AN ABSTRACT OF THE THESIS OF

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Title: PLANT AND SEED DEVELOPMENT IN FOUR CUPHEA SPECIES

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Abstract approved: ____________________
Don F. Grabe

Cuphea is a potential source of medium-chain triglycerides for manufacture of soaps, pharmaceuticals and nutritional products. Indeterminate flowering and seed shattering are wild-type plant characteristics that make it difficult to determine when to harvest for maximum yield of seed and oil.

The primary objective of this study was to investigate the relationship between stage of Cuphea seed development and yields of seed and oil. A secondary objective was to determine the effect of photoperiod on plant development and flowering.

The flowering patterns of C. laminuligera Koehne, C. leptopoda Hemsley, C. lutea Rose and C. wrightii Gray were determined in the greenhouse. The effect of photoperiod on flowering of the four species was studied under 8/16 and 16/8-h light/dark cycles at 10/25°C in growth chambers. Seed development of C. lutea and C. wrightii was compared in two greenhouse and one field experiment by

harvesting seeds at frequent intervals from tagged flowers and measuring several quality components.

Two opposite branches formed at each of the first two nodes in *C. wrightii*, the first four in *C. lutea*, the first five in *C. leptopoda* and the first six in *C. laminuligera*. All species formed one branch $node^{-1}$ thereafter. The first flowers developed in the axil of the second single branch in all species. All species flowered under 8 and 16-h photoperiods.

The maximum seed dry weight was attained by 18 days after anthesis in both species in the 1985 greenhouse studies. At this time, dry weight was 2.7 mg $seed^{-1}$, moisture content was 36% and oil content was 43% in *C. lutea*. Measurements for *C. wrightii* were 1.9 mg $seed^{-1}$ dry weight, 37% moisture and 43% oil content. Simple correlation coefficients for oil and dry weight were 0.97 and 0.96 for *C. wrightii* and *C. lutea*, respectively. Seed growth rate of *C. lutea* was 1.4 times that of *C. wrightii*. Similar relationships between seed quality components were evident in the 1986 greenhouse and 1985 field experiments.

Seeds of *C. lutea* were mature at the time of emergence from the calyx tube when grown in the field. Waiting beyond this time for green seeds to turn yellow or brown before harvesting does not increase seed yield or oil content. Since the four species flowered under 8 and

16-h photo periods, it appears Cuphea may be grown over a wide range of latitudes.

Plant and Seed Development in Four *Cuphea* Species

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INTRODUCTION

Oil from *Cuphea* seed contains high amounts of medium-chain fatty acids which are used in the manufacture of industrial, medicinal and nutritional products. The present source of these acids is coconut and palm oil of which about a billion pounds are imported annually by the U.S. (Thompson, 1984). Imported supplies are subject to wide fluctuations in quality and price. Since 1983 Oregon State University, USDA and private industry have co-operated in conducting research to study the feasibility of developing *Cuphea* as an economically viable new oil crop in the Pacific Northwest and other parts of the U.S.

Cuphea species have several agronomic characteristics which impede their domestication. These include indeterminate growth and flowering, seed dormancy and shattering, and viscid glandular hairs on stems, leaves and flowers. Indeterminate flowering leads to seeds ripening over a period of several weeks. At maturity, the ovaries rupture, exposing placental tissue and seeds (Hirsinger and Robbelen, 1980). The exposed seed shatters easily. These factors make it difficult to determine when to harvest for maximum yield of seed and oil. Seed shattering is believed to be the most limiting constraint to domestication. In addition, seeds are dormant when harvested, making it difficult to establish good plant stands from freshly harvested seed. Viscid glandular hairs make mechanical harvesting and handling difficult because seeds stick to each other and to equipment. *Cuphea* domestication requires detailed understanding of all aspects of its seed technology.

This study was undertaken to compare plant growth, flowering and seed development characteristics of several *Cuphea* species. Such information is needed for further work on seed production, timing of seed harvesting, and selection of superior plant types.

LITERATURE REVIEW

Cuphea is a diverse genus, having about 260 annual and perennial species (Hirsinger and Knowles, 1984; Thompson, 1984). It is native to tropical and subtropical areas of North, South and Central America. Some varieties of *C. ignea* and *C. llavea* are popular ornamentals in warm areas of the U.S.A. (Miller et al., 1964). Seed oil from *Cuphea* species contains high amounts of medium-chain triglycerides (Miwa et al., 1960) which are used in the manufacture of industrial, medicinal and pharmaceutical products (Babayan, 1981). There is strong interest in developing *Cuphea* as an oil crop in order to have a domestic source of medium-chain triglycerides to replace imported coconut and palm oil.

Vegetative Development and Flowering

In many crops vegetative development depends on temperature and plant population. Warm temperature enhances vegetative growth (Went, 1953; Seddigh and Jolliff, 1984; Lawn and Hume, 1985). In soybean, warm day temperature compensates for low night temperature so that node formation at 30/12°C was higher than at 20/20°C (Lawn and Hume, 1985). Speed of seedling development at a particular temperature is a rapid technique for evaluating seedling vigor (Cooper et al., 1980). In birdsfoot trefoil, seedling development was positively correlated with greenhouse yield, field vigor ratings and forage yield (Cooper et al., 1980). One important component of yield is branches plant^{-1}. This is affected by plant population. In soybean, nonoptimum plant population reduces branch yield components rather than main stem components (Board, 1985). In beans, interplant competition resulted in fewer branches and pods plant^{-1} on types that set the majority of their pods on lower nodes (Lucas and Milbourn, 1976; Kueneman and Wallace, 1979; Mauk et al., 1983).

In *Cuphea*, flowers are axillary and borne on short lateral shoots. The main stem axis continues vegetative growth and flowering concurrently. This causes seed to mature over a period of several weeks (Hirsinger, 1984). Flowers are singly set rather than combined in inflorescences (Robbelen and Hirsinger, 1982). Two main factors causing changes in flowering time in many crops such as cotton, soybean and subclover are temperature and photoperiod (Aitken, 1955; Board and Hall, 1984; Schweitzer and Harper, 1985). Generally a short photoperiod hastens flowering. There is also a temperature x photoperiod interaction. In sugarbeet, lettuce and subclover, long days hastened flowering of vernalized plants (Aitken, 1955; Dennis, 1984). Removal of leaves and flowers also affects flowering time. In cotton, removing flowers hastens fruit set (Dale, 1959; Kennedy et al., 1986). In soybean, leaf removal hastens flowering (Goli and Weaver, 1986), while the opposite was found in subclover (Collins and Aitken, 1970). This has important applications in crop management because time of flowering can be controlled, by mowing or grazing, so that seed harvesting is done at a favorable time.

Maturity

Early efforts to estimate seed maturity dealt with visual indicators such as browning of the plant, leaf or stem senescence, and external appearance of the seed unit (spike, panicle, ear). Later, attention was directed towards stage of seed development. Measurements of moisture content, dry matter accumulation, viability and seedling vigor became common. Studies of this kind have been described for cereals (Harlan, 1920; Collier, 1963; Rajanna and Andrews, 1970), forage crops (Anderson, 1955; Hyde et al., 1959), safflower (Leininger and Urie, 1964) and soybeans (TeKrony et al., 1979).

Maturity was defined as the point in plant growth when maximum grain development is first attained (Aldrich, 1943). The time required to reach maximum dry weight was termed relative maturity. Later, the term physiological maturity was used to refer to the time when a seed reaches its maximum dry weight (Shaw and Loomis, 1950). This is also referred to as functional maturity (Delouche, 1958) and morphological maturity (Anderson, 1955). Despite differences in the concept of maturity, it is generally accepted that physiological maturity refers to the time when maximum dry weight is first attained in seed development.

