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The Development and Fecundity of the Oriental Fruit Moth, Grapholitha (Cydia) Molesta (Busck) Under Controlled Temperatures and Humidities.

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Ghulam-Ullah Chaudhry

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Ray Hutson
Major professor

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THE DEVELOPMENT AND FECUNDITY OF THE ORIENTAL FRUIT MOTH, GRAPHOLITHA (CYDIA) MOLESTA (BUSCK) UNDER CONTROLLED TEMPERATURES AND HUMIDITIES

By

GHULAM-ULLAH CHAUDHRY

A THESIS

Submitted to the School of Graduate Studies of Michigan
State College of Agriculture and Applied Science
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GHULAM-ULLAH CHAUDHRY ABSTRACT

The development and fecundity of the oriental fruit moth, Grapholitha (Cydia) molesta (Busck) was studied under several controlled temperatures of 50.5° to 95° F. and relative humidities of 35%, 70% and 100%. The optimum range of temperature for this insect was 75°-85° F. It could develop at 95° F. under high humidities only. The incubation period was lowest under 70% relative humidity at temperatures of 65° to 95° F. At low temperatures of 50.5° and 60° F. the eggs developed best under 100% relative humidity. The eggs tolerated an exposure of forty hours to 98° F. and twenty-one hours to 105° F., but their incubation period increased by 24-40 hours as compared to those kept throughout at an optimum temperature.

The threshold of development for eggs was 40° and 44° F.; for pupae 46.5° and 52.5° F. under relative humidities of 100% and 35%, respectively. For larvae it was 43.5° F. The eggs and pupae can develop at lower temperatures when exposed to high humidity than under low humidity.

The larvae of the fruit moth entered into a short diapause for a period of 31 to 60 days and into a long diapause of over 60 days during September to November, 1950, under various conditions of temperature and humidity. A substantially larger number of larvae entered into and completed their long diapause when the relative humidity to which they were exposed during the cocoon period was high enough. Generally out of the total number of moths emerging at various temperatures about 50%, 33% and 0.0% moths emerged from the long cycle larvae under relative humidities of 100%, 70% and 35%, respectively. This adaptation ensures greater survival for this species in regions where a high humidity of 80-90% prevails in late summer and fall.

Photoperiodism did not affect the induction or duration of larval diapause as the larvae went into hibernation even when grown in darkness. The real cause which initiates diapause may be inherent.

The viability of the pupae was usually highest under saturated atmosphere. The moths laid more eggs if their preimaginal life had been under higher humidities.

The present distribution of the oriental fruit moth in temperate regions appears to be governed by relative humidity.

In humid areas the insect is more abundant than in dry areas. This difference is explained here by the influence of relative humidity on its development and on the successful completion of larval diapause; higher humidities favouring this insect and lower humidities affecting its biotic potential adversely.

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I. INTRODUCTION

The oriental fruit moth, Grapholitha (Cydia) molesta (Busck) is an important insect pest of peach and other stone fruits, apple, quince and pear. The larvae bore into tender shoots of peach, which is the major host plant in the United States of America, and later they attack its fruits. In the case of other hosts the pest generally attacks fruits. The moth was reported first in 1916 doing considerable damage to peach trees within a radius of twenty miles around Washington, D. C. Subsequent investigations showed that it was introduced into that locality on flowering cherries imported from Japan about three years earlier. By 1918 the pest had spread to New Jersey, New York and Connecticut; ever since it has been spreading to deciduous orchards in all directions. In spite of strict quarantine measures the pest is now well established in California.

Outside the United States of America the oriental fruit moth has been recorded from Canada, Italy, France, New Zealand, Australia, China and Japan. In Japan its damage was first noticed in Okayama Prefecture in 1901 and 1902, as reported by Harukawa (12) and Haeussler (14). It is now generally distributed throughout the central and southern parts of Japan. Both fruits and twigs of peach, sand pear, pear, quince, apple, apricot, black plum, Chines malus, and only the twigs of cherry, Japanese flowering cherry (Pyrus triflora), sand cherry, Japanese apricot (Prunus ume) and plum are attacked. In Japan it is of primary importance as a pest of sand pear which is of more importance as a fruit crop than is the peach.

So far the oriental fruit moth is not reported from Pakistan and India, although two closely related species, the codling moth, Carpocapsa (Cydia) pomonella (Linn) and the peach twig borer, Anarsia lineatella Zell. are serious pests in the temperate fruit growing areas of these countries. It would be interesting to find out some of the factors which may have prevented the spread of Grapholitha molesta to this area. It is just possible that the moth did not gain access to this region. It is more likely that climatic conditions were not quite suitable for its development. An analysis of these factors may bring out some limitations responsible for its absence in those regions.

The biology and control of the fruit moth has been studied extensively at different agricultural experiment stations in the United States of America, Canada and Japan. In almost all these investigations, the insects were studied either in the field or under uncontrolled conditions in the laboratory. Hence, it is not possible to evaluate the effect of various environmental factors on this pest. Comparatively little is known about the potentialities of this insect, the rate of its development, upper vital limits for the various stages, the viability of its pre-imaginal stages and the fecundity and longevity of adults under different controlled conditions. The tendency of modern ecologists has been to study insects only in the field. Accurate analysis of observations in the field is very difficult. In spite of the fact that varying temperatures in nature are more important from an ecological point of view, the research problem must pass through the laborious stages of investigation under constant temperatures in order to lay a foundation for their proper understanding. Laboratory and field ecology are interdependent and both are essential. By correlating the results of study in the laboratory with those in the field it is sometimes possible to solve problems of insect abundance. Uvarov (29) emphasized the importance of properly planned studies in the laboratory so as to utilize the results in understanding the problems in nature.

Control of the oriental fruit moth has depended to a large extent in the past on useful parasites. In order to assess properly the potentialities of a pest and its parasites, a knowledge of their behavior under different controlled conditions of environment is of fundamental importance. These studies reveal the conditions under which the pest and the parasites flourish and multiply best.

Temperature is the greatest single factor which affects the geographic distribution of any species of insects on this earth. The biotic potential, its behavior, form and structure, all are influenced by this environmental factor. Apart from its direct effects, temperature influences other factors, such as light, moisture, movement of air, etc. The distribution of animals in many parts of the world is more or less closely tied up with temperature. Another factor which controls the geographic range of an organism is moisture.

With these points in view investigations on the ecology of the oriental fruit moth were started in 1950 at East Lansing, Michigan, by rearing the insect under constant temperatures and relative humidities. Apart from this, meteorological data from three typical stations in U. S. A. have been compared with those of three typical peach and apple growing areas in Pakistan, in order to explore the possibilities for the establishment of the oriental fruit moth in the latter country.

II. TECHNIQUE AND METHODS

Collection

About a dozen hibernating larvae of the oriental fruit moth were received from Benton Harbor, Michigan, in the winter of 1950. During May, 1950, several visits were made to that area, where quince and peach trunks were examined for hibernating larvae and pupae. These attempts did not prove as useful as anticipated, because each time very few specimens could be collected. In all about two dozen moths emerged. They died after laying only five eggs.

On account of extended cold weather the pest did not make its presence noticeable in the Lansing area till about the end of June, 1950. Peach orchards around Lansing, Mason and Grand Rapids were examined frequently during June to September, 1950. The infestation in twigs of peach was never more than 0.1%. On some individual trees it would range from 2-5 infested shoots. Wilted shoots with the larvae boring inside were cut and brought to the laboratory.

Rearing

The cut shoots were kept standing in moist sand and this generally allowed the larvae to become full grown and come out for pupation in corrugated paper sheets provided for this purpose. The pupae were kept at room temperature (70 - 80° F.). The moths emerging from this material were liberated for oviposition in cages of 10" x 10" x 8" size, made of wooden frames. The sides and top of this type of cage were covered with thin muslin, which was applied from inside. The cage was kept at room temperature over moist sand in a large enamel tray. A wad of cotton wool soaked in thin sugar solution was kept in each cage for the moths to feed upon. Fresh peach shoots in small bottles and tubes filled with water were kept in cages for the moths to lay eggs upon. The bottles and tubes were wrapped with cloth to prevent the moths from laying eggs on the glass.

The shoots with eggs on them were removed from the cages every morning. A few hours before the hatching of the larvae the shoots were kept over partly sliced apples in glass dishes and beakers. The dish was then kept at the temperature at which the larvae were to be reared. The larvae entered the apples soon after hatching. Generally they would leave the fruit only after they were full grown and ready to spin cocoons. The entire rearing in the laboratory was done on Jonathan apples removed from the trees in August and stored at 50° F. A known number of full grown larvae were then transferred to corrugated paper strips kept in small glass vials, for spinning cocoons and pupation. The mouth of each vial was covered with cloth to prevent the larvae from escaping. They were then kept at the required temperature and humidity.

The moths emerging from the vials were released in cages for oviposition. As these cages were to be kept in incubators they were smaller than those kept for general rearing at room temperature. They consisted of 6" diameter wire loops supported by 8" long pieces of wire. Sides and top were covered with thin muslin. They were kept on moist sand in glass dishes. The moths were fed on sugar solution soaked in cotton wool. The eggs laid by moths on green peach shoots were counted daily and the shoots changed. A regular supply of green peach shoots was maintained by raising seedlings in the greenhouse.

Temperature Control

For 60° and 65° F. a refrigerating cabinet fitted with a special electric thermostatic control was used. For higher temperatures electric incubators, with accurate thermostatic controls were employed. A thermograph was kept in each of them to record temperature. Fluctuation of temperature was not more than 0.5° F.

Humidity Control

Constant humidities in closed space, can be obtained by using sulphuric acid solutions or supersaturated salt solutions. In these experiments salt solutions were used. This method has an advantage in that a standard solution is maintained which gives constant humidity. It does not require frequent changing and does not spoil easily. Chemically pure salts appropriate for each relative humdity at different temperatures were used (16). They were placed at the bottom of desiccators and just enough distilled water was added as to cover the surface of the salt.

III. NOMENCLATURE AND DESCRIPTION OF SPECIES

The oriental fruit moth was described by August Busck of the U. S. Bureau of Entomology as Laspeyresia molesta. The description was published by Quintance and Wood in 1916 (21). Prior to the above Frogatt mentioned this insect as an unidentified enemy of peach in Australia under the popular name, peach tip moth (8). Enquiries made by Haeussler (14) in Japan revealed that this insect was known in Japan in 1901 and 1902, especially as a pest of sand pear.

Heinrich (15) placed this moth in the genus Grapholitha Treitschke, family Olethreutidae.

The pest has been known under several common names in the past, e.g., peach tip moth, smaller pear borer, oriental peach worm, oriental peach moth and oriental fruit moth. The last name was most widely used in American literature and was, therefore, adopted by the American Association of Economic Entomologists as the approved name.

The European writers, particularly the entomologists in England, place this species in the genus Cydia Hubner as suggested by Walsingham and Durrant in Biologia. They substituted

Cydia H. for Carpocapsa Trietschke and designated Laspeyresia Hubner as a synonym. The Review of Applied Entomology published from London continues to refer the oriental fruit moth under the genus Cydia H.

Following is the original description prepared by Busck:

Laspeyresia molesta, n. sp.

Head dark, smoky fuscous; face a shade darker, nearly black; labial palpi a shade lighter fuscous; antennae simple, rather stout, half as long as the forewings, dark fuscous with thin, indistinct, whitish annulations. Thorax blackish fuscous; patagia faintly irrorated with white, each scale being slightly white-tipped. Forewings normal in form; termen with slight sinuation below apex; dark fuscous, obscurely irrorated by white-tipped scales; costal edge blackish, strigulated with obscure, geminate, white dashes, four very faint pairs on basal half and three more distinct on outer half besides two single white dashes before apex; from the black costal intervals run very obscure, wavy, dark lines across the wing, all with a strong outwardly directed wave on the middle of the wing; on the middle of the dorsal edge the spaces between three of these lines are more strongly irrorated with white than is the rest of the wing, so as to constitute two faint and poorly defined white dorsal streaks. All these markings are only discernible in perfect specimens and under a lens; ocellus strongly irrorated with white, edged by two broad perpendicular, faint bluish metallic lines and containing several small deep black, irregular dashes, of which the fourth from tornus is the longest and placed farther outward, so as to break the outer metallic edge of ocellus; the line of black dashes as well as the adjoining bluish metallic lines are continued faintly above the ocellus in a curve to the last geminate costal spots; there is an indistinct, black apical spot and two or three small black dots below it; a thin but distinct, deep black, terminal line before the cilia,

cilia dark bronzy fuscous. Hind wings dark brown with costal edge broadly white; cilia whitish, underside of wings lighter fuscous with strong irridescent sheen; abdomen dark fuscous with silvery white underside; legs dark fuscous with inner sides silvery, tarsi blackish with narrow, yellowish white annulations.

Alar expanse; 10-15 mm.
United States National Museum type 20664.

The female genitalia consist of two closely approximated, setose egg-guides, like elongate phylloclades of Opuntia sp. Some setae on the outer margins of egg-guides are longer than the rest. Large scales caudad of the last abdominal segment form a fan-shaped structure covering the egg-guides from the dorsal side. In the male the two gray, acuminate claspers form a dark slit between them on account of the presence of a large number of black setae on the mesal surfaces.

Description of Stages

The Egg: The egg is whitish, scale-like semitransparent, circular to oval in outline, flat, upper surface slightly rugose and convex, diameter 0.65 mm. to 0.75 mm. The eggs are generally laid on the upper surface of peach leaves. However, in the laboratory they are laid on both sides of the leaf as well as on the shoot. Before hatching the black head of the larva is conspicuously visible through the egg-shell.

<u>The Larva</u>: The larva resembles that of the codling moth in several respects but is smaller in size. The young larva is dirty cream in colour, becomes pink when almost full grown. The following is essentially the description given by Garman (9): Head capsule black and shining, sometimes provided with pale markings; body pinkish white, the prothoracic and anal shields usually brown; length of full-grown larva 12-15 mm.

Length of labium one and one-half time its width, cardo as long as the stipes; mentum expanded at the caudal extremity and with two heavy setae near the middle; maxillary palpi three segmented, the basal segment with a long seta on the inner surface; galea-lacinia with four distinct teeth, two of which are chitinized, the tips of the chitinized projections with blunt tubercles, labial palpi slender, composed of two segments, a very short globular, distal segment tipped with a long seta and a long proximal segment with a short seta at the apex; tip of the labium heavily chitinized; antennae four-segmented, the third segment with a long seta near the distal end, the distal segment about one-half the diameter of the preceding segment, and provided with a blunt projection and a long seta; third segment with two short setae, one long seta and a blunt projection similar to that of the distal segment.

Thorax and abdomen: Segment nine of the abdomen with alpha sometimes represented by a tubercle or short seta near the dorso-meson delta (II) located on the same pinnaculum with rho (III); kappa (IV) and mu (V) on the same pinnaculum and about equidistant; kappa (prespiracular) group of the prothorax with the middle seta longest and equidistant from the remaining two; kappa group (V and VI) bisetose on segments one to eight, pi (VII) group unisitose on segments seven, eight and nine. Crochets uniordinal; densely placed in a complete circle; the lateral hooks sometimes short, number of crochets on prolegs 3 to 6 varying from 30 to 46, hooks of irregular length infrequent. Crochets of the anal prolegs in full grown larvae 19 to 22, the cuticle immediately cephalid without thickset pad of spines, anal fork with 5-7 spines usually of equal length and parallel, the two mesal spines sometimes blunt.

The full grown larva of the oriental fruit moth can be distinguished from that of the closely related species codling moth, Carpocapsa pomonella (Linn.), and the peach twig borer, Anarsia lineatella Zell. by the following characters:

Character	Oriental fruit moth	Codling moth	Peach twig borer
1. Habits of larva and host plants	Bores into the twigs of peach, nectarine, apricot and fruits of quince, peach, apple and plum.	Bores into fruits of apple, pear and quince.	Bores into twigs of peach, plum, apricot and almond. Later in season fruits of these trees.
2. Color	Pink, usually pinkish.	Dirty white or pink.	Light to reddish brown.
3. Length	10-12 mm.	14-16 mm.	10-11 mm.
4. Width	3-4 mm.	4-5 mm.	3-4 mm.
5. Pinaculae around primary setae	Inconspicuous.	Inconspicuous.	Distinctly pigmented.
6. Crochets	Form a complete circle.	Form a complete circle.	Broken into two groups.
7. Anal fork	Present with 4-7 almost parallel prongs.	Absent.	Present with generally 6 prongs, more or less divergent.

The Pupa: The larvae in summer spin thin silken cocoons, whereas those overwintering make thick cocoons. The freshly formed pupa, 4.5 to 5.5 mm. in length (inside the cocoon) is uniformly brown. It gradually turns dark red. One to two days before the emergence of the adult the wing pads turn black. The abdomen is composed of ten segments. The last three apparently fused together; the cephalic margins of segments 2 to 9 with a row of heavy setae, the caudal margins of segments 2 to 7 with rows of much finer setae, the caudal margin of the tenth segment with six heavy spines between which are somewhat longer hooked setae; and with two short setae present on each side of the anal rise.

IV. DEVELOPMENT AND VIABILITY OF <u>GRAPHOLITHA MOLESTA</u>

Following its discovery in the District of Columbia in 1916 the oriental fruit moth, *Grapholitha molesta* was studied extensively at several agricultural experiment stations in the U. S. A. The first report on its life history was published by Garman (9) in 1917 followed by that of Wood and Selkregg (30). Stearns (26) carried out extensive studies in an open air insectary during 1919 and 1920 in Northern Virginia. Stearns and Peterson (27) studied the life and seasonal history in New Jersey, Snapp and Swingle (24) in Georgia, Garman (10) in Connecticut, Stearns and Neiswander (28) in Ohio, Eddy and Nettles (7) in South Carolina and Alden and Clarke (2) in Georgia. In all these cases the investigators studied the insect either in the orchard or in the insectary and made little attempt to correlate the development of oriental fruit moth with temperature and humidity.

Harukawa (13) investigated the relation of temperature to the growth of the moth in Japan. Peterson and Haeussler (20) also studied some aspects of the life history of this moth in relation to temperature, either prevailing in the orchard or in the insectary. They attempted to correlate the development of the various broods with the mean temperatures prevailing in the orchard and the insectary. Some experiments under almost constant temperatures were carried out by Harukawa. He paid little attention to humidity as he believed that relative humidity did not much influence the results of his experiments. Dustan (6) working in the Niagara Peninsula of Canada, made some observations to find out the effect of mean temperature and humidity in the insectary on the development and fecundity of oriental fruit moth.

During the present investigation the development and fecundity of the oriental fruit moth was studied in the laboratory under constant temperature and humidity conditions and the results are described below.

1. Egg Stage

(a) Effect of temperature on development

(i) Incubation period: The incubation period of the oriental fruit moth has been studied by several workers in the past. Under insectary conditions Stearns (26) found it to be 7.39 days on an average with a minimum of 4 days and a maximum of 10 days for the first brood as compared to an average of 5.59 days, minimum of 3 days and maximum of 8 days for the fourth brood. His figures for 1919 were quite different from those for 1920. Stearns and Neiswander (28) working in Ohio recorded an incubation period of 4.4, 4.9, 6.05, and 9.4 days for the second, third, fourth and fifth broods respectively with a maximum of 17 days and a minimum of 3 days.

Harukawa (13) reported that under constant temperatures the incubation period was 3.3 days at 32.8°-33° C., 4.1 days at 32.2°-32.3°, 3.2 days at 31.0°-31.3°, 3.3 days at 28.3°-28.5°, 4.2 days at 24.4°-24.6°, 6.2 days at 20.2°-20.5° and 12.9 days at 14.9° C. There seems to be some contradiction in these observations. Garman (10) gave 12 to 15 days as the incubation period at a temperature of about 60° F. Peterson and Haeussler (20) working at Riverton, New Jersey, correlated incubation period with the rise and fall of temperature in their open air insectary. They found it to vary from 3.5 to 6 days in summer, 7-14 days in early spring and 20 days or longer in late fall. They found a minimum time of 60-65 hours under more or less controlled conditions but they did not mention the temperature.

None of these workers studied the effect of humidity on incubation period. The results obtained under constant temperatures and humidities in the present investigation are given in Table I and shown graphically in Figures 1 to 3. Under 70% relative humidity it was 7.5 days at 60°, 5.75 days at 65°, 3.9 days at 75°, 3.27 days at 85°, 2.75 days at 94° and 3.3 days at 95° F. The incubation period continued to decrease with the rise of temperature until a minimum of 2.75 days was reached at 94° F., thereafter it again started increasing. From these data it is clear that the eggs of this insect continue to develop at fairly high temperatures.

(ii) Threshold of development: The relation of incubation period to temperature is shown in Figures 1 to 3. The reciprocals of the periods multiplied by one hundred are also plotted. The theoretical threshold of development as shown by the intersection of the lines of indices of development and the temperature axes (3, 18 and 22) in Figures 1 to 3, lies at 40° to 44° F., depending upon the relative humidity prevailing at the time; least under 100% and highest under 35% relative humidity. Dustan (6) reported an incubation period of 33.5 days at an average daily temperature of 45.6° F. In fall and spring there

TABLE I

THE INCUBATION PERIOD (DAYS) OF EGGS OF *GRAPHOLITHA MOLESTA* UNDER DIFFERENT CONDITIONS

Temperature °F.	Relative Humidity 100%		Relative Humidity 70%		Relative Humidity 35%	
	Incubation Period	No. of Observations	Incubation Period	No. of Observations	Incubation Period	No. of Observations
60	7.0	83	7.5	51	8.0	36
65	5.81	237	5.75	152	6.0	161
75	4.16	180	3.9	138	4.2	116
85	3.3	117	3.27	125	3.4	124
94	2.76	45	2.75	44	-	-
95	3.5	31	3.3	42	-	-

ANALYSIS OF VARIANCE
for data for 60° to 85° F.

Source of variation	D.F.	S.S.	Mean S.	F
Temperature	3	31.29	10.43	1212.79^{++++}
Humidity	2	0.24	0.12	13.95^{++}
Temperature x Humidity	6	0.35	0.0583	6.77^{+}
Error	68		0.0086	

TABLE I (Continued)

++++	Highly significant
++	Significant
+	Significant

$6 = \sqrt{.0086} = 0.093$

$6_{m_1} = 0.093/(\sqrt{32})$

$6_{m_3} = 0.093/(\sqrt{25})$

$6_{m_1 - m_3} = 0.93\sqrt{(1/32 + 1/25)} = 0.024$

$t_{3-1} = (5.26 - 4.97)/0.024 = 12$

$t_{2-1} = (5.035 - 4.970)/0.025 = 2.6$

Conclusions: (i) The difference between 100% and 35% relative humidity is highly significant.

(ii) The difference between 100% and 70% relative humidity is not significant at 1% level but is slightly significant at 5% level.

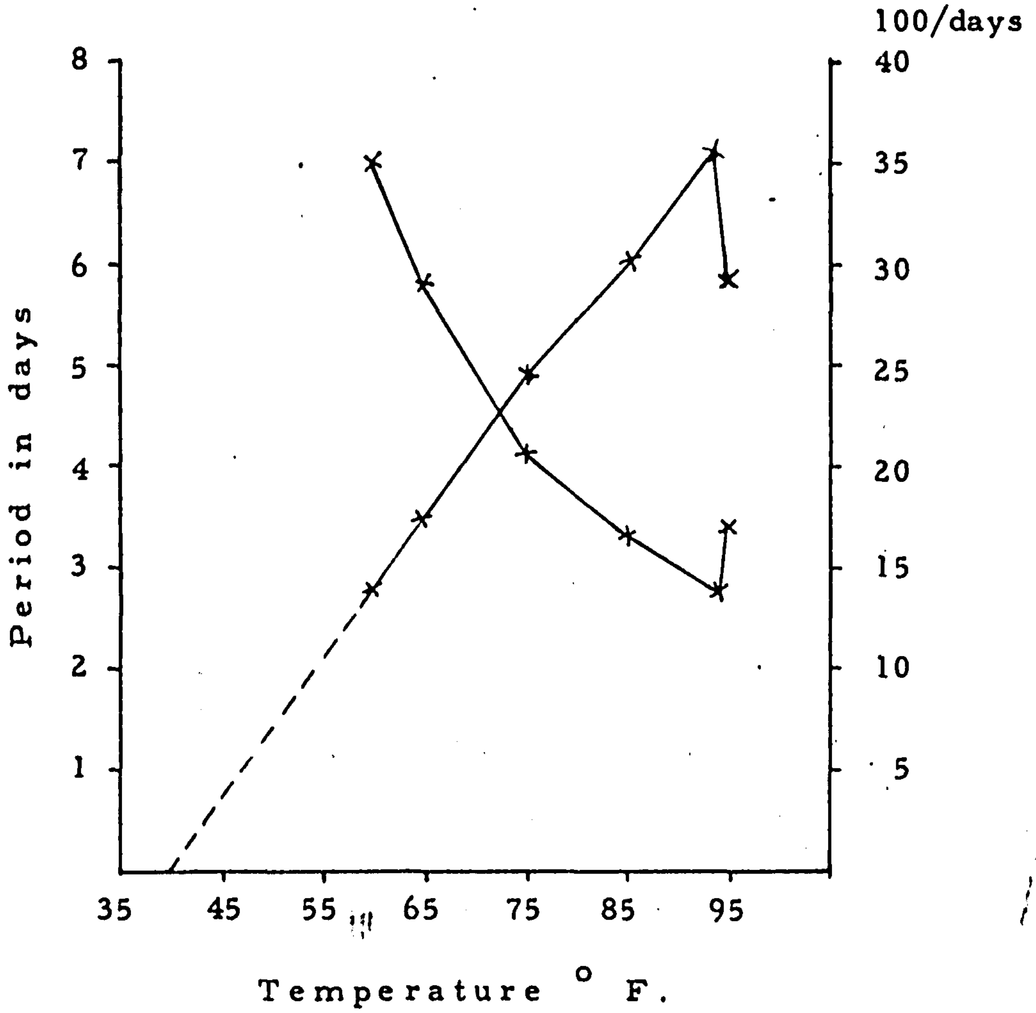

FIGURE 1

INCUBATION PERIOD OF, AND INDEX OF DEVELOPMENT FOR EGGS OF G. MOLESTA AT CONSTANT TEMPERATURES AND 100% RELATIVE HUMIDITY

