is strongly influenced by photoperiod. This phenomenon was also noted in other years in other adapted poppy lines. Generally, plant height, number of capsules per plant, and yield of both seed and capsule material declined with delay in planting date. Planting dates earlier than November 6 might have resulted in taller and more productive plants. Subsequent experiments were planted to give information on this question.

The narrow range in color index of the capsule material suggests that time of planting and size of plants has little if any effect on the percentage by weight of morphine in the mature capsules.

A second planting trial was grown during the following season, 1951-52, to determine the effect of earlier planting on crop behavior. Five replicated plantings of No. 40 seed were made between October 23 and December 26. Although excellent seedling emergence occurred, an infestation of salt marsh caterpillars (*Estigmene acrea*) depleted stands so badly that observed yield values alone do not necessarily indicate the most desirable time of planting.

The reduced plant population did not appear to affect plant height but did result in increased branching and larger numbers of capsules per plant. In general, the ratio of capsule weight to seed weight was lower in 1952 than in 1951 and was probably due to lower interplant competition. Seed and capsule yields are given in table 3. Other growth and harvest data are not available.

TABLE 3.--Yields of poppy seed and capsule material planted on 5 dates at Mesa, Ariz., in 1951

Date planted	Mean yield ¹		Capsule-to-seed ratio
	Seed ²	Capsule material ³	
-----Pounds per acre-----			
10/23	443	282	0.64
11/2	644	657	1.02
11/26	752	672	.89
12/12	404	282	.70
12/26	241	312	1.30

¹Three replications. Harvested area of a plot, 146.6 ft².

²Differences among mean seed yields not significant.

³Differences among mean capsule yields significant at 5-percent level.

A third planting trial was attempted during the 1954-55 season. No. 40 poppy seed was planted on six dates from October 22, 1954, to January 13, 1955. Again, salt marsh caterpillars were numerous and stand reduction was severe. In addition, beet curly top virus, transmitted to the poppies from nearby

experimental forage and vegetable plantings, further depleted stands, especially in the earlier dates of planting. Yield determinations consequently mean little if anything.

On the basis of experience with these three time-of-planting trials and other poppy plantings over many years, November planting of poppies in the Salt River Valley of Arizona and probably also in the Yuma Valley can be expected to give the most satisfactory results.

Early experience, unsupported by data from controlled experiments, led to the assumption that optimum plant behavior might be expected when plants were thinned to around 9 inches apart where two rows were planted on beds spaced 40 inches from center to center. This thinning results in a plant population of 34,862 plants per acre. In an attempt to develop information on the relationship between plant population and measurable attributes, an experiment was planted in late November 1955, using No. 40 seed.

Eight thinning treatments were imposed in January at the fourth to sixth true leaf stage with plants spaced 1, 2, 4, 6, 9, 12, 15, and 18 inches apart in rows. Thinning was repeated in February to insure elimination of plants in excess of desired numbers. Little insect activity was noted in the early life of the crop, but by late February symptoms of curly top disease had appeared. In spite of insect control efforts, 50 percent plant mortality due to curly top occurred before maturity, thus effectively destroying the experiment. No further opportunity to conduct such an experiment at Mesa ever appeared.

Breeding and Variety Development

As indicated earlier in this report, some work had been done at Bard and at Yuma to isolate poppy lines adaptable to the climatic and soil conditions of the area. Variety development work was continued at Mesa on a very limited scale during 1950-57 after which it was terminated. The specific objective of the program was to develop varieties of poppy adapted to central Arizona and meeting certain requirements for satisfactory commercial production and condiment and medicinal uses. The following requirements were included:

1. Adaptation to soil and climatic conditions of the area.
2. Ability to produce high yields of both seed and capsule material.
3. High extractable morphine content of capsule material.
4. Blue seeds to meet demands of the bakery trade.
5. Capsule indehiscence to prevent seed losses due to shattering.
6. Short plants of uniform capsule height having long peduncles to facilitate mechanized harvesting of capsules.
7. Resistance to disease and lodging.

Planting materials each season included selfed seed from selected plants grown during a previous year (fig. 3) as well as new seed introductions, usually from foreign sources. Standard cultural methods were employed with plantings made in November or early December. Because of the limitations of space, time, and personnel, plant populations had to be kept very small, usually no greater than 100 plants for a single entry in the nursery. At times, the press of work on other experimental crops adversely affected the timeliness of poppy work.