Of the many procedures used to estimate maturity, the most common is to compare the relationship of maturity to accumulation of dry weight in the seed, moisture content and germination. Days from anthesis to maximum dry weight is a common estimate of maturity. In Cuphea, Hirsinger and Knowles (1984) reported that seed is fully ripe about a week after the cone-shaped placenta, with attached seeds, breaks through the calyx tube to expose the seed. From the time when the calyx tube opens to expose the seed until the seed is fully ripe, there was no difference in oil content. In Cuphea procumbens, lipid accumulation in developing seeds increases greatly between 11 and 14 days after flowering (Slabas et al., 1982). In subclover, Taylor (1980) found seed development in the cultivar Daliak to be complete 42 days after flowering in the greenhouse. Physiological maturity is attained at 28 days after flowering in safflower (Leininger and Urie, 1964), 27 in birdsfoot trefoil (Anderson, 1955) and 24 in red clover (Hyde et al., 1959). In cereals, a close relationship exists between seed moisture content and maximum dry weight. Moisture content of seeds at the time of maximum dry weight was reported to be 42% for barley (Harlan, 1920), 45% for oats (Frey et al., 1958), 40% for wheat (Burnett and Bakke, 1930) and 27% for sorghum (Clark et al., 1968).

Dessureaux et al. (1948) reported corn kernel moisture percentages between 31 and 44% at maximum dry weight. Kernel moisture percentage was later found to be inferior to maximum kernel dry weight as an indicator of physiological maturity (Shaw and Thom, 1951).

Seeds of many species are capable of germinating long before physiological maturity (Copeland and McDonald, 1985). Germination increases with days after anthesis (Anderson, 1955; Grabe, 1956; Frey et al., 1958; Rajanna and Andrews, 1970).

In Cuphea, fresh seed is dormant due to a hard seed coat (Hirsinger and Knowles, 1984; Janick and Whipkey, 1986). Fresh seeds can germinate when the testa is removed or scarified (Hirsinger and Knowles, 1984). Excised embryos from dormant seeds of Cuphea wrightii can germinate when grown on a basal medium (Janick and Whipkey, 1984).

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PLANT AND SEED DEVELOPMENT IN *CUPHEA*

ABSTRACT

Cuphea is a potential source of medium-chain triglycerides for manufacture of soaps, pharmaceuticals and nutritional products. Indeterminate flowering and seed shattering are wild-type plant characteristics that make it difficult to determine when to harvest for maximum yield of seed and oil.

The primary objective of this study was to investigate the relationship between stage of *Cuphea* seed development and yields of seed and oil. A secondary objective was to determine the effect of photoperiod on plant development and flowering.

The flowering patterns of *C. laminuligera* Koehne, *C. leptopoda* Hemsley, *C. lutea* Rose and *C. wrightii* Gray were determined in the greenhouse. The effect of photoperiod on flowering of the four species was studied under 8/16 and 16/8-h light/dark cycles at 10/25^{o}C in growth chambers. Seed development of *C. lutea* and *C. wrightii* was compared in two greenhouse and one field experiment by harvesting seeds at frequent intervals from tagged flowers and measuring several quality components.

Two opposite branches formed at each of the first two nodes in *C. wrightii*, the first four in *C. lutea*, the first five in *C. leptopoda* and the first six in *C. laminu-*

ligera. All species formed one branch $node^{-1}$ thereafter. The first flowers developed in the axil of the second single branch in all species. All species flowered under 8 and 16-h photoperiods.

The maximum seed dry weight was attained by 18 days after anthesis in both species in the 1985 greehouse studies. At this time, dry weight was 2.7 mg $seed^{-1}$, moisture content was 36% and oil content was 43% in C. lutea. Measurements for C. wrightii were 1.9 mg $seed^{-1}$ dry weight, 37% moisture and 43% oil content. Simple correlation coefficients for oil and dry weight were 0.97 and 0.96 for C. wrightii and C. lutea, respectively. Seed growth rate of C. lutea was 1.4 times that of C. wrightii. Similar relationships between seed quality components were evident in the 1986 greenhouse and 1985 field experiments.

Seeds of C. lutea were mature at the time of emergence from the calyx tube when grown in the field. Waiting beyond this time for green seeds to turn yellow or brown before harvesting does not increase seed yield or oil content. Since the four species flowered under 8 and 16-h photoperiods it appears Cuphea may be grown over a wide range of latitudes.

Additional index words: Cuphea laminuligera Koehne, Cuphea leptopoda Hemsley, Cuphea lutea Rose, Cuphea

wrightii Gray, maturation, dry weight, moisture, flowering, photoperiod.

Plant and Seed Development in *Cuphea*

INTRODUCTION

Seeds of *Cuphea* species are potential sources of medium-chain triglycerides for manufacture of soaps, detergents and pharmaceutical products (Miller et al., 1964; Babayan, 1981; Thompson, 1984). All known species of *Cuphea*, however, have several wild-plant characteristics which must be eliminated before a suitable agronomic plant type can be developed for agronomic purposes (Robbelen and Hirsinger, 1982; Hirsinger and Knowles, 1984).

The flowering habit of *Cuphea* is indeterminate, with flowers produced over a period of 1 to 2 months (Hirsinger, 1984). Development of the seeds takes place within the calyx tube. As seeds enlarge, the calyx tube bursts. The placenta, with attached seeds, becomes erect and breaks through the pericarp and calyx tube. The seeds shatter soon after (Hirsinger and Knowles, 1984). To obtain reasonable seed yields, seeds are harvested several times during the season with a non-destructive vacuum-harvester (Hirsinger, 1984). The vacuum-harvested seed contains a mixture of green, yellow and brown seeds, but the relationship of seed color to maturity and oil content is not known. Indexes of seed maturity have been determined for cereals (Harlan, 1920; Bartel, 1941; Hallauer and Russell, 1962; Clark et al., 1968) and many other species (Grabe, 1956; Frey et al., 1958; Leininger and Urie, 1964; Browne, 1978; TeKrony et al., 1979), but rarely for indeterminate species such as Cuphea.

This study was undertaken to compare plant growth, flowering and seed development characteristics of several Cuphea species. Such information is needed for further work on seed production, timing of seed harvesting and selection of superior plant types.

MATERIALS AND METHODS

Species selected for study were *Cuphea lutea* Rose, *C. wrightii* Gray, *C. laminuligera* Koehne and *C. leptopoda* Hemsley. The first two are self- and the last two are cross-pollinated. Vegetative development studies were conducted in the greenhouse, flowering patterns were studied in the greenhouse and growth chambers, while seed maturity studies were carried out in the greenhouse and field.

Vegetative Development

Vegetative development of the four species was studied in the greenhouse during the 1984-85 and 1985-86 seasons. Seeds were planted in soil in 15-cm plastic pots on 12 February 1985 and 17 December 1985. Fertilizer (8-10-10) and lime were added to a soil mixture of 1 part soil, 1 part peat and 1 part sand at the rate of 4 and 8 g kg^{-1} of soil, respectively. Seedlings were thinned to 4 plants pot^{-1}. Temperature was controlled to approximately 25^{o}C during daytime and 18^{o}C at night. Light from F48T12/CW/VHO fluorescent tubes was used to extend daylength to 16 h. The experimental design was a randomized complete block with three replications.

The branching pattern of each species was determined at several stages of development beginning 18 days after planting in 1985 and 19 days in 1986.

Flowering

Greenhouse Studies

The normal flowering habit of the four species under 16-h daylengths was observed on the same plants used for the vegetative development studies. Observations were made of the number of days to beginning of flowering and the node at which the first flower formed.

