BOLLWORM RESISTANCE IN HIGH TANNIN COTTON

By

NONGPORN ALLAPACH KITBAMROONG

Bachelor of Science in Agriculture
Kasetsart University
Bangkok, Thailand
1969

Master of Science in Entomology
University of Kentucky
Lexington, Kentucky
1974

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
DOCTOR OF PHILOSOPHY
July, 1984

BOLLWORM RESISTANCE IN HIGH TANNIN COTTON

Thesis Approved:

J. W. Young
Thesis Adviser

William A. Drew

Linda J. Wilson

Laval M. Verhalen

Don C. Peters

Norman N. Durham
Dean of the Graduate College

ACKNOWLEDGMENTS

The author wishes to express her deepest appreciation to her major adviser, Dr. Jerry H. Young, for his guidance, encouragement, and valuable suggestions throughout this study.

She also wishes to acknowledge her advisory committee, Dr. Don C. Peters, Dr. William A. Drew, Dr. Laval M. Verhalen, and Dr. Linda J. Willson for their suggestions and constructive criticisms. Also, she would like to thank Dr. R. L. Burton for his generosity in providing the bollworm population used for laboratory rearing and Dr. M. F. Schuster for providing the high tannin lines used in this study.

Recognition is also due to those who assisted in the collection of the research data presented, specifically the personnel working on the cotton project in the Department of Entomology.

An additional word of appreciation is due to Dr. Laval M. Verhalen and to his staff, Mrs. Jane E. Baker and Mrs. Lynda K. Baker, at the Cotton Quality Research Laboratory for determining the fiber quality of the lint samples from each plot.

The author also thanks the Royal Thai Government for permission to leave Thailand to pursue her advanced degrees.

A special thanks is due to the author's parents, Mr. Prasarn and Mrs. Suparp Allapach, for their exceptional influence and encouragement.

Finally, the author wishes to express special appreciation to her husband, Charas Kitbamroong, for his support, encouragement, and patience and to her children, Kitipan, Vorapol, and Montakarn, for their understanding and patience during this long educational program.

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER I

INTRODUCTION

Upland cotton, Gossypium hirsutum L., is the most important fiber crop grown in the United States and elsewhere in the world. It is also the major field crop most heavily impacted by insects. In many years, over 47% of the insecticides applied to agricultural crops in the United States are applied to cotton (Wilson et al., 1977). In addition, herbicides, nematocides, and fungicides are widely used on the crop.

The problems with heavy usage of pesticides are now familiar. Resistance to insecticides in cotton appeared in the mid 1950's and has continued to the present. Resurgence of secondary pests and, probably most importantly, the recognition by the general public that massive infusion of hazardous chemicals into the environment is detrimental to society have forced entomologists and plant breeders to seek other methods for pest control (Brown, 1951; Stern et al., 1959; Carson, 1962; van den Bosch et al., 1971). The development of insecticide resistance has led to what van den Bosch (1978) has termed "the pesticide treadmill", i.e., larger and larger amounts of insecticides are applied at more frequent intervals, then the insecticide is abandoned when it's no longer effective, and another (often more

hazardous) insecticide is applied instead. The process is repeated again and again. The problem has led to investigations into the use of natural enemies of the pest for control because pesticides normally act in an unselective manner killing beneficial insects along with the pests. Host-plant resistance is another tool being investigated for control of cotton pests. Almost all plants have secondary metabolites or morphological characteristics which diminish the effects of herbivorous insects. Many plants may have several of these features in combination. During the period of intensive insecticide usage, these characteristics were largely ignored because cotton breeders and entomologists knew that only a few applications of relatively inexpensive insecticides were necessary to control pests.

The bollworm, Heliothis zea (Boddie), is a classic example of the misuse of insecticides. This species along with the tobacco budworm, Heliothis virescens (F.), are the most important pests of cotton in most areas of the United States and for the nation as a whole. The bollworm and tobacco budworm certainly are the most important pests in the area of this study, namely, southwestern Oklahoma. The bollworm has risen to its present prominent position solely because the application of insecticides destroyed its predators (Adkisson et al., 1964; van den Bosch et al., 1969; Luck et al., 1977).

The bollworm is indeed a major pest in the United

States as evidenced by estimated lint yield losses from the pest of 3.0, 3.1, and 2.1% in 1979, 1980, and 1981, respectively. This impact could be converted into an estimated 442,000, 328,000, and 323,000 bales for those 3 years.

Net losses due to the bollworm in Oklahoma alone were 31,000 bales (Hamer, 1980), 22,000 bales (Hamer, 1981), and 33,000 bales (Head, 1982) in 1979, 1980, and 1981, respectively. These losses could be converted into percentages as 6.0, 10.0, and 8.0%, respectively.

Although not widely used, host-plant resistance was recognized in cotton prior to the advent of modern insecticides. Painter (1951) has compiled an excellent review of the early reports which include the blister mite, Eriophyes gossypii Banks; leafhoppers, Empoasca spp.; tobacco thrips, Thrips tabaci Lindeman; and the pink bollworm, Pectinophora gossypiella (Saunders), among others. Schuster (1979) and Niles (1980) list the major morphological characters and secondary plant metabolites imparting insect resistance in upland cotton which include glabrousness, nectariless, high gossypol, and high tannins. Other possibilities for use are strip cropping (Robinson et al., 1972) and developing early maturing cultivars (Gaines, 1941; Caldwell et al., 1979; Niles, 1980).

This study was undertaken with the following objectives: (1) to compare high tannin cotton with cultivars of cotton and with lines having known factors for

resistance to bollworm attack; (2) to study the effects of high tannin on seedcotton and lint yield and on fiber quality; and (3) to initiate the development of cotton with suitable agronomic qualities plus high tannin.

This study is deemed especially appropriate at this time because once more, a crucial period on the "pesticide treadmill" has been reached. Early modern day control of the bollworm utilized DDT and other chlorinated hydrocarbon compounds. The bollworm not only developed resistance to these chemicals, but the compounds were removed from the market because of their environmental hazards as well. Subsequently, the carbamates were used for a brief period; but they never really provided effective control of Heliothis. The next series of compounds were tne organophosphates by themselves or in combinations with cyclic terpenes. Virtually all of these compounds are now useless, at least in the western United States. The currently used insecticides are a group or synthetic pyrethroids, but recent evidence in some areas exists that dosages have had to be increased to achieve erfective control (Leigh, 1984; Price, 1984). Most observers believe that in a very short time, the synthetic pyrethroids will also be ineffective against the bollworm. If this happens, no insecticide alternatives are available at present. The last "line of defense" against this most serious pest of cotton would have been "breached". Cotton production in the United States and in many other parts of the world would

then be restricted to those few and isolated areas with low pest impact.

CHAPTER II

REVIEW OF LITERATURE

Tannins are chemical compounds frequently found in many plant species. They are secondary plant products which also occur widely in numerous plant parts. Thatcher (1921) reported that tannins were found in roots of several species of tropical plants; in bark and wood of the stems of oaks, Quercus spp.; pines, Pinus spp.; and hemlocks, Tsuga spp.; in leaves of sumac, Rhus spp., and rhododendron, Rhododendron spp.; in fruits, especially in the green or immature stage; and in seed of several plant species, either before or after germination. He also mentioned that tannin was found in certain special structures such as gland cells, cells of the pulvini, laticiferous tissues, and abundantly in galls. In India, Mishra and Singh (1981) found tannin in fecal pellets of Indarbela quadrinotata Walk. larvae after the larvae fed on bark of certain trees.

The six chemical properties of tannin have been described by Thatcher (1921) as follows:

1. Tannins are noncrystalline substances which form colloidal solutions with water, which have an acid reaction, and which have a sharp astringent taste.

2. Tannins form insoluble compounds with gelatin-

containing tissue, i.e., the process used in the conversion of hide into leather.

3. Tannins form soluble, dark blue or greenish black compounds with ferric salt, the common ink.

4. Tannins are precipitated from solutions by many metallic salts such as lead acetate, stannous chloride, and potassium bichromate.

5. Tannins precipitate out of solution albumins, alkaloids, and basic organic coloring.

6. Most tannins, in alkaline solutions, absorb oxygen from the air and become dark brown or black in color.

Stansbury et al. (1950) reported, after tannins were dried *in vacuo* at 105°C, their composition was 61.19% carbon, 4.33% hydrogen, and no methoxyl substance. Tannin did not have a definite melting point and became quite dark at 230 to 240°C. Swain (1977) stated that the molecular weight of the average tannin was approximately 1200 to 1500 daltons and that tannins precipitated all proteins by forming multiple hydrogen bonds between the phenolic-hydroxyl groups of the tannin and the various nitrogen-containing groups of the protein. Berenbaum (1980) reported that the tannin-protein complex was relatively stable at acidic and neutral pH levels, but that it tended to dissociate at more alkaline levels.

Tannin is divided into two types: hydrolysable and condensed (or proanthocyanins). Hydrolysable tannin consists of a sugar core, usually glucose, and the hydroxyl

groups which are acylated by gallic acid or its congeners. The condensed tannins, on the other hand, are polymerized C-C linked polyhydroxyflavans (Swain, 1977).