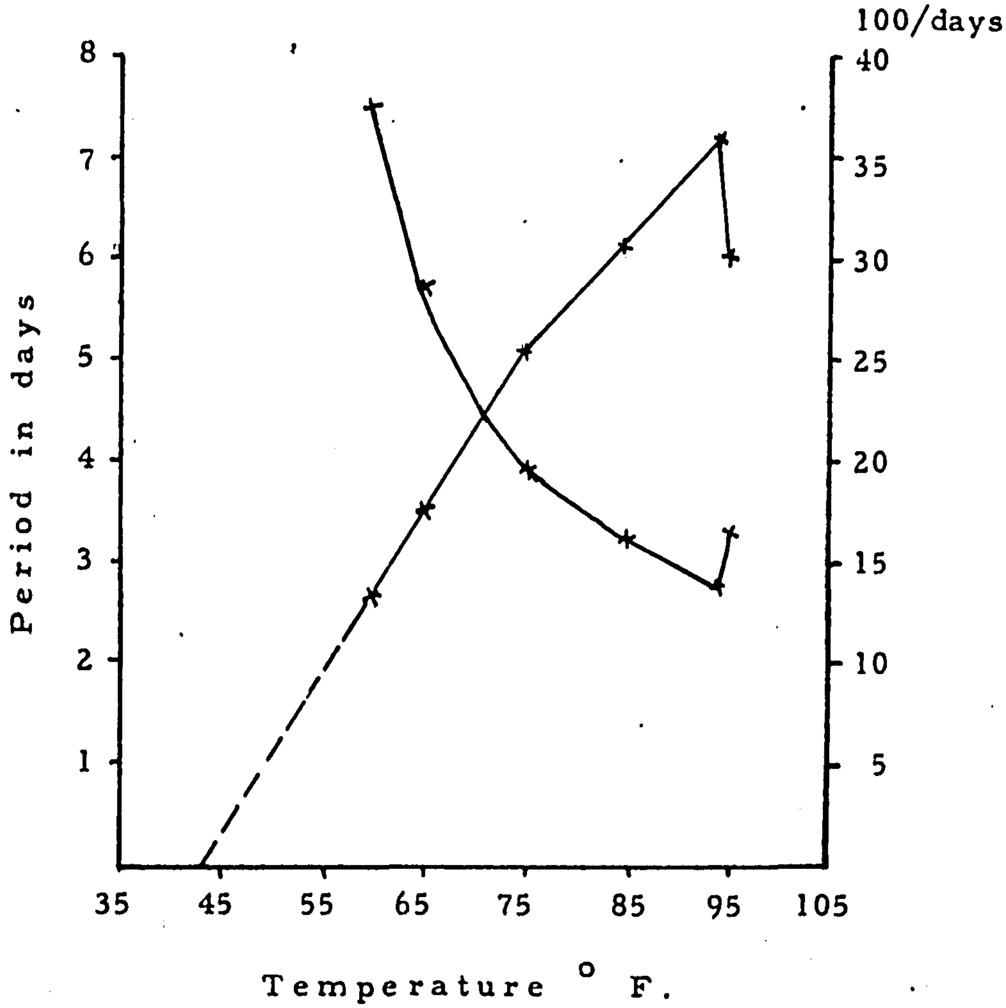

FIGURE 2

INCUBATION PERIOD OF, AND INDEX OF DEVELOPMENT FOR EGGS OF G. MOLESTA AT CONSTANT TEMPERATURES AND 70% RELATIVE HUMIDITY

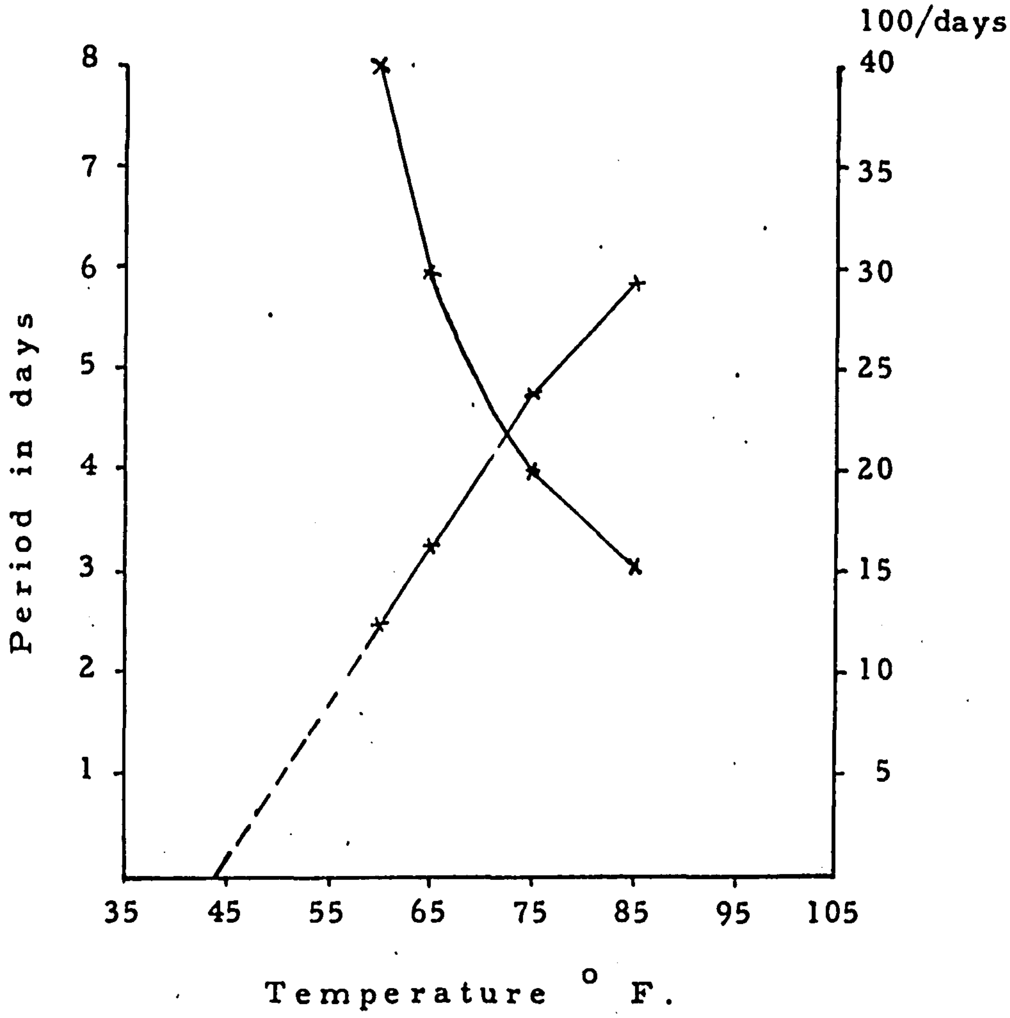

FIGURE 3

INCUBATION PERIOD OF, AND INDEX OF DEVELOPMENT FOR EGGS OF G. MOLESTA AT CONSTANT TEMPERATURES AND 35% RELATIVE HUMIDITY

are wide fluctuations in daily temperature. Some development would occur at higher temperatures, whereas it would cease at lower temperatures, thereby considerably lengthening the incubation period. In the present investigations eggs kept at 50.5° F. hatched in 24 and 25 days under 100% and 70% relative humidity, respectively. The graph drawn by Harukawa (13) shows the threshold of development to be 10° C. (50° F.) which appears to be very high. Shelford (23) gave 44° to 49° F. as the threshold of development for the codling moth, *Carpocapsa pomonella*, depending upon humidity, other weather factors and with the generation and the individual. The eggs of the oriental fruit moth can, therefore, develop at lower temperatures than those of the codling moth.

(iii) *Upper vital limit*: The lines of indices of development in Figures 1 to 3 are fairly straight up to a temperature of 75° F. at each of the three relative humidities. After this they decline towards the right, indicating that although incubation is quicker at temperatures above 75° F., the rate of development is not maintained uniformly. The bend is least under 70% relative humidity and greatest under 35%, showing the strong influence of humidity on the rate of development. Glenn (11) in the case of the codling moth found 76° F. as the temperature of maximum development. The two species seem to have approximately the same temperature for maximum development. The upper vital limit is slightly above 95° F., probably 96°. Eggs kept at 95° F. failed to hatch under 35% relative humidity, although they hatched at higher humidities. Eggs kept at 98° F. for 48 hours did not hatch under any relative humidity but they were able to withstand short exposures to a temperature of 105° F. as shown in Table II. Eggs laid during the evening at a room temperature of 70°-80° F. were exposed in the morning to temperatures of 98° F. and 105° F., for two hours, four hours, six hours, twenty-one hours, twenty-four hours, thirty-six hours, etc., and were then transferred to the room temperature, till hatching, if viable. A portion of the eggs from each lot was kept as a check at the room temperature. Examination of Table II shows that an exposure of 48 hours to 98° F. was fatal for the eggs. Exposures of less than 40 hours were not so harmful. The incubation period was significantly lengthened on account of these exposures. It usually ranged from 4.5 to 5.0 days as compared to 3.8 days for the check, showing that these exposures retarded or arrested

TABLE II

EFFECT OF SHORT EXPOSURES TO HIGH TEMPERATURE ON THE DURATION AND VIABILITY OF EGGS OF GRAPHOLITHA MOLESTA

		Exposed to High Temperature									Control	
		Relative Humidity										
		100%			70%			35%				
High Temp Employed °F.	Period of Exposure (Hrs.)	No. of Eggs Exposed	No. of Eggs Hatched	Total Incubation Period	No. of Eggs Exposed	No. of Eggs Hatched	Total Incubation Period	No. of Eggs Exposed	No. of Eggs Hatched	Total Incubation Period	Per cent Viability	Incubation Period (Days)
95	48	50	48	3.0	50	47	3.0	50	29	3.25	96	4.5
98	24	30	24	4.62	30	24	4.66	30	17	4.75	98	3.8
98	36	30	25	4.7	30	18	4.8	30	4	5.0	98	4.0
98	40	30	22	4.75	30	12	5.0	30	-	-	98	3.8
98	48	30	-	-	30	-	-	30	-	-	98	3.8
105	4	30	27	4.02	30	26	4.12	30	18	4.37	98	3.75
	6	30	25	4.5	30	25	4.5	30	18	4.5	98	3.8
	21	28	12	5.3	28	12	5.5	32	8	5.75	98	3.8

the development of eggs. Black spots, showing almost full development of the larvae inside egg shells appeared in the majority of cases even though actual hatching did not occur, indicating that some development continued even at 98° F. and that it is slightly above the upper vital limit for the eggs. Eggs exposed for a duration of twenty-one hours to 105° F. hatched in 5.3 to 5.75 days; those exposed for six hours took only 4.5 days to hatch. The viability of eggs exposed to 105° F. for twenty-one hours ranged from 43% under 100% relative humidity to 25% under a relative humidity of 35%. In nature even though the relative humidity of the air may be low, the eggs being laid on green succulent leaves and shoots may not suffer to any appreciable extent. However, longer exposures to 105° F. would affect the viability of the eggs very adversely. Shorter exposures to temperatures above 105° F. may be equally harmful.

(b) Effect of humidity on development of eggs

The influence of humidity on the rate of development of eggs is given in Tables I and II. The development is slightly more under 70% relative humidity at medium temperatures.

The difference is not well marked, especially at higher temperatures. Generally eggs kept under 70% relative humidity hatched a couple of hours before others hatching under 35% relative humidity and at about the same time under saturated conditions. These observations show that the egg-shell of this insect does not easily allow loss of moisture from the egg contents. The flat and scale-like appearance of the eggs may be quite helpful in this respect. Furthermore, as the eggs are laid on green succulent tissues of the plant they are in a safe position to escape damage from low humidity of the air.

(c) Effect of temperature and humidity on viability

The viability of eggs of *Grapholitha molesta* varies considerably under different conditions particularly at adverse temperatures. Stearns (26) reported 57.98%, 56.84%, 57.14% and 66.1% viability of eggs for the first, second, third and fourth brood respectively. Stearns and Neiswander (28) in Ohio found the viability of eggs to be 97.57%, 98.2%, 96.6% and 91.3% for the second, third, fourth and fifth brood respectively.

Data on the viability of eggs obtained during the present investigation are given in Tables II and III and depicted graphically

TABLE III

THE VIABILITY OF EGGS OF _GRAPHOLITHA MOLESTA_ UNDER DIFFERENT CONDITIONS

Temperature °F.	Relative Humidity								
	100%			70%			35%		
	Total No. of Eggs	No. of Eggs Hatched	Per cent Viability	Total No. of Eggs	No. of Eggs Hatched	Per cent Viability	Total No. of Eggs	No. of Eggs Hatched	Per cent Viability
60	92	83	90	68	51	75	50	36	72
65	256	237	92.5	196	152	77.5	208	161	77.4
75	183	180	98.3	140	138	98.6	132	116	87.8
85	120	117	97.5	128	125	97.5	160	124	77.5
94	50	45	90.0	50	44	88	50	0	0.0
95	90	31	34.0	80	42	52.5	60	0	0.0

in Figures 4 and 5. It was 90%, 92.5%, 98.3%, 97.5% and 90% under saturated relative humidity at constant temperatures of 60°, 65°, 75°, 85° and 94° F., respectively. The corresponding values under relatively dry conditions of 35% relative humidity were 72%, 77.4%, 87.8%, 77.5% and 0.0%. At a constant temperature of 95° F. the viability was 34%, 52.5% and 0.0% under relative humidities of 100%, 70% and 35%, respectively. No eggs hatched when exposed to 98° F. for 40 hours under 35% relative humidity, whereas 73.3% and 40% hatched under 100% relative humidity and 70% relative humidity, respectively. An exposure of 21 hours at 105° F. reduced the viability of eggs to 43% under higher humidities and to 25% under the low humidity of 35%. It is evident from these data that the eggs of the oriental fruit moth can tolerate fairly high temperatures and low humidities. Under medium temperatures the viability was seldom less than 75%, even under the lowest humidity tried. Near the upper vital limit, the deleterious effect of low humidity became markedly pronounced as eggs under 35% relative humidity failed to hatch at 94° and 95° F. Near saturated relative humidities are, therefore, beneficial and drier conditions are harmful. The influence of relative humidity

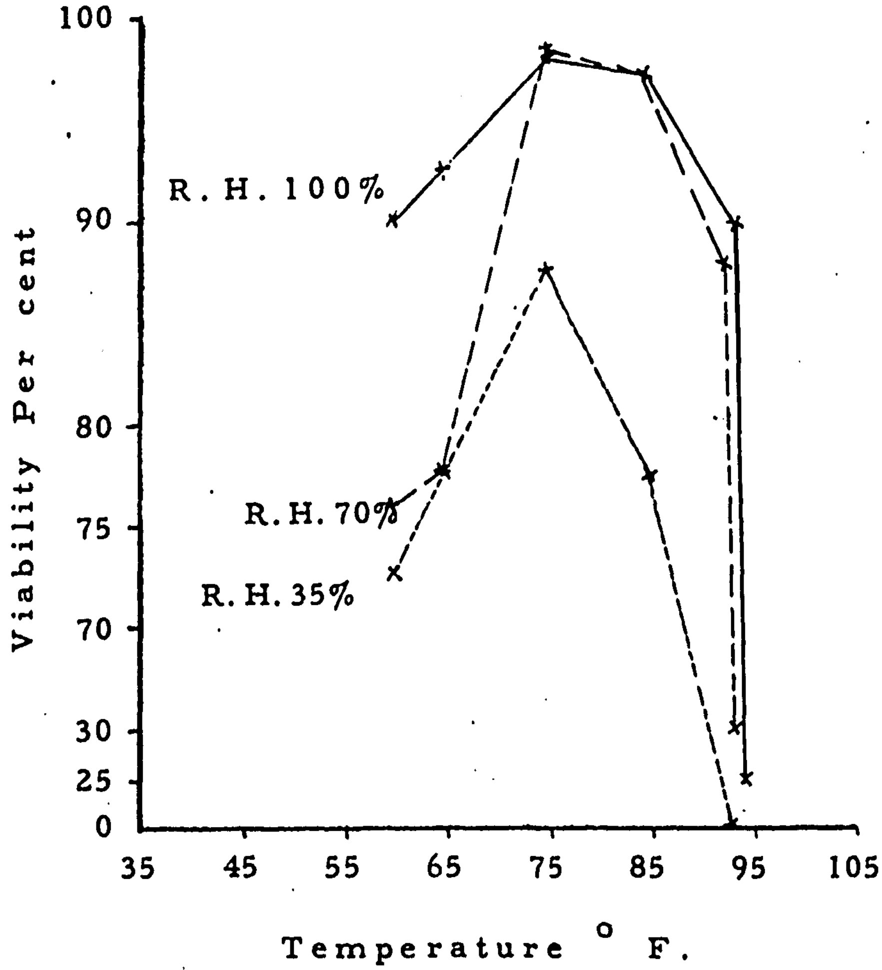

FIGURE 4

VIABILITY OF EGGS OF G. MOLESTA
UNDER DIFFERENT CONDITIONS

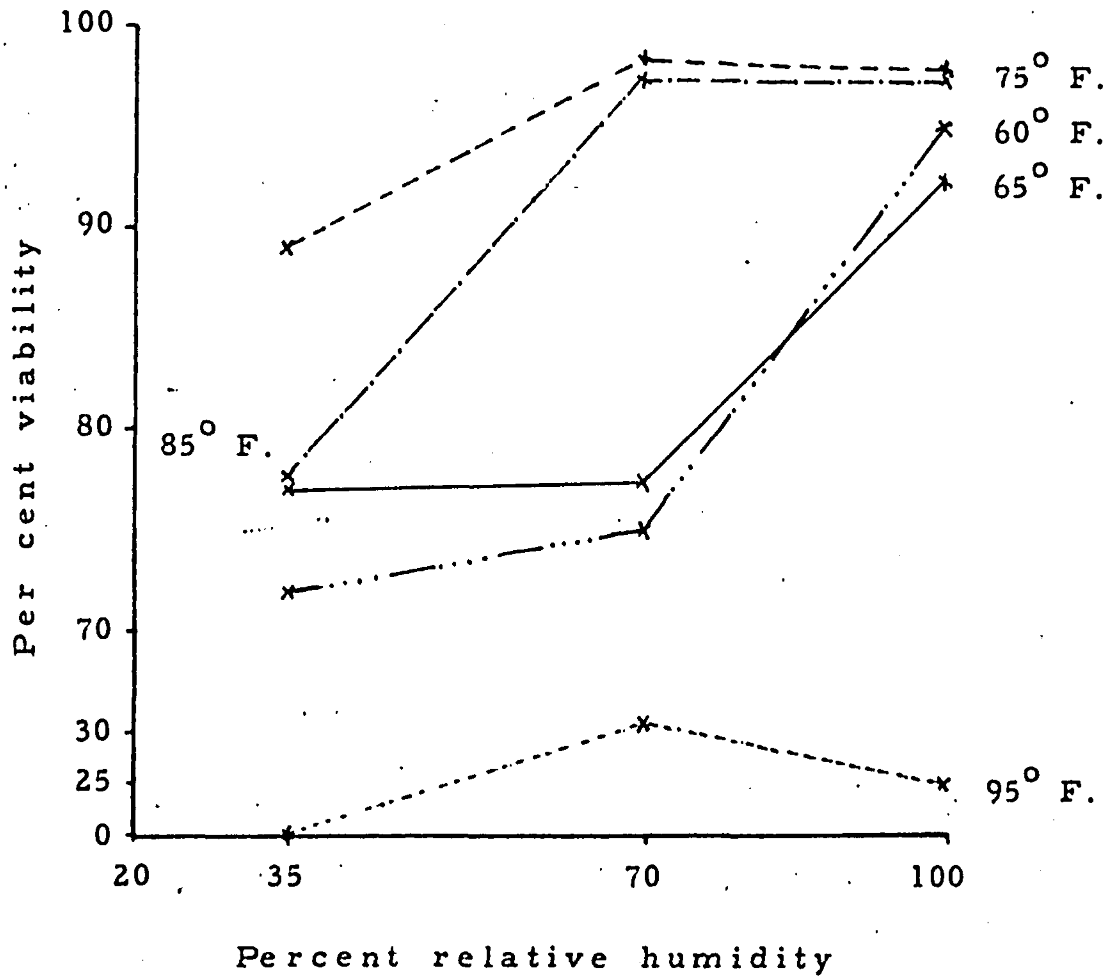

FIGURE 5

VIABILITY OF EGGS OF G. MOLESTA
UNDER DIFFERENT CONDITIONS

seemed to be more marked on the viability of the eggs than on the incubation period.

2. Larval Stage

(a) Effect of temperature on development

(i) Duration: The larval period of the oriental fruit moth in this discussion is taken to mean the growing period, the interval between the eclosion and the time the larva starts spinning a cocoon. The spinning of the cocoon may have been either for immediate pupation or for the purpose of hibernation. The feeding period of the larvae varies considerably in nature at different places depending upon the altitude, latitude of the place and the time of the year. The quantity, quality and kind of food have been known to influence the length of this period. Apart from the above factors there are large individual variations within one lot of larvae kept under uniform conditions.

The larvae had been studied extensively in different states of the U. S. A. but the durations were given generally according to the brood. They were reared in the insectary under uncontrolled conditions of temperature. Dickson (5) studied them under constant temperatures but he did not mention the duration of the feeding period. Harukawa (13) reported the growing period under more or less constant temperatures from Japan, although he was not sure of accuracy of his experiments and he found it difficult to arrive at definite conclusions based upon those results. He found the growing period to be 10.8 days at 33° C., 8.6 days at 30°, 9 days at 27°, 10.3 days at 25°, 15.4 days at 20° and 21.8 days at 17° C. Stearns (26) while working in Virginia found it to be 18.98 days on an average, with a minimum of 9 days and a maximum of 30 days for the first brood. Corresponding data given by him for the second brood was 14.57 days, 9 days and 22 days; for the third generation 17.1 days, 11 days and 22 days, for the fourth generation 45.43 days, 25 days and 69 days respectively. Stearns and Peterson (27) in New Jersey recorded a maximum feeding period of 25 days in 1924, 34 days in 1925, a minimum of 8 days each year and averages of 14.4 and 14.3 days, respectively. In 1924 the mean daily temperature for the feeding period of this brood was 65.4° F.; in 1925, 70.1° F. Peterson and Haeussler (20) found that late in the season in New Jersey, the overwintering larvae in particular required 50-115 days to become full grown. At an average temperature of 66.5° F., Dustan (6), working in Ontario, Canada, found the larval feeding period to be 28 days when fed on storage apples and 20 days when supplied with peach shoots. In late fall at an average temperature of 46.5° F. he found that some caterpillars required 80-92 days to become full grown.

In the present investigation the larvae were fed on stored apples, and were reared at constant temperatures of 65°, 75°, 85° and 95° F. As the larvae always feed by boring into the food saturated with moisture they could not be grown on semi-dry food. The results are given in Table IV and shown graphically in Figures 6 and 7. The average larval period was 36.81 days at 65° F., 24.41 days at 75°, 20.45 days at 85° and 18.0 days at 95° F., respectively. The corresponding maximum period was 58 days, 36 days, 38 days and 25 days; and the minimum of 22 days, 14 days, 10 days and 11 days, respectively. The rate of development increased uniformly up to 75° F. Above 75° F. the same rate of development was not maintained. A constant temperature of 75° F., thus appears to be very close to the optimum temperature for larval development, the optimum range probably terminates at 85° F. or even at a lower temperature.

TABLE IV

THE DURATION AND VIABILITY OF LARVAL STAGE OF
GRAPHOLITHA MOLESTA UNDER
DIFFERENT CONDITIONS

Temperature °F.	Larval Period in Days			No. of Larvae Kept	No. of Larvae Which Spun Cocoons	Viability Percent
	Average	Maximum	Minimum			
65	36.81	58	22	7580	958	12.65
75	24.41	36	14	7706	1286	16.7
85	20.45	38	10	6429	1182	18.4
95	18.0	25	11	1538	228	14.8

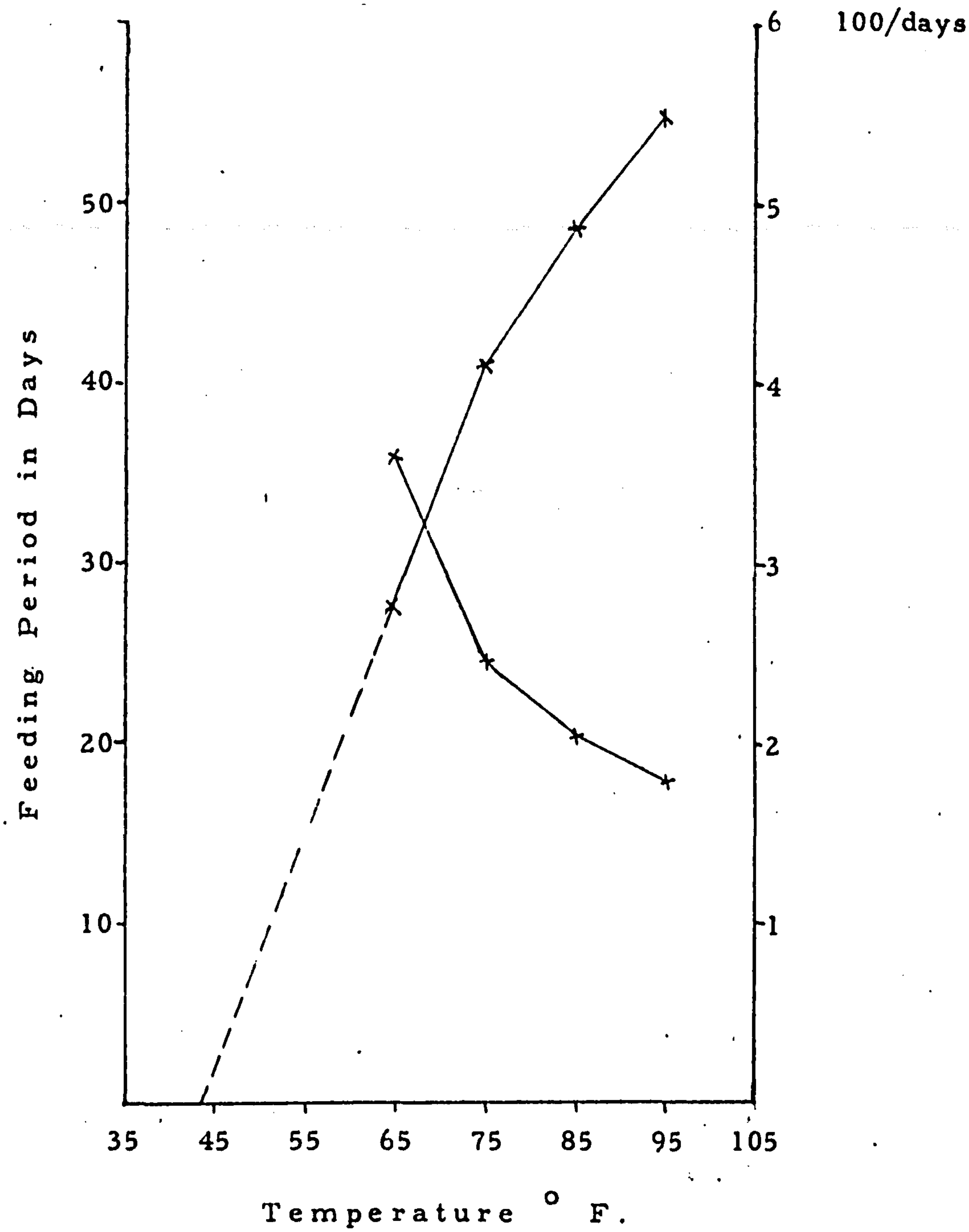

FIGURE 6

THE FEEDING PERIOD OF LARVAE IN APPLES AT CONSTANT TEMPERATURES AND INDEX OF LARVAL DEVELOPMENT OF G. MOLESTA

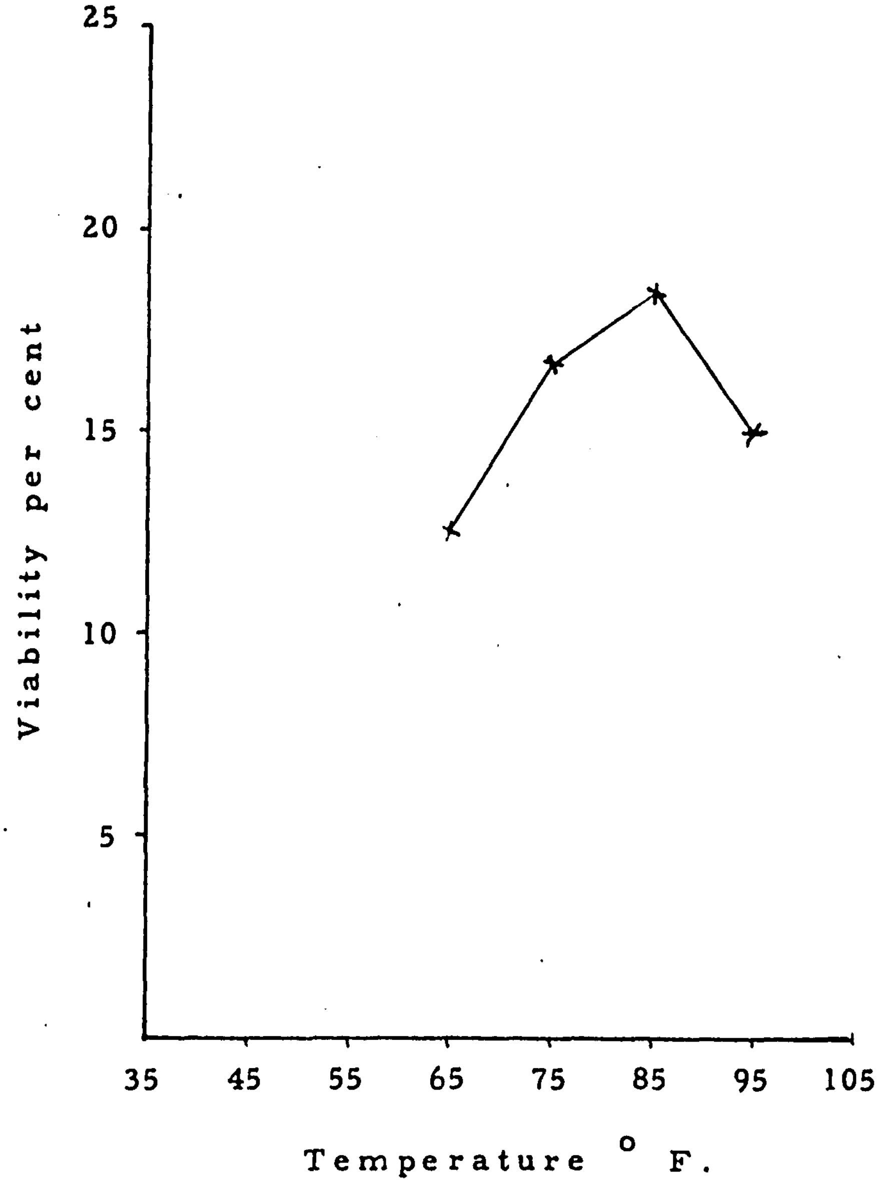

FIGURE 7

VIABILITY OF LARVAE OF G. MOLESTA, REARED ON APPLES AT CONSTANT TEMPERATURES

(ii) Threshold of development: The relation of larval feeding period to temperature is shown in Figure 6. The reciprocals of the periods multiplied by one hundred are also plotted. This line is called the index of development. In Figure 3 given by Harukawa (13) the line of index of development crosses the temperature axis at 10° C. (50° F.) which seems to be high. However, he himself was not sure of the accuracy of his experiments. This line, according to present experiments, crosses the temperature axis at 43.5° F. This temperature is the theoretical threshold of development. The actual threshold may lie slightly below 43.5° F. This temperature is 0.5 to 3.5° lower than that for the eggs (Figures 1-3) depending upon the relative humidity to which the eggs were exposed. This would indicate that the larvae continue to develop at temperatures lower than those for eggs. This enables the larvae hatching late in the season in fall to continue to develop for a longer period and thus helps them to become full grown before entering into diapause.