Growth Chamber Studies

The effect of daylength on flowering was studied in 1986 in two growth chambers (Controlled Environments, Model E7). Seeds were planted in soil in 10 x 10 x 10 cm plastic pots on 7 March 1986. Seedlings were thinned to four per pot. Soil, fertilizer and lime were as for the greenhouse studies. The experimental design was a randomized complete block with four replications.

The temperature in both chambers alternated daily between $10^{\circ}C$ for 16 h and $25^{\circ}C$ for 8 h. One chamber was set at an 8/16-h light/dark cycle and the other at a 16/8-h cycle. Four 25-watt incandescent bulbs and eight 40-watt F48T12/HO/CW fluorescent tubes provided a photosynthetic photon flux density (PPFD) of approximately 200 mol m^{-2} s^{-1}. PPFD was measured with a L1-COR Solar Monitor, Model L1-1776 with a quantum sensor L1-190SB.

Main stem height, the number of main stem nodes and primary branches, and the node at which the first flower was formed were determined for each species 54 days after planting.

Seed Maturity

Seed development and maturation of *C. lutea* and *C. wrightii* were studied in the greenhouse and field.

Greenhouse Studies

Seed maturation of both species was studied during the 1984-85 and 1985-86 seasons. Seeds were planted in 15-cm plastic pots on 12 February 1985 and 17 December 1985 and seedlings were thinned to 4 plants pot^{-1}. Temperature was controlled to approximately 25°C during daytime and 18°C at night. Light from F48T12/CW/VHO fluorescent tubes was used to extend daylength to 16 h. The experiment design was a randomized complete block with three replications. Approximately 1000 flowers of *C. lutea* and *C. wrightii* were tagged with cotton thread at anthesis, different colored thread indicating different times of anthesis. Tagging was done on 26 and 27 April 1985 and 7 and 8 March 1986.

Seeds from 25 flowers per replication were collected approximately every 3 days beginning 5 days after anthesis in both years. Harvesting continued for 21 days in 1985 and 20 days in 1986. Seed dry weight was determined after drying for 24 h at 100°C. Percentage moisture content was determined on a wet-weight basis. Oil content was determined on a dry weight basis according to the method of Comstock and Culbertson (1958). A 0.2-g sample of seeds was compressed at 103.5 MPa, each sample was put in a 50 x 50 mm envelope made from No. 1 Whatman filter paper, and the oil was extracted in hexane at 25°C for 72 h.

Field Study

C. lutea was planted 17 May 1985 near Corvallis, OR on Woodburn silt loam (fine-silty, mixed, mesic, Aquultic Argixeroll) soil. Fertilizer (16-20-0) was incorporated into the seed bed before planting at 145.6 kg ha^{-1}. Seeds were drilled with an Ojyord plot drill 0.5 cm deep in rows 0.76 m apart at the rate of 9.1 kg ha^{-1}. Plot size was 9.1 x 30.8 m. The experimental design was a randomized complete block with 4 replications.

About 1200 flowers were tagged on 23 and 24 September 1985. Collection of seeds began 5 days later. Tagging of flowers, collection of seed and analyses of seed dry weight and moisture and oil content were performed as in the greenhouse experiment. Seeds were harvested at approximately 2-day intervals beginning 29 September and harvesting continued until 24 days after anthesis.

Data were analyzed by analysis of variance procedures and separation of treatment means was done by Fisher's protected least significant different (LSD) values.

RESULTS AND DISCUSSION

Vegetative Development

Each species had a different but consistent branching pattern. In *Cuphea wrightii*, two opposite branches formed at each of the first two nodes, with only one branch per node thereafter. Two opposite branches formed at the first four nodes in *C. lutea*, the first five nodes in *C. leptopoda* and the first six nodes in *C. laminuligera*. All species formed one branch per node thereafter. Branches became progressively shorter at each succeeding node until no branches, but only leaves and flowers, were formed near the apex. Secondary and tertiary branches developed in the lower part of the plant canopy, but no additional branching orders were observed.

Flowering

The first flowers formed in the axil of the second single branch in each species, with *C. wrightii* invariably flowering at the fourth node and *C. laminuligera* at the eighth node. *C. wrightii* was the earliest to flower at 30 and 26 days, and *C. leptopoda* was the latest at 46 and 41 days in 1985 and 1986, respectively (Table 1). The first flowers produced seed in the self-pollinated species (*C. wrightii* and *C. lutea*).

In the growth chamber photoperiod study, all species flowered under short and long days (Table 2). The node at which the first flower formed was not as consistent in growth chambers as in the greenhouse. The first flower always appeared in the axil of the second single branch, but the number of opposite branches at the lower nodes varied somewhat between plants. The first flowers developed earlier at lower nodes under 8-h days, and the plants were shorter with fewer primary branches and main stem nodes under short days (Table 2).

According to Wareing and Phillips (1981), species with an indeterminate flowering habit flower under both long and short daylengths. Short daylengths generally hasten flowering (Board and Hall, 1984; Schweitzer and Harper, 1985).

Seed Development and Maturity

Greenhouse Studies

Changes in moisture and oil percentages and weight of seed dry matter and oil during seed development in 1985 are shown in Figures 2 and 3. Maximum seed dry weight in both species was reached by 18 days after anthesis. At this time seeds of *C. wrightii* and *C. lutea* averaged 1.90 and 2.70 mg seed^{-1}. Since the seed-filling duration for both species was identical, the seed growth rate of *C. lutea* was 1.4 times that of *C. wrightii*.

When maximum dry weight was first attained, the moisture content was about 36%. Moisture percentage remained at this level for the next 8 days, in contrast to the continued decline in moisture that occurs in many species after maximum dry weight is reached (Harlan, 1920; Frey et al., 1958; Anderson, 1955; Leininger and Urie, 1964; Browne, 1978; TeKrony et al, 1979).

The rate of oil accumulation paralleled that of dry matter accumulation in both species. The attainment of maximum oil content coincided with the attainment of maximum dry weight at 18 days after anthesis. Oil contents were 0.83 mg $seed^{-1}$ in C. wrightii and 1.17 mg $seed^{-1}$ in C. lutea. The simple correlation coefficients for oil and dry weight were 0.97 and 0.96 for C. wrightii and C. lutea, respectively, indicating that seed dry weight is also an accurate index of oil content.

The maximum percentage of oil was established somewhat earlier than total oil content, reaching 44.9% in C. wrightii in 13 days and 42.2% in C. lutea in 11 days. These oil percentages compare with those reported for other Cuphea species of 36 for C. painteri, 34 for C. ignea and 33 for C. carthagenensis (Miller et al., 1964).

The developing seeds ruptured the calyxes of C. wrightii 13 days after anthesis and those of C. lutea in 14 days. After the calyx opens the seed is not protected and, under field conditions, shatters readily from rain and wind movements. The seeds did not shatter in the greenhouse, however, making it possible to study seed development for another 11 or 12 days after opening of the calyx. At the time the seeds ruptured the calyx they were still green, but they gradually turned yellow and then dark brown.

C. wrightii averaged four seeds per flower, while *C. lutea* averaged five. These numbers contrast to previous reports of three and five seeds per flower (Hirsinger and Knowles, 1984).