The hydrolysable tannins occurred only in dicotyledonous plants. It was found, for example, in galls and leaves of Rhus semialata, fruit of Terminalia chebula, acorn cups of Quercus valonea, wood of Castanea sativa, fruit pods of Caesalpinia spp., and fruit, twigs, and roots of Punica granatum, etc. (Haslam, 1966). The condensed tannins were found in all classes of plants, especially in plants with highly developed vascular systems (Swain, 1977). The differences between hydrolysable and condensed tannins have been described by Haslam (1966), Bate-Smith (1975), Swain (1977), and Lane and Schuster (1981). Haslam (1966) noted that only the hydrolysable tannin can be hydrolyzed by acids or enzymes. Swain (1977), however, stated that hydrolysable tannins were biodegradable and precipitated protein two to five times more than condensed tannins. Bate-Smith (1975) reported that the properties of condensed tannin which could affect antibiotic activity included series (A or B), kind (procyanidins, prodelphinidins, or mixed polymers), molecular weight, concentration, and astringency. Lane and Schuster (1981) noted that concentration and the resulting astringency were the key factors for resistance in cotton.

Tannin is one of the most important groups of defensive secondary metabolites (Swain, 1977). One of many early reports on the effect of tannin was made by Thatcher (1921)

who stated that tannin served as a preventive growth substance to parasitic fungi. Later, Cadman (1960) reported that tannin inhibited the infection capability of a virus. The function of tannin to protect plants from biological attack, particularly by phytophagous insects, was mentioned in the report of Feeny (1968). Swain (1977) mentioned that tannin was the main deterrent in plants that possessed an unacceptable taste in unripe fruit such as bananas, Musa spp., and persimmons, Diospyros spp. Furthermore, he noted that tannin deterred herbivorous animals, such as Aldabra tortoises and Colobus monkeys, from plants. Sanders (1977) reported that tannin provided some measures of resistance to microbial attack for the peanut, Arachis hypogaea L. Other physiological functions of tannins were their abilities to protect plant cells from dessication, a storage of reserve materials which relate to carbohydrate metabolism, regulation of cellular oxidation, protection of cell turgor, or accumulation of metabolic waste products (Feeny, 1970).

Biological functions of tannin have been proposed by many scientists. Goldstein and Swain (1965) proposed that tannin inhibited the activities of B-glucosidase and other enzymes. Feeny (1968) reported that tannin reduced the availability of dietary protein. Duffy (1980) reported that tannins in large amounts were toxic to some insects by causing physiological stress. Berenbaum (1980) believed that condensed tannin tended to cross-link with protein and formed insoluble complexes in living systems which, in turn,

could combine with available nitrogen in leaf materials and interfere with the digestive system of insects. However, Klocke and Chan (1982) reported that the inhibition of growth by tannin was due to a reduction in food consumption.

Research on the effects of plant tannins on insects has been conducted under both field and laboratory conditions. However, the results reported at times come to different conclusions. Russell (1962) conducted feeding experiments of the lesser rice weevil, Sitophilus oryzae L., on grain sorghum, Sorghum bicolor (L.) Moench. He exposed sorghum with various seed sizes, seed colors, degrees of hardness, and tannin contents to the weevils. He found that the population increase of the lesser rice weevil was negatively correlated with the hardness of sorghum grain. He suggested that the high tannin content might play a role in avoidance of oviposition.

In alfalfa, Medicago sativa L., different concentrations of tannic acid were sprayed on test fields. All concentrations of tannic acid decreased the feeding of the alfalfa weevil larvae, Hypera postica Gyllenhal, and increased the mortality of larvae when higher concentrations were applied (Bennett, 1965). Tannic acid also acted as a feeding repellent in his study.

Feeny (1968) reported that the winter moth larvae, Operophtera brumata L., generally fed on oak leaves in the spring when young leaves were developing. He found that hydrolysable tannins were present throughout the season, but

condensed tannin did not appear in the leaves until late May. The most damage by larvae on oak leaves occurred when the tannin concentration was very low or absent. Feeny (1968) concluded that the reduction in larval growth rate and pupal weight were due to an interaction between tannin and protein which, in turn, reduced the availability of protein to the larvae.

Feeny (1970) studied the tannin content and nutrient changes in oak leaves due to seasonal variations relative to the winter moth caterpillar. He found that early feeding of the caterpillar in the spring coincided with maximum leaf-protein and minimum leaf-sugar content. Also, he showed that tannin increased in the summer when leaf toughness was also increasing. Since winter moth larvae feed on oak leaves mainly during spring and deferred feeding in summer time, he postulated that tannin in oak leaves was an inhibiting factor to larval feeding. Furthermore, ne noted that tannin might indirectly affect larval feeding by reducing the availability of nitrogen and by influencing leaf palatability.

Pree (1977), in reporting the results of an experiment conducted on crab apples, Malus spp., found that the development of apple maggot larvae, Rhagolitis pomonella Walsh, depended on the cultivar. The degree of resistance of the cultivar to the insect was correlated with total phenol content. However, bioassay with an artificial diet suggested that qualitative differences were also present

between susceptible and resistant cultivars. He also noted that the addition of gallic, tannin, O-coumaric acid, quercetin, naringenin, and d-catechin to the diet at 1000 ppm prevented larval development.

Bernays (1978) fed grasshopper species wheat, Triticum spp., with and without added tannin. She found that hydrolysable tannin had a deleterious effect on the graminivorous, Locusta migratoria (L.), by causing severe damage to the peritrophic membrane and the epithelium of the midgut and caeca. Later, Bernays et al. (1980) studied the growth and development of 15 Acridoidea species under laboratory conditions. Tannic acid at various concentrations was added to the diet. The acid showed no deleterious effects to polyphagous species and exhibited beneficial effects to two species, Anacridium melanorhodon (Walker) and Atractomorpha crenaticeps australis (Rehn). In contrast, tannin reduced growth rate and caused poor survival in graminivorous acridids.

In Australia, Macauley and Fox (1980) reported that phenols and condensed tannins were found in leaves of seven Eucalyptus species. The concentrations of these compounds were variable and usually high in the young and older leaves throughout the growing season.

Miah et al. (1981) conducted a comparative study in Bangladesh of two jute, Corchorus olitorius L. and C capsularis L., cultivars and 14 jute mutants fed to Apion corchori Marsh. Five of the mutants were resistant to the

insect. Miah et al. (1981) originally thought pith diameter was a source of resistance; but they concluded that stem toughness and tannin content, rather than pith diameter, were the most important factors for resistance.

In England, Bernays (1981) reported that hydrolysable tannins such as tannic acid had different effects on insects ranging from positive to negative. Condensed tannin, on the other hand, showed either no effect or a deterrent effect; but it was not phagostimulatory. The reactions between plant tannins and insects depended on tannin concentrations and insect species.

In Czechoslovakia, Pospisil (1982) reported on the response of the Colorado potato beetle, Leptinotarsa decemlineata Say, to tannin. Potato, Solanum tuberosum L., leaves were treated with tannin and then fed to larvae and adults. Larvae of the first three instars died of starvation within 3 days, and the final instar larvae pupated with insufficient food reserves to complete their life cycle. He concluded that tannin acted as an antifeedant agent to these beetles.

Schultz and Baldwin (1982) found that leaves of red oak damaged by gypsy moth larvae, Lymantria dispar L., produced tannin coefficient, total phenolics, hydrolysable and condensed tannins, dry matter content, and toughness higher than those of undamaged leaves. They suspected that these qualitative changes might be the factors conditioning further outbreaks of gypsy moth larvae.

Perring et al. (1982) in Texas evaluated grain sorghum characteristics for resistance to the Banks grass mite, Oligonychus pratensis Banks. They first believed that leaf tannin, maturity time, senescence, leaf bloom, and midrib juiciness were important for resistance. However, there was no indication that resistance could be attributed to leaf tannin, leaf bloom, and midrib juiciness. Instead, leaf stress was found to promote mite reproduction and increased damage. They concluded that leaf stress should be a key factor for consideration in the development of resistant cultivars.

Lawson et al. (1982) tried to correlate resistance of oak leaves with orange striped oakworm larvae, Anisota senatoria J. E. Smith. Leaves of six oak species differing in concentrations of leaf water, nitrogen, and tannin were fed to the larvae. Only nitrogen content affected larval consumption, utilization, and growth. They postulated that secondary compounds synthesized during leaf development inhibited season herbivores by forming an indigestible complex with protein. However, they noted that late season leaves can be utilized by many insects.

Bernays and Chamberlain (1982) fed to locusts and grasshoppers, Schistocerca gregaria (Forsk), wheat leaves treated with various tannin concentrations and nutrients. Leaf lipids had little deterrent effect. The amino acid slightly enhanced feeding, but did not affect the taste of tannin. They suggested that plant tannin occurring in

mature leaves provided a relatively low nutritive value to insects, thus, providing a nonpreference or deterrent effect.

In cotton, research on the effects of tannins has emphasized economically important insects. The results and conclusions reported were, however, indefinite and varied with cultivars and pests.