Glenn (11) and Shelford (23) found 47.5° F. as the theoretical threshold of development for the larvae of the codling moth. In calculating day degrees, they employed 50° F. as the starting point. Thus, larvae of the oriental fruit moth can develop at temperatures lower than those for the larvae of the codling moth. The former could continue to develop for a longer period in late fall as compared to those of the codling moth. The larvae of the codling moth in nature go into hibernation much earlier than those of the oriental fruit moth. This probably is one of the reasons for the smaller number of generations in the case of the codling moth under similar set of conditions.

(b) Effect of temperature on viability

Information on the effect of temperature on larval viability is rather scanty. Harukaw's (13) data based on a small number of individuals show that there was 14% mortality at 20° C., 20.8% at 25° C., 12.6% at 27° C., 40% at 33° C. and 81.2% at 34° C. Stearns and Neiswander (28) studied the effect of food on the larval viability. They found that viability was 44%, 33%, 56.9%, 12% and 13.3% when the larvae were fed on peach, plum, apple, pear and quince, respectively.

In the present experiments the larval viability as shown in Table IV and Figure 7 was found to be 12.65%, 16.7%, 18.4%

and 14.8% at 65°, 75°, 85° and 95° F., respectively. These figures are rather low, probably because they are based on the rearing of several thousand young larvae in small cages. Growth of fungus and free water accumulating from apples were also responsible in reducing the number of larvae reaching maturity. In cases where a few individuals were reared the viability was sometimes as high as 50-70%. In nature also it would be expected that the mortality of the larvae would be high on account of the unavailability of the right type of food at the proper time, driving rains, diseases, parasites, predators and several unknown factors. Gummosis from the twigs and fruits of peach injured by larval borings is of common occurrence and not infrequently creates conditions unsuitable for the survival of the larvae feeding therein.

3. Pupal Stage

The full grown larvae of the oriental fruit moth leave the fruit in which they feed and come to the top of the rearing dish for the purpose of spinning cocoons. These larvae were removed every day from dishes kept at various constant temperatures. They were counted and put in small glass vials containing short strips of corrugated paper. They would readily spin cocoons. The period after a larva starts spinning up to the time it pupates inside the cocoon is called the prepupal period. Several workers in the past have mentioned this duration separately from the pupal period. This necessitates tearing the cocoon and disturbing the larvae or the use of semi-transparent paper. For the present investigation it was not considered necessary to determine this period apart from the pupal period. Whenever the pupal period or pupal stage is mentioned hereafter, it should be taken to mean the entire period after the larva started spinning a cocoon to its final emergence as a moth.

The pupae are considerably influenced by temperature and humidity, perhaps more so than the eggs. Stearns (26) found the pupal period to be 14.49 days, 12.88 days and 12.55 days for the first, second and third brood respectively in one year in northern Virginia. In another year the corresponding period was 15.24 days, 13.94 days, 15.02 days respectively. Stearns and Neiswander (28) working in Ohio found it to be 15.2 days, 16.7 days and 16.5 days for the second, third and fourth brood, respectively in 1927. For the summer individuals they mentioned 32 days as the maximum and 7 days as the minimum. Peterson and Haeussler (20) found it to vary from 8 to 33 days with an average of 14 days under New Jersey conditions. They illustrated the relationship between the average temperatures existing during summer and the pupal period. It was 10.5 days at 83^{o} F., 12.5 days at 75^{o} F. and 16 days at 68^{o} F. Harukawa (13) from Japan reported it as 8.4 days at 33^{o} C., 7.2 days at 30^{o} C., 8.9 days at 29^{o} C., 10 days at 25^{o} C., 14.6 days at 20^{o} C. and 21.5 days at 17.1^{o} - 17.4^{o} C. He realized that his results were not satisfactorily regular above 28^{o} C., although he did not give any explanation for the irregularities.

The results from the present investigation under various constant temperature combinations and relative humidities are given in Tables V and VI and are shown in Figures 8-13.

(a) Effect of temperature on development

(i) Duration: There were two sets of experiments in order to find out the influence of temperature on the pupal stage. In one set the pupae were kept at the same temperature at which the eggs and larvae were grown. Under these conditions the

TABLE V

PUPAL PERIOD (DAYS) OF GRAPHOLITHA MOLESTA UNDER DIFFERENT CONDITIONS

Temperature °F.		Relative Humidity					
		100%		70%		35%	
Pupal Stage at	Eggs and Larvae Reared at	No. of Obser-vations	Aver-age Pe-riod	No. of Obser-vations	Aver-age Pe-riod	No. of Obser-vations	Aver-age Pe-riod
65	65	32	19	56	20.8	18	24.5
75	75	132	14.3	50	15	78	17.3
85	85	134	12.0	94	13.0	90	14.2
95	95	12	11.0	25	11.5	7	12.5
85	75	104	11.2	94	12	No moth emerged out of 135 pupae	
85	65	44	16.4	24	22	One (out of 78 pupae)	15
65	85	76	21.5	38	23.2	30	25.2

TABLE VI

VIABILITY OF PUPAE OF <u>GRAPHOLITHA MOLESTA</u>
UNDER DIFFERENT CONDITIONS

Temperature °F.		Relative Humidity								
		100%			70%			35%		
Pre Pupae and Pupae at	Eggs and Larvae Reared at	No. of Pupae	No. of Moths Emerged	Via-bility Per cent	No. of Pupae	No. of Moths Emerged	Via-bility Per cent	No. of Pupae	No. of Moths Emerged	Via-bility Per cent
65	65	268	112	41.8	392	96	24.5	214	18	8.4
75	75	390	280	71.8	357	180	50.4	256	104	40.6
85	85	196	134	68.36	176	96	54.55	294	94	31.97
95	95	86	12	14.0	63	25	39.6	62	7	11.3
85	75	184	128	69.56	270	136	50.37	260	0	0.0
85	65	96	44	45.83	120	44	36.7	78	1	1.2
65	85	266	122	45.86	160	42	26.25	198	30	15.1

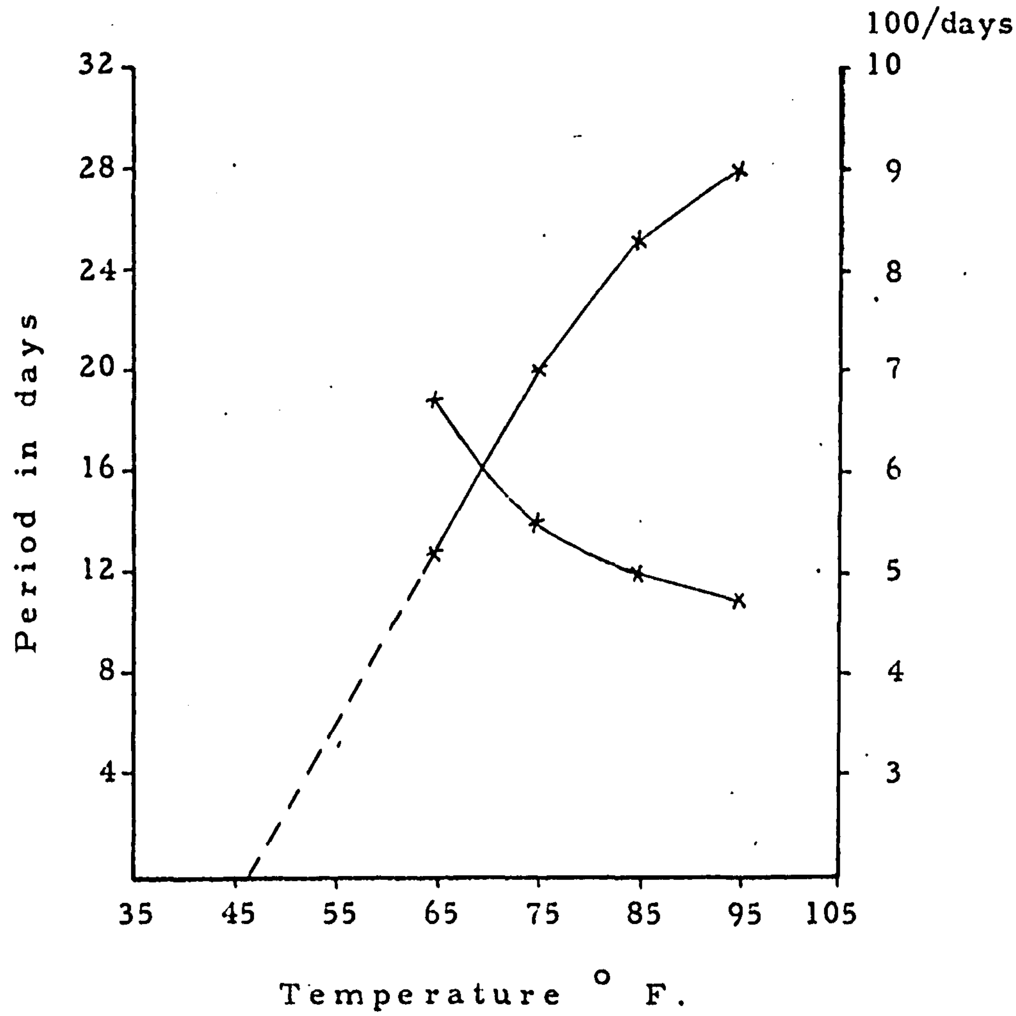

FIGURE 8

PUPAL PERIOD AND INDEX OF DEVELOPMENT FOR PUPAE OF G. MOLESTA AT CONSTANT TEMPERATURES AND 100% RELATIVE HUMIDITY

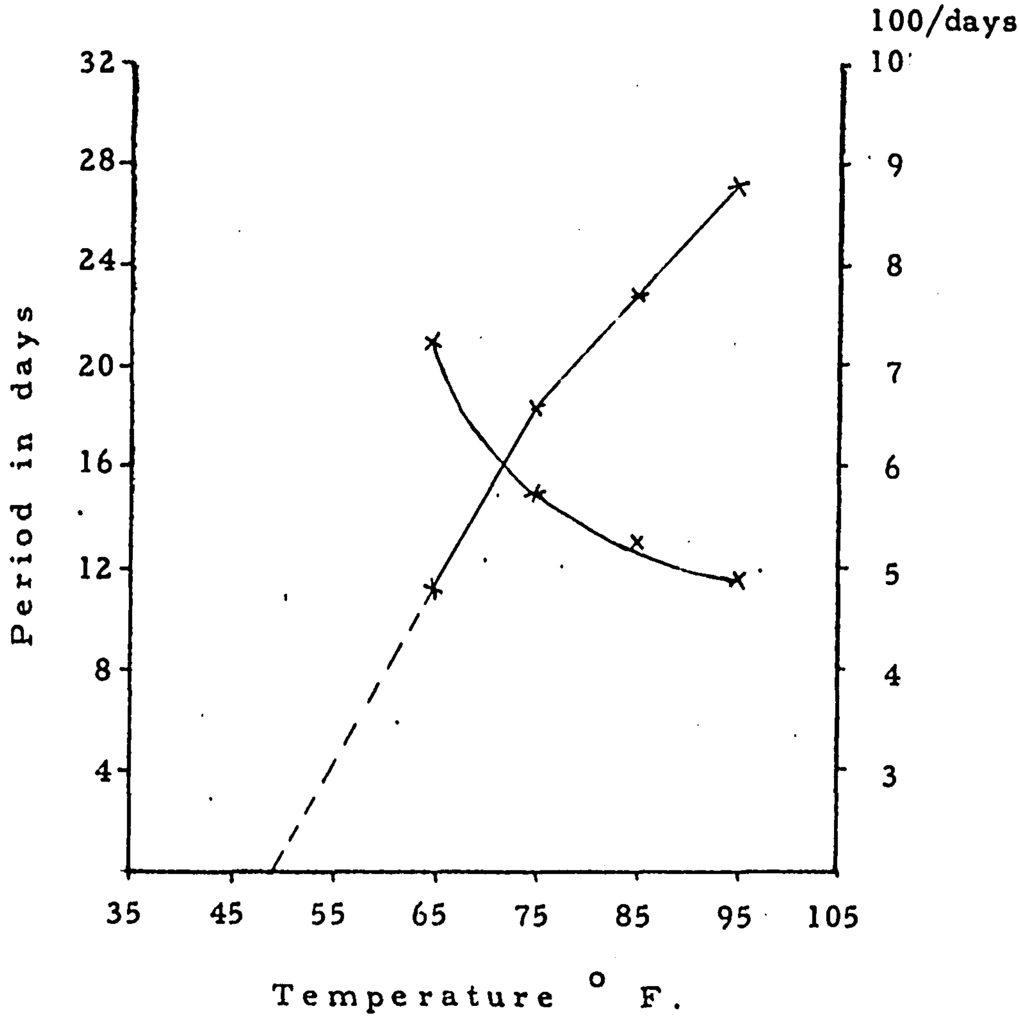

FIGURE 9

PUPAL PERIOD AND INDEX OF DEVELOPMENT FOR PUPAE OF G. MOLESTA AT CONSTANT TEMPERATURES AND 70% RELATIVE HUMIDITY

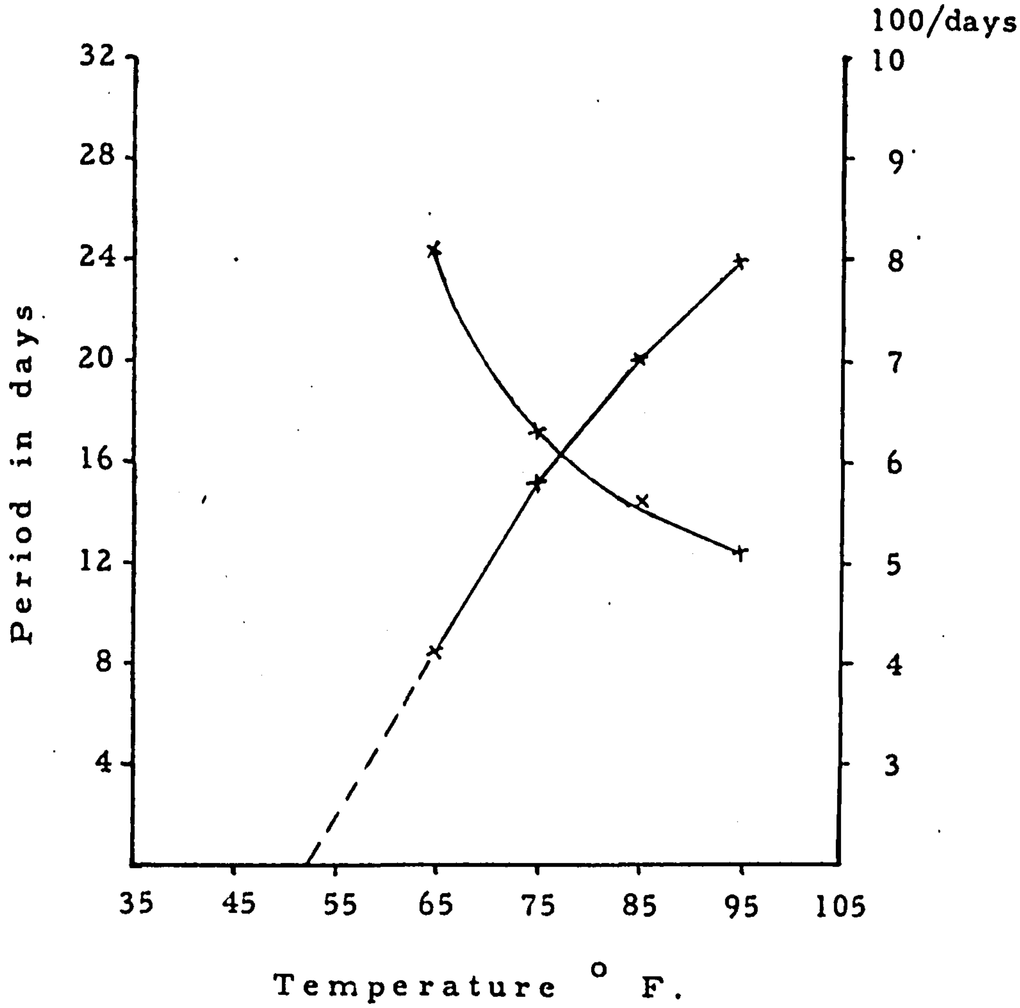

FIGURE 10

PUPAL PERIOD AND INDEX OF DEVELOPMENT FOR PUPAE OF G. MOLESTA AT CONSTANT TEMPERATURES AND 35% RELATIVE HUMIDITY

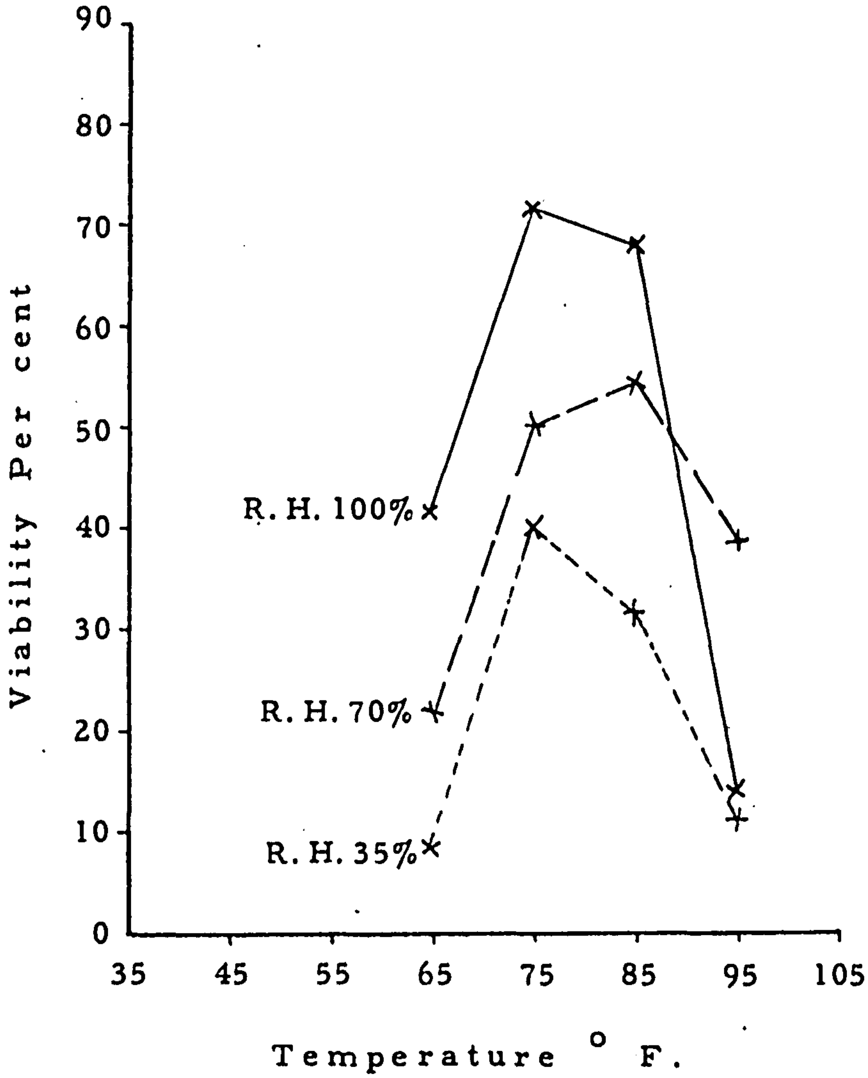

FIGURE 11

VIABILITY OF PUPAE OF G. MOLESTA
UNDER DIFFERENT CONDITIONS

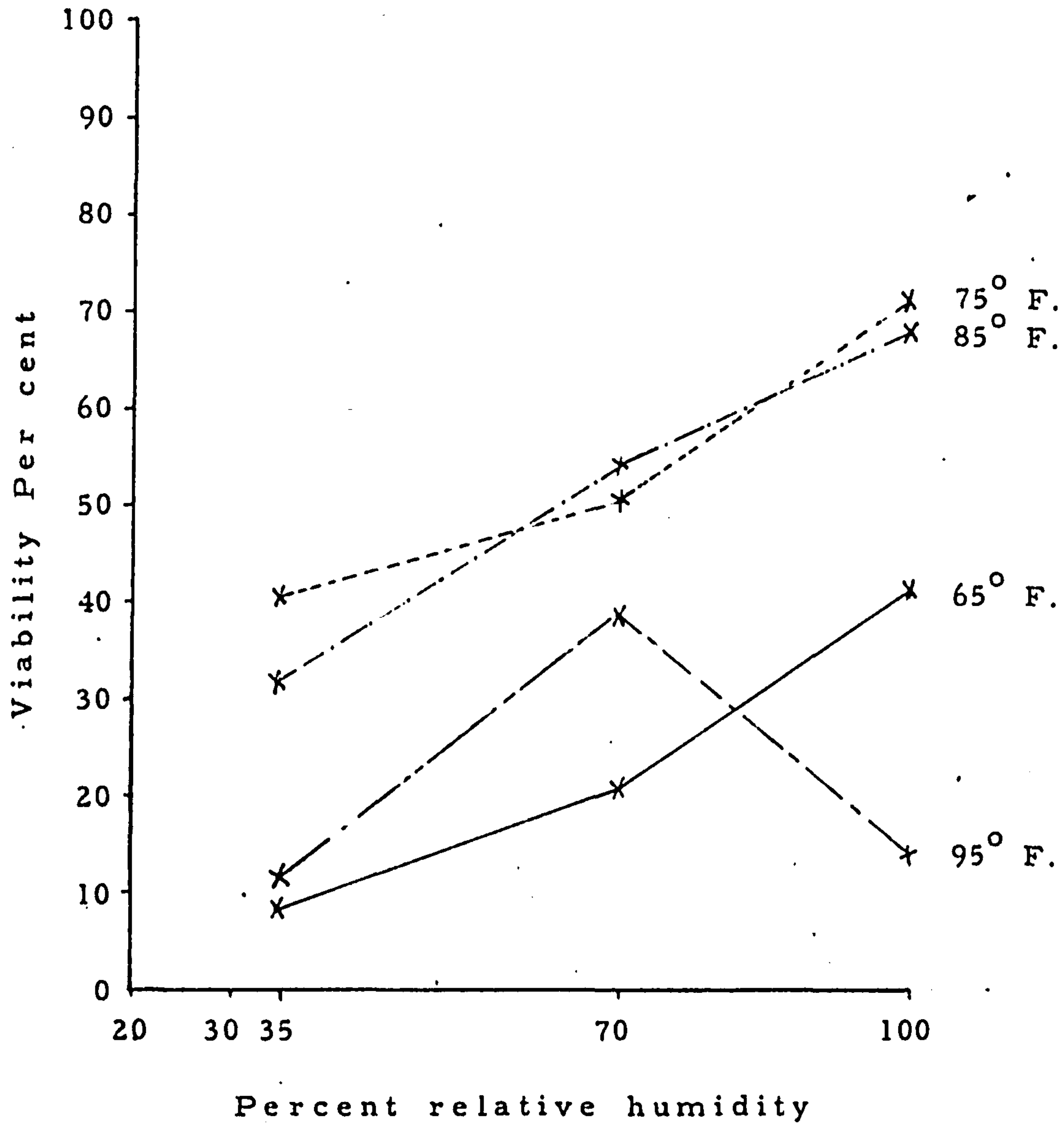

FIGURE 12

VIABILITY OF PUPAE OF G. MOLESTA UNDER DIFFERENT CONDITIONS (Eggs and larvae reared at the same temperature at which pupae were kept)