The relative rates of development of each quality component were similar in experiments repeated in 1986, although the absolute values varied somewhat (Figures 3 and 4). The values at maturity for each seed component in *C. wrightii* were as follows (with 1985 values in parentheses): number of days to maximum dry weight, 19 (18); seed dry weight, 1.89 mg $seed^{-1}$ (1.90); moisture content, 32% (37%); oil weight, 0.59 mg $seed^{-1}$ (0.83 mg $seed^{-1}$) and oil percentage, 31% (43%). For *C. lutea* the values were: seed dry weight, 2.62 mg $seed^{-1}$ (2.70 mg $seed^{-1}$); moisture content, 42% (36%); oil weight, 0.64 mg $seed^{-1}$ (1.17 mg $seed^{-1}$) and oil percentage, 24% (43%).

Field Study

The time course of seed development of *C. lutea* seeds in the field in 1985 is shown in Figure 5. Relationships between quality components were similar to those in the greenhouse. Maximum dry weight was reached in 21 days after anthesis compared to 18 days in the greenhouse. Moisture contents at maximum dry weight were 45 and 35% in the field and greenhouse, respectively. Oil contents at maximum dry weight were 34 and 24% in the field and greenhouse, respectively. At maturity, seeds produced in the field were smaller than those produced in the greenhouse, weighing 1.97 mg seed^{-1} compared to 2.36 mg seed^{-1} in the greenhouse. Calices opened 20 days after anthesis compared to 14 days in the greenhouse. The generally slower development in the field could be attributed partially to cooler temperatures, especially at night.

Seed color at maximum dry weight was still green in both field and greenhouse. Shattering occurred about 4 days after maturity in the field, but the seeds remained on the plants indefinitely in the greenhouse. These studies show that Cuphea seeds in the field are mature at the time they rupture the calyx tube and oil content is not increased by delaying harvest until the green seeds turn yellow or dark brown.

The 21-day seed maturation period for C. lutea is relatively short compared to most crop species. Examples of seed maturation periods in other species include 17-18 days in smooth bromegrass (Grabe, 1956); 24-26 days in wheat (Bartel, 1941); 36 days in sorghum (Clark et al.,

1968) and 60-63 days in corn (Hallauer and Russell, 1962).

Based on the information gained from these studies, seeds of *C. lutea* and *C. wrightii* are mature at the time of emergence from the calyx tube. Waiting beyond this time for green seeds to turn yellow or brown before harvesting does not increase seed yield or oil content. Since the four species flowered under 8 and 16-h photoperiods, it appears *Cuphea* may be grown over a wide range of latitudes.

Table 1. Flowering pattern of four *Cuphea* species in the greenhouse

Species	Appearance of first flower: Days after planting	Node number+
	1985	
C. laminuligera	40	8
C. leptopoda	46	7
C. lutea	35	6
C. wrightii	30	4
$LSD_{0.05}$	3.8	0.9
	1986	
C. laminuligera	30	8
C. leptopoda	41	7
C. lutea	39	6
C. wrightii	26	4
$LSC_{0.05}$	2.9	0.6

+Nodes on each main stem were numbered acropetally beginning at the cotyledonary node.

Table 2. Effect of daylength on flowering and vegetative characteristics of four *Cuphea* species in growth chambers at 10/25°C. Measurements were taken 54 days after planting.

Species	Main stem height		Primary branches		Main stem nodes		Nodes with first flower+	
	8 h	16 h	8h	16 h	8 h	16 h	8 h	16 h
	cm		no. plant^{-1}		no. stem^{-1}		no.	
C. laminuligera	26	31	3.2	7.2	8.6	15.7	4.5	4.9
C. leptopoda	15	24	0.4	5.7	8.5	12.1	5.4	8.1
C. lutea	17	16	2.8	7.7	7.4	10.3	3.4	5.6
C. wrightii	13	30	0.2	5.2	4.7	12.7	2.7	3.9
Daylength mean	18	25	1.7	6.4	7.3	12.7	4.0	5.6
$LSD_{0.05}$ Species	4		1.1		1.6		0.4	
Daylength	2		0.8		1.1		0.3	
Species x daylength	5		NS		2.2		0.6	

+Nodes on each main stem were numbered acropetally beginning at the cotyledonary node.

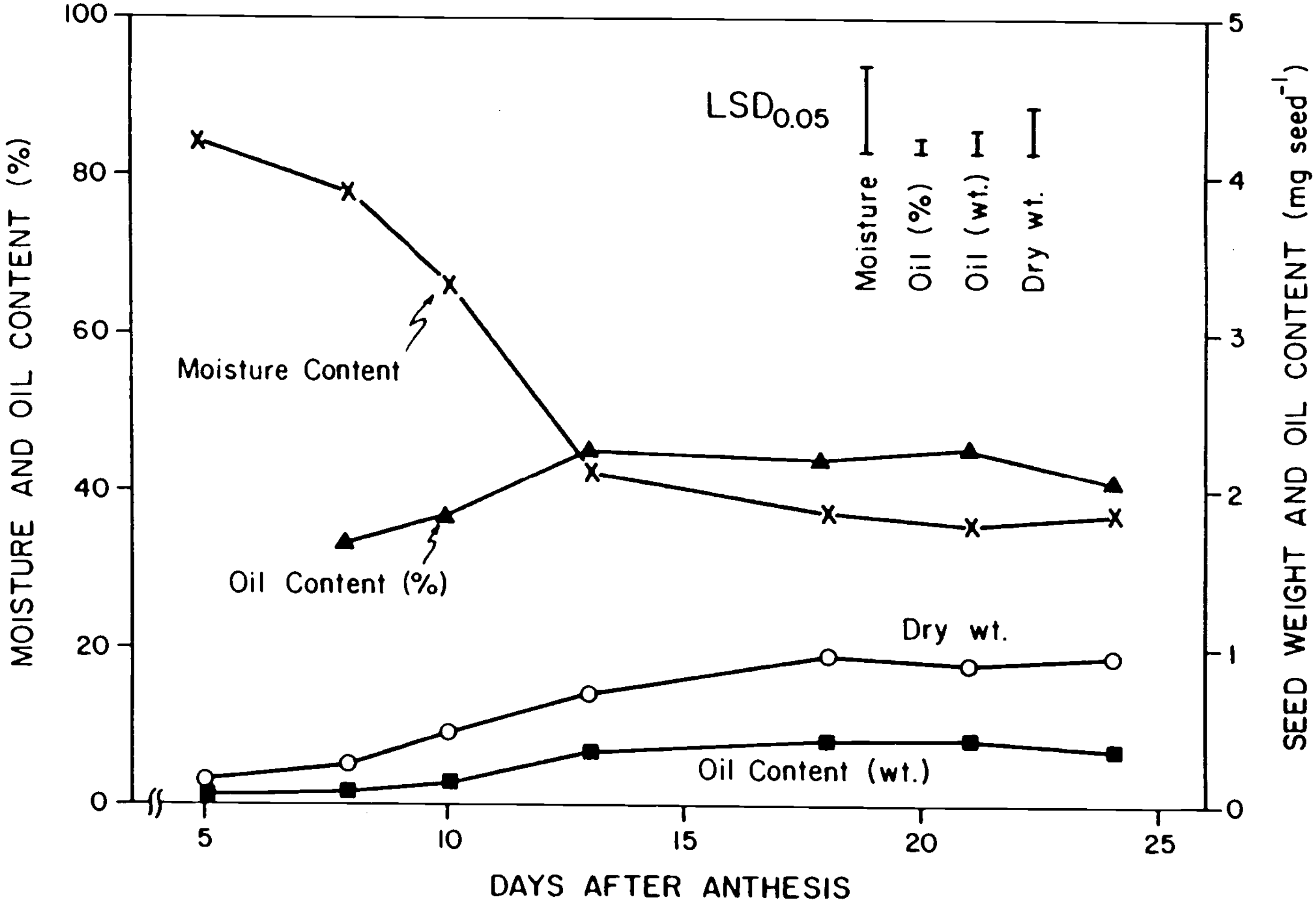

Figure 1. Dry weight, moisture and oil content of <u>Cuphea wrightii</u> seeds at various stages of maturity. Greenhouse, 1985.