Figure 3.--Harvesting capsule of "selfed" blue-flowered poppy plant from seed increase planting of variety No. 40 at Yuma, Ariz., May, 1951.

The selection of material from a previous year's nursery to be planted again for further study was based on how well a selection satisfied the foregoing requirements, including item No. 3, morphine content. However, in three out of the seven years' data on morphine, analyses of capsule material had not been received from the laboratory by planting time. Consequently, in those years (1952, 1953, and 1956) selection of seed to be planted had to be based only on observations of plant behavior in the field and estimates of yield potential.

Most of the poppy seed acquisitions planted in the nurseries were identified with Plant Introduction (P. I.) serial numbers. Unfortunately, in all years except the 1950-51 season nearly all of the P.I. numbers identifying the new acquisitions are missing. None of the 43 new acquisitions planted in 1950 survived the nursery screening.

Although some detailed data are available from the nursery plantings at Mesa during the period from 1950 to 1957, very little of it is of value because seed stocks of nearly all lines have been lost. Only the stockpiled increase of eight lines remain. These will be discussed later in this report. Some techniques employed in the breeding program and some information developed may be of interest and are discussed. Nursery plantings and supporting studies are briefly outlined by years in table 4.

TABLE 4.--*Summary of nursery plantings and supporting studies, Mesa, Ariz., 1950-57*

Crop year	Entries in nursery			Number plants selfed	Number crosses made	Supporting studies
	From previous year(s)	New introductions	Total			
1950-51	23	43	66	1,233	11	
1951-52	128	0	128	1,300		Bagging test, capsule position
1952-53	99	3	102	(¹)	48	Capsule wounding
1953-54	164	2	166	(¹)		
1954-55	61	12	73	1,500		
1955-56	132	30	162	(¹)		
1956-57	134	15	149	(¹)		

¹Not recorded.

POPPY PLANT BEHAVIOR

At the outset of poppy work at Mesa, an ongoing program of variety and cultural development to extend over a period of many years was anticipated. Observations on the vegetative development and breeding behavior of the plant were made. The relationship between morphine content of the mature capsule and its position on the plant as well as injury involved in controlled pollination were explored.

Thus, it was noted that when a flower bud appears and the peduncle begins to elongate rapidly, the bud tips to one side until it hangs upside down on the inverted stem. Several days before the bud opens, the peduncle begins to straighten up so that the bud is again upright. At that time, the sepals or bud scales, usually two, began to "slip," that is, the lower edges of the sepals, which overlap slightly, begin to slide past each other. At that time, the anthers dehisce, and the stigma is receptive. By the following day, the flower usually is fully open. Opium poppy pollen is heavy and apparently not subject to dispersal by wind. It is much sought after by honeybees, however, which will visit plantings in bloom in large numbers. In a single flower, 20 to 30 bees have been observed at the same time.

Poppy plants that are uncrowded usually have many branches, each of which terminates in an inflorescence. Normally, the bud on the terminal shoot opens first. The bud on the topmost branch opens next, then the bud on the next highest branch, and so on. A No. 40-type plant growing in isolation may have as many as 15 blooms, and the latest ones to open may not have time to mature seed

before the plant dies. On the other hand, crowded plants may produce no more than one or two capsules, which are usually smaller than those of uncrowded plants. Under optimum field conditions, four to six capsules per plant are produced.

Plants selected in the nursery for later propagation were always bagged to insure self-pollination and to avoid outcrossing (fig. 4). At maturity, the bagged capsule was separated from the seed and analyzed for morphine content. Some controlled crossing was done to study the pattern of inheritance. Both parents of a cross were sampled for morphine content. In the female parent, either the capsule involved in the cross-pollination or another capsule on the same plant was analyzed.

Figure 4.--Bag clipped shut over flower left for 6 days to exclude foreign pollen. Kraft paper bags used here due to shortage of preferred vegetable parchment.

The questions was raised as to what variability in morphine content, if any, existed between capsules on the same plant, and what effect on morphine content might result from the wounds inflicted on the inflorescence during the selfing and crossing operations and also from insect or other injury. Two simple experiments were conducted to shed light on the matter.

In the first experiment (1952), all flowers on each of 10 randomly selected No. 40 plants were labeled as to date of blooming and position on the plant. Analysis of the capsule material showed some variability in morphine content among capsules on the same plant, but no definite pattern or trend. The terminal capsule was found to be slightly larger in size and weight than those borne on branches. Later observations indicated that the morphine content of the terminal capsule is slightly but consistently lower than that of secondary capsules on the same plant.