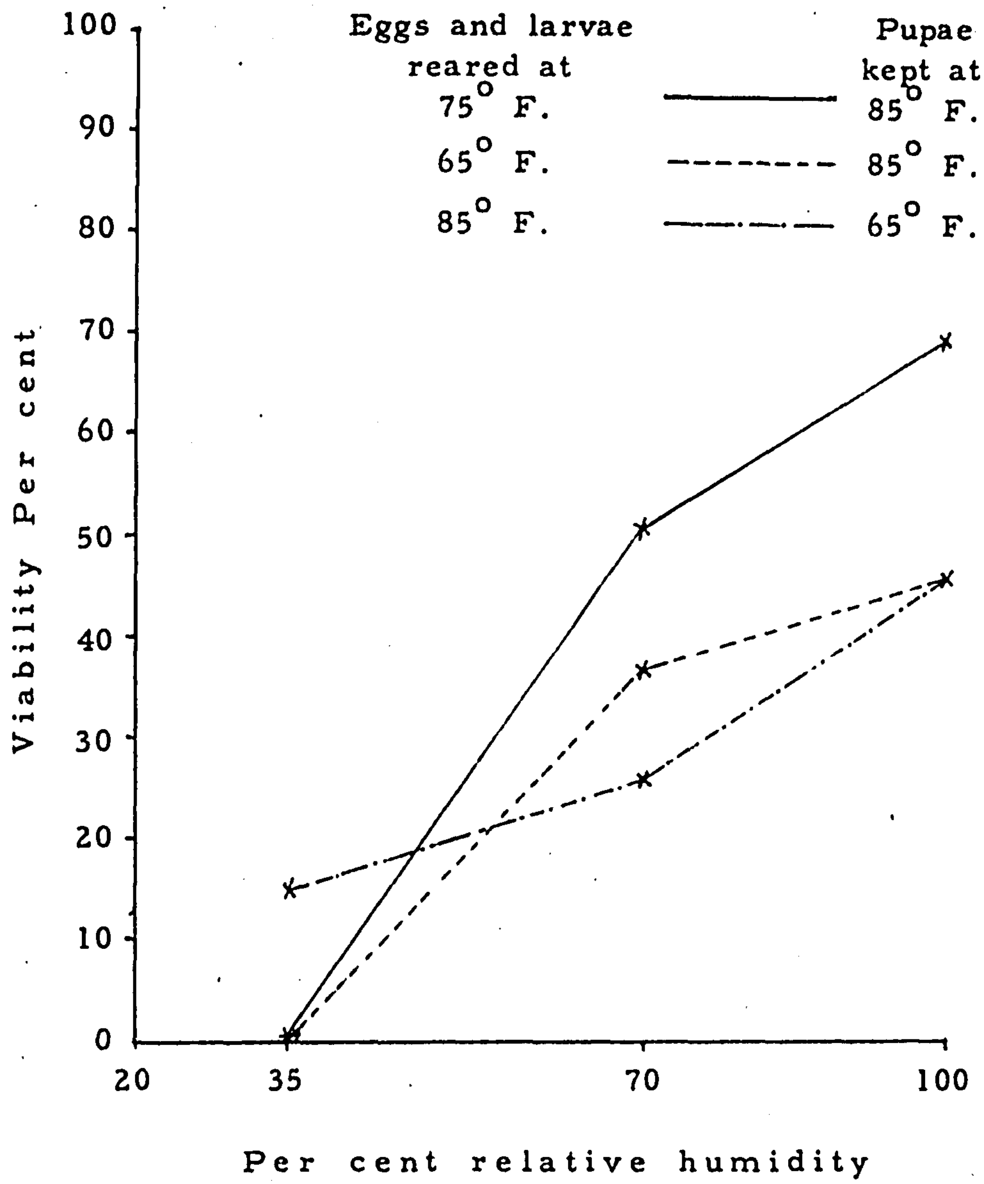

FIGURE 13

VIABILITY OF PUPAE OF <u>G</u>. <u>MOLESTA</u> UNDER VARIOUS CONDITIONS
(Eggs and larvae reared at a temperature different
from the one at which pupae were kept)

pupal duration was 19 days, 14.3 days, 12.0 days and 11.0 days at a constant temperature of 65°, 75°, 85° and 95° F., respectively, under a relative humidity of 100%. In the second set the larvae reared at 65° and 75° F. were transferred to 85° F., and those fed at 85° taken to 65° F. during their cocoon period. The duration under 100% relative humidity was 11.2 days at 85° F. (larvae from 75°), 16.4 days at 85° F. (larvae from 65° F.) and 21.5 days at 65° F. (larvae from 85° F.). Under the straight set the duration continued to decrease with the rise of temperature. The decrease was not uniform especially between 75° and 95° F. From the second set it is clear that the temperature at which the larvae were grown had a distinct influence on the duration of the pupae kept at another temperature. Larvae grown at 65° F. had a longer duration, almost one and a half times greater as compared to those fed at 75° F. and subsequently transferred to 85° F. in each case. Another interesting feature is that the pupae formed from larvae grown at 65° F. and kept at 65° F. had a shorter duration as compared to those which were transferred from a high temperature of 85° F. to a low temperature of 65° F. during their cocoon period. Thus rising temperatures in spring shorten the pupal duration and decreasing temperatures in fall lengthen the pupal period. In the former case the interest of the species lies in bring forth its adults, and consequently eggs, early in the season to take advantage of new growth and to complete more generations, whereas, in the latter case there is a greater tendency to arrest development due to approaching unfavorable weather conditions.

(ii) Threshold of development: An examination of Figures 8-10 shows that the theoretical threshold of development for the pupae lies at 46.5° F., 49° and 52.5° F. under relative humidities of 100%, 70% and 35%, respectively. These figures seem to be very significant. Under moist conditions the pupae were able to continue development at lower temperatures as compared to those exposed to a dry set of conditions. In areas with moist climate, particularly in those having relative humidities varying from 80-90% the pest could start development early in spring and thus increase to large proportions and cause serious damage. On the other hand, under dry conditions the insect would continue to be inactive until the temperature has risen well above 52.5° F. and would lag behind and not be able to build up its population quickly.

The threshold of development for the pupae is higher than that for eggs or larvae. This appears to be another insurance provided by the species to tide over inclement weather. The eggs and larvae which are not hibernating continue to develop even at low temperatures to reach maturity. In the pupal condition development would not proceed unless the weather has sufficiently warmed up. The eggs and subsequent larvae from them would be exposed to more favourable conditions.

It is interesting to compare these data with those of the codling moth given by Shelford (23). He calculated 50.1° and 51.4° F. as the threshold of development for relative humidities of 70-97% and 50-60% respectively. These figures are practically of the same order as those for the oriental fruit moth reported above; that is the theoretical threshold of development is lower in high humidity experiments as compared to that in the low humidity ones. The difference between the values at high and low humidities is more in the case of the oriental fruit moth, showing that this species prefers more moist conditions for its pupal development than does the codling moth.

(iii) <u>Optimum</u> <u>and</u> <u>upper</u> <u>vital</u> <u>limits</u>: The indices of development (Figures 8-10) show uniform acceleration up to a temperature of 75° F. Above this they deflect towards the right showing that the rate of development slows down above 75° F. The decline is less steep under 100% relative humidity than under 35% relative humidity. This decline is more than that for the larvae, showing that higher temperatures are comparatively more detrimental for the pupae than for the larvae.

The effect of low temperatures on cocooning larvae was not determined as they are expected to tolerate fairly low temperatures prevailing in temperate regions. This will not be materially different from other insects particularly from the codling moth. According to Newcomer and Whitcomb (19),

> A winter temperature of -25° F. or colder may kill all the codling moth larvae above snow line, a temperature of -20 to 25° F. may kill 80 to 90 per cent of the larvae, a temperature of -15° to -20° F. may kill 70 to 80 per cent, while a temperature of only -7° or -8° F. kills only about four per cent of the wintering larvae.

(b) Effect of humidity on development

The data in literature on this aspect is extremely meagre. In fact, it is surprising how this important aspect of the influence of humidity on pupal development received so little attention from workers in the past. As the pupal stage of the oriental fruit moth is generally passed outside the green tissues it may be considered likely that comparatively drier conditions should suit the pupae better. Present investigations show that this is not the case. Saturated atmosphere was found to be more useful. It may be, that in nature high humidity is maintained near the surface of the soil by evaporation of moisture from the soil and on account of the presence of luxuriant growth of grasses and weeds around the trees where most of the pupae are found. Frequent rains during the active season would also help in keeping the humidity high.

In these experiments the pupal period was found to be shortest under 100% and longest under 35% relative humidity. It was 19 days, 14.3 days, 12 days and 11.0 days under 100% relative humidity as compared to 24.5 days, 17.3 days, 14.2 and 12.5 days, under 35% relative humidity, at constant temperatures of 65°, 75°, 85° and 95° F., respectively. A low relative humidity was extremely detrimental to pupae kept at 85° F. when their egg and larval periods had been at 75° or 65° F., as very few moths emerged from a large number of pupae. The moths emerging under 100% relative humidity at 95° F. were deformed and short lived; those emerging under

70% relative humidity were well formed, active and lived longer.

(c) Effect of temperature and humidity on viability

The viability of the pupae of the oriental fruit moth is influenced both by temperature and relative humidity. At the medium range of temperatures the effect of humidity is well marked. The data is presented in Table VI and shown in Figures 11-13. At constant temperatures of 65°, 75°, 85° and 95° F., the viability was 41.8%, 71.8%, 68.36% and 14.0% under a relative humidity of 100%; 24.5%, 50.4%, 54.55% and 25% under a relative humidity of 70%; 8.4%, 40.6%, 31.97% and 11.3% under a relative humidity of35%, respectively. On the whole viability was maximum at 75° F. under different relative humidities as compared to other temperatures, with that at 85° F. coming very close to it. At variable temperatures pupae exposed to 85° F. but formed from larvae reared at 65° F. had a viability of 45.83%, 36.7% and 1.2% under a relative humidity of 100%, 70% and 35% respectively. On the other hand pupae formed from larvae reared at 85° F. and kept at 65° F. had a viability of 45.86% under a relative humidity of 100%, 26.25% under 70% humidity and 15.1% under the low humidity of 35%. The viability was always highest under saturated atmosphere at all the combinations of temperatures tried. Usually it was about one and a half times the figure for 70% relative humidity. The per cent viability was generally least under 35% relative humidity; under one set of temperatures it was even zero.

The viability of pupae exposed to 65° F., and 35% relative humidity but formed from larvae reared at 85° F. was almost double of those which had the entire life at 65° F. This means that a greater number of larvae which matured under higher temperatures were able to complete their life successfully at low temperatures combined with low humidity (to which the pupae were exposed) as compared to those which were reared at low temperatures and the pupae exposed to low temperature and low humidity.

A viability of 15.1% under 35% relative humidity is a little less than one-third of 45.86% viability under saturated conditions at temperatures of 65° F. for pupae and 85° F. for the larval stage. This is rather significant. In areas of low humidity in late summer and early fall a lesser number of moths would emerge. Consequently the damage to fruit in those areas is likely to be less. On the other hand places which are more humid at that time may have larger emergence of moths and there is a greater likelihood of damage to fruits from the late broods of larvae.

4. Larval Diapause

The larvae of the oriental fruit moth like those of several other species go into hibernation, i.e., enter diapause in late summer and fall to tide over unfavorable weather and food conditions. The larvae spin thick silken cocoons and then rest inside them for an extended length of period before transforming into pupae. Several workers have attempted to investigate the causes which initiate diapause. Those may be falling temperatures in fall, some change in the quality and water content of food, relative humidity, photoperiodism, hormones or some inherent factors. These have been very ably reviewed by Dickson (5). Although the present investigation was not directed towards finding out the factors responsible for inducing diapause several interesting features have been revealed. The results of these observations are given in Tables VII to IX.

TABLE VII

PERIOD OF DIAPAUSE PLUS PERIOD OF PUPATION FOR SHORT CYCLE LARVAE* OF <u>GRAPHOLITHA</u> <u>MOLESTA</u> UNDER DIFFERENT CONDITIONS

Temperature °F.		Relative Humidity					
		100%		70%		35%	
Period at	Eggs and Larvae Reared at	Average Period	No. of Observations	Average Period	No. of Observations	Average Period	No. of Observations
65	65	39	8	Nil	Nil	Nil	Nil
75	75	46.7	8	49	15	53	18
85	85	Nil	Nil	35	2	44.5	4
85	75	34.3	24	34.8	42	Nil	Nil
85	65	Nil	Nil	34.4	20	Nil	Nil
65	85	Nil	Nil	Nil	Nil	Nil	Nil
65	75	Nil	Nil	Nil	Nil	Nil	Nil

* Total period extending from thirty-one to sixty days

TABLE VIII

PERIOD OF DIAPAUSE PLUS PERIOD OF PUPATION FOR LONG CYCLE LARVAE* OF *GRAPHOLITHA MOLESTA* UNDER DIFFERENT CONDITIONS

Temperature °F.		Relative Humidity											
		100%				70%				35%			
Hibernating Larvae and Pupae Kept at	Eggs and Larvae Reared at	Average	Maximum	Minimum	No. of Observations	Average	Maximum	Minimum	No. of Observations	Average	Maximum	Minimum	No. of Observations
65	65	139	241	75	72	110	137	88	8	No moth emerged from hibernating larvae			
						140	170	109	32**				
75	75	87.7	126	62	140	76.6	104	63	15	74	85	67	8
85	85					None entering diapause							
85	75					None entering diapause							
85	65					None entering diapause							
65	85	132.5	184	124	46	109.5	143	76	4	No moth emerged from larvae entering diapause			
65	75	162	179	113	18	130	160	110	17	No moth emerged from larvae entering diapause			

* Total period more than sixty days

**Hibernating larvae transferred to room temperature and 100% relative humidity on March

TABLE IX

PERCENT EMERGENCE OF MOTHS OF GRAPHOLITHA MOLESTA UNDER DIFFERENT CONDITIONS

Temperature °F. Hibernating Larvae and/or Pupae Kept at	Temperature °F. Eggs and Larvae Reared at	Percentage of Moths Emerging from Larvae in Short Cycle, % Relative Humidity 100	Short Cycle 70	Short Cycle 35	Medium Cycle, % Relative Humidity 100	Medium Cycle 70	Medium Cycle 35	Long Cycle, % Relative Humidity 100	Long Cycle 70	Long Cycle 35
65	65	28.57	58.33	100	7.13	0.0	0.0	64.3	41.67	0.0
75	75	47.14	60.0	75.0	2.86	20.0	17.3	50.0	20.0	7.7
85	85	100	97.9	95.74	0.0	2.1	4.26	0.0	0.0	0.0
85	75	81.25	69.1	0.0	18.75	30.9	0.0	0.0	0.0	0.0
85	65	100	54.5	100	0.0	45.5	0.0	0.0	0.0	0.0
65	85	62.3	90.5	100	0.0	0.0	0.0	37.7	9.5	0.0
65	75	47.0	75.0	100	0.0	0.0	0.0	53.0	25.0	0.0

The period of diapause can be divided into two categories, short diapause for a period of 31-60 days and long diapause for a duration of over 60 days. Larvae belonging to both of these categories were found among those reared at various constant temperatures and relative humidities.

(a) Short Diapause

(i) Effect of temperature: Larvae entering short diapause were found at constant temperatures of 65°, 75° and 85° F. and at some of the variable temperatures (Table VII). The average duration including pupal period was 39 days at 65° F., 46.7 days at 75° F. under 100% relative humidity and 35 days at 85° F. under 70% relative humidity. The maximum average was of 53 days at 75° F. and 44.5 days at 85° F. The largest number of larvae in this category was found among those reared at 75° F. and then transferred to 85° F. during the cocoon period. Next to this was a constant temperature of 75° F. prevailing in the egg and larval stages, as well as after they had spun cocoons. A larval temperature of 65° F. followed by 85° F. during the cocoon life was third in having quiescent larvae. Larvae reared at high temperatures of 75°

F. and 85° F. and then transferred to 65° F. did not enter into short diapause, chiefly because they went into long diapause.

This period of short diapause appears to be different from the period of quiescence which is induced by low temperatures and easily terminated when the material is transferred to a high temperature as it came about even at optimum temperatures. In fact the largest number and longest period of "short diapause" was in the case of larvae reared at the optimum temperature of 75° F. Some even hibernated at the relatively high temperature of 85° F. It could not have been the result of unfavorable temperature or humidity or even food, as the same kind of food was given in all cases. It would not be due to the effect of light as all the material was reared in darkness except for the time of taking daily observations. This phenomenon appears to be based more on genetical factors than anything else.

(ii) Effect of humidity: Cocooning larvae were kept under relative humidities of 100%, 70% and 35% at various temperatures and the results are summarized in Table VII. The effect of humidity on this aspect is rather distinct. At a constant temperature of 65° F. no larva entered short diapause under relative humidities of 70% and 35%, whereas a few did behave so under saturated atmosphere. At 75° F. the largest number became quiescent with an average period of 53 days under 35% relative humidity; the number and period decreasing with the rise of humidity. Under 100% relative humidity none entered short diapause at 85° F. prevailing in the larval as well as in the cocoon period. A few, however, went into diapause under drier conditions. A fairly large number of cocooning larvae held at 85° F. with feeding period at 75° F. entered short diapause under more moist conditions, but fewer under 100% relative humidity than under 70%. A low humidity of 35% under the same conditions was fatal as out of 135 cocooned larvae none emerged as a moth. Several cocooned larvae at 85° F. with growing period at 65° entered quiescence under 70% relative humidity; none entered diapause under 100% relative humidity. Over 98% died without emerging as moths under 35% relative humidity. The duration of short diapause (for 34 days or so) of larvae held at 85° F. with growing period either at 75° or 65° was almost the same. However, in the latter case (growing period at 65° F.) there were no hibernating larvae under 100% relative humidity as they all emerged as moths within a reasonable period. Under these set of temperature conditions there was almost complete mortality of cocooned larvae at 35% relative humidity.

From the above it could be inferred that this species may overcome unfavorable conditions brought about by low humidity by inducing short diapause in the prepupal stage even though the prevailing temperature is optimum; unless the humidity is so low as to be fatal when prevailing over an extended period.

(b) Long Diapause

In this category are included all those larvae in cocoons which emerged as moths after a period of at least sixty days in the present investigation. It includes the subsequent pupal period as the larvae were generally not disturbed while in cocoons. Some of the previous workers have mentioned the larval period in cocoon separately from the pupal period either by disturbing the larvae or by a limited number of observations on material kept in partly transparent corrugated paper. This was not considered essential in these experiments.

(i) Effect of temperature: The cocoon period of the larvae of oriental fruit moth under insectary conditions had been determined by several workers at various places. Stearns and Peterson (27) reported the combined cocoon and pupal period as varying from 91 to 303 days with an average of 248 days. Peterson and Haeussler (20) at Riverton, New Jersey found it to be 258.85 days in 1925 and 252.40 days in 1926, on an average. The maximum figures for the corresponding years were 306 days and 307 days, and the minimum 131 days and 176 days. Snapp and Swingle (24) recorded the average hibernation period including pupal stage as 208.4 days, 189.3 days and 182.5 days for the fifth, sixth and seventh brood respectively. Their maximum was 278 days and a minimum of 135 days. From these data it is clear that the period of diapause of this moth varies considerably under different conditions and seems to be influenced by temperature.

The data on diapause under various conditions studied during the progress of the present work are given in Tables VIII and IX. An examination of these tables shows that the larvae went into diapause at constant temperatures of 65° and 75° F.; and under variable temperatures when cocoons formed by larvae grown at 75° and 85° F. were transferred to 65° F. The feeding larvae as well as the cocooned ones and pupae were kept in total darkness except for short durations when they were taken out for examination or the doors of the incubators and refrigerators were opened for other observations. At a constant temperature of 65° F., 64.3%, 41.67% and 0.0% of the larvae successfully completed their diapause under relative humidities of 100, 70 and 35%. At 75° F. the corresponding figures were 50%, 20%, and 7.7%. Under variable temperatures at 65° F., 37.7%; 9.5% and 0.0% larvae successfully completed hibernation when they had been grown at 85° F. as compared to 53%, 25% and 0.0% when reared at 75° F. under relative humidities of 100, 70 and 35% respectively.

The maximum duration of diapause including the pupal period was 241 days at 65° F. (larvae grown at 65° F.), 184 days at 65° F. (larvae reared at 85° F.), 162 days at 65° F. (larvae reared at 75° F.) and 126 days at 75° F. (larvae reared at 75° F.). None of the larvae entered diapause when kept at 85° F. whether they were fed at 85°, 75° or 65° F. This simulates spring and midsummer conditions. The period of two months' diapause at 79° F. mentioned by Dickson (5) appears to belong to the category of "short diapause." The relative influence of temperatures prevailing during the feeding period and the cocoon period is quite clear from the data given above. Except for those larvae kept permanently at 65° F., the higher the temperature from which they were transferred to 65° F., the longer the diapause. This is in agreement with the observations in orchards. Larvae hibernating early in fall or summer when the temperatures are high have a longer diapause than those hibernating later in the season.

Dickson (5) studied some of the factors governing the induction of diapause in the oriental fruit moth. He postulated that diapause in the larvae of this moth is induced by a hormone or hormone-like substance that is produced by the larva during the larval feeding period. He further concluded that this hormone is produced by a two-phase reaction, which required darkness for one phase and light for the other and that the induction of diapause is controlled by temperature and daily exposure to light during the larval feeding period. According to him very few larvae grown in the absence of light entered diapause. The present observations do not support his theory, particularly with regard to the effect of light. As will be seen from Table VIII and reported above 64.3% larvae successfully completed diapause and emerged as moths, even though they were grown in total darkness at 65° F. and 50% when reared at 75° F. and kept at the same temperature of 75°. Larvae reared at 75° and 85° and kept at 65° F. also went into diapause in fairly large numbers, particularly under 100% relative humidity. The actual number of larvae which went into diapause must be much higher than the number of moths emerging from them as there would naturally be considerable mortality in the hibernating stock.

The real cause which may initiate diapause in the oriental fruit moth larvae appears to be inherent and may to some extent be governed by the nature and quality of food on which the larvae are fed. Dickson used small immature apples to feed the larvae, whereas, in the present investigation they were fed on almost mature apples picked up in August and stored at about 50° F. until needed. This difference in food in the two investigations, may to some extent be responsible for some of the conflicting results obtained. Larvae reared during April, May and June, 1951, on the same kind of apples stored at about 50° F. did not enter diapause except very few individuals.

Isely (17) could not find any relationship between the transformation of the larvae of codling moth, Carpocapsa pomonella, and the relative ripeness of the fruit on which they were fed.

(ii) Effect of humidity: The relative humidity to which the hibernating larvae are exposed seems to have a great influence on the extent and successful completion of diapause. The actual number of larvae going into diapause was not determined in these experiments as they were not disturbed in the cocoons but the proportion is believed to be fairly high. Squire (25) reported that the diapause in the larvae of pink bollworm, Pectinophora gossypiella (Saund.) depends upon the moisture content of the seeds in which they feed. In the case of the oriental fruit moth the question of water content of food is relatively unimportant. An examination of Tables VIII and IX shows that relative humidity acts more on the prepupal and pupal stages. None of the larvae in diapause kept under 35% humidity at any temperature with the exception of those at 75° F. emerged as moths. At 75° F. it was only 7.7% emergence. The hibernation was most successful under 100% relative humidity and to an appreciable extent under 70% relative humidity.

5. Emergence of Moths Under Different Conditions

The percentage of moths emerging from larvae of different cycles under various conditions is shown in Table IX. The larva of the oriental fruit moth according to the present investigation can be divided into the following categories:

(a) Short cycle larvae: Those larvae which had the prepupal plus pupal period less than thirty days under any set of conditions are called short cycle ones. They pupated soon after spinning cocoons and emerged as moths.

(b) Medium cycle larvae: Included in this class are those larvae which had the prepupal plus pupal period varying from thirty-one to sixty days. At the end of this period they emerged as moths.

(c) Long cycle larvae: The long cycle larvae were those which entered into a diapause of over sixty days irrespective of temperature and humidity. At the end of this period they emerged as moths without being transferred to another set of conditions.

It may be noted however, that these larvae represent only those which were able to complete their life cycle successfully and finally emerged as moths. The actual number belonging to each category must have been larger, particularly under the long cycle class, of which many might have died in the cocoons.

The duration of period for the various classes of larvae is given in Tables V, VII and VIII and explained in earlier chapters. The relative proportions of those which completed their life cycles as based on the emergence of moths under different conditions are given in Table IX.

(i) Effect of temperature: It may be seen from Table IX that at a constant temperature of 65° F. and 75° F. all kinds of larvae were found. At a constant temperature of 85°, larvae were mostly in short cycle, some in medium but none in long cycle, whether the larvae were fed at 85°, 75° or 65° F. before they were exposed to 85° F. If the larvae grown at either 75° or 85° F. were kept at 65° F. during their cocoon period they belonged to the category of short cycle or to that of long cycle larvae as none emerged as moths under the medium cycle.

(ii) Effect of humidity: The effect of relative humidity on this aspect is well marked. A low humidity of 35%, on the whole was highly injurious to the development and viability of cocooned larvae. There was very little emergence in case the larvae grown at 65° or 75° were kept at 85° F. under 35% humidity. This means that in areas where with the rise of temperature in June-July there is a drop in relative humidity, the cocooned larvae will have very little chance to emerge as moths.

At 65° F. all moths were from short cycle larvae under 35% relative humidity, none was from medium or long cycle; whereas under 100% relative humidity 28.57% were from short cycle, 7.13 from medium and 64.3 from long cycle larvae. At 75° F. and 100 per cent relative humidity there were 47.14%, 2.86% and 50% moths from short, medium and long cycle larvae, respectively, as compared to 75%, 17.3% and 7.7% under 35 per cent humidity; 60%, 20% and 20% under 70 per cent relative humidity, respectively. Under the variable temperature experiments (eggs and larvae grown at 75° and 85° and cocooned larvae kept at 65°) moths were either from short cycle or long cycle larvae. None were from medium cycle larvae. At these temperatures (65° F. for cocooned larvae and pupae, 85° or

75° F. for eggs and growing larvae) if the humidity was low all moths were from short cycle larvae, none from the long cycle ones. If the larvae were grown at 85° F. and kept at 65° F. and 100 per cent relative humidity there were 62.3% moths from short cycle and 37.7% from long cycle larvae; under 70 per cent humidity the ratio was 90.5:9.5. In case the larvae were reared at 75° F. and during their cocoon period were exposed to 65° F. the ratio of short to long cycle was 47:53 under 100 per cent relative humidity, as compared to that of 75:25 under 70 per cent humidity. Under 35 per cent relative humidity practically 100 per cent emerged as moths in the short cycle series at most of the temperatures. In fact the only exception was at 75° F. constant. Generally there was about half of the emergence from long cycle series if the relative humidity had been 100%; about one-third if it had been 70%; and nil under 35% relative humidity (except 7.7% at 75° F.). This indicates that in areas where low relative humidity prevails during late summer and early fall the oriental fruit moth has a strong tendency to emerge as moths and not go into hibernation. Under these conditions the pest would remain active for a longer period and consequently suffer from subsequent severe cold spells. Hibernation of the cocooned larvae is absolutely essential for the survival of the oriental fruit moth in temperate regions. If the conditions are dry very few larvae would enter diapause or complete it successfully. Very few moths would emerge in the following spring on the return of favourable conditions. On the other hand, substantially larger number of larvae enter diapause or complete it successfully if the relative humidity to which they are exposed is high enough. This ensures greater survival of this species in regions where high humidity prevails in late summer and fall.