Maxwell et al. (1967) in the laboratory fed adult and larval diet treated with various tannin concentrations to boll weevils, Anthonomus grandis Boheman. Tannin at the concentrations of 0.2, 0.6, 0.8, and 1.0% significantly reduced weight of the boll weevil, but did not reduce feeding and oviposition. Tannin and quercetin exhibited some negative effects on the development of the boll weevil. Phenol and tannin concentrations were highest in the seedcoat, bark, and root of cotton plants. These results led the researchers to conclude that tannin in the cotton bud was less than 1%, but that approximately 0.67% of tannin was adequate to protect the crop from an outbreak of the boll weevil. Hedin et al. (1978) reported that several substances from cotton plants such as gossypols, caryophyllenes, gallic acids, and tannins had effective suppressant properties to the gut bacteria of the boll weevil.

Chan and coworkers (1978) studied growth inhibition of lepidopterous larvae using extracted cotton constituents. The condensed tannin, flavonoids, terpene aldehydes, and

cyclopropenoid fatty acids were isolated from leaves and parts of squares of Gossypium barbadense L., cultivar 'Pima S-4', and fed to larvae of three lepidopterous species in artificial diet. They found that the ED50 (the effective dosage level required to reduce larval growth to 50% of control weight) required for growth inhibition of tobacco budworm, bollworm, and pink bollworm larvae ranged from 0.1 to 0.7% by weight of the diet. The condensed tannins possessed essential potency against the three insect species. High gossypol content in anthers had little effect on growth of tobacco budworm larvae. In contrast, diets with corolla powder high in flavonols showed strong inhibitory effects.

Chan et al. (1978) extracted condensed tannin from the flower bud of the Texas 254 race of cotton, G. hirsutum L., and applied it to tobacco budworm larvae. The condensed tannin was the major antibiotic component in cotton, comprising 3.4% of the dried flower bud. The diet with condensed tannin at 0.2% concentration retarded growth of budworm larvae to about 84%. They concluded that condensed tannin was probably the "X-factor" previously reported by Lukefahr et al. (1974). Furthermore, they noted that the retarding effect of condensed tannin to larvae was important for population control. The higher natural mortality occurred because the larvae developed slowly and were thus predisposed to diseases and predators.

Lane and Schuster (1979) found that several cotton

cultivars were resistant to two-spotted spider mites, Tetranychus urticae Koch. Based on a histochemical study, many wild strains of cotton which did not flower during the summer at their location possessed high tannin content and were resistant to spider mites. The cottons that flowered during the summer always had lower tannin content and were susceptible to spider mites. Tannin content varied in cotton plant parts, i.e., it was higher in buds; lower in leaves, bark, and tap root; but lowest in wood and secondary roots. Tannin appeared to affect the vitality of spider mites.

Schuster (1979) observed vital development of Heliothis feeding on several cotton genotypes with different tannin content. A high rate of larval mortality occurred on the Texas 1055 and HT 35-4 cotton stocks after 24 hours of feeding. After 48 hours, larvae consumed more plant tissue from HT 35-4 cotton, but declined after 72 hours. Tannin reduced feeding of larvae at all instars. Since higher tannin concentrations were found in HT 35-4, Texas 1055, and other race stocks than in commonly grown cultivars, he concluded that tannin was a feeding deterrent and antibiotic material.

Schuster and Lane (1980) evaluated field resistance of bollworm to high tannin cottons, and they found a significant correlation between condensed tannin content in cotton and worm number. Worm numbers were reduced 75% in the high tannin lines compared to the susceptible check and

were equal to the resistant check (HG-DDS-N1). In most cases, worm numbers and damaged squares were observed accordingly. However, with one exception, a high tannin line was damaged about as much as the susceptible cultivar 'Lankart 57'.

Schuster and Lane (1981) found that resistance due to tannin in cotton correlated with fully expanded leaves, but not with unfolding leaves. The tannin contents of either leaf increased with age from first square to post bloom. Similar trends were observed in both low vs. high tannin breeding lines. They only differed in levels.

Lane and Schuster (1981) reported that primitive G. hirsutum races of cotton were almost immune to spider mites. These strains contained condensed tannin at about 20% of their dried weight. However, some races containing condensed tannin nearly equal to the resistant plants were still susceptible. Qualitative differences were noted in condensed tannin in cotton due to seasonal changes and growth stages. They believed that condensed tannin quantity and its resulting astringency provided spider mite resistance to cotton plants.

Waiss et al. (1981) added allelochemicals to artificial diets and fed them to the bollworm. They found that young larvae were retarded in growth and development more than older ones. They proposed the selection of tannins and flavonoids in a host-plant resistance (HPR) program, but cautioned that the resistant cultivars should have

considerable amounts of allelochemicals during fruit development.

Waiss et al. (1981) reviewed the literature on insect growth inhibitors in crop plants. They mentioned that condensed tannin suppressed larval growth, development, and reproduction. They indicated that plant selection for higher gossypol content may simultaneously increase biosynthetic activity for the production of tannin and other flavonoids since gossypol and tannin share part of a common pathway.

Another study on the vital development of the bollworm larvae was reported by Reese et al. (1982) who showed that condensed tannin, as well as maysin and pinitol, effectively retarded growth development of the larvae. Furthermore, they found a significant negative correlation between tannin concentration and the amount ingested by larvae which led them to conclude that a reduction in ingestion was a major factor in growth reduction.

The effects of tannin on the spotted bollworm, Earias vittella F., were presented in two reports by Sharma and Agarwal (1982a). The result of one study indicated that larval weight, weight gain, and growth rate of the spotted bollworm fed with cotton bolls from different genotypes varied considerably. These attributes were negatively correlated with gossypol content. The effect of gossypol was most pronounced in the early larval stages. Tannin, on the other hand, showed similar effects but later in the

larval stage. In the second study, Sharma and Agarwal (1982b) found that acetone extract of cotton square powders caused the highest mortality to spotted bollworm larvae, followed in order by gossypol, tannic acid, tannin, and anthocyanin. Larvae (fed on diets with added gossypol or tannin) could not complete their life cycle while the solvent extracts, except for the hexane extract of bolls, decreased pupal weight. They concluded that gossypol, tannin, anthocyanin, and other secondary substances present in cotton squares and bolls could be used as a source of biochemical resistance.

In the same year, Sharma and coworkers (1982) published data that survival and postembryonic development of the spotted bollworm were significantly different when fed on 23 genotypes from three cotton species (G. arboreum, G. barbadense, and G. hirsutum). The tannin contents of the bolls were significantly and negatively correlated with adult emergence and negatively correlated with the incidence of spotted bollworm. Pigmented segregants of crosses between resistant and susceptible genotypes of G. arboreum were rich in tannin and gossypol.

Klocke and Chan (1982) reported that bollworm larvae exhibited growth inhibition when fed an artificial diet with added cotton condensed tannin. Larval susceptibility depended on condensed tannin concentration and on the size of the larvae. Protease and invertase activities in the midgut caecal wall decreased as did total protein and sugar

levels in the haemolymph. However, these decreases had no effect on assimilation or efficiency of food conversion. They concluded that growth inhibition could be attributed to a reduction in food consumption.

Chakravorty et al. (1982) reported that cotton cultivars containing higher concentrations of tannin in the seedcoat, bur, or other fruiting components and lesser quantities of protein in anthers per bud and kernel per seed showed higher tolerance to the pink bollworm. Significant differences in the concentration of tannin in seedcoat, bur, and other fruiting parts were observed among cultivars in G. hirsutum and G. arboreum; and tannin percentages in fruiting parts (other than the petals) were greater in the latter species.

Parrott et al. (1983) reported that an application of methomyl to cotton plants caused an increase in the level of anthocyanins and tannins and a reduction in the chlorophyll content in mature leaves, but not in expanding leaves.

In the same year, Schuster et al. (1983) applied pydrin and dipel on high tannin cotton lines to control tobacco budworm larvae. They demonstrated that high tannin lines increased square feeding, but reduced boll feeding significantly. Dipel was more effective on high than on low tannin plants which was indicated by boll damage on high tannin lines seven-fold less than that on low tannin lines. Condensed tannin exhibited a growth rate retardant effect on

larvae similar to that of the pydrin treatment on low tannin lines.

CHAPTER III

MATERIALS AND METHODS

This research was conducted at the Agronomy Research Station, Perkins, Okla., and at the Entomological Laboratory at Oklahoma State University, Stillwater in 1981, 1982, and 1983. Field plots were planted in a randomized complete block design with four replications, each plot consisting of one row 13.7 m long with approximately 1.8 m alleys and rows 1.0 m apart. Each plot was buffered on both sides by a row of the cultivar 'Westburn M'. Plantings were made at the seeding rate of 33.6 kg per ha and were thinned by hand to a plant population of approximately two to three per 30.5 cm. Standard cultivation and other agronomic practices were observed. No irrigation was used. Plantings were made on June 11, 1981; June 14, 1982; and June 20, 1983. Harvests were made on January 7, 1983; and January 10, 1984. The cultivars studied were obtained from commercial seed sources. The experimental lines investigated were obtained from M. J. Lukefahr, Brownsville, Texas; M. F. Schuster, Dallas, Texas; and F. D. Wilson, Tucson, Ariz.; as well as two developed by the Oklahoma Agricultural Experiment Station.