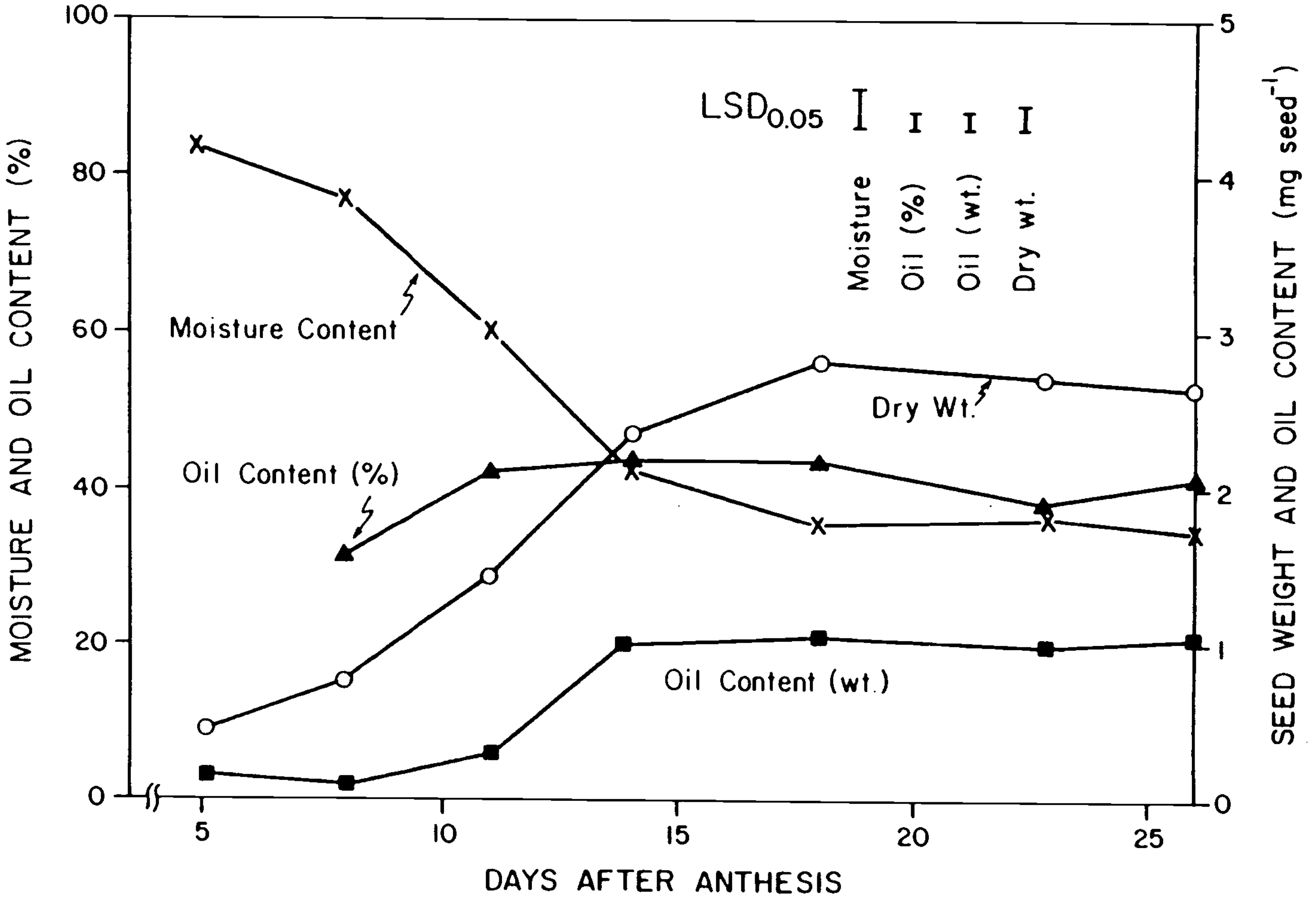

Figure 2. Dry weight, moisture and oil content of _Cuphea lutea_ seeds at various stages of maturity. Greenhouse, 1985.

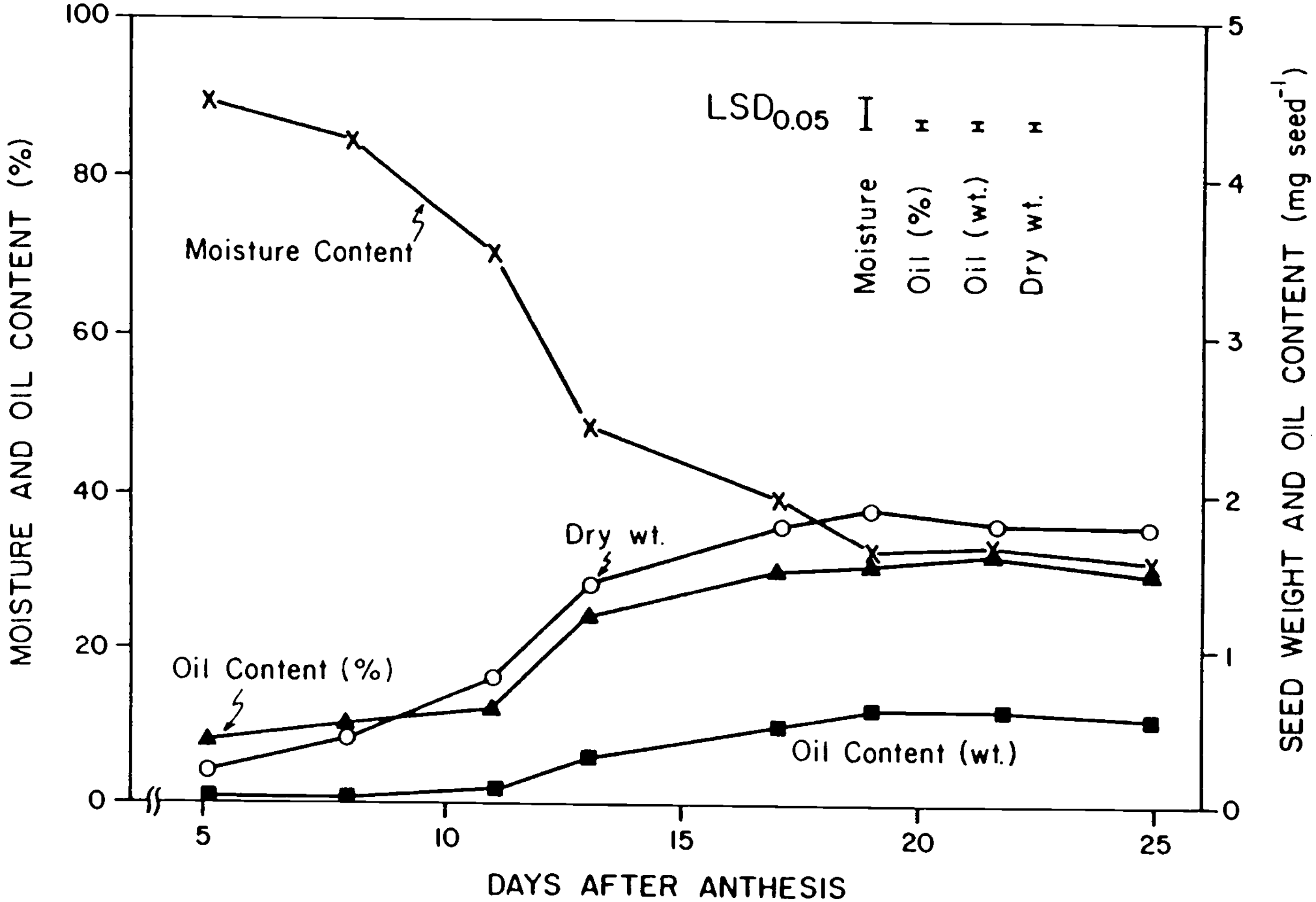

Figure 3. Dry weight, moisture and oil content of *Cuphea wrightii* seeds at various stages of maturity. Greenhouse, 1986.