In the second experiment (1953), 70 healthy No. 40 plants were randomly selected before flowering began, 10 for each of 7 wounding treatments as follows:

1. Removal of sepals and petals just prior to normal flower opening and the exposed stamens and pistil left uncovered.
2. Same as No. 1 except covered immediately with parchment bag as in the ordinary selfing procedure.
3. Same as No. 1 except covered with light muslin pollinating bag such as that used in selfing safflower.
4. The capsule was scored with the point of a sharp knife 3 days after petal drop. Three very shallow incisions were made on each of two sides.
5. Same as No. 4 but only after the capsule was fully enlarged but still green and succulent.
6. Capsules were incised at both stages of growth as described in treatments 4 and 5 above.
7. Capsule was scarified with very coarse sandpaper when fully enlarged but still green and succulent.

One flower or capsule on each plant was selected for treatment, usually the first or second one to bloom on a plant. On each plant, a duplicate flower was selected to serve as a control so that paired comparisons could be made. In nearly every case, the flowers selected for treatment and control were the first two to open on a plant. In each treatment, five of the flowers or capsules treated were first blooms while controls on the same plants were second blooms. The reverse was true in the remaining five plants. This was intended to prevent any bias due to possible effect of position or flowering sequence on morphine content of capsules.

Treatments were imposed between April 15 and May 5. Capsules were harvested in early June and observations were made on capsule size and condition and mature seed content. Capsules were analyzed for morphine content after removal of seed. The data are presented in table 5.

The data in table 5 indicate a definite trend toward a higher morphine content in capsules subjected to the first three wounding treatments than in controls. On the basis of these data, then, to obtain an accurate evaluation of the morphine content of a given plant, it would appear desirable to submit for individual plant assay only those capsules that have not been subjected to the removal of the perianth and bagged.

Actually, in subsequent selfing operations only the sepals were removed before bagging the bud (fig. 5). Care was taken to tear open the bag before fungal activity in the sloughed-off petals could damage the tender young capsules. Wounding capsules after flowering to increase morphine for commercial production is probably impractical.

In 64 out of 70 comparisons, terminal capsules were larger in size than secondary capsules. The amount of seed in terminal capsules was generally greater than that in secondaries. The amount of seed in wounded capsules was somewhat less than that in controls. This difference was greatest in treatments involving removal of the perianth.

TABLE 5.--Morphine content of wounded poppy capsules and controls under seven wounding treatments,
Mesa, Ariz., 1953

Plant number	Perianth removed				Incised stage				Scarified Late					
	Not bagged		Parchment		Muslin		Early			Late		Both		
	W ¹	C ²	W	C	W	C	W	C		W	C			
-----Percent of dry weight-----														
1	0.4	0.4	0.7	0.4	0.5	0.4	0.4	0.7	0.4	0.6	0.5	0.5	0.6	0.4
2	.5	.3	.4	.4	.4	.5	.3	.3	.4	.4	.3	.4	.3	.3
3	.4	.3	.5	.5	1.0	.7	.5	.3	.3	.3	.3	.4	.5	.3
4	.5	.3	.4	.4	.5	.4	.4	.3	.4	.3	.3	.3	.3	.3
5	.4	.4	.4	.3	.3	.6	.3	.3	.4	.4	.4	.3	.4	.4
6	.3	.3	.3	.3	.3	.4	.5	.3	.3	.4	.4	.4	.3	.4
7	.4	.3	.3	.4	.3	.6	.4	.4	.5	.3	.3	.3	.4	.4
8	.6	.6	.3	.4	.5	.4	.3	.3	.4	.4	.3	.3	.3	.3
9	.5	.3	.4	.3	.3	.3	.3	.3	.4	.3	.4	.3	.3	.3
10	.4	.4	.3	.4	.5	.4	.3	.3	.3	.3	.4	.3	.4	.3
Mean ³	.44	.36	.40	.38	.46	.47	.37	.35	.38	.37	.36	.35	.38	.34

¹Wounded.
²Control.

³Mean of 1, 2, and 3 (W): 0.433.
Mean of 4, 5, 6, and 7 (W): 0.372.

Mean of all wounded: 0.399.
Mean of all controls: 0.374.

Figure 5.--Removing sepals from unopened bud of selected poppy plant in preparation for bagging. Petals left in place to third day. Identifying tag attached to peduncle.