Thus the present geographic distribution of the oriental fruit moth appears to be largely governed by the relative humidity prevailing during July to November, the period when larvae enter diapause. In humid areas the pest is far more serious than in the drier regions. This difference is explained by the influence of relative humidity on the successful completion of diapause; higher humidities favouring it and lower humidities affecting it adversely, by breaking the defense of this insect against unfavourable conditions.

In the case of codling moth, _Carpocapsa pomonella_, hot and dry conditions are considered more favourable. Cutright (4) has reported from Ohio that in hot and dry season injuries to apple by the larvae of codling moth appeared early and increased rapidly while in a cool wet season it was the reverse. Therefore, both species although resembling each other in several respects may not necessarily be equally serious in the same region. If one is more abundant in an area or in a particular season most likely the other one may not be so, and _vice versa._

V. THE FECUNDITY OF GRAPHOLITHA MOLESTA UNDER DIFFERENT CONDITIONS

The fecundity of G. molesta under insectary and near orchard conditions had been extensively studied in the past by several workers. Stearns and Peterson (27) got an average of 7, 23 and 40 eggs per female for the first, second and third brood moths in New Jersey. In Georgia Snapp and Swingle (24) found that the average number of eggs per female was 11.3, 6.4, 16.9, 30.5, 62.9, 50.0 and 66.5 eggs; for the spring, first, second, third, fourth, fifth and sixth broods respectively. Alden and Clarke (2) reported an average of 46.09 eggs per female with a maximum of 221 eggs at Thomaston, Georgia. Harukawa (12) got an average of 21.9 to 66.2 eggs per female in different experiments in Japan.

Dustan (6) carried out some experiments on the influence of temperature and moisture on the adults of oriental fruit moth in Toronto, Canada. He found that the females laid 98% of the daily total of eggs during the late afternoon, from three hours before to one hour after sunset. The hour of maximum deposition was that starting two hours before sunset. In his experiments the moths completely stopped egg laying as long as they were in total darkness. Ahmad and Ghulamullah (1) found normal oviposition in similar darkness by the moths of the spotted bollworm of cotton, Earias fabia (Stoll.). Under more or less controlled temperature conditions the data for selected moths given by Dustan (6) were 4 eggs, 135 eggs, 114 eggs per female at a temperature range of 94.5 to 96.3° F., 88.8 to 90.8° F. and 79.3 to 85.4° F., respectively. He did not mention the number of moths liberated in each battery jar. This only shows that some moths did lay eggs under high temperatures. The pre-imaginal life history of those moths had not been given. In another set of experiments he got an average of 29.3 eggs per female, fed on moisture and liberated in cages having moist sand at the bottom, as compared 7.7 eggs per female in the case of unfed moths kept in dry cages. High humidity at the time of oviposition is thus more conducive for egg laying than low humidity. If this is true the moths may not be able to lay their full quota of eggs on plants in areas in which relative humidity is low, particularly in the afternoon and evening.

In the present investigation moths emerging from pupae kept under different conditions were liberated in small cages described earlier. In order to provide suitable conditions for oviposition an almost continuous supply of peach seedlings was maintained in the green house. Peach shoots with their lower ends immersed in water in small bottles were supplied to the moths for egg laying inside the cages. The bottom of the cages was partly filled with moist sand. The glass bottle containing peach shoot was covered with cloth to prevent oviposition on it. In the case of this species it was found extremely difficult to obtain eggs from individual pairs liberated in these cages. Consequently several pairs were kept together at various temperatures. Many times only a small number of males and females would emerge from the same stock on one day. In these cases moths emerging over a period of several days were kept together in the same cage. As a result of this it was not possible to determine the preoviposition, oviposition and the post oviposition periods for the moths or the longevity of the two sexes. However a record of the number of males and females, added or dying each day was maintained. The moths were fed on thin sugar solution soaked in cotton wads.

The observations on the oviposition of moths reared and kept at constant temperatures are given in Table X. The pre-imaginal as well as the imaginal life was always in darkness.

(i) <u>Effect of temperature</u>: It will be seen (Table X) that generally the females laid very few eggs. Many of them died without laying any eggs. Whether it was due to darkness can not be said definitely as the provision of light in some cases did not improve their record of oviposition. The highest average of 12.7 eggs per female was at 75° F. At 85° F. the average was 9.8 eggs when the preimaginal life had been at 85° F., 11.3 eggs if the larvae were grown at 75° F. and 0.3 eggs if the growing period of the larvae had been at 65° F. If the preimaginal life was at 65° and imaginal life at 75° F. the average was 7.46 eggs. Under a constant temperature of 65° F. throughout the entire life of moths the maximum average was 0.5 eggs. The optimum temperature for egg laying was therefore 75° F. constant. Moths at 65° F. from cocoons at 65° F., but larvae grown at 75° or 85° F. laid very few eggs, the maximum average was 4.3. This set is somewhat similar to the moths from overwintering material. The spring brood moths are known to lay very few eggs.

TABLE X

THE FECUNDITY OF GRAPHOLITHA MOLESTA UNDER DIFFERENT CONDITIONS

Temperature °F.			Relative Humidity at Which Pupae Were Kept					
			100%		70%		35%	
Adults at	Pupae Kept at	Eggs and Larvae Reared at	Average No. of Eggs per Female	No. of Pairs	Average No. of Eggs per Female	No. of Pairs	Average No. of Eggs per Female	No. of Pairs
65	65	65	0.3	26	0.5	24	0.0	8
75	75	75	12.7	48	8.7	20	6	26
85	85	85	6.2	40	9.8	38	2.2	27
85	85	65	0.3	20	0.0	20	Very few moths	
65	65	85	0.0	28	4.3	16	0	14
85	85	75	11.3	42	3.4	28	No moths emerged	
65	65	75	0.25	12	1.0	24	0.0	7
75	65	65	7.46	13	-	-	-	-

(ii) Effect of humidity: The effect of low humidity during the cocoon life on the fecundity of moths is well pronounced and is clearly shown by the observations summarized in Table X. Generally maximum oviposition was from material exposed to 100% relative humidity. The second best was under 70% humidity. Moths emerging from material kept at 35% humidity laid very few eggs and in several cases did not lay any eggs. At some set of temperatures no moth could emerge from pupae kept at the low humidity tried. It is therefore, evident from these observations that low humidity during their cocoon period is injurious to the fecundity of moths. In fact moths with larval life at 65° F., 75° F. and 85° F. with cocoon and adult life at 65° F. did not lay any eggs if the relative humidity during the cocoon period was 35%. Low relative humidity, therefore, is not only injurious to the development of this species but is also equally or even more harmful to the egg-laying capacity of the moths.

(iii) Experiments at room temperature: In addition to experiments at constant temperatures and humidities moths emerging from material grown at an ordinary room temperature of 70-80° F. were liberated in larger cages of 10" x 10" x 8" size, kept over moist sand in enamel trays. The eggs laid by these moths were counted every day. The oviposition of these moths is recorded in Table XI. Twelve pairs which emerged during May, 1950, from overwintering larvae laid a total of five eggs only. During July and 1-15 August, 1950, moths emerging from larvae collected from peach shoots in the orchard laid 42.0 and 48.6 eggs on an average per female respectively. The highest average of 74.5 eggs per female based on observations of 105 pairs reared on apples was obtained during the period September 24th to October 15th, 1950. During the last two weeks of October, 1950, the average dropped to 37 eggs per female, although the larvae in this period were also fed on the same variety of apples as those of the previous period. During November, 1950, and January, 1951, there were 9.4 and 9.2 eggs per pair respectively. In February, 1951, the average was lowest, i.e., 3.3 eggs per female. This may be due to the fact that the moths had emerged from overwintering material. The average increased to 9.6 in March, 9.3 in April, 57.1 eggs in May and 65.4 in June, 1951.

The following factors might have been responsible for inducing greater oviposition under laboratory conditions:

TABLE XI

THE FECUNDITY OF GRAPHOLITHA MOLESTA MOTHS AT ROOM TEMPERATURE (70-80° F.)

Period	No. of Pairs	Total No. of Eggs	Average No. of Eggs per Female	Source of Material
May, 1950	12	5	0.4	Overwintering larvae
July, 1950	30	1260	42.0	Larvae from peach shoots
August (1-15), 1950	24	1166	48.6	Larvae from peach shoots
August (16-31), 1950	35	1630	46.6	Larvae reared on Jonathan apples stored at about 50° F.
September (1-7), 1950	14	462	33	Same as above
September (8-15), 1950	54	1885	35	Same as above
September (16-30), 1950	50	2210	44	Same as above
Sept. 24 to Oct. 15, 1950	105	7827	74.5	Same as above
October (16-31), 1950	50	1847	37.0	Same as above
November, 1950	16	150	9.4	Same as above
January, 1951	17	156	9.2	Same as above
February, 1951	21	70	3.3	Same as above
March, 1951	44	424	9.6	Same as above
April, 1951	34	316	9.3	Same as above
May, 1951	40	2284	57.1	Same as above
June (1-15), 1951	36	2355	65.4	Same as above

(a) Effect of wide fluctuation in temperature.

(b) Large size of the cages.

(c) More number of moths in each cage.

(d) Presence of light in the room during the day.

(e) The relative length of day and night in different months.

There was wide fluctuation in the average for different periods during the year even in the laboratory where conditions were almost similar throughout. It is impossible to postulate the real cause or causes without further investigation of this aspect. It may be that successive generations lay varying number of eggs which may be controlled (among other things) by genetical factors.

VI. METEOROLOGICAL DATA AND INCIDENCE OF THE ORIENTAL FRUIT MOTH

Meteorological data for the years 1948 to 1950 for three places representing inland peach growing areas of the United States of America are given in Tables XII-XIV, XVIII-XX, XXIII-XXV and shown graphically in Figures 14-31. These places are: Columbus, Ohio (Latitude 39°58' N. Longitude 83° W. Elevation 724 feet); Grand Junction, Colorado (Latitude 39°06' N. Longitude 108°32' W. Elevation 4,849 feet); and Lansing, Michigan (Latitude 42°47' N. Longitude 84°36' W. Elevation 859 feet). The data for the above places is compared with those of Parachinar (Latitude 33.8° N. Longitude 70.1° E. Elevation 5,784 feet), Quetta (Latitude 30.3° N. Longitude 67° E. Elevation 5,508 feet) and Peshawar (Latitude 34° N. Longitude 71.5° E. Elevation 1,149 feet). These are given in Tables XV to XVII, XXI, XXII, XXVI to XXVIII and illustrated by graphs in Figures 14-31.

It will be seen from the above mentioned tables and figures that the mean maximum temperature for June to August, 1950, was 80.5° to 83.4° F. at Columbus; 86.8° to 88.4° F.

TABLE XII

METEOROLOGICAL DATA FOR COLUMBUS, OHIO
FOR THE YEAR 1950

Month	Temperature °F.				Rainfall in Inches	% Relative Humidity at 7:30 a.m.
	Average					
	Daily Maximum	Daily Minimum	Monthly	Highest		
Jan.	48.8	32.1	40.4	74	6.86	82
Feb.	41.1	26.0	33.6	65	3.22	82
Mar.	46.5	28.5	37.5	80	1.31	77
Apr.	55.8	37.1	46.4	75	3.80	75
May	74.5	54.3	64.4	87	1.15	82
June	80.5	60.2	70.4	94	1.95	83
July	83.4	64.3	73.9	89	2.96	85
Aug.	81.9	62.3	72.1	94	3.52	85
Sept.	74.7	57.3	66.0	88	2.31	90
Oct.	69.6	50.2	59.9	83	1.58	89
Nov.	45.3	30.9	38.1	80	4.92	84
Dec.	34	19.4	26.7	57	3.04	84

TABLE XIII

METEOROLOGICAL DATA FOR GRAND JUNCTION, COLORADO FOR THE YEAR 1950

Month	Temperature °F.				Rain-fall in Inches	% Relative Humidity at 5:30 a.m.
	Average			Highest		
	Daily Maximum	Daily Minimum	Monthly			
Jan.	33.6	12.6	23.1	48	1.40	81
Feb.	44.4	24.2	34.3	65	0.47	75
Mar.	53.0	29.5	41.3	68	0.42	61
Apr.	66.3	38.9	52.6	82	0.54	50
May	72.6	45.5	59.1	86	0.46	47
June	86.8	54.7	70.8	95	0.01	30
July	88.4	61.4	74.9	97	1.00	52
Aug.	88.3	59.1	73.7	96	0.21	40
Sept.	78.3	54.0	66.2	97	1.05	57
Oct.	75.7	45.7	60.7	83	Traces	35
Nov.	53.3	29.8	41.6	69	0.32	56
Dec.	45.6	25.1	35.4	53	0.30	72

TABLE XIV

METEOROLOGICAL DATA FOR LANSING, MICHIGAN FOR THE YEAR 1950

Month	Temperature °F.				Rain-fall in Inches	% Relative Humidity at 7:30 a.m.
	Average			Highest		
	Daily Maximum	Daily Minimum	Monthly			
Jan.	38.9	20.7	29.8	65	3.61	83
Feb.	30.8	16.8	23.8	41	3.34	84
Mar.	35.8	20.6	28.2	60	2.39	80
Apr.	48.2	31.3	39.8	67	4.53	81
May	70.2	45.6	57.9	86	1.96	74
June	76.2	55.8	66.0	89	4.71	78
July	80.5	56.8	68.7	90	4.34	82
Aug.	77.9	56.1	67.0	89	2.45	85
Sept.	69.6	50.7	60.2	81	3.02	91
Oct.	63.5	45.0	54.3	81	1.22	88
Nov.	40.8	27.1	34.0	79	2.97	83
Dec.	28.8	16.3	22.6	49	1.97	84

TABLE XV

METEOROLOGICAL DATA FOR PARACHINAR, PAKISTAN FOR THE YEAR 1950

Month	Temperature °F.				Rain- fall in Inches	% Rel- ative Humid- ity at 8:00 a.m.
	Average					
	Daily Max- imum	Daily Min- imum	Monthly	Highest		
Jan.	49.8	28.6	39.2	68	2.03	69
Feb.	51.8	31.3	41.5	78	2.63	68
Mar.	59.8	38.6	49.2	81	4.34	60
Apr.	68.7	46.9	57.8	87	4.03	58
May	79.5	55.6	67.5	100	2.31	46
June	87.7	63.7	75.7	101	2.00	43
July	87.1	66.4	76.7	102	3.52	60
Aug.	84.7	64.8	74.7	95	3.70	67
Sept.	81.2	58.6	70.0	92	2.11	56
Oct.	74.2	48.7	61.5	88	0.95	45
Nov.	64.7	39.3	52.0	81	0.40	48
Dec.	54.8	32.5	43.6	73	1.23	63

TABLE XVI

METEOROLOGICAL DATA FOR QUETTA, PAKISTAN FOR THE YEAR 1950

Month	Temperature °F.				Rainfall in Inches	% Relative Humidity at 8:00 a.m.
	Average			Highest		
	Daily Maximum	Daily Minimum	Monthly			
Jan.	50.2	27.6	38.9	78	1.94	78
Feb.	53.6	30.8	42.2	80	1.98	75
Mar.	63.6	38.3	51	84	1.74	67
Apr.	74.0	45.8	60	91	0.98	63
May	83.8	51.9	67.8	98	0.39	54
June	91.6	58.7	75.1	103	0.17	54
July	94.0	65.0	79.5	103	0.46	61
Aug.	92.2	61.6	76.9	103	0.33	56
Sept.	86.2	49.7	67.9	97	0.04	52
Oct.	75.7	38.9	57.3	91	0.12	49
Nov.	65.4	32.1	48.7	81	0.28	55
Dec.	55.5	28.5	42.0	76	1.01	73

TABLE XVII

METEOROLOGICAL DATA FOR PESHAWAR, PAKISTAN FOR THE YEAR 1950

Month	Temperature °F.				Rain-fall in Inches	% Relative Humidity at 8:00 a.m.
	Average					
	Daily Maximum	Daily Minimum	Monthly	Highest		
Jan.	63	40.4	51.7	77	1.44	71
Feb.	66.2	44	55.1	86	1.53	76
Mar.	74.8	52.4	63.6	99	2.44	69
Apr.	85.2	60.5	72.8	108	1.76	56
May	97.0	70.4	83.7	118	0.77	36
June	105.0	77.2	91.1	120	0.31	36
July	102.5	80.2	91.3	122	1.26	58
Aug.	98.2	78.9	88.5	118	2.03	67
Sept.	95.0	71.8	83.4	110	0.81	60
Oct.	87.8	60.5	74.1	101	0.23	52
Nov.	76.8	48.9	62.8	91	0.31	53
Dec.	66.7	40.9	53.8	83	0.67	65

TABLE XVIII

METEOROLOGICAL DATA FOR COLUMBUS, OHIO
FOR THE YEAR 1949

Month	Temperature °F.				Rain-fall in Inches	% Relative Humidity at 7:30 a.m.
	Average			Highest		
	Daily Maximum	Daily Minimum	Monthly			
Jan.	44.1	30.8	37.4	63	6.74	84
Feb.	46.4	29.5	38.0	64	2.53	79
Mar.	50.4	33.7	42.0	76	3.03	81
Apr.	59.7	41.6	50.6	78	2.84	79
May	75.9	53.4	64.6	92	2.05	79
June	85.9	66.1	76.0	94	4.47	82
July	88.9	69.7	79.3	96	3.24	86
Aug.	84.9	66.0	75.4	94	2.37	88
Sept.	72.0	52.6	62.3	84	2.86	89
Oct.	70.4	51.4	60.9	86	1.31	86
Nov.	51.4	36.2	43.8	73	1.21	80
Dec.	45.2	29.0	37.1	64	2.37	81

TABLE XIX

METEOROLOGICAL DATA FOR GRAND JUNCTION, COLORADO FOR THE YEAR 1947

Month	Temperature °F.				Rain-fall in Inches	% Relative Humidity at 5:30 a.m.
	Average			Highest		
	Daily Maximum	Daily Minimum	Monthly			
Jan.	34.6	9.5	22	48	0.40	82
Feb.	47.4	24.5	36	58	0.11	79
Mar.	56.8	31.5	44.2	70	0.60	67
Apr.	63.9	38.0	51	78	0.59	61
May	79.0	49.6	64.3	93	0.41	50
June	80.6	52.6	66.6	94	1.38	56
July	93.7	63.2	78.4	101	0.09	51
Aug.	87.0	61.1	74.0	99	1.27	65
Sept.	84.3	55.6	70.0	94	0.26	49
Oct.	68.5	44.5	56.5	86	1.98	68
Nov.	44.0	25.0	34.5	69	0.69	78
Dec.	37.9	19.3	28.6	49	0.49	88

TABLE XX

METEOROLOGICAL DATA FOR LANSING, MICHIGAN FOR THE YEAR 1949

Month	Temperature °F.				Rain-fall in Inches	% Relative Humidity at 7:30 a.m.
	Average			Highest		
	Daily Maximum	Daily Minimum	Monthly			
Jan.	35.6	20.6	28.1	55	3.48	84
Feb.	34.6	20.1	27.4	53	2.47	81
Mar.	42.1	25.6	33.8	71	2.61	81
Apr.	57.4	35.1	46.2	76	1.87	78
May	71.6	47.4	59.5	89	2.35	72
June	82.5	60.8	71.7	91	4.89	80
July	84.8	63.4	74.1	96	4.78	83
Aug.	81.8	58.7	70.2	93	1.61	88
Sept.	67.1	47.3	57.2	85	1.91	83
Oct.	65.5	44.3	54.9	84	2.35	86
Nov.	42.9	29.0	36.0	67	1.60	85
Dec.	38.4	23.8	31.1	62	4.70	83

TABLE XXI

METEOROLOGICAL DATA FOR PARACHINAR, PAKISTAN FOR THE YEAR 1949

Month	Temperature °F.				Rainfall in Inches	% Relative Humidity at 8:00 a.m.
	Average			Highest		
	Daily Maximum	Daily Minimum	Monthly			
Jan.	51.9	28.5	35.2	64	0.85	74
Feb.	47.3	30.8	39	63	3.29	76
Mar.	59.9	39.8	49.8	78	7.19	60
Apr.	75.6	52.3	64	87	2.24	46
May	85.2	61.3	73.2	92	2.99	47
June	83.0	61.0	72	91	0.83	40
July	87.6	67.6	77.6	99	4.06	66
Aug.	82.9	63.6	73.2	88	4.21	75
Sept.	84.1	62.8	73.5	90	1.51	60
Oct.	73.8	48.9	61.4	83	0.01	43
Nov.	62.3	37.5	50.0	71	0.08	37
Dec.	55.5	32.6	44	66	0.61	71

TABLE XXII

METEOROLOGICAL DATA FOR PESHAWAR, PAKISTAN
FOR THE YEAR 1949

Month	Temperature °F.				Rainfall in Inches	% Relative Humidity at 8:00 a.m.
	Average					
	Daily Maximum	Daily Minimum	Monthly	Highest		
Jan.	62.9	40.8	51.8	73	2.04	81
Feb.	64.4	42.7	53.5	75	0.69	75
Mar.	72.8	52.3	62.5	87	2.82	71
Apr.	89.1	63.0	76.0	102	1.24	60
May	100.7	73.5	87.1	108	0.56	43
June	99.5	74.6	87.0	109	0.47	39
July	99.7	80.0	89.8	110	0.15	70
Aug.	97.2	77.6	87.4	103	0.39	56
Sept.	97.7	75.4	86.5	103	0.27	65
Oct.	85.7	59.7	72.7	93	-	53
Nov.	75.9	45.5	60.7	85	-	42
Dec.	67.3	38.5	52.9	76	0.07	50

TABLE XXIII

METEOROLOGICAL DATA FOR COLUMBUS, OHIO FOR THE YEAR 1948

Month	Temperature °F.				Rain-fall in Inches	% Relative Humidity at 7:30 a.m.
	Average					
	Daily Maximum	Daily Minimum	Monthly	Highest		
Jan.	29.7	14.7	22.2	58	2.16	87
Feb.	41.2	24.0	32.6	66	2.75	85
Mar.	53.7	34.6	44.2	77	3.86	81
Apr.	66	45.9	56.0	89	4.39	81
May	71.1	51.0	61.0	87	3.34	80
June	83.1	61.7	72.4	95	3.94	81
July	86.6	67.4	77.0	94	5.25	85
Aug.	85.4	63.4	74.4	100	2.31	87
Sept.	79.3	58.5	68.9	92	2.25	86
Oct.	61.7	43.6	52.6	75	1.98	88
Nov.	55.2	40.7	48.0	71	3.99	88
Dec.	43.5	29.5	36.5	65	2.24	85

TABLE XXIV

METEOROLOGICAL DATA FOR GRAND JUNCTION, COLORADO FOR THE YEAR 1948

Month	Temperature °F.				Rain-fall in Inches	% Relative Humidity at 5:30 a.m.
	Average			Highest		
	Daily Maximum	Daily Minimum	Monthly			
Jan.	36.2	14.7	25.4	48	0.50	84
Feb.	40.8	19.6	30.2	54	1.56	84
Mar.	45.6	25.3	35.4	65	1.54	76
Apr.	65.9	39.8	52.8	84	0.48	56
May	78.1	49.4	63.8	92	0.22	41
June	84.3	55.4	69.8	94	0.64	54
July	93.4	60.8	77.1	98	0.86	50
Aug.	89.2	59.5	74.4	97	1.78	59
Sept.	84.7	54.4	69.6	97	0.64	51
Oct.	69.2	39.4	54.3	83	0.57	55
Nov.	42.7	22.3	32.5	62	0.70	79
Dec.	38.4	18.3	28.4	57	0.70	77

TABLE XXV

METEOROLOGICAL DATA FOR LANSING, MICHIGAN FOR THE YEAR 1948

Month	Temperature °F.				Rainfall in Inches	% Relative Humidity at 7:30 a.m.
	Average			Highest		
	Daily Maximum	Daily Minimum	Monthly			
Jan.	24.2	9.3	16.8	39	1.52	84
Feb.	31.3	14.7	23.0	50	2.03	84
Mar.	42.7	23.6	33.2	64	5.21	82
Apr.	60.9	39.8	50.4	82	2.52	75
May	64.7	43.7	54.2	81	5.35	75
June	75.0	54.7	64.8	86	4.44	79
July	83.6	60.8	72.2	92	1.65	81
Aug.	83.1	58.5	70.8	98	1.86	85
Sept.	76.7	53.6	65.2	89	1.62	86
Oct.	58.5	37.9	48.2	75	1.01	87
Nov.	49.1	36.7	42.9	66	2.49	85
Dec.	35.1	22.3	28.7	57	2.23	86

TABLE XXVI

METEOROLOGICAL DATA FOR PARACHINAR, PAKISTAN FOR THE YEAR 1948

Month	Temperature °F.				Rain-fall in Inches	% Relative Humidity at 8:00 a.m.
	Average			Highest		
	Daily Maximum	Daily Minimum	Monthly			
Jan.	53.4	32.1	42.7	60	0.53	66
Feb.	53.0	32.4	42.7	61	2.50	77
Mar.	58.6	38.6	48.6	67	4.48	70
Apr.	70.1	50.3	60.2	84	2.93	63
May	84.8	56.5	70.6	92	1.29	37
June	85.0.	75.7	80.4	93	1.92	49
July	88.5	67.2	77.8	97	1.65	64
Aug.	84.2	65.5	79.8	89	3.64	80
Sept.	83.7	61.2	72.5	89	1.15	61
Oct.	76.9	45.1	61.0	84	0.12	45
Nov.	65.2	38.9	52.0	70	-	40
Dec.	51.7	33.0	42.4	66	4.62	71

TABLE XXVII

METEOROLOGICAL DATA FOR QUETTA, PAKISTAN
FOR THE YEAR 1948

Month	Temperature °F.				Rain-fall in Inches	% Relative Humidity at 8:00 a.m.
	Average			Highest		
	Daily Maximum	Daily Minimum	Monthly			
Jan.	54.1	25.3	39.7	61	0.16	82
Feb.	52.9	31.6	42.2	64	2.12	84
Mar.	68.8	38.7	53.7	75	1.32	86
Apr.	75.7	47.9	61.8	88	0.42	72
May	87.3	53.9	70.6	92	0.03	51
June	90.0	59.9	75.0	97	0.06	56
July	95.2	65.7	80.5	98	0.11	62
Aug.	92.0	61.0	76.5	98	0.02	59
Sept.	87.9	49.7	68.8	95	-	54
Oct.	76.3	39.9	58.1	83	0.32	60
Nov.	63.5	26.5	45.0	73	-	50
Dec.	55.0	29.3	42.1	70	1.04	83

TABLE XXVIII

METEOROLOGICAL DATA FOR PESHAWAR, PAKISTAN FOR THE YEAR 1948

Month	Temperature °F. Average Daily Maximum	Temperature °F. Average Daily Minimum	Temperature °F. Average Monthly	Temperature °F. Highest	Rainfall in Inches	% Relative Humidity at 8:00 a.m.
Jan.	65.9	40.3	53.1	71	0.12	74
Feb.	65.6	43.3	54.5	73	1.16	82
Mar.	72.7	50.2	61.5	84	2.02	73
Apr.	86.3	63.1	74.7	101	2.15	64
May	100.0	74.8	87.4	107	0.19	40
June	100.8	76.9	88.8	110	0.26	42
July	102.2	80.3	91.2	114	3.26	74
Aug.	93.5	77.4	85.5	100	1.09	62
Sept.	94.0	73.9	83.9	99	0.04	53
Oct.	88.4	63.0	75.7	94	0.12	51
Nov.	76.4	46.8	61.6	85	–	56
Dec.	64.0	42.9	53.5	73	1.56	75