1981 Test

In 1981, 15 cultivars and strains were evaluated. They are listed in Table I along with their sources and known resistance factors, if any.

TABLE I

COTTON CULTIVARS AND STRAINS GROWN IN 1981

Cultivars and Strains	Resistance Factors*	Source
'Westburn M'	None	Cultivar
'Stoneville 213'	None	Cultivar
'Lockett 77'	None	Cultivar
A-3	Unknown	F. D. Wilson
HT 3	Tannins	M. F. Schuster
HT 35-14-3	Tannins	M. F. Schuster
HT 35-4-3	Tannins	M. F. Schuster
E-7	HG	J. H. Young
F-10	HG	J. H. Young
DDS II	N, G, HG	M. J. Lukefahr
HG-6-8-N	N, G, HG	M. J. Lukefahr
HG-1845 N	N, G, HG	M. J. Lukefahr
NSCM 10	N, G, HG	M. J. Lukefahr
HGP 913	N, G, HG	M. J. Lukefahr
HG 6-1-N	N, G, HG	M. J. Lukefahr

*N = nectariless; G = glabrous; and HG = high gossypol.

Each experimental line was examined by individual plants to ensure that the described features or nectariless, glabrous, and high gossypol were present. Tannins cannot be

determined by inspection. Sufficient numbers of mature squares were selfed to ensure seed for subsequent years. A natural infestation of the bollworm occurred during 1981 with populations above 10,000 larvae per acre. Three artificial infestations of laboratory reared larvae were made on August 3, 7, and 14. These infestations were accomplished using the method of Jenkins et al. (1982) which utilizes a mixture of cob grits and newly hatched larvae. Those infestations proved to be inadequate as virtually none of the larvae survived (Young, 1983; Mshiu, 1984). The larvae used in 1981 and in subsequent years were reared in the laboratory. The dietary formula used for this purpose was derived from that of Burton (1967). The ingredients of the formula were as follows:

1.	Water for dissolving agar	1240 ml
2.	Agar	50 g
3.	Hot water	1300 ml
4.	Dried pinto bean, *Phaseolus vulgaris* L.	420 g
5.	Wheat germ	200 g
6.	Dried torula yeast	128 g
7.	Ascorbic acid	13 g
8.	Methyl *P*-hydroxy benzolate	8 g
9.	Sorbic acid	4 g
10.	Formaldehyde 10%	32 ml

The ingredients of the diet, i.e., the dried pinto bean, wheat germ, dried torula yeast, ascorbic acid, methyl *P*-hydroxy benzolate, and sorbic acid were weighed as

indicated and stored in a refrigerator.

At preparation time, the formaldehyde was added to the diet which was then mixed with boiling water in a blender at medium speed. Agar (dissolved in warm water) was then poured into the blender and well mixed with the previously prepared diet. The diet was poured into plastic pill cups and left to cool at room temperature.

Newly hatched bollworm larvae were transferred using small brushes to the artificial diet in pill cups at approximately two to three larvae per cup. The bollworms were maintained in the cups by covering with lids and storing the containers in an incubator at a temperature of 26°C and a day length of 14 hours for some 25 to 30 days, until emergence of adults was observed. The adults were then transferred to a prepared 4.5 liter paper box for reproduction. About 1 to 2 weeks later, first instar larvae were obtained for field infestation or recycling of reproduction.

At the infestation stage, the newly hatched larvae were collected from the adult cage and put into a mason jar capped for immediate transportation to the test field.

Breeding Work

One of the objectives of this experiment was to initiate development of a cotton cultivar with desirable agronomic features and high tannin content. Crosses and their reciprocals were made between 'Westburn M' and

'Simwalt 82' with three high tannin lines, i.e., HT 3, HT 35-14-3, and HT 35-4-3. The 11 crosses obtained are listed in Table II. The cross with HT 35-4-3 X 'Simwalt 82' was not obtained primarily because of the low square and flower production by HT 35-4-3. 'Westburn M' and 'Simwalt 82' are two releases from the Oklahoma Agricultural Experiment Station in 1976 and 1982, respectively. They are stormproof and storm resistant cultivars, respectively, with the agronomic capabilities to produce good yield in Oklahoma under dryland or moderate irrigation.

TABLE II

CROSSES MADE IN 1981

Entry No.	Pedigree
V81-002	'Westburn M' X HT 3
V81-003	HT 3 X 'Westburn M'
V81-004	'Westburn M' X HT 35-4-3
V81-005	HT 35-4-3 X 'Westburn M'
V81-006	HT 35-14-3 X 'Westburn M'
V81-007	HT 35-14-3 X 'Simwalt 82'
V81-008	'Simwalt 82' X HT 35-14-3
V81-009	'Simwalt 82' X HT 3
V81-010	'Simwalt 82' X HT 35-4-3
V81-060	'Westburn M' X HT 35-14-3
V81-061	HT 3 X 'Simwalt 82'

The hybrids were produced in 1981. At maturity, seed

of the crosses were collected, ginned, delinted, and sent to the Cotton Winter Nursery at Colima, Mexico, to produce the F_2 generation for 1982 plantings.

Such large plant numbers of the high tannin lines had to be used to make crosses that yield data in 1981 would have been misleading. Thus, no yield or fiber quality data were recorded for them in that year. However, observations of larval behavior were made and described.

1982 Test

The experimental design and number of replications employed in 1981 were also used in 1982, and the F_2 generation of the high tannin crosses was compared with selected cultivars and lines known to have other resistant factors (Table I). Those materials tested in 1982 are listed in Table III. All experimental lines with morphological resistance factors were examined by individual plants for those characteristics to ensure that the critical factors were present. Methods used for examination were those described by Lukefahr (1977) and Schuster (1981).

Artificial infestations of all plants were made by placing two larvae per plant in the plant terminals in approximately 10 m of row. This was necessary because other information (Mussett, 1981; Mshiu, 1984) demonstrated that in Oklahoma the cob grits method of larval application was inadequate. Boll damage was assessed by calculating the percentage of mature bolls damaged in each plot. As in

1981, behavioral traits of bollworm larvae were recorded for all plant types.

TABLE III

COTTON CULTIVARS, STRAINS, AND F_2 POPULATIONS GROWN IN 1982

Genotype	Description
'Westburn M'	Cultivar
'Stoneville 213'	Cultivar
'Stoneville 825'+	Cultivar
HGP 913	Strain
HG-1845 N	Strain
HG-6-8-N	Strain
HT 3	Strain
HT 35-14-3	Strain
HT 35-4-3	Strain
DDS II	Strain
V81-002 'Westburn M' X HT 3	F_2 population
V81-003 HT 3 X 'Westburn M'	F_2 population
V81-004 'Westburn M' X HT 35-4-3	F_2 population
V81-005 HT 35-4-3 X 'Westburn M'	F_2 population
V81-006 HT 35-14-3 X 'Westburn M'	F_2 population
V81-007 HT 35-14-3 X 'Simwalt 82'	F_2 population
V81-008 'Simwalt 82' X HT 35-14-3	F_2 population
V81-009 'Simwalt 82' X HT 3	F_2 population
V81-010 'Simwalt 82' X HT 35-4-3	F_2 population
V81-060 'Westburn M' X HT 35-14-3	F_2 population
V81-061 HT 3 X 'Simwalt 82'	F_2 population

+Cultivar not previously included.

The F_2 generation was obviously segregating and an attempt was made to select those plants conforming to rather narrow chemical and morphological parameters (Schuster,

1982). Evaluation of fiber quality was conducted at the Oklahoma Agricultural Experiment Station Cotton Quality Research Laboratory in cooperation with L. M. Verhalen and staff. Data analysis was conducted using standard statistical procedures. Comparisons among means were made at the 0.05 probability level using the Duncan Multiple Range Test.

All high tannin segregating populations were carefully screened for their chemical characteristics and were selfed. After maturity, the bolls were harvested, ginned, delinted, treated with fungicides, and sent again to the Cotton Winter Nursery at Colima, Mexico, for production of F_4 seed. Seedcotton yield, lint production, and fiber quality were examined in the 1982 test.

Yield data were measured from 2.1 X 1 m^2 in kg per ha. Fiber quality was measured as fibrograph, micronaire, and stelometer. Fibrograph measurement was made with a fibrograph machine at 2.5% and 50% span length in inches and then converted into millimeters, and is also expressed as a uniformity index which is the ratio of 50% span length over 2.5% span length. Fiber fineness and coarseness was measured with the micronaire machine in standard micronaire units. The stelometer machine was employed to measure fiber tenacity in grams-force per tex (gf/tex) and converted into millinewtons per tex (mN/tex).

1983 Test

In 1983, the experiment was planted in the same manner as the previous 2 years. The notable exceptions were the addition of five cultivars and the deletion of two high tannin and several high gossypol lines. Ten F_4 populations of the 11 crosses made in 1981 were also included. V81-061 was not included in 1983 due to insufficient seed. In 1983 problems were encountered in establishing stands in the plots because of excessive moisture and low temperatures. The cultivars, strains, and F_4 populations established and tested in 1983 are listed in Table IV.