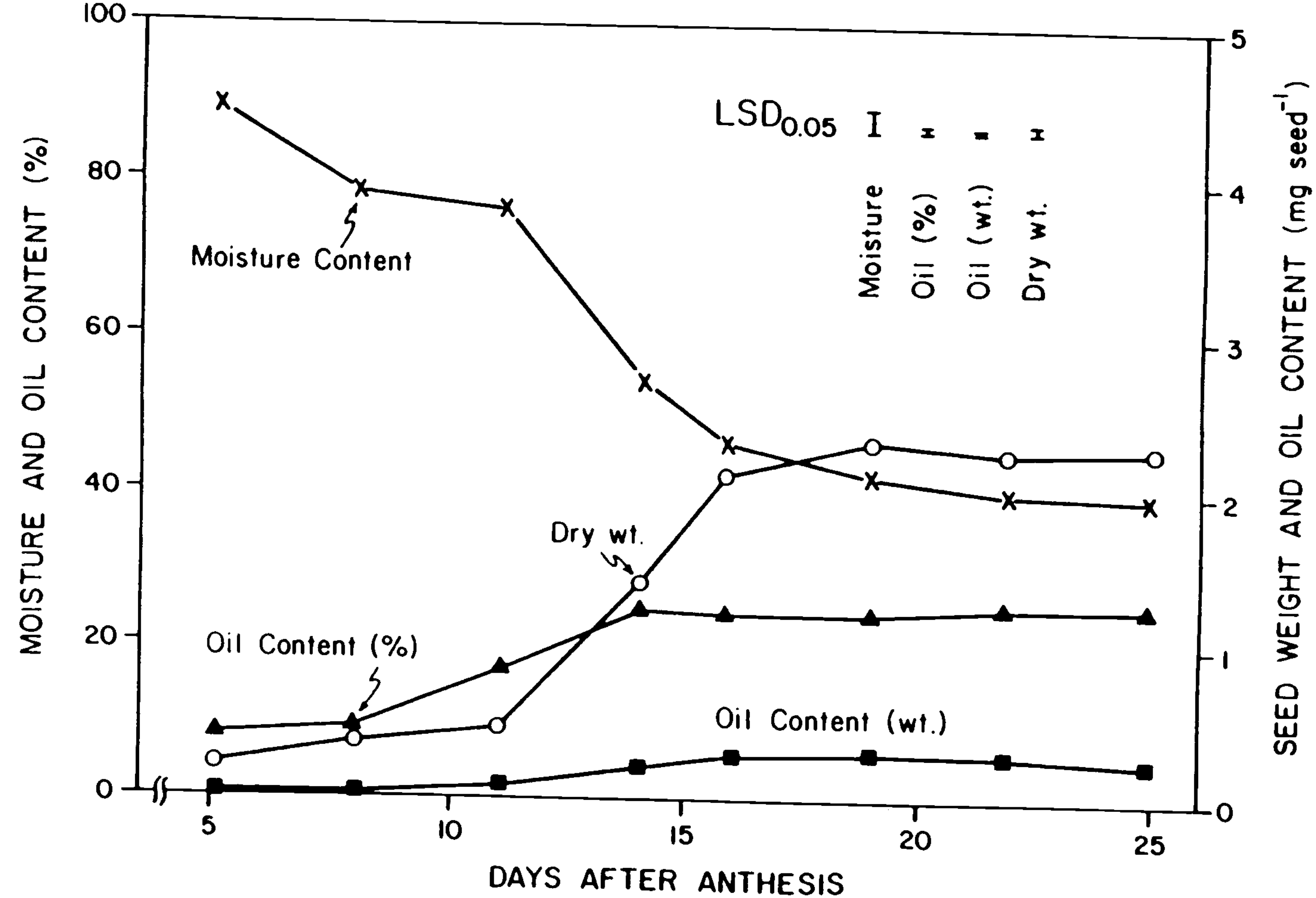

Figure 4. Dry weight, moisture and oil content of <u>Cuphea</u> <u>lutea</u> seeds at various stages of maturity. Greenhouse, 1986.

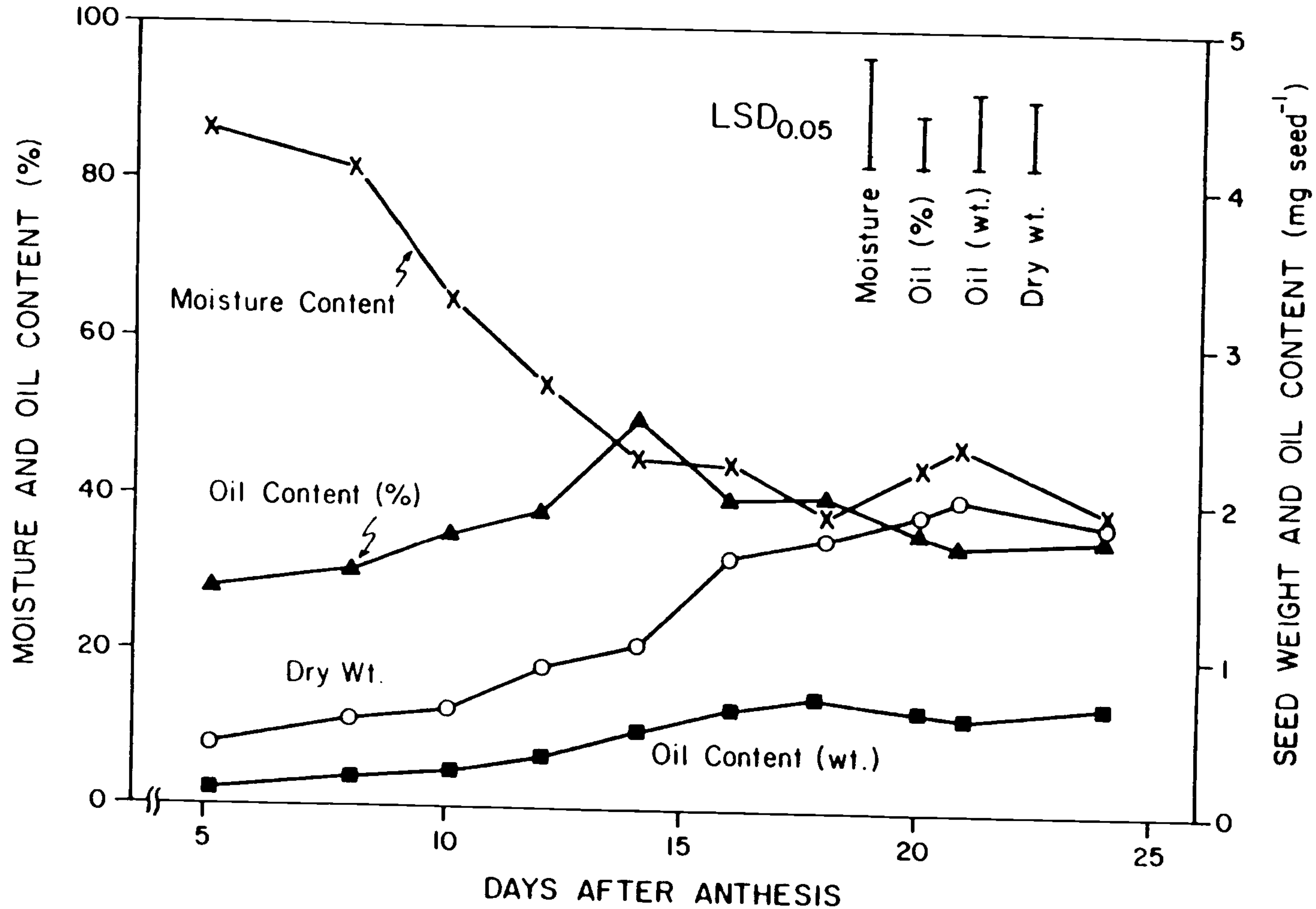

Figure 5. Dry weight, moisture and oil content of Cuphea lutea seeds at various stages of maturity. Field, 1985.