In 1951, 11 crosses were made between plants having distinctly different floral and vegetative characteristics. The purpose of the crosses was to make a preliminary study of the factors and techniques involved in controlled cross-pollination of poppies. Sepals were removed from a bud selected for female parentage when the bud was nearly upright but just before the sepals began to slip. The flower was then emasculated and bagged. Petals were left intact to minimize the shock of wounding. At that stage, anther dehiscence had not occurred, but viability of pollen was assumed. Pollen shedding was observed repeatedly when sepal slipping was in progress just before opening of the buds.

On the following day, cross-pollination was effected by removing the freshly dehiscent anthers from a bud selected for male parentage and dusting the pollen onto the stigma of the female parent. The bag was then replaced over the cross-pollinated bud to exclude pollen carriers. After 3 or 4 days, the bag was ripped open, and the petals were removed. The torn bag was left attached to the stem as a marker.

Of the 11 crosses, 9 produced seed that were planted in the nursery the following year along with selfed seed from the parent plants of each cross. All F₁ progenies exhibited characteristics of the male parents. Consequently, the crosses were deemed to have been successful and the proper technique used.

During the 1952-53 season, a multiple crossing program was begun as part of a projected long-range breeding program. A total of 14 inbred lines, including what was regarded as the best of the material at hand, were selected for intercrossing. Theoretically, 91 combinations are possible among 14 individuals. Actually, only 48 cross-pollinations resulted in production of mature seed. Differences in date of flowering and lack of time prevented many combinations

from being made. Of the 14 lines, 4 did not begin to bloom until the other 10 were finished.

During the following season, the F₁ progenies were planted. Floral and other external manifestations indicated that 40 of the 48 progenies were actually crosses. One of the eight remaining entries appeared to be a self as it did not carry the dominant purple flower of the male parent but was white flowered like the female parent. In the other seven entries, each F₁ population resembled both parents, which were alike in each case.

In most crosses made in 1951 and 1953, heterosis appeared to be lacking. Where wide differences in plant height or size occurred between parents, the offspring was intermediate between the two. For the most part, the morphine percentages in the F₁ fell near to those of the parents, but there was no clear-cut pattern in this respect. Because of the transfer of poppy work to another agency 3 years later, no varieties were developed out of the intercrossing program.

Disease and insect problems during the last 3 years of the breeding program severely hampered efforts, and some material was lost. The last nursery to be planted, in 1956, was almost totally destroyed, leaving only remnant seed with which to begin the seed stockpiling program in 1958.

SEED INCREASE FOR STOCKPILING

In 1958, the large stockpile of No. 40 poppy seed grown at Yuma and Brawley in 1951 was apparently losing its viability rapidly. Isolated increase plantings were hastily made in December 1958, with seed of nine lines developed in the nursery at Mesa. In each case, the lines selected for increase had been inbred through bagging and self-pollination in nurseries from 3 to 10 generations. In several instances, the seed of two or more selfed plants of the same line was composited. Segregation for flower and seed color was still evident in several lines.

All plantings except one were made on experiment stations controlled by the University of Arizona. One planting was made on the farm of a private cooperator. All except one planting produced some seed. In most instances, however, seed yield was so low that plantings were repeated in succeeding years to bring the quantity of stockpiled seed of each line up to an acceptable level. The quantity of seed of each of the eight stockpiled lines is presented in table 6 along with some information about each.

The eight lines, of which the seed was increased, were grown in several comparative yield trials. The first trial was planted at Mesa during the 1959-60 season but was destroyed by curly top disease before maturity. During the following season, the same eight lines were planted at both Mesa and Yuma. The planting at Mesa was again struck by curly top disease but much less severely than during the previous season. The Yuma planting was almost totally free of disease, but during the early period of growth, birds attacked the emerging seedlings reducing the stand in three of five replications to the extent that yields from them were meaningless. However, the remaining two replications remained untouched, and the performance of all lines was excellent. Calculated yield values, in pounds per acre, are given for the two locations in table 7.