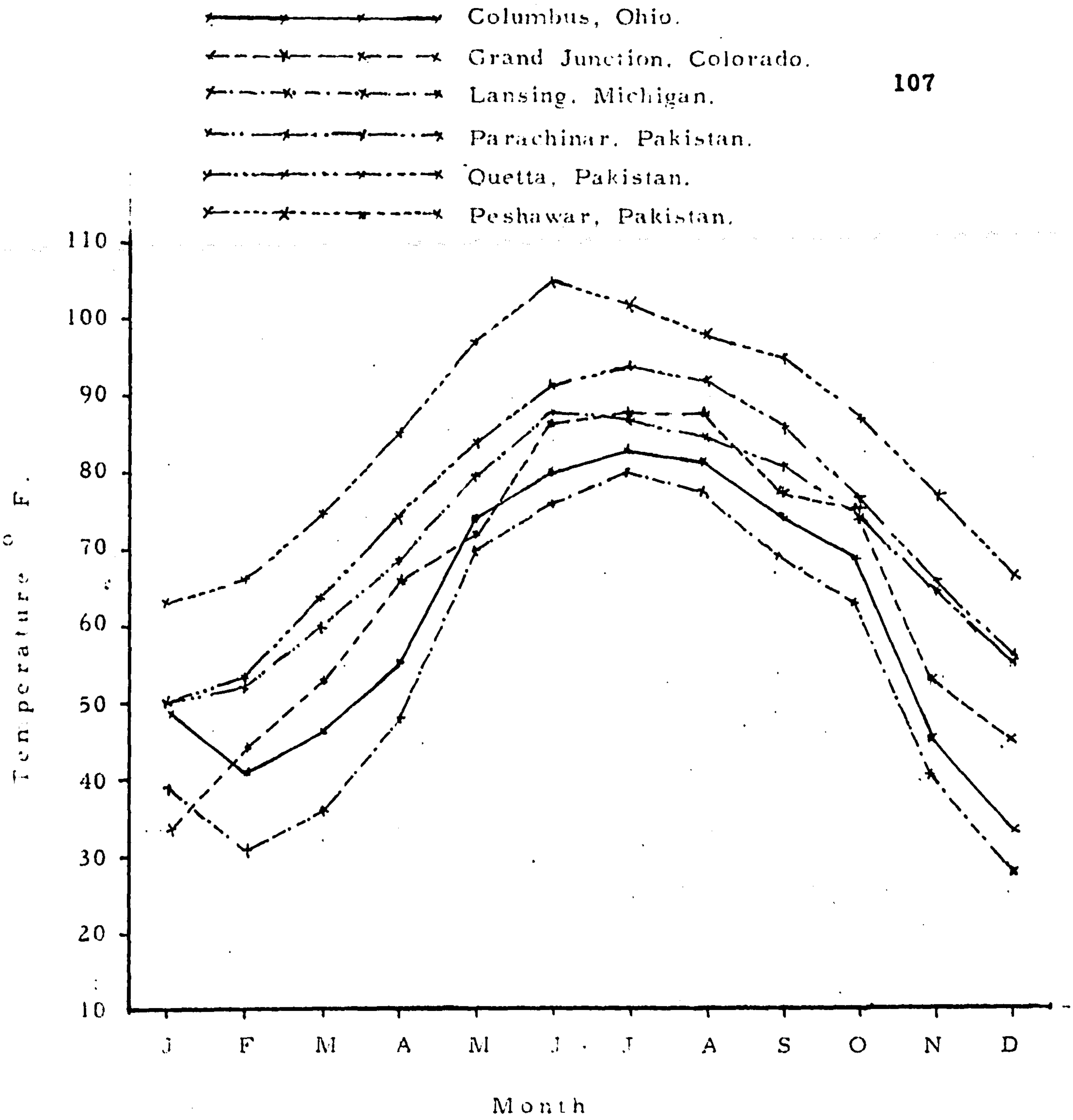

FIGURE 14

MEAN MAXIMUM TEMPERATURE °F. 1950

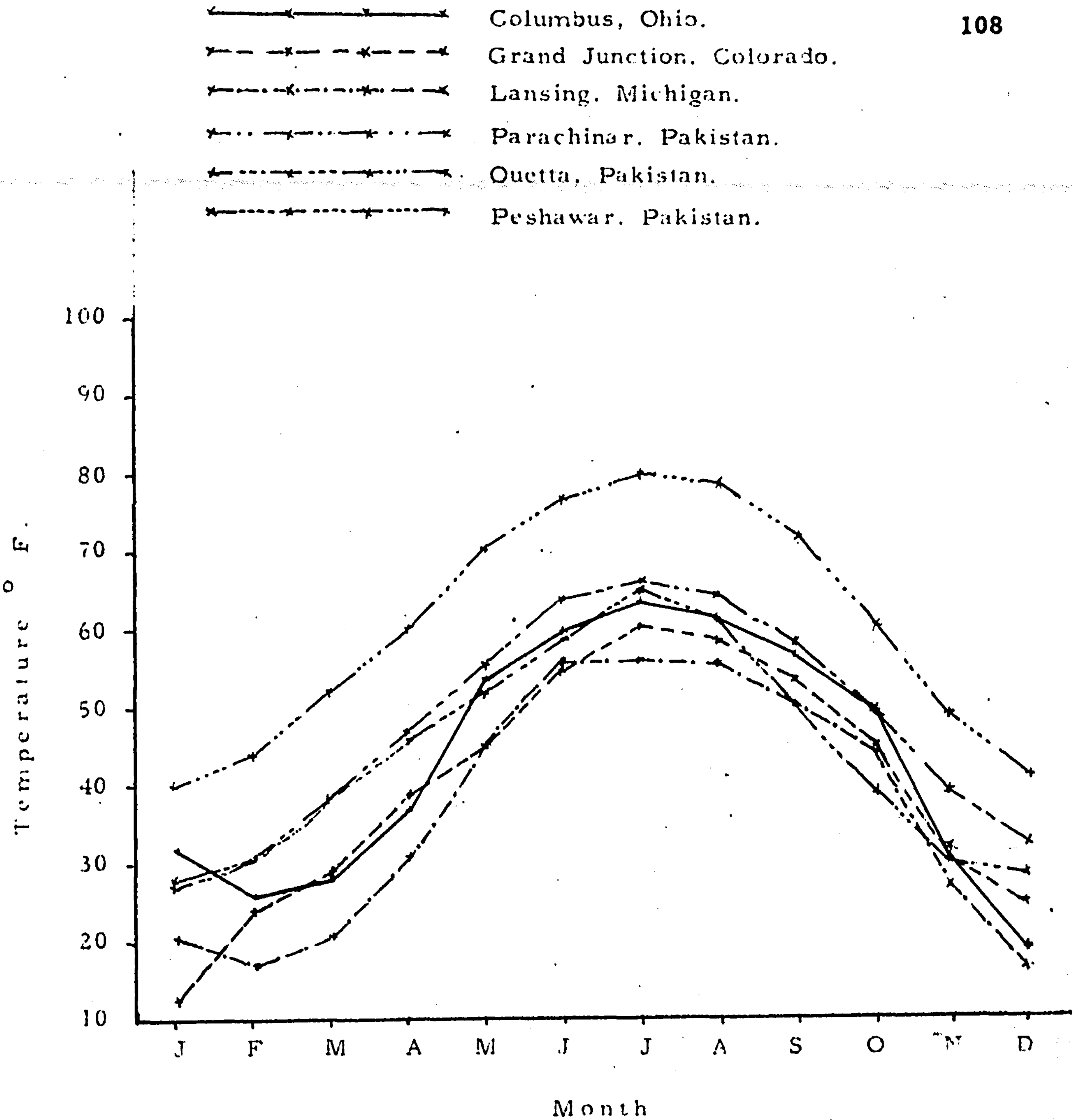

FIGURE 15

MEAN MINIMUM TEMPERATURE ° F. 1950

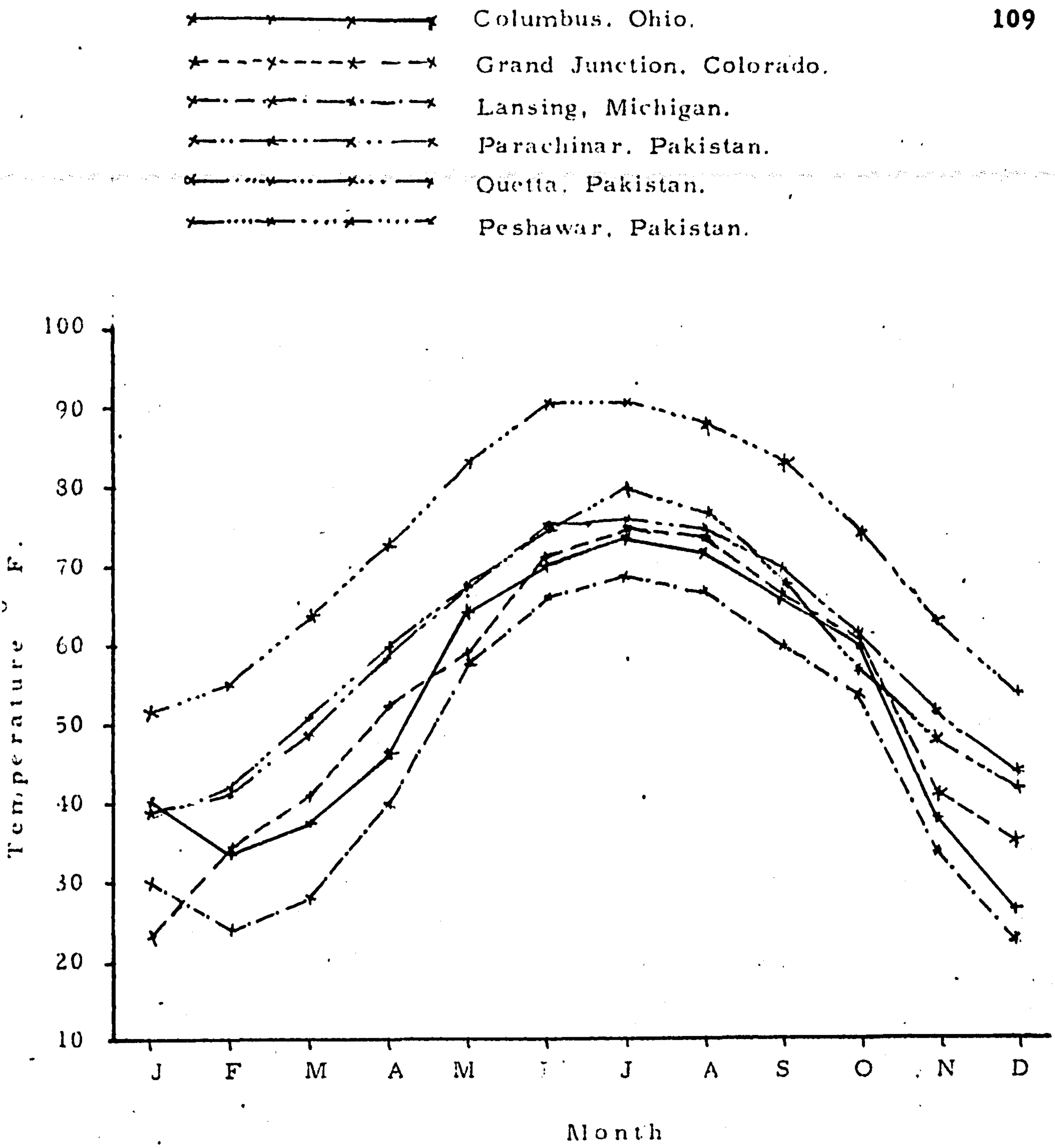

FIGURE 16

AVERAGE MONTHLY TEMPERATURE ° F. 1950

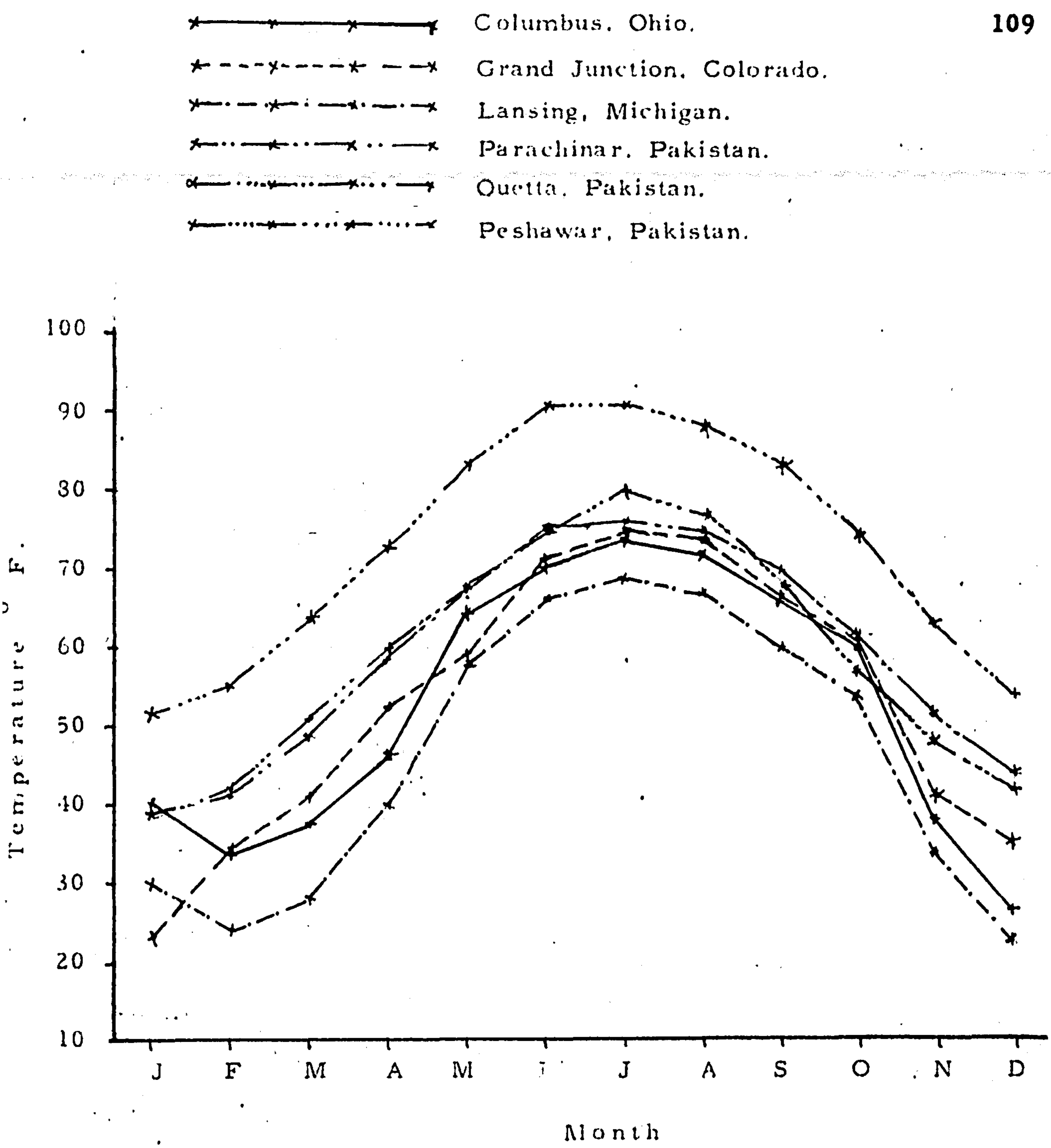

FIGURE 16

AVERAGE MONTHLY TEMPERATURE ° F. 1950

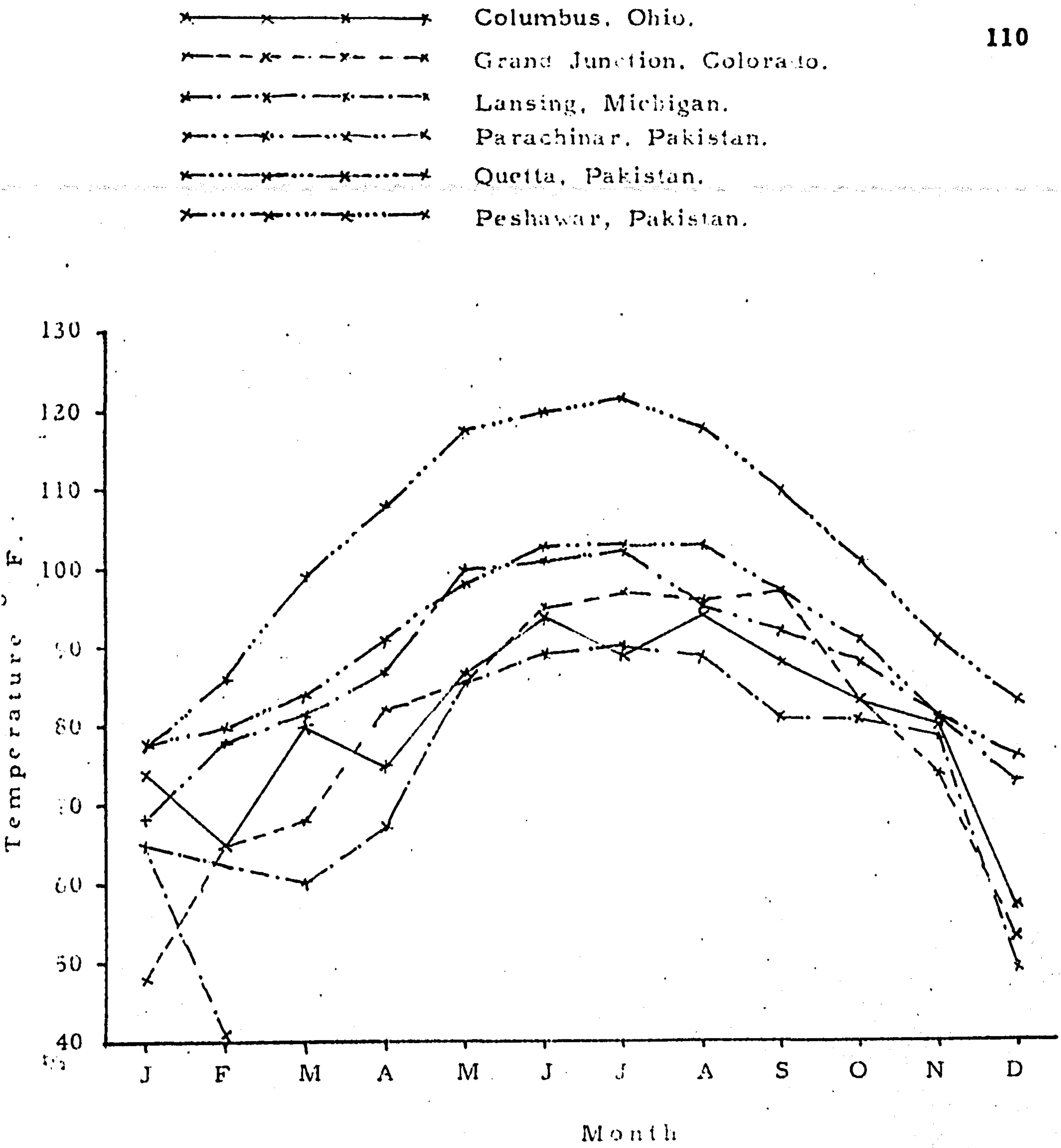

FIGURE 17

HIGHEST TEMPERATURE ° F. DURING THE MONTH, 1950

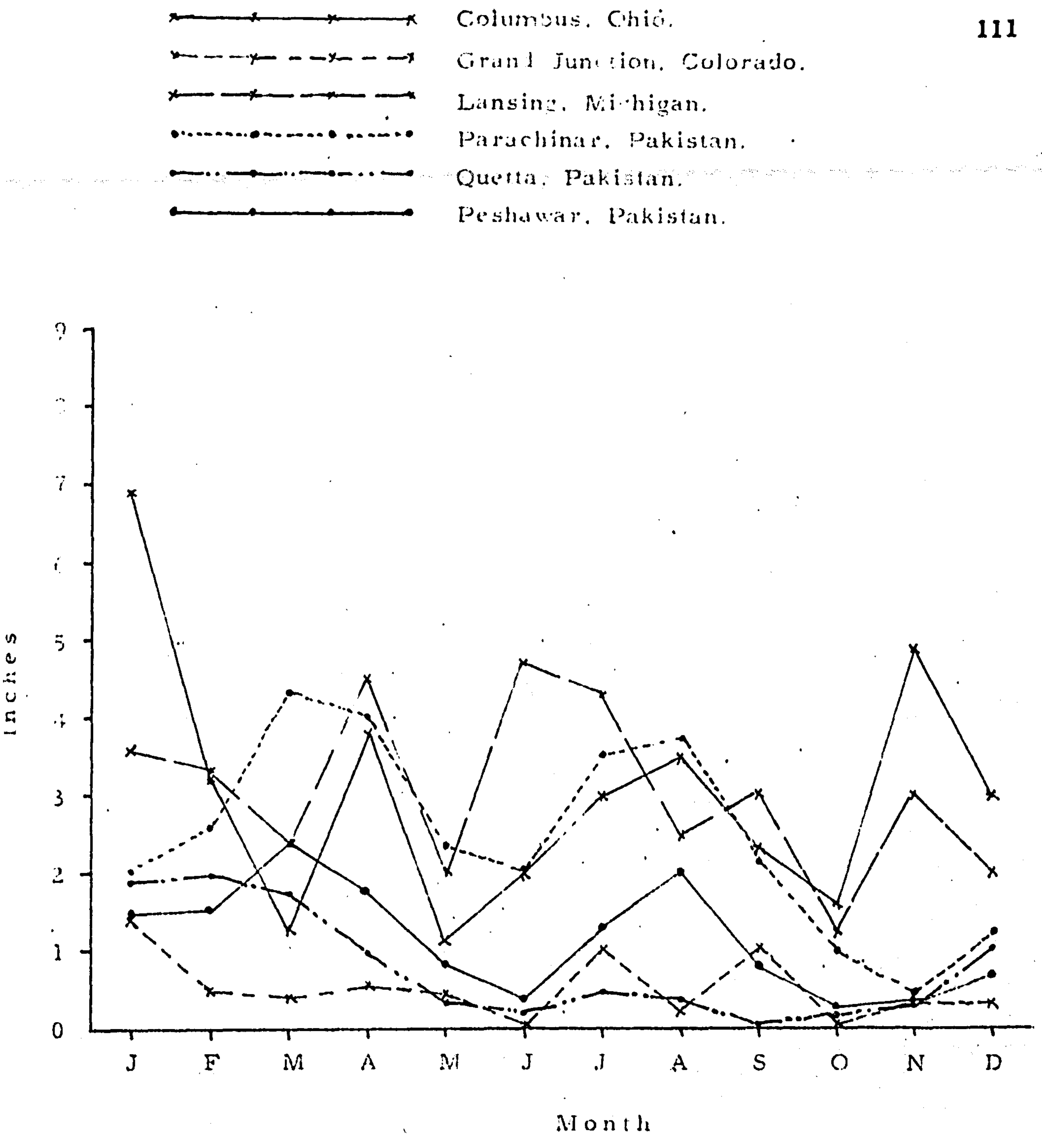

FIGURE 18

MONTHLY RAINFALL, 1950

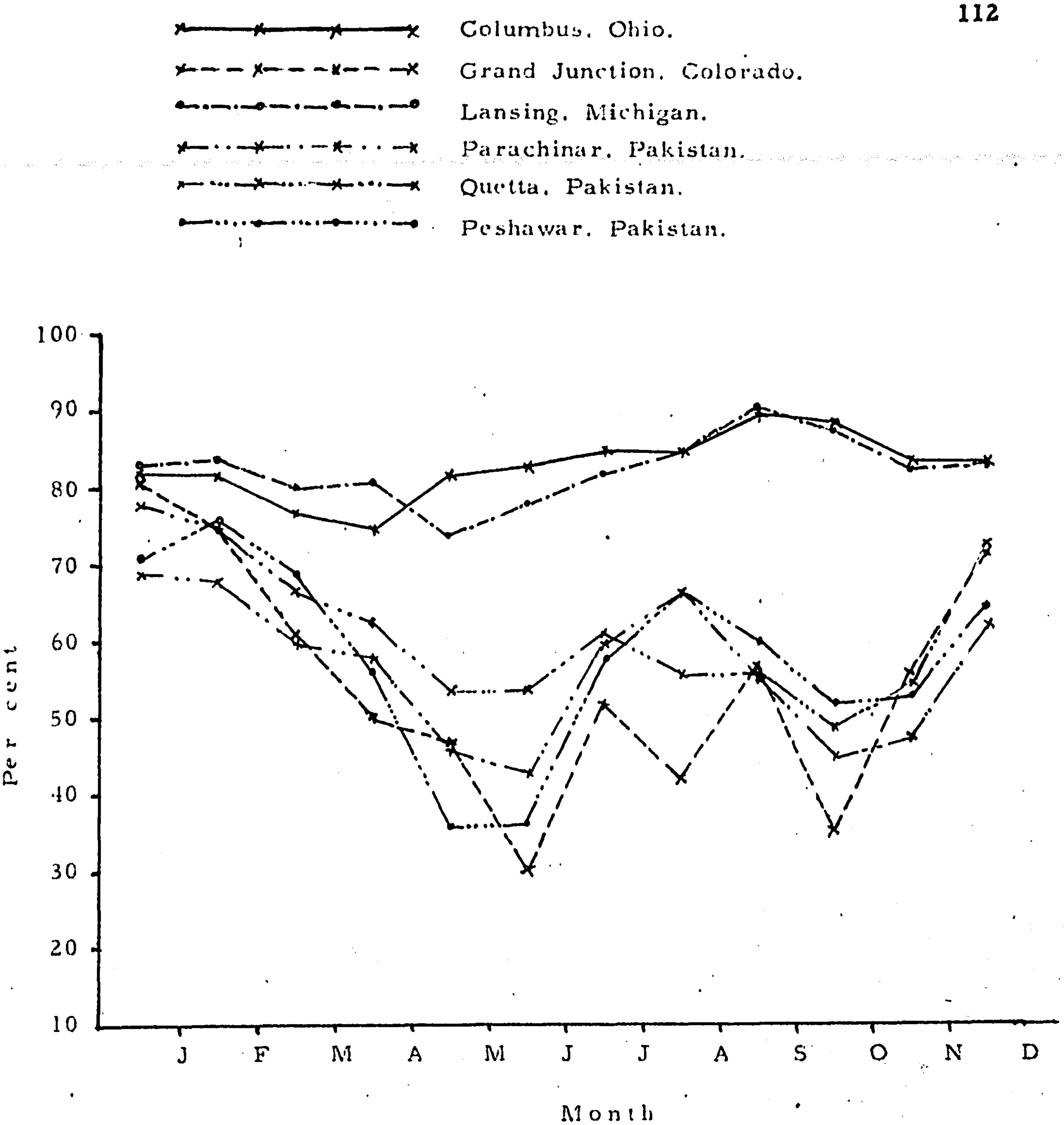

FIGURE 19

MEAN RELATIVE HUMIDITY, 1950

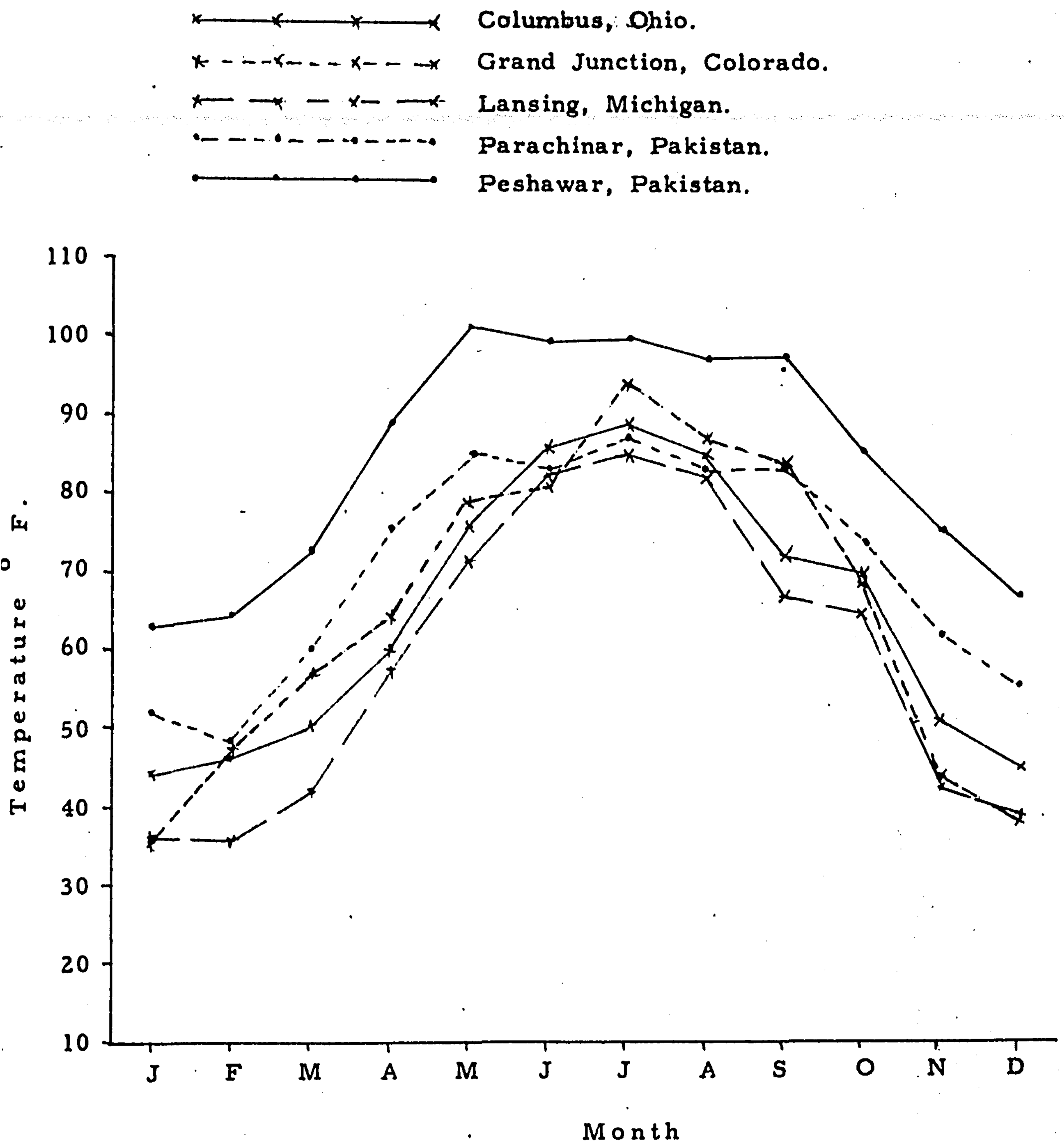

FIGURE 20

MEAN MAXIMUM TEMPERATURE °F. 1949
(Grand Junction - 1947)