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APPENDIX

Appendix Table 1. Effect of temperature, light and seed age on germination of three species of *Cuphea*

Temperature	Species	Age of seed (months) 6 Light	6 Dark	12 Light	12 Dark	18 Light	18 Dark	Temperature mean Light	Temperature mean Dark
°C		%							
10	*C. laminuligera*	4	9	11	19	21	28		
	C. lutea	7	35	67	69	71	68		
	C. wrightii	0	0	0	0	3	0	20	25
15	*C. laminuligera*	39	36	88	77	77	68		
	C. lutea	87	76	96	93	91	87		
	C. wrightii	31	40	88	88	56	17	62	61
20	*C. laminuligera*	59	29	81	81	73	76		
	C. lutea	91	75	100	92	96	92		
	C. wrightii	37	12	91	88	60	31	76	64
25	*C. lmainuligera*	37	44	79	88	87	77		
	C. lutea	84	29	92	52	92	83		
	C. wrightii	31	11	96	87	57	52	73	58
30	*C. laminuligera*	36	27	88	85	84	64		
	C. lutea	37	13	63	27	79	13		
	C. wrightii	19	53	88	92	45	35	60	36
10/20	*C. laminuligera*	55	37	83	88	75	56		
	C. lutea	95	89	99	97	95	85		
	C. wrightii	15	13	84	75	43	21	71	63
15/25	*C. laminuligera*	67	55	80	92	77	68		
	C. lutea	92	95	100	95	95	97		
	C. wrightii	44	13	89	89	80	41	80	72
20/30	*C. laminuligera*	43	44	95	94	75	74		
	C. lutea	91	89	92	96	95	97		
	C. wrightii	25	25	91	90	63	63	75	75
Age means		47	36	81	76	70	58		
$LSD_{0.05}$		20	15	20	15	20	15		

Appendix Table 1. (Cont.)

Species x age means (averaged over temperature)

Species	6		12		18		Species mean		$LSD_{0.05}$	
	Light	Dark	Light	Dark	Light	Dark	Light	Dark	Light	Dark
	%									
C. laminuligera	42	35	76	78	71	64	63	59	6	5
C. lutea	73	61	89	75	89	78	84	71		
C. wrightii	25	11	78	76	51	33	51	40		
$LSD_{0.05}$	Light	Dark								
	6	5								

Age x temperature means (averaged over species)

Temperature	6		12		18		Species mean		$LSD_{0.05}$	
	Light	Dark	Light	Dark	Light	Dark	Light	Dark	Light	Dark
°C	%									
10	4	15	80	29	32	32	20	25	10	8
15	62	39	91	87	76	66	76	64		
25	51	28	91	77	79	71	73	58		
30	31	11	26	60	69	37	60	36		
10/20	47	47	92	87	71	54	71	63		
15/25	55	54	90	92	84	69	80	72		
20/30	68	53	88	94	78	78	75	75		
$LSD_{0.05}$	Light	Dark								
	12	8								

Appendix Table 1. (Cont.)

Temperature x species means (averaged over age)

Temperature	C. laminuligera Light	C. laminuligera Dark	C. lutea Light	C. lutea Dark	C. wrightii Light	C. wrightii Dark	Temperature mean Light	Temperature mean Dark	$LSD_{0.05}$ Light	$LSD_{0.05}$ Dark
°C	%									
10	12	19	48	57	1	0	20	25	11	8
15	68	61	91	85	58	36	72	61		
20	71	62	96	86	63	44	76	64		
25	68	70	89	55	61	50	73	58		
30	69	59	60	58	51	44	60	36		
10/20	71	60	96	91	47	36	71	63		
15/25	75	72	96	96	71	48	80	72		
20/30	71	71	93	94	60	60	75	75		
	Light	Dark								
$LSD_{0.05}$	13	9								

$LSD_{0.05}$	Light	Dark
Age	9	7
Species	4	3
Temperature	4	3
Temperature x species x age	17	14

Appendix Table 2. Effect of harvesting date on seed yield, oil content, weight and color of two *Cuphea* species in the field.

Days after planting	Seed Produced: Total	Seed Produced: Recovered	Seed Produced: Shattered	1000-seed weight	Oil content+	Green seed
	kg ha^{-1}	kg ha^{-1}	kg ha^{-1}	g	%	%
***Cuphea wrightii* (1984)**						
105		10.40		1.586	37.9	51.5
111		7.59		1.413	39.2	62.0
118		30.23		1.426	38.0	52.0
127		85.60		1.637	36.4	70.8
134		30.28		1.613	37.1	88.6
141		37.41		1.518	38.7	84.7
$LSD_{0.05}$		15.61		NS	NS	3.9
***Cuphea lutea* (1985)**						
114	22.40	15.22	7.18	2.608	36.8	37.8
121	16.01	1.30	14.71	2.240	35.9	77.3
130	4.65	2.71	1.94	2.435	33.7	78.3
138	24.77	21.63	3.14	2.377	30.8	30.9
145	50.47	33.54	16.93	2.673	31.1	20.5
152	44.66	12.02	32.64	2.272	32.6	82.9
163	48.95	2.18	46.77	1.629	33.1	96.4
$LSD_{0.05}$	8.50	6.72	6.95	0.091	NS	11.2

+Calculated on dry matter basis.

Appendix Table 3. Effect of multiple harvests on seed yield, weight and oil content of two *Cuphea* species in the field. Yield is total of several harvests and weight and oil content are averages of separate harvests at different dates on the same plot.

Number of harvests	Recovered yield	1000-seed weight	Oil+ content
	kg ha^{-1}	g	%
	Cuphea wrightii (1984)		
1	107.41	1.482	35.6
2	156.23	1.514	34.8
3	204.03	1.609	35.2
$LSD_{0.05}$	32.91	NS	NS
	Cuphea lutea (1985)		
1	21.63	2.377	30.8
2	30.86	2.442	32.7
3	32.98	2.283	31.2
4	39.94	2.279	34.3
$LSD_{0.05}$	10.56	0.098	NS

+Calculated on dry matter basis.

Appendix Table 4. Seed yield, weight and oil content of two *Cuphea* species harvested at different dates in the greenhouse.