Three artificial infestations of the bollworm were made in 1983: July 20, July 31, and August 14. Each infestation was made by attaching larvae to the terminals. Massive infestations as described by Oliver et al. (1967), Hall et al. (1980), and Jenkins et al. (1982) have not been successful in Oklahoma. This is probably due to the state's dry, semi-arid climate. The only artificial infestations which have produced viable larvae (Mussett, 1981; Mshiu, 1984) were produced by placing one newly hatched larvae directly on a terminal of a plant. Yield data and fiber quality were measured in the same manner as in 1982

In 1981, 1982, and 1983 behavioral studies were made using <u>in situ</u> observations of individual larvae on various cultivars and strains. In 1981, 128 larvae were observed for periods of at least 30 minutes on at least 3 successive days. Many other larvae were observed, but observations

were not complete because of death due to predators or to unknown causes. In 1982, 182 larvae were observed in the same manner; and 84 were observed in 1983.

TABLE IV

COTTON CULTIVARS, STRAINS, AND F_4 POPULATIONS GROWN IN 1983

Genotype	Description
'Westburn M'	Cultivar
'Stoneville 213'	Cultivar
'Stoneville 825'	Cultivar
'Deltapine 61'+	Cultivar
'Cascot C-13'+	Cultivar
'Paymaster 404'+	Cultivar
'Paymaster 145'+	Cultivar
'GSA 75'+	Cultivar
HG-1845 N	Strain
HT 3	Strain
DDS II	Strain
V81-002 'Westburn M' X HT 3	F_4 population
V81-003 HT 3 X 'Westburn M'	F_4 population
V81-004 'Westburn M' X HT 35-4-3	F_4 population
V81-005 HT 35-4-3 X 'Westburn M'	F_4 population
V81-006 HT 35-14-3 X 'Westburn M'	F_4 population
V81-007 HT 35-14-3 X 'Simwalt 82'	F_4 population
V81-008 'Simwalt 82' X HT 35-14-3	F_4 population
V81-009 'Simwalt 82' X HT 3	F_4 population
V81-010 'Simwalt 82' X HT 35-4-3	F_4 population
V81-060 'Westburn M' X HT 35-14-3	F_4 population

+Cultivar not previously included.

In 1981, 1982, and 1983, percent of boll damage was assessed by examining the entire row. Boll damage was used because square and bloom damage are not reliable indicators as suggested by results of these behavioral studies and results of Schuster (1981).

CHAPTER IV

RESULTS AND DISCUSSION

In 1981, 11 hybrids were obtained by crossing high tannin lines with 'Westburn M' and high tannin lines with 'Simwalt 82'. Artificial infestations of bollworms were applied on cultivars and strains which were not crossed. An increase in the population of bollworms was observed. Chemical insecticide was sprayed one time to save the stands; however, the square damage caused by bollworms was not evaluated.

In 1982, 10 cotton cultivars and 11 F_2 populations were planted. The population of bollworms was low during the growing season even though artificial infestations had been applied. No insecticide was sprayed. High populations of predators such as soft-winged flower beetles, Collops spp., spiders and lady beetles, Hippodamia spp. were found. Yields and fiber properties were evaluated. Yield data are presented in Table V. V81-060 produced the highest seedcotton yield, 2001 kg/ha, but did not statistically differ from other treatments except from DDS II downward to HT 35-4-3 in the table. The lowest yield was produced from HT 35-4-3. Two F_2 populations, V81-060 and V81-004, produced statistically higher seedcotton yields than their

TABLE V

YIELD OF SEEDCOTTON AND LINT AT PERKINS, OKLA., IN 1982

Entry	Seedcotton Yield		Lint Yield	
	kg/ha		kg/ha	
V81-060	2001	a*	660	a
Westburn M	1890	ab	633	ab
HGP 913	1578	a-c	525	a-c
V81-004	1520	a-d	514	a-c
V81-009	1485	a-e	475	a-d
V81-002	1467	a-e	487	a-d
Stoneville 213	1445	a-e	480	a-d
V81-006	1430	a-e	446	b-f
Stoneville 825	1385	a-e	456	a-e
DDS II	1362	b-e	428	b-f
HG-1845 N	1340	b-e	436	b-f
V81-003	1294	b-e	403	c-f
HG-6-8-N	1289	b-e	428	b-f
V81-005	1047	c-f	310	c-g
V81-008	995	c-f	328	c-g
HT 35-14-3	985	c-f	276	d-g
HT 3	976	c-f	272	d-g
V81-010	920	d-f	283	d-g
V81-061	897	d-f	253	e-g
V81-007	872	ef	233	fg
HT 35-4-3	599	f	179	g

*Means followed by the same letter were not significantly different at the 0.05 probability level by Duncan's Multiple Range Test.

respective high tannin parents. The other nine F_2 populations were comparable to their respective high tannin parents. Seedcotton yields of F_2 populations varied from the highest to the lowest levels. Similarly, the highest lint was also produced from V81-060, 660 kg/ha and statistically higher than V81-006, and DDS II downward to HT 35-4-3 in Table V. Two F_2 populations, V81-060 and V81-004, had higher lint yields than their respective high tannin parents, and the other nine F_2 populations were comparable to their respective high tannin parents.

Fiber properties are presented in Table VI. It was found that HT 35-4-3 had the longest fiber and significantly differed from the others when 2.5% and 50% span length were measured. V81-008 had the shortest fiber at 2.5% span length, and HG-6-8-N had the shortest fiber at 50% span length.

In terms of uniformity index, V81-009 had the highest uniformity index, 49.8; the lowest uniformity index was observed in HG-6-8-N and V81-061.

The highest value for average micronaire was found in HG-6-8-N with 4.6, while the lowest value was observed in V81-061 with 3.3. However, the average micronaire for 11 F_2 populations ranged from 3.82 to 4.45.

For fiber strength, V81-060 and DDS II yielded the highest fiber strength values, 202.1 and 202.6 mN/tex, respectively. V81-004 yielded the lowest fiber strength value, 167.3 mN/tex.

TABLE VI

COTTON FIBER QUALITY AT PERKINS, OKLA., IN 1982

Entry	Fibrograph 2.5% span length	Fibrograph 50% span length	Fibrograph Uniformity index	Micronaire	Stelometer 1/8" gauge
	mm	mm	ratio	units	mN/tex
HT 35-4-3	29.1 a*	13.3 a	45.9 bc	4.3 a-c	192.0 a-c
Stoneville 825	28.0 ab	13.3 ab	47.4 a-c	4.3 a-c	183.4 b-e
V81-061	27.7 a-c	12.5 a-e	45.1 c	3.3 d	191.0 a-d
Stoneville 213	27.2 b-d	12.7 a-e	46.8 bc	4.4 a-c	178.7 b-e
V81-010	27.1 b-d	12.6 a-e	46.4 bc	4.3 a-c	193.5 ab
HT 3	27.0 b-e	12.4 b-f	46.0 bc	3.7 cd	173.6 de
HT 35-14-3	26.8 b-e	12.8 a-d	47.8 a-c	3.7 b-d	183.6 b-e
V81-002	26.6 b-e	12.3 c-f	46.4 bc	4.2 a-c	174.1 c-e
V81-009	26.3 c-e	13.1 a-c	49.8 a	4.5 ab	187.9 a-d
V81-004	26.3 c-e	12.2 c-f	46.5 bc	4.0 a-c	167.3 e
HG-1845 N	26.3 c-e	12.4 c-f	47.1 a-c	4.1 a-c	193.7 ab
DDS II	26.1 de	12.1 d-f	46.5 bc	4.2 a-c	202.6 a
HGP 913	26.0 de	12.1 d-f	46.3 bc	4.3 a-c	180.2 b-e
V81-003	25.9 de	12.3 c-f	47.5 a-c	4.2 a-c	178.8 b-e
V81-060	25.9 de	12.1 d-f	46.9 bc	3.8 b-d	202.1 a
Westburn M	25.7 de	11.8 ef	46.0 bc	4.2 a-c	182.5 b-e
V81-007	25.6 de	12.3 c-f	48.0 a-c	3.9 a-d	180.5 b-e
HG-6-8-N	25.6 de	11.5 f	45.1 c	4.6 a	183.2 b-e
V81-005	25.6 de	12.3 c-f	48.2 ab	4.2 a-c	181.5 b-e
V81-006	25.5 de	12.2 c-f	47.9 a-c	4.1 a-c	186.1 a-d
V81-008	25.4 e	12.1 d-f	47.4 a-c	4.3 a-c	178.7 b-e

*Means followed by the same letter were not significantly different at the 0.05 probability level by Duncan's Multiple Range Test.

In 1983, seedcotton and fiber quality were also evaluated. The seedcotton and lint yields are presented in Table VII. Since high tannin parents of the derived F_4 populations except HT 3 were not included, so comparisons for seedcotton yields as well as lint yields were made with cultivar 'Stoneville 213' where necessary. The highest seedcotton was produced from HG-1845 N, 1501 kg/ha, but did not statistically differ from other treatments except 'Cascot C-13', 'Stoneville 213', and V81-008. The lowest yield was produced from V81-008, 1069 kg/ha. Three F_4 populations, V81-009, V81-003, and V81-002 produced statistically the same seedcotton yields as their high tannin parent, HT 3. In other comparisons, only V81-010 F_4 population produced statistically higher seedcotton yield than cultivar 'Stoneville 213'.