TABLE 6.--Stockpiled opium poppy seed grown in Arizona during 1959-66

Line	Origin ¹	Flower color	Seed color	Capsule character ²	Morphine ³	Year grown	Stockpile
					Percent		Pounds
B40-L1-5b	Uncertain	Purple ⁴	Blue and lavender ⁴	i	0.57-0.63	1959	50
B40-6-3	--do--	Purple	Blue ⁴	i	0.63	1960	306
B60-40-5	--do--	Purple ⁴	Blue ⁴	d	0.68-0.77	1962	58
M83	PI No. 221946	--do--	--do--	i	0.34-0.42	1965	81
M89	PI No. 223458	White	White	i	0.44-0.53	1960	48
M91	PI No. 223520	--do--	--do--	i	0.38-0.55	1964	41
M92	PI No. 223797	Mixed ⁵	Mixed ⁵	i	0.48-0.59	1966	78
M93	PI No. 223798	White	White	i	0.55-0.61	1963	26

¹The three B lines (identity lost) originated from introductions first planted at Bard, Calif., 1945-46. The 5 M lines were from Afghanistan.

²i= indehiscent; d= dehiscent.

³Determined by Wolff, Northern Utilization Research and Development Division; method of Pride and Stern.

⁴Impure, some white flowers and seed.

⁵Both white and purple flowers, white and blue seed.

TABLE 7.--Yields of poppy seed and capsule grown at Yuma and Mesa, Ariz., 1961

Variety	Mesa ¹		Yuma ²	
	Seed	Capsules	Seed	Capsules
-----Pounds per acre-----				
B40-6-3	749	737	1,219	1,005
B40-L ₁ -5b	572	623	950	842
B69-40-5	679	562	1,324	786
M83	815	634	1,619	995
M89	588	576	1,195	892
M91	615	584	1,847	1,084
M92	627	614	1,365	1,058
M93	701	724	1,294	1,021

¹Values given for Mesa are means of four replications.

²Values given for Yuma are means of two replications.

DISEASE AND INSECT PROBLEMS

The most destructive disease encountered was curly top caused by a virus carried by leafhoppers. It was present to some degree in every poppy planting and was devastating at times. Because of the wide variety of crops usually grown on experiment stations, it was always difficult and usually impossible to isolate poppy planting from leafhopper harboring crops. Available insecticides were only partially successful in controlling the insects.

Poppy plants appear to be susceptible to curly top at all stages of growth. Early attacks usually resulted in death of the plants while still in the rosette stage of growth. Usually, the first symptoms noted were stunted growth and a slight yellowing of foliage. Within days, affected plants became quite yellow and leaf necrosis began, resulting in complete death of the plant within several weeks. Older plants, when attacked by curly top, also became yellowed and growth was retarded; however, death of the plants was usually slower. Plants attacked just before blooming invariably aborted the flowers. Those infected after blooming usually produced nonviable seed or no seed at all, and the prematurely dry capsule was often shrunken and purple, whereas the remainder of the plant often stayed green until healthy plants declined. A few plants had one or more capsules so affected while other capsules on the same plant remained healthy and produced normal viable seed.

The best defense against curly top appeared to be isolation from susceptible crops and weeds, timely application of insecticides effective against leafhoppers, and establishment of fairly closely spaced plant populations and late thinning. The incidence of curly top was usually highest where thin stands occurred and along the margins of plots adjacent to bare ground, which is attractive to leafhoppers when not feeding.

The only two other diseases of any consequence noted in the poppy plantings were a leaf spotting ailment and a stalk rot, both of which appeared in the first nursery planted at Mesa in 1950 and thereafter were not noted. Causal organisms were identified as *Xanthomonas papavericola* and *Erwinia papaveris*, respectively, by J. G. Brown of the Plant Pathology Department of the University of Arizona. Affected plants were confined mainly to the late-blooming lines among the new introductions.

Aphids usually appeared on poppies throughout most of the growing season. At times, infestations were severe. Parathion was effective in controlling the aphids, which congregated mainly on the undersurface of the leaves. The extent of damage to plants caused by aphids could not be assessed. Thrips were also noted on the plants. Both thrips and aphids were believed responsible for the tiny spots of dried latex or opium that appeared on the developing capsules after petal fall, giving them a speckled appearance.

The only other insect of interest in the poppy plantings at Mesa was the salt marsh caterpillar, *Estigmene acrea*. Tremendous populations of this insect built up in cottonfields during late summer and devoured the cotton leaves, usually late in the fall after the cotton crop was mature. Little effort at control was made since the insects' depredations saved the cotton grower the expense of chemically defoliating the crop in preparation for mechanical picking. As soon as the food supply approached exhaustion, however, the caterpillars would begin a mass migration in search of greener pastures. At that stage of development, the caterpillars were practically immune to control by insecticides. The only practical means of protecting a neighboring field was to install a barrier completely around it. The most effective barrier consisted of an 8-inch strip of anodized aluminum foil with one edge set 2 inches into the soil to hold it vertical. Caterpillars could not crawl up the smooth surface.