Days after Planting	Yield		1000-seed weight		Oil Content*	
	C. lutea	*C. wrightii*	*C. lutea*	*C. wrightii*	*C. lutea*	*C. wrightii*
	g plant^{-1}		g		%	
			1985			
69	0.6	1.8	2.623	1.700	30.7	37.5
77	1.6	4.3	2.835	2.137	29.7	35.9
104	9.3	9.5	3.183	2.254	36.5	35.3
Species mean	3.8	5.2	2.880	2.030	31.5	36.6
$LSD_{0.05}$						
Species	0.4		0.142		0.5	
Harvest dates	0.5		NS		0.7	
Species x harvest dates	NS		NS		NS	
			1986			
86	0.9	1.5	2.895	1.995	32.3	35.4
106	2.3	2.5	2.827	1.843	33.4	37.3
126	2.8	2.8	2.717	1.937	34.7	36.9
146	3.4	4.3	2.646	1.793	34.8	37.4
Species mean	2.3	2.8	2.771	1.892	33.8	36.8
$LSD_{0.05}$						
Species	0.2		0.136		0.6	
Harvest dates	0.3		NS		0.9	
Species x harvest dates	NS		NS		NS	

*Calculated on dry matter basis.

Appendix Table 5. Effect of multiple harvests on seed yield, weight and oil content of two *Cuphea* species grown in the greenhouse in 1986. Yield is total of several harvests and weight and oil content are averages of separate harvests at different dates from the same plants.

Number of harvests	Yield		1000-seed weight		Oil Content+	
	C. lutea	*S. wrightii*	*C. lutea*	*C. wrightii*	*C. lutea*	*C. wrightii*
	—— g plant^{-1} ——		—— g ——		—— % ——	
1	1.165	1.646	2.791	2.002	34.3	37.3
2	2.318	3.393	2.821	1.954	34.2	37.6
3	3.415	4.563	2.701	1.920	33.8	36.7
4	3.660	3.896	2.743	1.933	33.5	37.2
Species mean	2.640	3.375	2.764	1.952	34.0	37.2
$LSD_{0.05}$ Species	0.286		0.367		0.8	
No. of harvests	0.405		NS		NS	
Species x harvests	NS		NS		NS	

+Calculated on dry matter basis.

Appendix Table 6. Effect of seed color on oil content+ of two *Cuphea* species grown in the greenhouse in 1986

Seed color	Species: *C. lutea*	Species: *C. wrightii*	Seed color mean
	%		
Green	32.2	36.2	34.2
Yellow‡	33.7	35.3	34.5
Dark brown	33.3	35.7	34.5
Species mean	33.1	35.7	
$LSD_{0.05}$ Species	0.9		
Seed Color	NS		
Species x seed color	NS		

+Calculated on dry matter basis.

‡In *C. lutea* the seed is purple.

Appendix Table 7. Effect of temperature on early vegetative growth of four *Cuphea* species in growth chambers. Daylength was 16 h and PPFD was 200 μmol m^2 s^1.

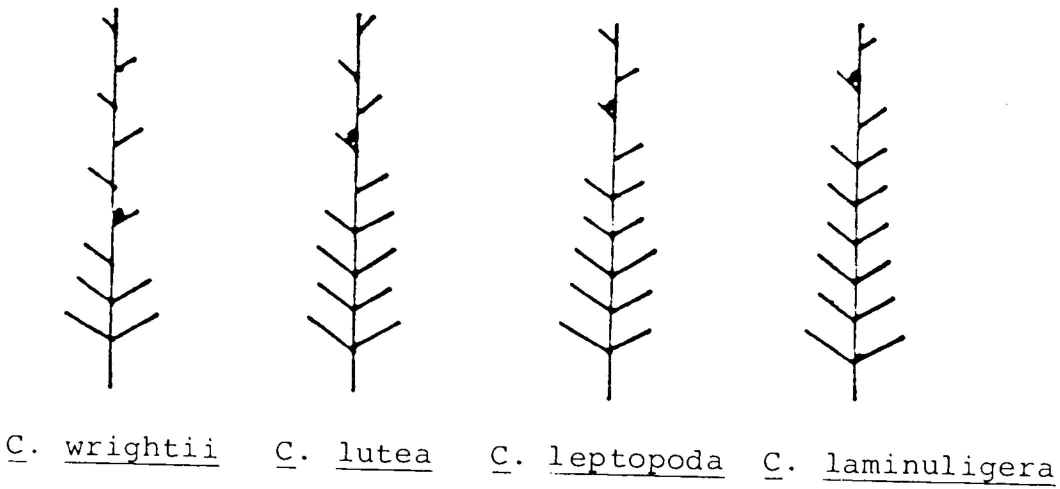
Days after Planting	Temperature	Plant height: *laminuligera*	*leptopoda*	*lutea*	*wrightii*	Temp. mean	Number of main stem nodes: *laminuligera*	*leptopoda*	*lutea*	*wrightii*	Temp mean
		cm					no.				
15	20/30	53	54	48	70	56	3.1	2.4	2.8	3.0	2.8
	10/25	30	30	24	25	27	2.1	2.0	2.1	2.0	2.1
	Species mean	42	42	36	48		2.6	2.2	2.5	2.5	
$LSD_{0.05}$											
	Species			6					0.1		
	Temperature			4					0.2		
	Species x temperature			8					0.2		
24	20/30	113	100	114	130	114	5.6	5.0	4.5	4.9	5.0
	10/25	68	46	66	63	61	3.9	4.0	3.3	3.5	3.7
	Species mean	91	73	90	97		4.8	4.5	3.9	4.2	
$LSD_{0.05}$											
	Species			10					0.4		
	Temperature			7					0.2		
	Species x temperature			NS					NS		

Appendix Table 8. Height, nodes, branches and flowers of four *Cuphea* species at different dates in the greenhouse.

Characteristic	Days after planting	Species: *laminuligera*	*leptopoda*	*lutea*	*wrightii*	$LSD_{0.05}$
				1985		
Branches						
Primary, no. plant^{-1}	35	12.8	11.6	9.0	8.2	NS
Secondary, no. primary branch^{-1}	47	0.1	1.7	2.2	3.9	0.2
	61	1.7	2.4	6.1	5.9	0.8
Main stem nodes, no. plant^{-1}	18	3.8	2.8	2.9	3.4	NS
	37	11.9	8.6	8.9	14.8	1.2
	47	20.8	18.7	13.9	22.8	2.6
	61	26.9	31.0	17.3	27.7	1.8
				1986		
Height, mm	19	53	52	35	86	14
	26	87	79	73	147	15
	35	199	150	178	322	33
	44	314	241	267	423	22
	72	788	633	442	487	57
	128	973	991	769	567	44

Appendix Table 8. (Cont.)

Branches						
Primary, no. plant^{-1}	19	0.5	0.3	0.8	1.2	NS
	26	1.1	0.7	2.7	4.2	NS
	35	4.8	3.2	8.2	6.3	NS
	44	9.6	7.4	9.9	9.5	NS
	72	11.3	12.7	18.7	10.3	2.5
	128	33.7	21.6	24.3	15.3	2.6
Secondary, no. primary branch^{-1}	72	6.7	7.2	12.0	6.2	0.8
	128	1.9	2.3	3.7	2.2	0.3
Main stem nodes, no.	19	4.1	3.4	3.3	4.0	NS
	62	5.7	4.6	5.1	5.6	NS
	35	10.5	7.2	8.3	12.3	1.2
	44	14.0	9.2	9.7	16.2	2.2
	72	33.0	43.0	21.7	18.7	1.2
	128	60.0	63.0	27.1	28.4	8.9
Flowers						
no. main stem^{-1}	72	24.2	26.0	12.3	20.7	1.4
	128	76.0	97.1	21.7	74.3	3.5
no. primary branch^{-1}	72	62.0	33.7	33.0	58.7	11.4
	128	139.0	278.3	50.3	108.7	3.5



Appendix Figure 1. Branching and flowering habits of four *Cuphea* species under greenhouse conditions. First flowers form in axil of second single branch in each species.