For lint, HG-1845 N produced the highest lint yield, 628 kg/ha, but did not statistically differ from other treatments except 'Stoneville 213' and V81-008. Three F_4 populations, V81-009, V81-003, and V81-002 produced statistically the same lint yield as their high tannin parent, HT 3. In other comparisons, only V81-009 and V81-010 had lint yields exceeding that of cultivar 'Stoneville 213'.

Fiber properties are shown in Table VIII. All treatments were not statistically different when 2.5% span length was measured. 'Paymaster 404' had the longest fiber and V81-010 had the shortest fiber at 50% span length.

TABLE VII

YIELD OF SEEDCOTTON AND LINT AT PERKINS, OKLA., IN 1983

Entry	Seedcotton Yield		Lint Yield	
	kg/ha		kg/ha	
HG-1845 N	1501	a*	628	a
V81-010	1479	ab	626	a
HT 3	1464	ab	621	a
GSA 75	1458	ab	567	a-c
V81-005	1389	a-c	581	ab
V81-060	1384	a-c	581	ab
V81-009	1373	a-c	608	a
Paymaster 404	1355	a-d	577	a-c
V81-003	1320	a-d	571	a-c
Deltapine 61	1307	a-d	533	a-c
V81-006	1280	a-d	575	a-c
V81-004	1275	a-d	565	a-c
Westburn M	1270	a-d	541	a-c
V81-002	1242	a-d	562	a-c
Stoneville 825	1242	a-d	533	a-c
V81-007	1239	a-d	529	a-c
Paymaster 145	1225	a-d	526	a-c
DDS II	1211	a-d	529	a-c
Cascot C-13	1180	b-d	542	a-c
Stoneville 213	1096	cd	464	b-c
V81-008	1069	d	459	c

*Means followed by the same letter were not significantly different at the 0.05 probability level by Duncan's Multiple Range Test.

TABLE VIII

COTTON FIBER QUALITY AT PERKINS, OKLAHOMA IN 1983

Entry	Fibrograph			Micronaire	Stelometer
	2.5% span length	50% span length	Uniformity index		1/8" gauge
	mm		ratio	units	mN/tex
V81-004	26.0 a*	11.0 a-c	42.3 a-c	4.3 a-c	176.1 ab
GSA 75	25.8 a	11.2 a-c	43.3 a-c	3.7 c	180.5 ab
V81-003	25.8 a	10.7 a-c	41.6 c	4.6 ab	181.5 ab
Paymaster 404	25.7 a	11.5 a	44.8 ab	4.3 a-c	184.1 ab
Paymaster 145	25.7 a	11.3 a-c	44.0 a-c	4.3 a-c	182.7 ab
V81-007	25.7 a	11.1 a-c	43.3 a-c	4.3 a-c	193.0 a
V81-060	25.6 a	11.1 a-c	43.4 a-c	3.9 a-c	179.5 ab
HT 3	25.5 a	11.2 a-c	43.9 a-c	4.1 a-c	191.3 ab
V81-005	25.3 a	10.8 a-c	42.5 a-c	4.0 a-c	181.2 ab
Westburn M	25.3 a	10.8 a-c	42.8 a-c	3.9 a-c	172.2 ab
Stoneville 213	25.3 a	11.3 a-c	44.8 ab	4.1 a-c	189.8 ab
HG-1845-N	25.3 a	10.9 a-c	43.3 a-c	4.2 a-c	184.6 ab
Cascot C-13	25.2 a	10.9 a-c	43.1 a-c	4.7 a	183.2 ab
V81-006	25.2 a	11.4 ab	45.3 a	4.1 a-c	182.7 ab
DDS II	25.1 a	10.8 a-c	43.1 a-c	4.0 a-c	171.2 ab
V81-002	25.0 a	10.7 a-c	42.6 a-c	4.2 a-c	168.9 b
V81-009	25.0 a	10.7 a-c	42.8 a-c	4.0 a-c	187.6 ab
V81-008	25.0 a	10.9 a-c	43.8 a-c	3.8 bc	171.2 ab
V81-010	25.0 a	10.4 c	41.8 bc	3.9 bc	176.1 ab
Deltapine 61	24.8 a	10.5 bc	42.3 a-c	3.7 c	182.2 ab
Stoneville 825	24.7 a	10.8 a-c	43.8 a-c	4.2 a-c	183.2 ab

*Means followed by the same letter were not significantly different at the 0.05 probability level by Duncan's Multiple Range Test.

V81-006 had the highest uniformity index, 45.3. The lowest uniformity index was observed in V81-003, 41.6.

The highest value for micronaire was found in 'Cascot C-13' with 4.7, and the lowest value of 3.7 was observed in 'GSA 75' and 'Deltapine 61'. However, the micronaire for 10 F_4 populations ranged from 3.8 to 4.6.

V81-007 had the highest fiber strength value, 193.0 mN/tex. V81-002 yielded the lowest fiber strength value, 168.9 mN/tex.

When considering the data from the two seasons, eight derived populations performed consistently for seedcotton yields. However, two derived populations, V81-010 and V81-007, had inconsistent performance for seedcotton yields, and one derived population, V81-061, could not be compared since F_4 seed of this cross were not planted due to insufficient amount.

For lint yield, seven derived populations performed consistently while three derived populations, V81-010, V81-007, and V81-005, performed inconsistently.

From this study, the results indicated that genotypes derived from high tannin lines with improved cotton cultivars yielded equal to or better than high tannin lines. Based on the assumption that artificial infestation or natural infestation occurred randomly and uniformly on the tested cotton cultivars, it is likely that tannin played some role in protecting cottons from bollworm damage, probably by means of formation of a relatively indigestible

complex with the available proteins, thus reducing the rate of assimilation of dietary nitrogen (Feeny, 1969), inhibition of ingestion (Reese et al., 1982), reduction in food consumption (Klocke and Chan, 1982), or signal of poor nutrient status and induced nonpreference (Bernays and Chamberlain, 1982). However, since the bolls damaged by bollworms were at low levels, it is likely to be inferred that resistance caused by tannin should be nonpreference rather than antibiosis. On the other hand, the population of bollworm may have been suppressed by an intense heat and deprived by predators in the test field since no insecticide application was made.

In this study, some cotton genotypes derived from high tannin lines with improved cotton cultivars showed good yields and acceptable fiber properties. Therefore, transferring of high tannin characters from genotypes to improved cotton cultivars by breeding seems to be quite possible. In case of lower fiber properties resulting from breeding procedures, genetic improvement could be obtained by a series of backcrosses. However, effective utilization of high tannin characters after breeding should require additional assay as proposed by Wilson and George (1981). Although much more research is needed, the derived high tannin cotton lines will play a significant role in a cotton protection program, especially in cotton host-plant resistance (HPR) program as proposed by Chan and Waiss (1982).

In this study it was noted from the first infestation that bollworm did not behave normally on high tannin lines. This has been confirmed by Schuster (1983). Normally, bollworm larvae, after hatching, enter the terminal of the cotton plant, feed for 2-3 days, then move to a nearby square and feed on it until it is destroyed. The larvae generally work down the plant to larger and larger squares, then to bolls. This was the behavior noted in this test on the cultivars 'Westburn M', 'Stoneville 213', and 'Lockett 77'. Of the 394 larvae observed in the three-year study, 111 were on these cultivars.

On high tannin lines (207 larvae) the type of behavior was notably different. The newly hatched larvae fed no longer than one day in the terminal. They then moved to a nearby square, but seldom fed for more than an hour - often less than 10 minutes. The process was repeated from one square to another. Eventually, they stopped and fed for periods of 2-3 hours. Thus counts of damaged squares did not give meaningful data, because often more squares were damaged on the high tannin lines than on the cultivars. This behavior was also observed on high gossypol lines such as HG-6-1-N, HG-6-8-N and HG-1845N (76 larvae observed), but less than 10% of the time. Schuster (1983) called this a feeding deterrent.

Statistical analysis of this data did not yield meaningful information except to confirm that the larvae do move more frequently. The enormous variability between

larvae in numbers, and types of fruit removed has only shown that more study is needed in this area. Such studies have been initiated in this department.

CHAPTER V

SUMMARY

The bollworm, Heliothis zea (Boddie), is one of the most important pests of cotton, Gossypium hirsutum L., in the southwestern United States. Damage caused by the bollworm seriously reduces the yield and fiber quality of cotton. Thus, it would be beneficial to find an effective control method to reduce the loss from this pest. Host-plant resistance is only one of many control methods. However, this means, if feasible, should provide an efficient, effective, and economical means of controlling bollworm populations in this valuable crop without environmental contamination.

In cotton, both morphological and chemical characters play an important role in control of pests. Four characters used as plant defenses to control bollworm population have been described as glabrousness, nectariless, high gossypol, and high tannins (hemigossypolone and heliocide H_1). Several reports were published on the effects of tannin on cotton pests in field and laboratory experiments in the 1970's.