Such a barrier was installed around poppy plantings whenever the danger of attack by salt marsh caterpillars appeared; however, the barrier was not completely effective in excluding the insects. Anything that would breach the barrier such as hard winds or rolling tumbleweeds, would allow caterpillars to enter and devour many poppy plants before the damage could be detected and repaired. In addition, caterpillars, in their attempts to scale the barrier, would leave a gummy deposit on the aluminum that would allow them to climb successively higher until eventually they could reach the top.

Damage due to saltmarsh caterpillars was severe enough in 1951 and in 1954 so that the earliest plantings of the date-of-planting experiments were partially destroyed. Later plantings were not affected because the insects had usually disappeared by late November.

Although cold damage to poppy plants can hardly be classed with damage caused by insects and diseases, it deserves some comment. At times, temperatures low enough to cause killing frosts occurred where experimental poppy plantings were growing. All stages of growth up to the appearance of flower buds were subjected, at one time or another, to such low nighttime temperatures. At no time during the early stage of growth of poppy plants was damage observed that could be attributed to low temperatures. Plants were observed several times in the seedling or rosette stages of growth heavily covered with frost with no apparent ill effects.

In early March 1954, however, a sudden frost (28° F or -2° C) followed a period of unseasonably mild weather. Out of 166 entries in the poppy nursery,

109 were damaged to some degree. The greatest damage was sustained by entries that had already begun to shoot upward and had flower buds in view. Very few plants were actually killed, but in the more severely damaged survivors the terminal flower buds were blasted and the growth habit of the plants greatly distorted. Most damaged plants, however, produced some viable seed.

Wind is a more serious hazard. Generally, poppies have to be thinned to the desired stand after plants are well established. Before thinning, the plants may be crowded enough to lend each other support and tend to be somewhat spindly. When thinned to single plants, the unsupported plant is vulnerable to the whipping action of hard winds that can break the top of the plant off at the ground. Such hard winds occurred on several occasions at both Mesa and Yuma, substantially reducing stands of plants that had just been thinned.

Later, when plants are at or near their maximum height, they are again susceptible to wind damage. In this case, damage may be associated with high nitrogen soil fertility and irrigation during or just prior to a period of hard wind. Irrigation causes the soil to be very soft and robs the plant of firm support for the roots. The lodging that results renders a field very difficult to harvest mechanically, and the loss of capsule material and seed may be great. This was observed in 1974 at Yuma in the course of a plant spacing trial conducted by the University of Arizona in cooperation with ARS.

CONCLUSIONS AND RECOMMENDATIONS

Opium poppy production research has been very limited in the United States. Yet, in spite of limited funding and personnel and a lack of consistent long-range planning, some significant results and experience were acquired upon which the following conclusions and recommendations are based.

Opium poppies can be grown successfully in the warm, irrigated Salt River Valley and Yuma Valley of Arizona and the Imperial Valley of California using cultural practices and equipment presently employed for production of other crops. Slight modification of existing harvesting machinery may be necessary.

Many of the cultural practices used in the production of head lettuce in the area are applicable to opium poppies through the vegetative stage of growth. A seeding rate of 12 ounces of unpelleted seed per acre resulted in full stands of plants. If precision planting equipment and pelleted seed are used, planting rates of 2 ounces of seed per acre should be possible. November planting resulted in the highest yields of seed and straw. The morphine percentage of the straw was not influenced by date of planting.

Frequent furrow irrigation to keep the soil surface moist after planting is necessary until seedlings emerge. Generally, five to eight irrigations after emergence, depending on the soil, appear to be necessary to prevent undue moisture stress. Poppies require moisture most during the fruiting stage. Precise moisture requirements of the crop are not known.

Precision planting probably could eliminate the need for thinning. However, where thinning is necessary, it should be done from 4 to 6 weeks following seedling emergence, after plants are well established and before interplant competition results in spindly growth. Newly thinned plants, deprived of the support of close neighbors, are susceptible to decapitation and stand reduction caused by strong winter winds.

The initial growth rate of poppy seedlings is slow. Weed control is usually necessary. Two or three cultivations are usually adequate. Cultivation after leaf spread exceeds 8 or 9 inches results in leaves being broken off. No information on weed control with herbicides was developed.