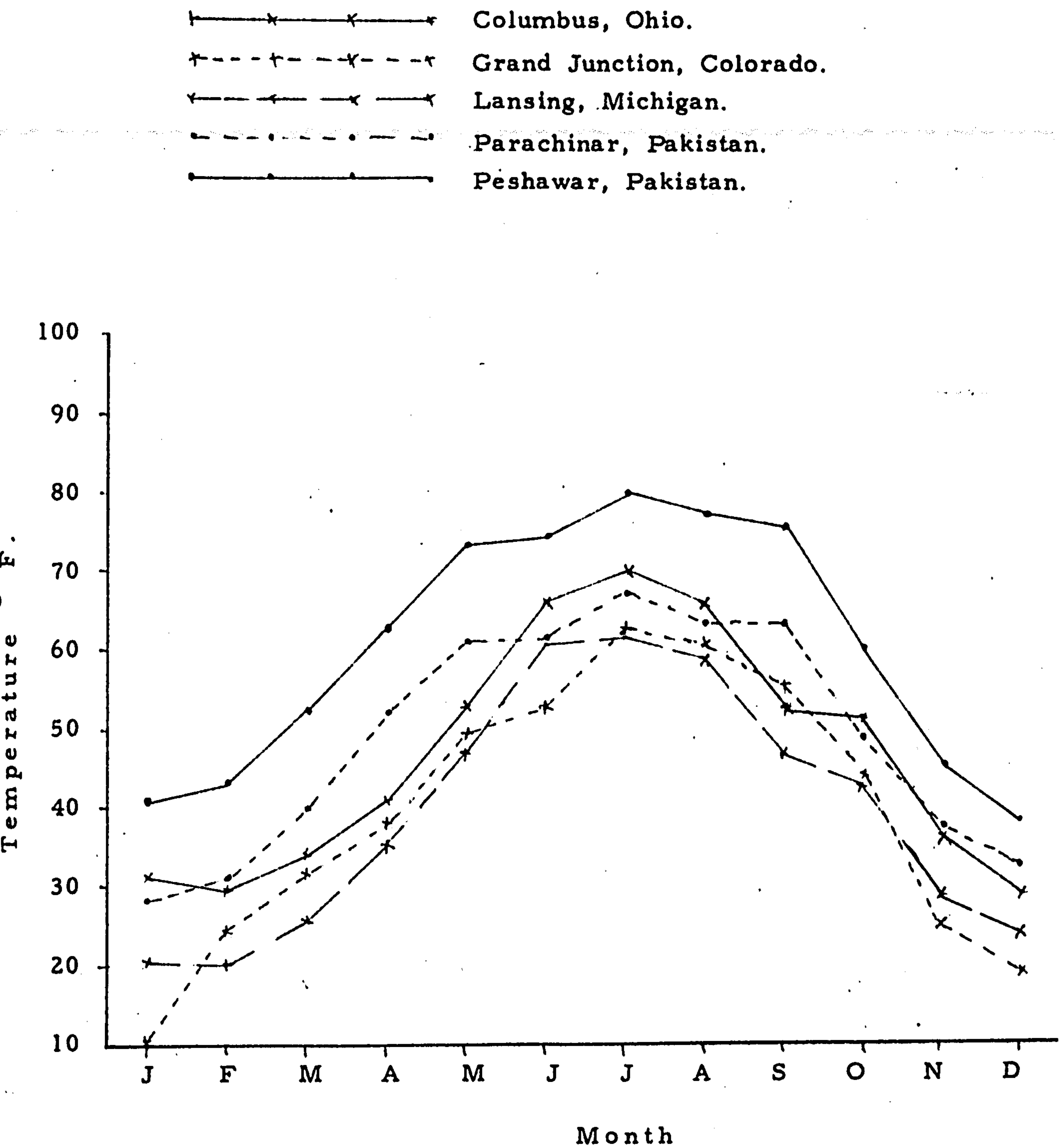

FIGURE 21

MEAN MINIMUM TEMPERATURE ° F. 1949
(Grand Junction - 1947)

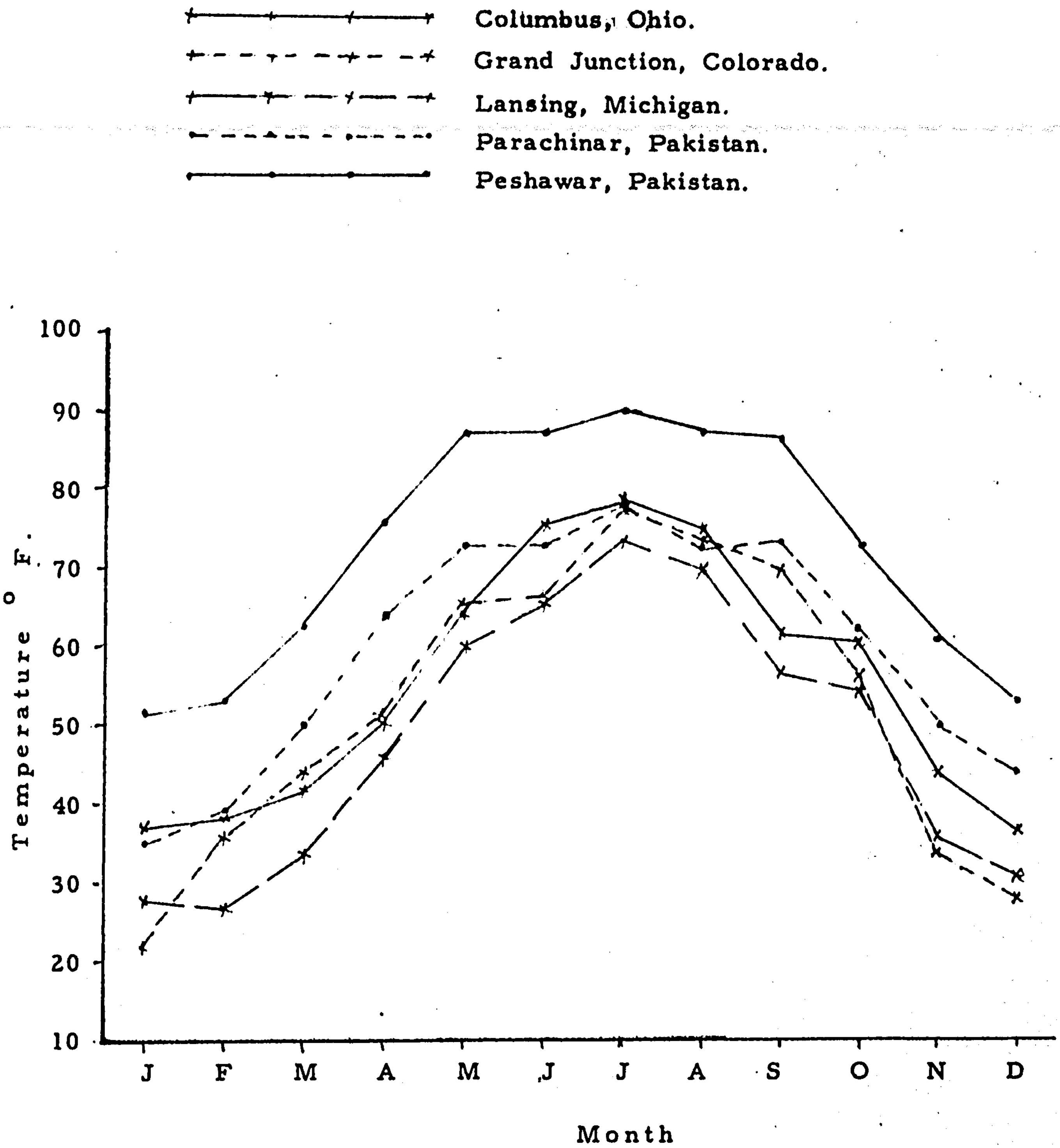

FIGURE 22

MEAN MONTHLY TEMPERATURE ° F. 1949
(Grand Junction - 1947)

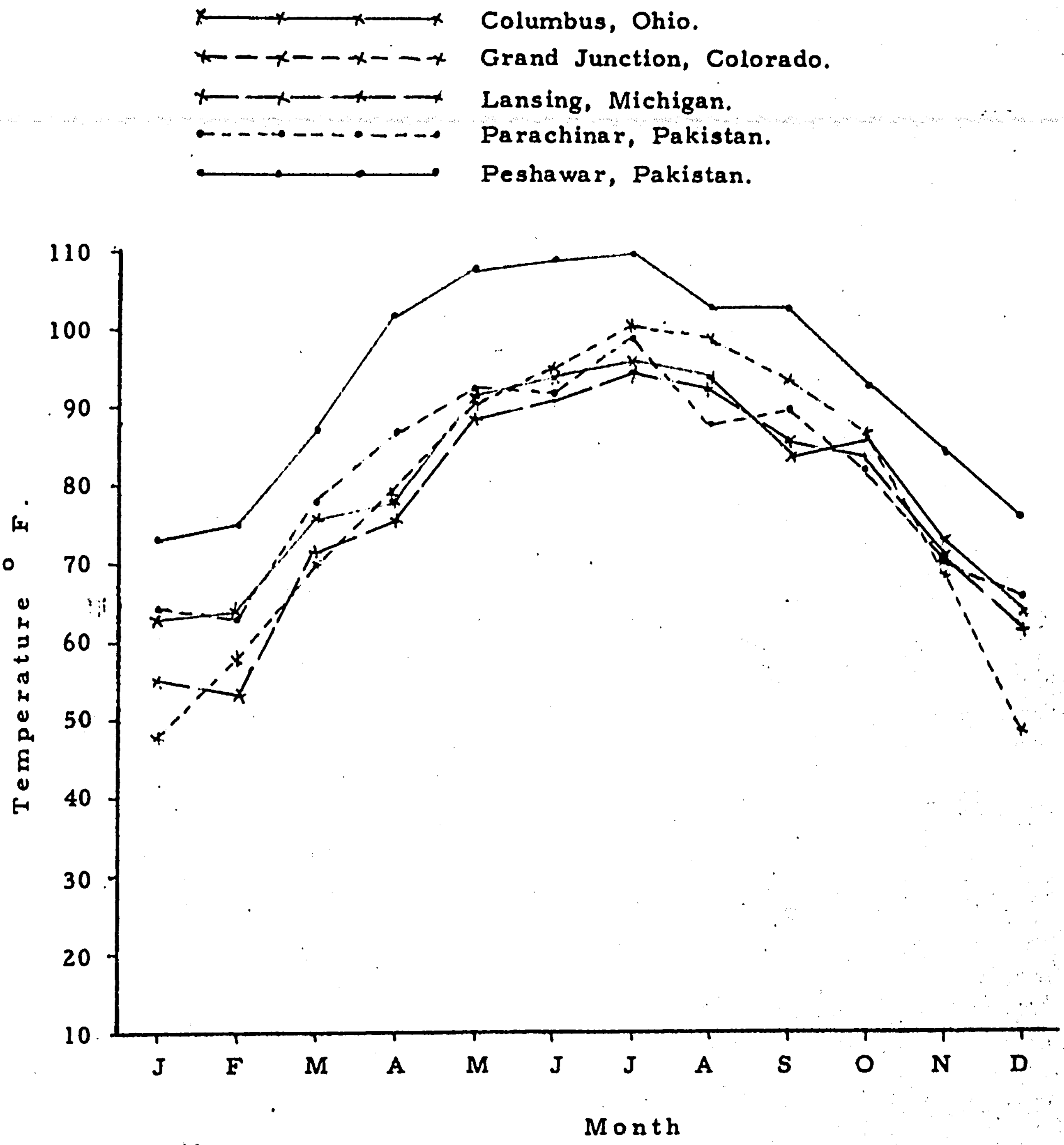

FIGURE 23

HIGHEST TEMPERATURE °F. DURING THE MONTH, 1949
(Grand Junction - 1947)

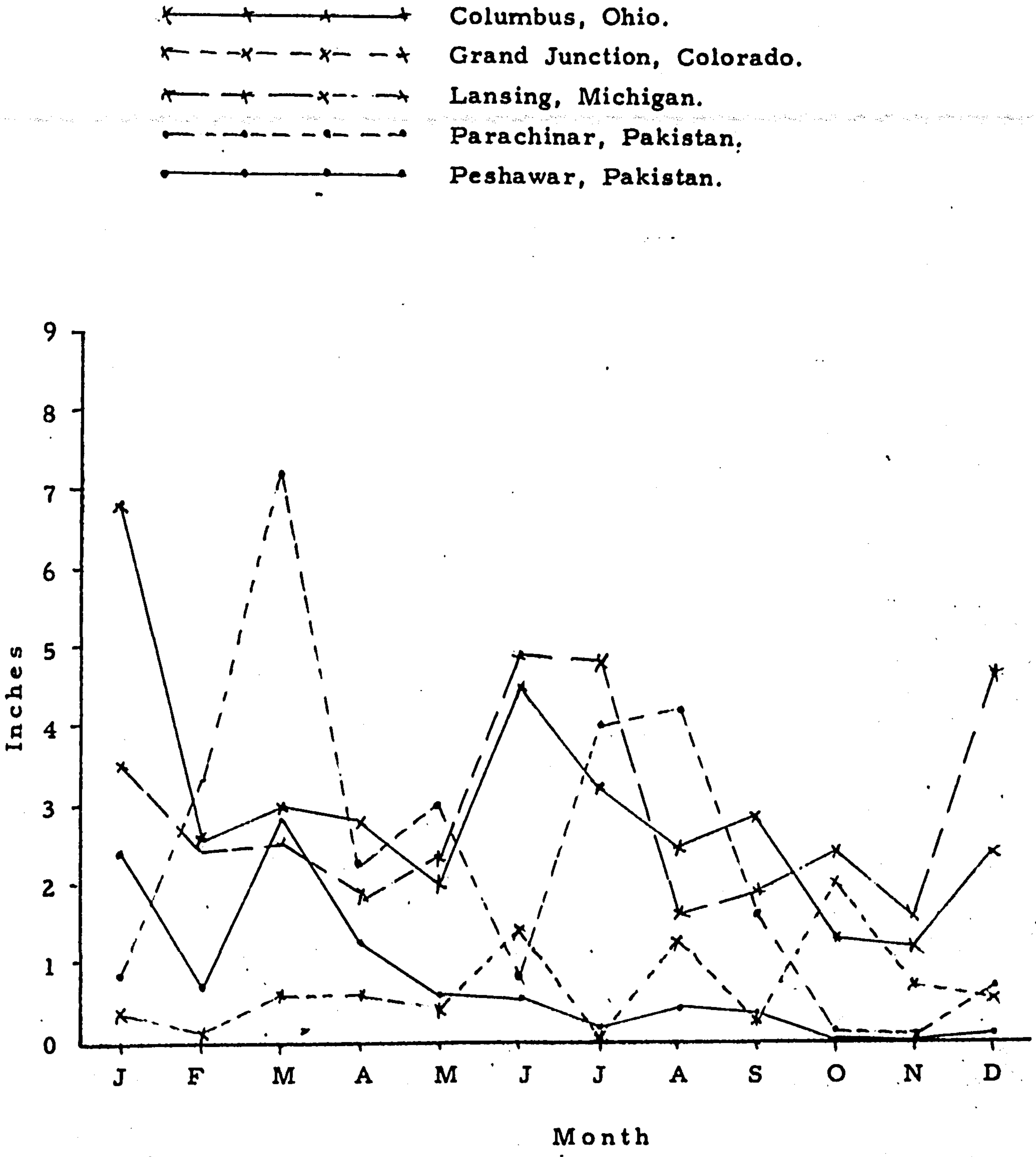

FIGURE 24

MONTHLY RAINFALL, 1949
(Grand Junction - 1947)

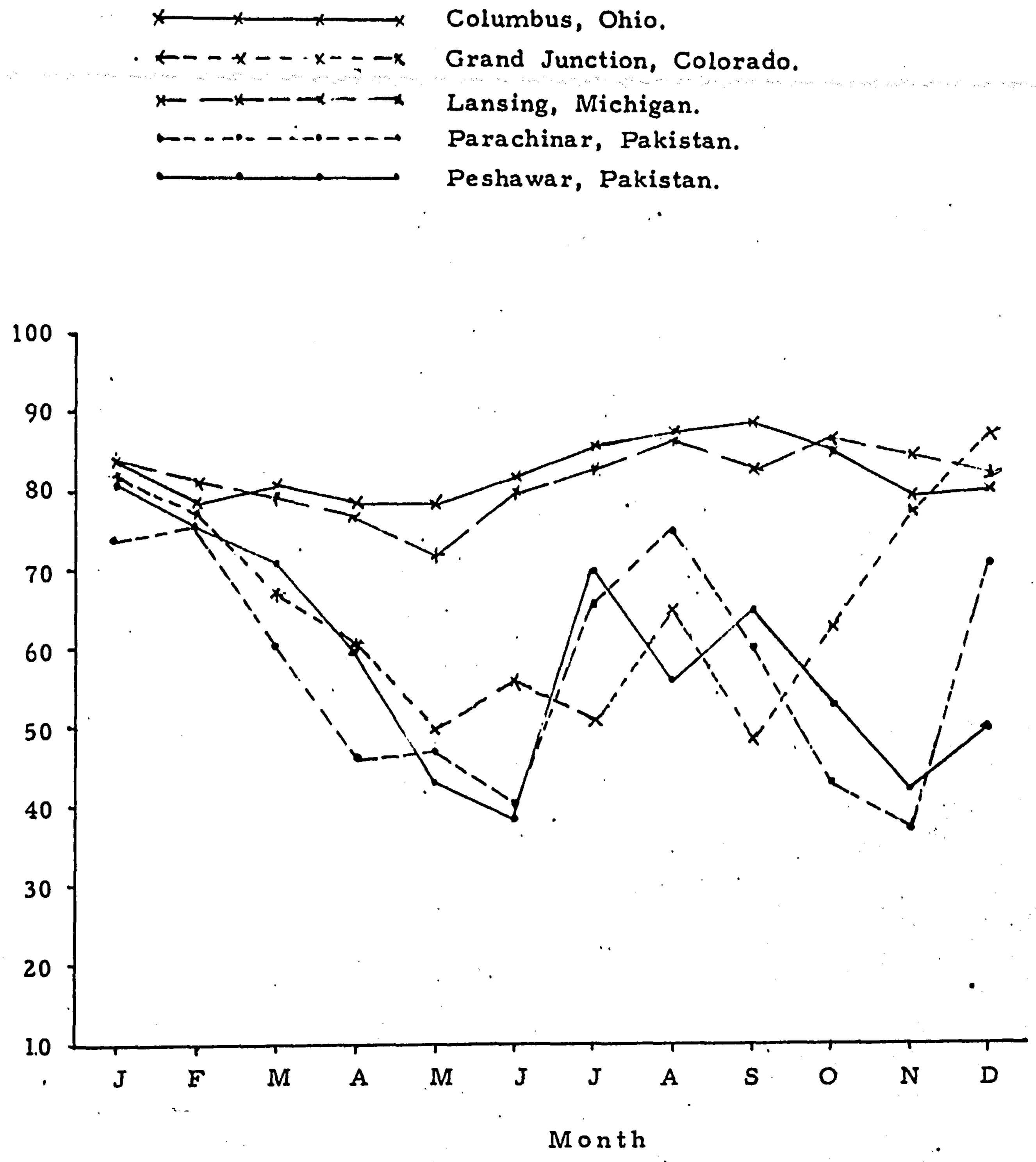

FIGURE 25

MEAN RELATIVE HUMIDITY, 1949
(Grand Junction - 1947)