This experiment attempted to compare the high tannin cotton with cultivars of cotton and with lines having known

factors for resistance to bollworm attack, to study the effects of high tannin on seedcotton and lint yield on fiber quality, and to initiate the development of a cotton with suitable agronomic properties plus high tannin.

In 1981, three high tannin lines (HT 3, HT 35-14-3, and HT 35-4-3) were crossed with improved cotton cultivars, 'Westburn M' and 'Simwalt 82'. The 11 hybrids were received, then collected and sent to Mexico for an advanced generation.

In 1982, 11 F_2 populations and 10 cotton cultivars and strains were grown at the Agronomy Research Station at Perkins, Oklahoma. The cotton yields and cotton fiber qualities were evaluated. Seedcotton yields as well as lint yields of two out of 11 F_2 populations were superior to their respective high tannin parents. The other nine F_2 populations were comparable to their respective high tannin parents. Seedcotton and lint yields of F_2 populations varied from highest to lowest levels.

In 1983, 10 F_4 populations and 11 cotton cultivars and strains were grown. The cotton yields and cotton fiber qualities were evaluated. Seedcotton yields as well as lint yields of three out of 10 F_4 populations were statistically the same as their common high tannin parent, HT 3. Only one F_4 population yielded statistically higher seedcotton yield than the adapted cultivar and two F_4 populations had lint yields exceeding the adapted cultivar.

In this study, the damaged squares and bolls caused by

bollworm larvae were not at very high levels. It is likely to be inferred that resistance caused by tannin should be nonpreference or antibiosis rather than tolerance. On the other hand, the bollworm population may be suppressed by an intense heat or the number of predators in the test field since no insecticide application was made. However, some cotton genotypes derived from high tannin lines with improved cotton cultivars showed good yields and acceptable fiber properties. Therefore, transferring of high tannin characters from genotypes to improved cotton cultivars by breeding seems to be quite feasible.

REFERENCES CITED

Adkisson, P. L., C. F. Bailey, and R. L. Hanna. 1964. Effect of the bollworm, Heliothis zea, on yield and quality of cotton. J. Econ. Entomol. 57:448-50.

Bate-Smith, E. C. 1975. Phytochemistry of proanthocyanidins. Phytochemistry 14:1107-13.

Bennett, S. E. 1965. Tannic acid as a repellent and toxicant to alfalfa weevil larvae. J. Econ. Entomol. 58:372-3.

Berenbaum, M. 1980. Adaptive significance of midgut pH in larval Lepidoptera. Am. Nat. 115:138-46.

Bernays, E. A. 1978. Tannins: An alternative viewpoint in graminivorous Locusta migratoria. Entomol. Exp. Appl. 24:244-53.

Bernays, E. A., D. Chamberlain, and P. McCarthy. 1980. The different species of Acridoidea. Entomol. Exp. Appl. 28:158-66.

Bernays, E. A. 1981. Plant tannins and insect herbivores: An appraisal. Ecol. Entomol. 6:353-60.

Bernays, E. A., and D. J. Chamberlain. 1982. The significance of dietary tannin for locust and grasshopper. J. Nat. Hist. 16:261-6.

Brown, A. W. A. 1951. Insect Control by Chemicals. John Wiley & Sons, New York. 817 pp.

Burton, R. L. 1967. Mass rearing the fall armyworm in the laboratory. USDA-ARS-33-117. 12 pp.

Cadman, C. H. 1960. Inhibition of plant virus infection by tannins. p. 101. In Phenolics in Plants in Health and Disease (ed. by Pridham, J. B.) Pergamon Press, Oxford.

Caldwell, W. D., J. E. Jones, D. R. Melville, K. B. Moppert, and D. F. Clower. 1979. Response of selected cotton genotypes to early season insect pests. p. 87. In Proc. Beltwide Cotton Prod. Res. Conf. Proc. Natl. Cotton Coun., Memphis, TN. (Abstr.)

Carson, R. L. 1962. Silent Spring. Houghton-Mifflin Co., Boston. 368 pp.

Chakravorty, S. C., A. K. Basu, and V. M. Sahni. 1982. Variability in tannin and protein content in fruiting parts in relation to the incidence of pink bollworm in cotton. Indian J. Agric. Sci. 52:767-73.

Chan, B. G., A. C. Waiss, Jr., R. G. Binder, and C. A. Elliger. 1978. Inhibition of Lepidopterous larval growth by cotton constituents. Entomol. Exp. Appl. 24:294-300.

Chan, B. G., A. C. Waiss, Jr., and M. J. Lukefahr. 1978. Condensed tannin, an antibiotic chemical from Gossypium hirsutum. J. Insect Physiol. 24:113-8.

Chan, B. G., and A. C. Waiss, Jr. 1982. Allelochemical inhibition of larval growth of pink bollworm. p. 133-35. In Proc. Beltwide Cotton Prod. Res. Conf. Natl. Cotton Coun. Am., Memphis, TN.

Duffy, S. S. 1980. Sequestration of plant natural products by insects. Annu. Rev. Entomol. 25:447-77.

Feeny, P. P. 1968. Effect of oak leaf tannins on larval growth of the winter moth Operophtera brumata. J. Insect Physiol. 14:805-17.

Feeny, P. P. 1969. Inhibitory effect of oak leaf tannins on the hydrolysis of proteins by trypsin. Phytochemistry 8:2119-26.

Feeny, P . P. 1970. Seasonal changes in oak leaf tannins and nutrients as a cause of spring feeding by winter moth caterpillars. Ecology 51:565-81.

Gaines, J. C. 1941. Varietal resistance. Texas Agric. Exp. Stn. Annu. Rept. 54:32.

Goldstein, J. L. and T. Swain. 1965. The inhibition of enzymes by tannins. Phytochemistry 4:185-92.

Hall, P. K., W. L. Parrott, J. N. Jenkins, and J. C. McCarty, Jr. 1980. Use of tobacco budworm eggs and larvae for establishing field infestations on cotton. J. Econ. Entomol. 73:393-5.

Hamer, J. 1980. Report of the cotton insect loss committee of the thirty-third annual conference on cotton insect research and control. p. 139. In Proc. Beltwide Cotton Prod. Res. Conf. Natl. Cotton Coun. Am., Memphis, TN.

Hamer, J. 1981. Report of the cotton-insect loss committee of the thirty-fourth annual conference on cotton insect research and control. p. 136. In Proc. Beltwide Cotton Prod. Res. Conf. Natl. Cotton Coun. Am., Memphis, TN.

Haslam, E. 1966. Chemistry of Vegetable Tannins. Academic Press, New York. 179 pp.

Head, R. B. 1982. Report of the cotton insect loss committee of the thirty-fifth annual conference on cotton insect research and control. p. 182. In Proc. Beltwide Cotton Prod. Res. Conf. Natl. Cotton Coun. Am., Memphis, TN.

Hedin, P. A., O. H. Lindig, P. P. Sikorowski, and M. Wyatt. 1978. Suppressant of gut bacteria in the boll weevil from the cotton plant. J. Econ. Entomol. 71:394-6.

Jenkins, J. N., W. L. Parrott, J. C. McCarty, Jr., and W. H. White. 1982. Breeding cotton for resistance to the tobacco budworm: Techniques to achieve uniform field infestations. Crop Sci. 22:400-4.

Klocke, J. A., and B. G. Chan. 1982. Effects of cotton condensed tannin on feeding and digestion in the cotton pest, Heliothis zea. J. Insect Physiol. 28:911-5.

Lane, H. C., and M. F. Schuster. 1979. Tannins in cotton. p. 43. In Proc. Beltwide Cotton Prod. Res. Conf. Natl. Cotton Coun., Memphis, TN. (Abstr.)

Lane, H. C., and M. F. Schuster. 1981. Condensed tannins of cotton leaves. Phytochemistry 20:425-7.

Lawson, D. L., R. W. Merritt, M. J. Klug, and J. S. Martin. 1982. The utilization of late season foliage by the orange striped oakworm Anisota senatoria (J. E. Smith). Entomol. Exp. Appl. 32:242-8.

Leigh, T. F. Personal Interview. Department of Entomology, University of California, Davis, California, February 12, 1984.

Luck, R. F., R. van den Bosch, and R. Garcia. 1977. Chemical insect control - A troubled pest management strategy. BioScience 27 (9):606-11.

Lukefahr, M. J., T. N. Shaver, D. E. Cruhm, and J. E. Houghtaling. 1974. Location, transference, and recovery of a Heliothis growth inhibition factor present in three Gossypium hirsutum race stocks. p. 93-5. In Proc. Beltwide Cotton Prod. Res. Conf. Natl. Cotton Coun., Memphis, TN.

Lukefahr, M. J. 1977. Varietal resistance to cotton insects. p. 236-7. In Proc. Beltwide Cotton Prod. Res. Conf. Natl. Cotton Coun., Memphis, TN.

Macauley, B. J., and L. R. Fox. 1980. Variation in total phenols and condensed tannins in Eucalyptus: Leaf phenology and insect grazing. Aust. J. Ecol. 5:31-5.

Maxwell, F. G., J. N. Jenkins, and W. L. Parrott. 1967. Influence of constituents of the cotton plant on feeding, oviposition, and development of the boll weevil. J. Econ. Entomol. 60:1294-6.