Growth stimulation and a deeper green plant color were observed when nitrogen and phosphorus were applied. Heavy applications of nitrogen are believed to promote lodging.

Opium poppies are susceptible to diseases caused by the organisms *Xanthomonas papavericola* and *Erwinia papaveris*. These were noted only in plantings made with seed introduced from foreign countries. No resistance to beet curly top disease was noted. The key to curly top control appears to be leaf hopper control and the establishment of full stands. Poppies are susceptible to aphid infestation throughout the life of the crop, requiring applications of an appropriate insecticide as needed. Salt marsh caterpillars severely reduced stands of plants on several occasions. Aluminum foil barriers were effective in excluding the caterpillars.

Poppies in the vegetative stages of growth appear immune to damage due to such frosts as occur in the experimental area. On the basis of a single observation, once the plant has entered the fruiting stage it becomes susceptible to frost damage. Wind can be hazardous to poppies, not only immediately after thinning but also to plants nearing maturity when fruits are large and heavy. A strong wind during or immediately after an irrigation can result in lodging of the plants. Thus, weather forecasts should be considered when scheduling irrigations during the fruiting season.

Poppies from different sources vary widely in morphological, chemical, and agronomic characteristics. The seed introductions screened in these studies best adapted to the experimental area came from India, Turkey, and Afghanistan. Selections from these sources having up to one percent morphine in the mature capsules were observed. Eight varieties, well adapted to conditions of the experimental area, were developed and seed stockpiled.

Yields of 995 pounds of seed and 855 pounds of seed free straw per acre were harvested from 36.5 acres at Yuma in 1951. This was accomplished without benefit of previous production experience, using a relatively unimproved seed source (No. 40, 0.54 percent morphine). Higher yields were observed in subsequent smaller scale plantings. I am confident that a properly conducted production research program over a period of 10 to 15 years can result in locally adapted varieties yielding at least 1,500 lb/acre of both seed and capsule material with an extractable morphine content of one percent or above.

APPENDIX

TABLE 1.--Temperature and rainfall data, University of Arizona Valley Experiment Station, Yuma, Ariz., 1941-70¹

Month	Temperature			Mean number days		Mean monthly precipitation
	Mean monthly	Mean maximum	Mean minimum	Maximum	Minimum	
				90° F or above	32° F or below	
-----Degrees Fahrenheit-----						
January	52.6	68.4	36.8	0	8	0.33
February	56.6	73.5	39.6	(2)	3	.23
March	61.1	78.0	44.1	2	1	.23
April	68.3	86.0	50.5	12	0	.09
May	75.4	93.9	56.9	23	0	.02
June	82.0	100.8	63.1	28	0	.01
July	90.1	106.6	73.6	31	0	.18
August	89.8	105.4	74.2	31	0	.31
September	84.0	101.5	66.4	29	0	.24
October	73.1	91.4	54.8	22	0	.20
November	61.1	78.2	44.0	2	1	.27
December	53.7	69.3	38.0	0	5	.46
Year	70.7	87.8	53.5	180	18	2.57

¹Latitude: 32°43'; longitude: 114°43'; elevation: 120 feet.

²Less than 1/2 day.

TABLE 2.--Temperature and rainfall data, University of Arizona Valley Experiment Station,
Yuma, Ariz., 1941-70¹

Month	Temperature			Mean number days		Mean monthly precipitation
	Mean monthly	Mean maximum	Mean minimum	Maximum	Minimum	
				90° F or above	32° F or below	
-----Degrees Fahrenheit-----						
January	50.3	64.9	35.6	0	9	0.84
February	53.9	69.3	38.5	(2)	5	.60
March	58.3	73.6	42.9	(2)	1	.77
April	66.3	83.0	49.5	7	0	.34
May	74.5	92.1	56.8	21	0	.14
June	82.6	100.8	64.4	29	0	.09
July	89.2	104.3	74.1	31	0	.82
August	87.4	101.8	72.9	30	0	1.20
September	82.2	98.5	65.9	28	0	.76
October	71.4	88.3	54.4	18	0	.53
November	59.1	75.4	42.7	1	2	.50
December	51.9	66.9	36.8	0	8	.93
Year	68.9	84.9	52.9	165	25	7.52

¹Latitude: 33°25'; longitude: 111°52'; elevation: 1,230 feet.

²Less than 1/2 day.

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