Miah, M. A. H., M. A. Chowdhury, and F. Rubbi. 1981. Susceptibility of jute mutants to Apion corchori Marsh in relation to anatomical character of stem. Sci. and Culture 47 (12):443-4.

Mishra, S. C., and R. Singh. 1981. Chemical composition of food and faecal matter of bark feeding Lepidopterous larvae Indarbela quadrinotata Walk (Lep. Indarbelidae) in relation to digestion. Indian J. of For. 4:107-9.

Mshiu, E. P. 1984. Tolerance of commercial cotton varieties to the cotton bollworm Heliothis zea (Boddie). Ph.D. Dissertation, Oklahoma State Univ., Stillwater. 61 pp.

Mussett, K. S. 1981. Tolerance of twelve cotton cultivars to the cotton bollworm (Heliothis zea Boddie). Ph.D. Dissertation, Oklahoma State Univ., Stillwater. 63 pp.

Niles, G. A. 1980. Breeding cotton for resistance to insect pests. p. 337-69. In F. G. Maxwell and P. R. Jennings (eds.) Breeding Plants Resistant to Insects. John Wiley & Sons, New York. 683 pp.

Oliver, B. F., F. G. Maxwell, and J. N. Jenkins. 1967. Measuring aspects of antibiosis in cotton lines to the bollworm. J. Econ. Entomol. 60:1459-60.

Painter, R. H. 1951. Insect Resistance in Crop Plants. Univ. Press of Kansas, Lawrence. 520 pp.

Parrott, W. L., J. C. McCarty, Jr., H. C. Lane, J. N. Jenkins, and P. A. Hedin. 1983. Effects of methomyl on the concentration of anthocyanin, tannin, and chlorophyll in cotton leaves. Southwestern Entomol. 8:94-7.

Perring, T. M., T. L. Archer, J. W. Johnson, and J. M. Phillips. 1982. Evaluation of several grain sorghum characteristics for resistance to the Banks grass mite. J. Econ. Entomol. 75:257-60.

Pospisil, J. 1982. The response of Leptinotarsa decemlineata (Coleoptera) to tannin as an antifeedant. Acta Entomol. Bohemoslovaca 79:429-34.

Pree, D. J. 1977. Resistance to development of larvae of the apple maggot in crab apples. J. Econ. Entomol. 70:611-14.

Price, R. G. Personal Interview. Department of Entomology, Oklahoma State University, Stillwater, Oklahoma, February 1, 1984.

Reese, J. C., B. G. Chan, and A. C. Waiss, Jr. 1982. Effects of cotton condensed tannin, maysin (corn) and pinitol (soybean) on Heliothis zea growth and development. J. Chem. Ecol. 8:1429-36.

Robinson, R. R., J. H. Young, and R. D. Morrison. 1972. Strip-cropping effects on abundance of Heliothis damaged cotton squares, boll placement, total bolls, and yields in Oklahoma. Environ. Entomol. 1:140-45.

Russell, M. P. 1962. Effects of sorghum varieties on the lesser rice weevil, Sitophilus oryzae (L.) I. Oviposition, immature mortality, and size of adults. Ann. Entomol. Soc. Am. 55:678-85.

Sanders, T. H. 1977. Changes in tannin-like compounds of peanut fruit parts during maturation. Peanut Sci. 4:51-3.

Schultz, J. C., and I. T. Baldwin. 1982. Oak leaf quality declines in response to defoliation by gypsy moth larva. Science 217:149-51.

Schuster, M. F. 1979. New sources of high tannin resistance to Heliothis in upland cotton resulting in feeding deterrence. p. 85-7. In Proc. Beltwide Cotton Prod. Res. Conf. Natl. Cotton Coun., Memphis, TN.

Schuster, M. F. Personal Interview. New Orleans, Louisiana, January 4, 1981.

Schuster, M. F. Personal Interview. Las Vegas, Nevada, January 3, 1982.

Schuster, M. F. Personal Interview. San Antonio, Texas, January 2, 1983.

Schuster, M. F., and H. C. Lane. 1980. Evaluation of high-tannin cotton lines for resistance to bollworms. p. 83-4. In Proc. Beltwide otton Prod. Res. Conf. Natl. Cotton Coun. Am., Memphis, TN.

Schuster, M. F., and H. C. Lane. 1981. Tannin content of cotton through the fruiting period and bollworm resistance. p. 83. In Proc. Beltwide Cotton Prod. Res. Conf. Natl. Cotton Coun. Am., Memphis, TN. (Abstr.)

Schuster, M. F., P. D. Calvin, and W. C. Langston. 1983. Interaction of high tannin with bollworm control by pydrin and dipel. p. 72-3. In Proc. Beltwide Cotton Prod. Res. Conf. Natl. Cotton Coun. Am., Memphis, TN.

Sharma, H. C. and R. A. Agarwal. 1982a. Consumption and utilization of bolls of different cotton genotypes by larvae of Earias vittella F. and effect of gossypol and tannins on food utilizations. Zeitschrift Fur Angewandte Zoologie 68:13-37. (Abstract from Review of Applied Entomol. Series A. Agric. 70:505-6.)

Sharma, H. C., and R. A. Agarwal. 1982b. Effect of some antibiotic compounds in Gossypium on the post embryonic development of spotted bollworm (Earias vittella F.). Entomol. Exp. Appl. 31:225-8.

Sharma, H. C., R. A. Agarwal, and M. Singh. 1982. Effect of some antibiotic compounds in cotton on post embryonic development of spotted bollworm (Earias vittella F.) and the mechanism of resistance in Gossypium arboreum. Indian Acad. Sci. Proc., Animal Sci. 19:67-77.

Stansbury, M. F., E. T. Field, and J. D. Guthrie. 1950. The tannin and related pigments in the red skins (testa) of peanut kernels. J. Am. Oil Chem. Soc. 27:317-21.

Stern, V. M., R. F. Smith, R. van den Bosch, and K. S. Hagen. 1959. The integrated control concept. Hilgardia 29:81-101.

Swain, T. 1977. Secondary compounds as protective agents. Annu. Rev. Plant Physiol. 28:479-501.

Thatcher, R. W. 1921. The Chemistry of Plant Life. McGraw-Hill Book Co., Inc., New York. pp. 94-101.

van den Bosch, R., T. F. Leigh, D. Gonzalez, and R. E. Stinner. 1969. Cage studies on predators of the bollworm in cotton. J. Econ. Entomol. 62:1486-9.

van den Bosch, R., T. F. Leigh, L. A. Falcon, V. M. Stern, D. Gonzalez, and K. S. Hagen. 1971. The developing program of integrated control of cotton pests in California. p. 377-94. In Biological Control (ed. by C. B. Huffaker) Plenum Press, New York.

van den Bosch, R. 1978. The Pesticide Conspiracy. Doubleday Co., Inc., New York. 226 pp.

Waiss, A. C., Jr., B. G. Chan, C. A. Elliger, and R. G. Binder. 1981. Biologically active cotton constituents and their significance in HPR. p. 61-3. In Proc. Beltwide Cotton Prod. Res. Conf. Natl. Cotton Coun. Am., Memphis, TN.

Waiss, A. C., Jr., B. G. Chan, C. A. Elliger, D. L. Dreyer, R. G. Binder, and R. C. Gueldner. 1981. Insect growth inhibitors in crop plants. Bull. Entomol. Soc. Am. 27:217-21.

Wilson, F. D., and B. W. George. 1981. Breeding cotton for resistance to pink bollworm. p. 63-5. In Proc. Beltwide Cotton Prod. Res. Conf. Natl. Cotton Coun. Am., Memphis, TN.

Wilson, M. C., A. C. York, and A. V. Provonsha. 1977. Practical Insect Pest Management 3. Insects of Vegetables and Fruit. Waveland Press, Inc., Illinois. p. 1.

Young, J. H. Personal Interview. Department of Entomology, Oklahoma State University, Stillwater, Oklahoma, January 10, 1983.

VITA γ

Nongporn Allapach Kitbamroong

Candidate for the Degree of

Doctor of Philosophy

Thesis: BOLLWORM RESISTANCE IN HIGH TANNIN COTTON

Major Field: Entomology

Biographical:

Personal Data: Born in Pattani, Thailand, March 18, 1946, the daughter of Prasarn and Suparp Allapach; married Charas Kitbamroong on October 20, 1970; and mother of three children, Kitipan, Vorapol, and Montakarn.

Education: Graduated from Trium Udom Suksa High School, Bangkok, Thailand, in April, 1965; received the Bachelor of Science degree in Agriculture from Kasetsart University, Bangkok, Thailand, in April, 1969; received the Master of Science degree in Entomology from the University of Kentucky, Lexington, Kentucky in December, 1974; and completed the requirements for the Doctor of Philosophy degree in Entomology from Oklahoma State University, Stillwater, Oklahoma, in July, 1984.

Professional Experience: Insect taxonomist, Division of Entomology, Northeast Agricultural Center, Thapra, Khonkaen, Thailand from 1969 to 1978; agricultural researcher, Kalasin Field Crop Experiment Station, Kalasin, Field Crop Institute, Department of Agriculture, since 1978.