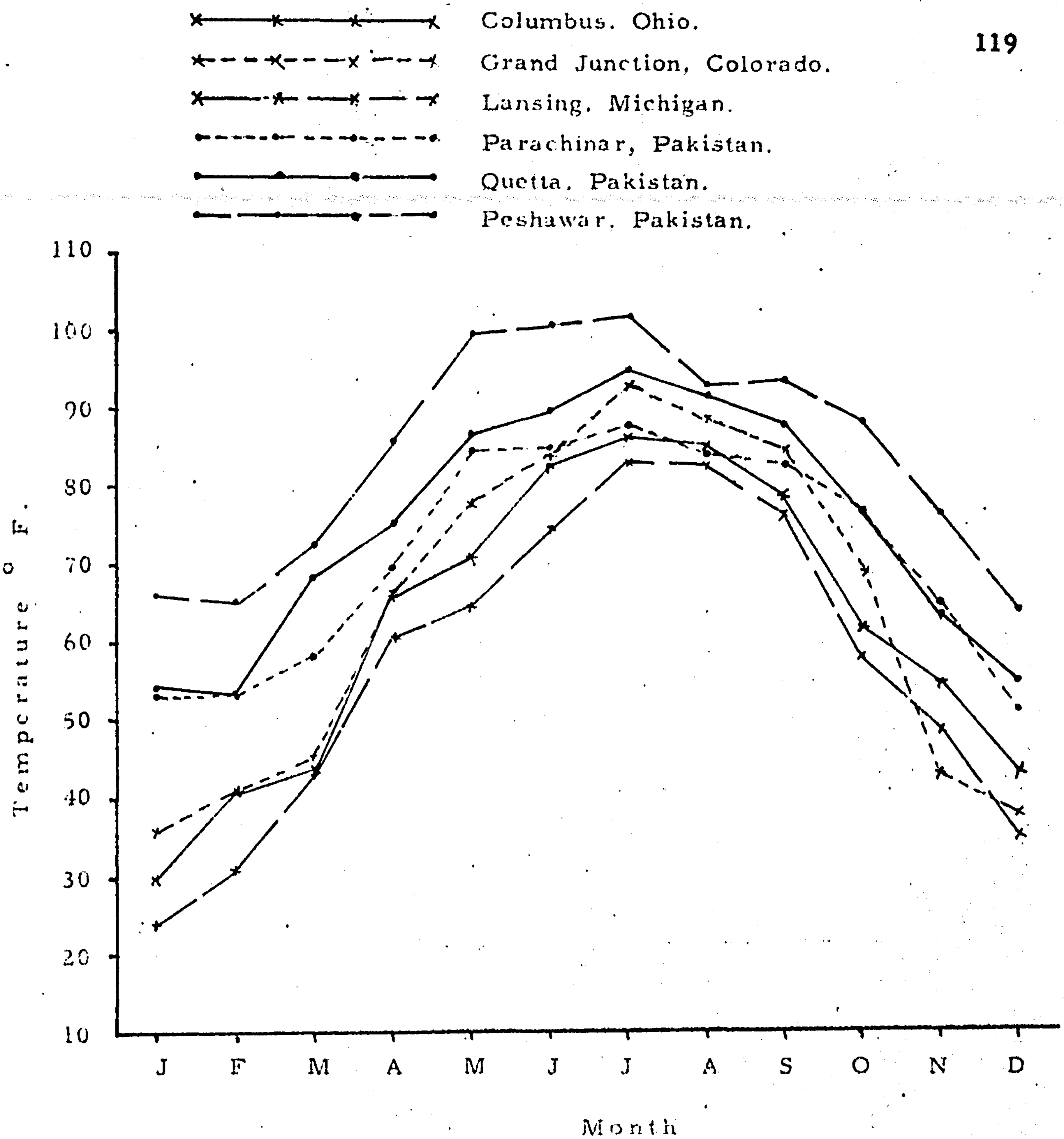

FIGURE 26

MEAN MAXIMUM TEMPERATURE ° F. 1948

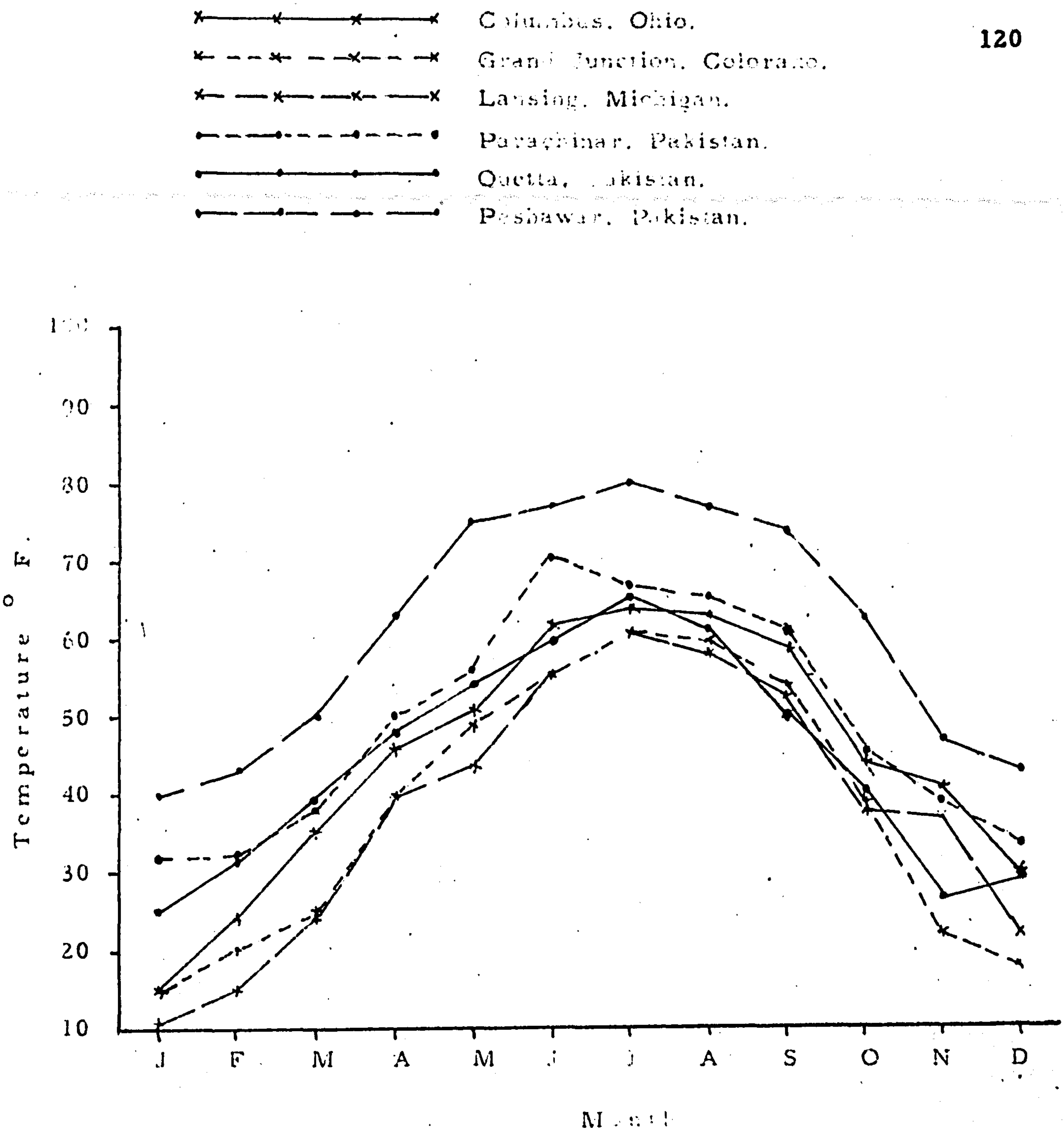

FIGURE 27

MEAN MINIMUM TEMPERATURE ° F. 1948

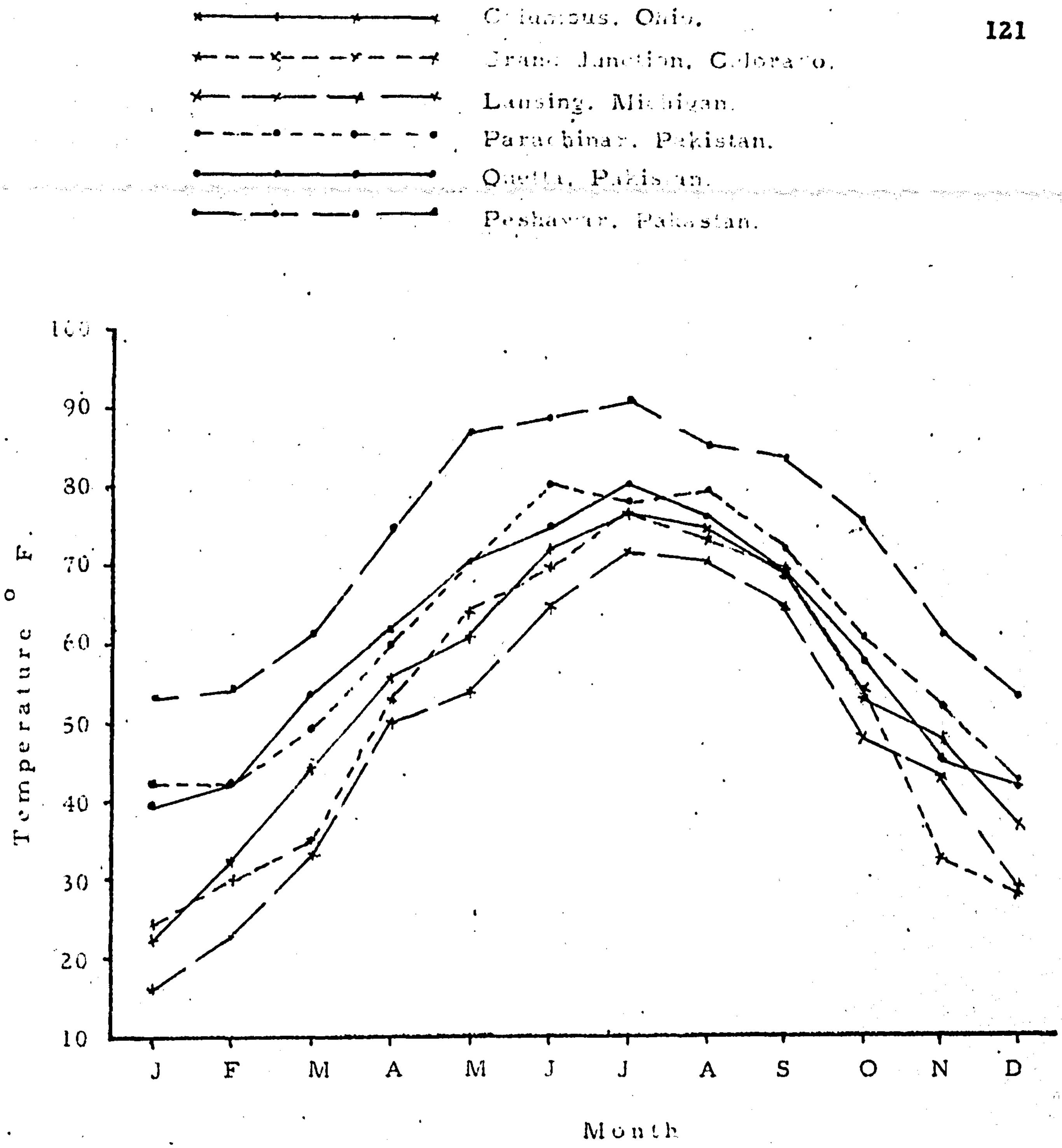

FIGURE 28

MEAN MONTHLY TEMPERATURE ° F. 1948

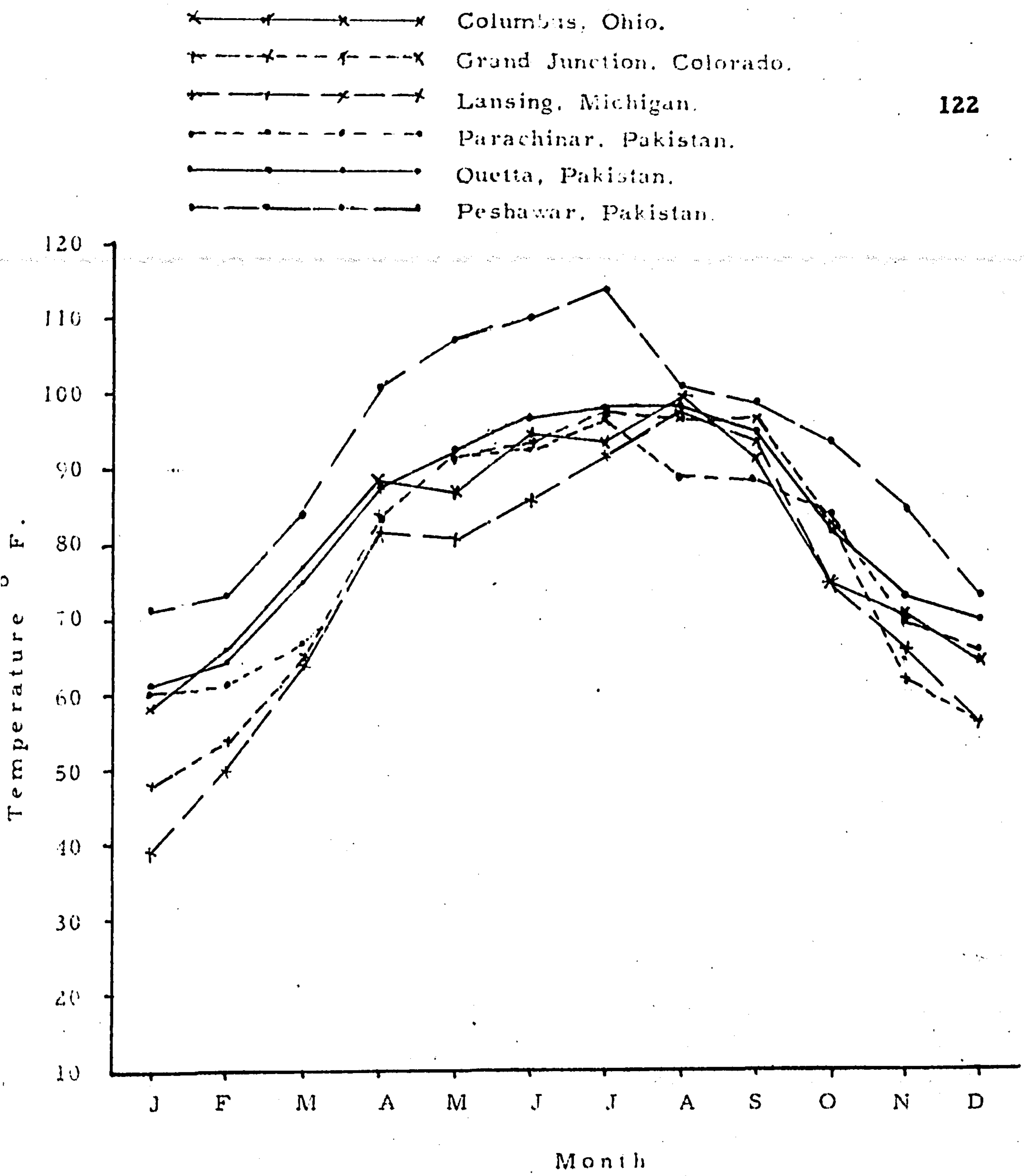

FIGURE 29

HIGHEST TEMPERATURE °F. DURING THE MONTH, 1948

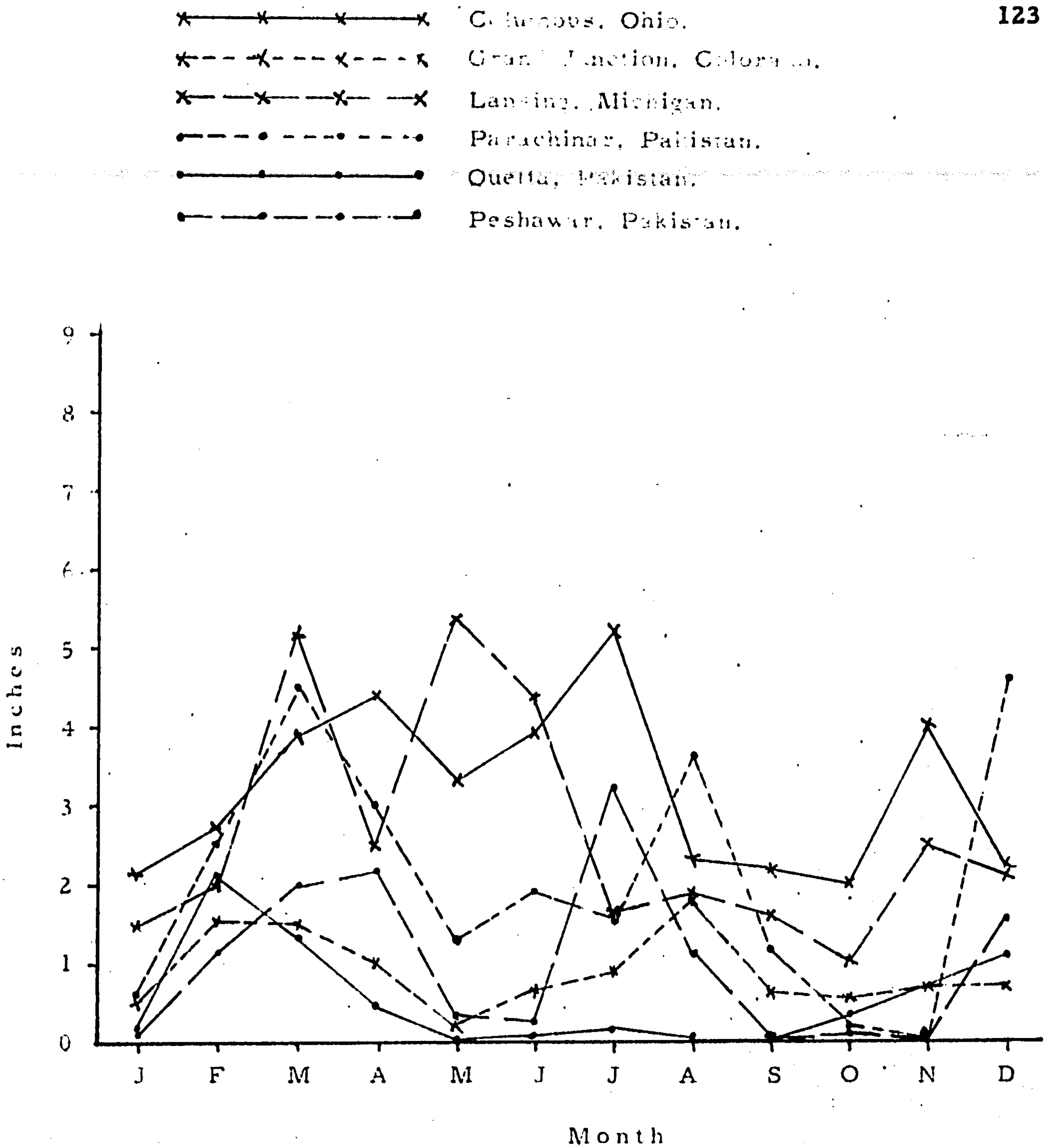

FIGURE 30

MONTHLY RAINFALL, 1948

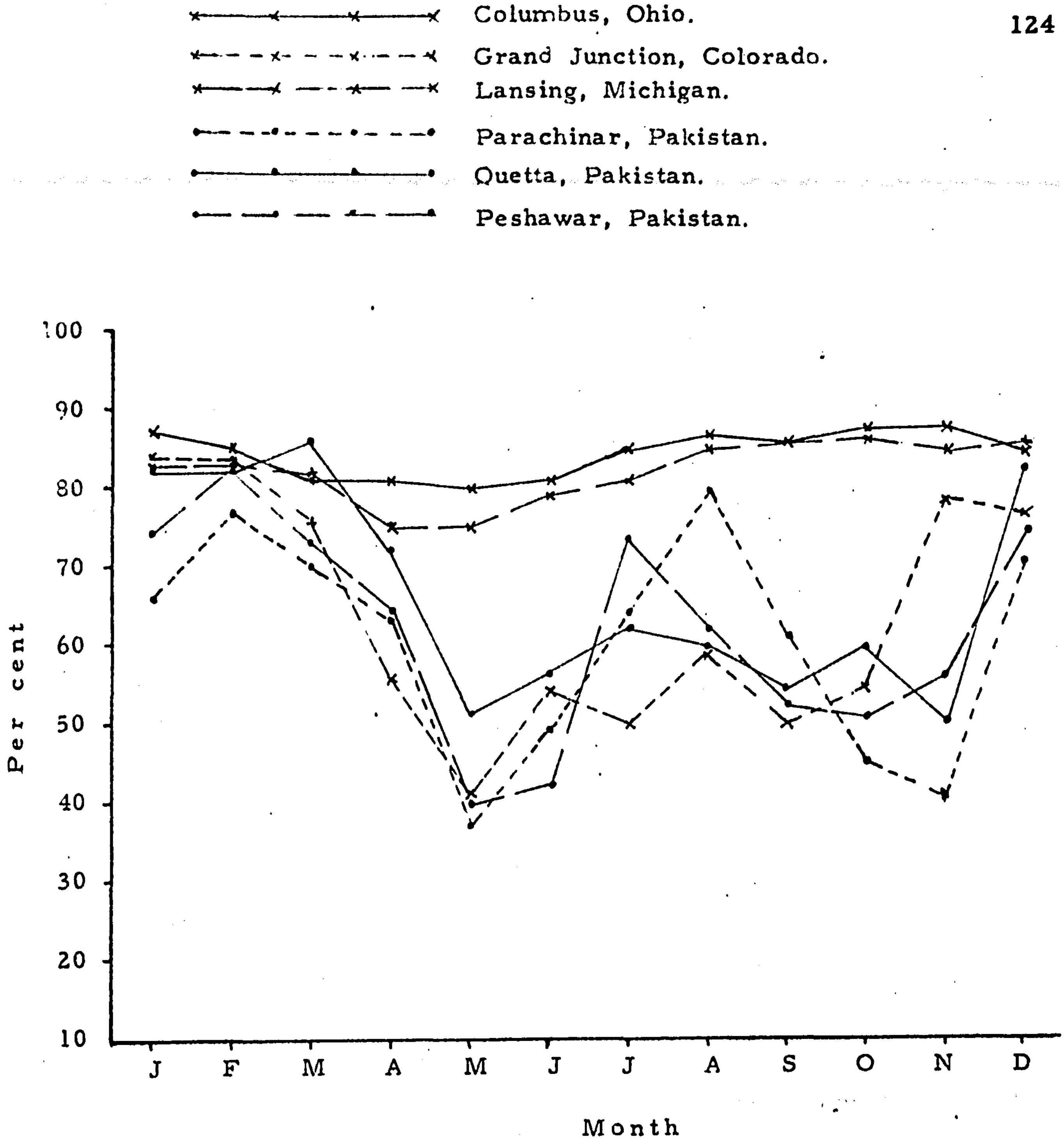

FIGURE 31

MEAN RELATIVE HUMIDITY, 1948

at Grand Junction; 76.2° to 80.5° F. at Lansing; 84.7° to 87.7° F. at Parachinar; 91.6° to 94° F. at Quetta; and 98.2° to 105° F. at Peshawar; respectively. The mean maximum for September 1950 was 74.7° F. at Columbus, 78.3° F. at Grand Junction, 69.6° F. at Lansing; 81.2° F. at Parachinar, 86.2° F. at Quetta and 95° F. at Peshawar. The temperatures for other months in the year are on the whole much higher in Pakistan than those in the United States of America for the stations under discussion. The highest temperature during the year 1950 was 94° F. in August at Columbus, 94° F. in July and September at Grand Junction, 90° F. in July at Lansing; 102° F. in July at Parachinar, 103° F. in June, July and August at Quetta and 122° F. in July at Peshawar. During 1948 the highest temperatures at Parachinar and Quette were below 98° F., almost the same as those at Columbus, Grand Junction and Lansing. Other figures for 1948 and the figures for 1949 show almost the same trend with slight variations from those for 1950. On the whole the temperatures for Pakistan stations were a few degrees higher than those for U. S. A. stations. The temperatures were within the upper vital limits for the various stages of the oriental fruit moth at Parachinar and

Quetta. The averages of daily minima and mean monthly temperatures were generally a few degrees above in the case of Parachinar and Quetta as compared to those for the stations in U. S. A. These temperatures were near the optimum for the oriental fruit moth especially during summer and fall; and would not affect its development deleteriously. At Peshawar the temperatures often time were much beyond the upper vital limits of this insect.

Rainfall at Columbus, Lansing and Parachinar during May to September every year was generally the same but was much more than that at Grand Junction and Quetta. The last two places had almost an equal amount of rainfall during that period.

The data with regard to relative humdity is rather interesting. At Columbus and Lansing it was rarely below 80%, usually between 80 and 90% throughout the year. Relative humidity at Grand Junction varied from 30-60% during May to September, with a marked tendency towards the lower side. The intensity of attack of the oriental fruit moth is highest at Columbus and least at Grand Junction. Although the pest is present at the latter place it has seldom attained the status of a major pest. This corroborates the findings in the laboratory based on constant temperature and humidity experiments, that low humidity, particularly in late summer and early fall is highly detrimental for the development of the oriental fruit moth. This probably limits the geographic distribution of this species.

In spite of good rainfall at Parachinar during May to September the relative humidity remained low. It varied from 40 to 70%, oftener between 50 and 60%, rarely going up to 75-80%. Parachinar is situated on a slope in the mountains. It appears that quick drainage of rainwater to lower levels prevents the rise of relative humidity. There were 5-7 rainy days every month and big downpours on a few days. These factors also would tend to keep the humidity low. The relative humidity at Quetta during May to September usually remained between 50 and 60% every year. Thus Quetta is similar to Grand Junction with regard to humidity but has higher temperatures. At Peshawar relative humidity was generally between 50-60% and the temperatures mostly high, often time going beyond the upper vital limits for the oriental fruit moth.

There is, therefore, little likelihood of this pest getting established at Peshawar. The codling moth with which the oriental fruit moth is often compared, is not known to exist at Peshawar. There are more chances for the oriental fruit moth to get introduced into Quetta area, particularly at Ziarat (elevation over 8,000 ft.) which receives more rainfall in summer. The probability of this insect becoming at least a minor pest in Parachinar area is rather high if by any chance it gains access to this region. The codling moth is already doing serious damage in Quetta and Parachinar; where it is believed to have been introduced not long ago. There may be several other regions in Pakistan and India, particularly in Kashmir where the oriental fruit moth could get established, if introduced. There are some areas where in all probability it would not become a pest, e.g., Peshawar; but there are other regions with meteorological conditions similar to those in the United States of America, where the insect could become a pest. It is, therefore, necessary on the part of the plant quarantine organizations of those countries to continue to adopt strict quarantine measures in order to check the introduction of the oriental fruit moth.

VII. SUMMARY AND CONCLUSIONS

The development and fecundity of the oriental fruit moth was studied under controlled temperatures of 60°, 65°, 85° and 95° F.; and relative humidities of 35, 70 and 100 per cent. The average incubation period was 7.0 days, 7.5 days and 8 days at 60° F. under relative humidities of 100%, 70% and 35%, respectively. The minimum incubation period was 2.75 days at 94° F., thereafter it increased to 3.5 days at 95° F. A large number of eggs withstood an exposure of 40 hours at 98° F., but an exposure of 48 hours proved fatal. An exposure of 21 hours to 105° F. reduced the viability of eggs to 25-43% and increased the incubation period by 36-40 hours.

The influence of relative humidity on the development of eggs though significant was not well-marked. The eggs hatched a couple of hours earlier under 70% humidity than those under low and high humidity except at 50.5° and 60° F. At 50.5° F. the incubation period was 24 days under 100% relative humidity and 25 days under 70% relative humidity. At 94° and 95° F. the eggs did not hatch under 35% relative humidity. The influence of relative humidity seemed to be more marked on the viability of the eggs than on the incubation period.

It is evident from the data that the eggs of the oriental fruit moth can tolerate fairly high temperatures and low humidities. Perhaps the flattened and scale like form of the eggs helps them in resisting the effect of adverse conditions.

The average feeding period of the larvae varied from 36.81 days at 65° F. to 18.0 days at 95° F. There were large individual variations within one lot of larvae kept under uniform conditions.

The duration of the pupal stage decreased with the rise of temperature from 19 days at 65° F. to 11 days at 95° F. The rate of development decelerated beyond 75° F. The temperature at which the larvae were grown had a distinct influence on the duration of the pupal period at another temperature. Pupae kept at 65° F. formed from larvae grown at 85° F. had a longer pupal duration as compared to those at other combinations of temperatures. The pupal period was found to be shortest under 100% and longest under 35% relative humidity. A low relative humidity was highly detrimental to pupae kept at 85° F. when their egg and larval periods had been at 65°

or 75° F. Usually the viability of pupae was about one and a half times the figure for 70% relative humidity. For pupae, at 65° F. and 35% relative humidity, formed from larvae grown at 85° F. it was less than one-third as compared to those kept under a saturated condition. The viability of pupae was always highest under saturated atmosphere at all the combinations of temperature tried. This means that in areas of low humidity in late summer and early fall a less number of moths emerge. Consequently, the damage to fruits in those areas is likely to be negligible. On the other hand places which are more humid may have larger emergence of moths, and proportionately greater damage to fruits from the late broods of larvae.

The theoretical threshold of development for eggs is found to be 40°-44° F. depending upon the relative humidity; lowest under 100%; and, highest under 35% relative humidity. For larvae it is 43.5° F.; whereas for pupae it varies from 46.5° F. to 52.5° F. under relative humidities of 100% and 35%, respectively. Under moist conditions the eggs and the pupae (two stages affected by humidity) continue development at lower temperatures, compared to those exposed to dry conditions. In areas with moist climate, particularly those having relative humidities varying from 80 to 90% the insect can start development early in spring and thus increase to large proportions and cause serious damage. The differences between thresholds of development for various stages at high and low humidities are more for the oriental fruit moth than in the case of the codling moth; showing that the former prefers more moist conditions for its development.

The larvae of the oriental fruit moth were found to enter into a short diapause for a period of 31 to 60 days, and, a long diapause with a duration of over 60 days under various temperatures and humidities. The largest number and longest period of "short diapause" was in the case of larvae reared at the optimum temperature of 75° F. and kept as cocoons at 75° or 85° F. Comparatively more larvae entered short diapause under drier conditions.

The maximum duration of "long diapause" including the pupal period was 241 days at 65° F. (larvae grown at 65° F.), 184 days at 65° F. (larvae reared at 85° F.), 162 days at 65° F. (larvae reared at 75° F.), 126 days at 75° F. (larvae reared at 75° F.). Except for those larvae kept permanently at 65° F., the higher the temperature from which they were transferred to 65°, the longer the diapause. This is in agreement with the observations in the orchards. Larvae hibernating early in fall or summer when the temperatures are high have a longer diapause than those hibernating later in the season. The hibernation was most successful under 100% relative humidity. These investigations have shown that photoperiodism did not have any appreciable effect on the induction of diapause, as 64.3% and 50% larvae successfully completed diapause and emerged as moths, even though they were grown in total darkness at 65° F. and 75° F., respectively. The real cause which initiates diapause in the larvae of the oriental fruit moth appears to be inherent and is to some extent influenced by the nature and quality of food on which they are fed.

The percentage of moths emerging under different conditions is given. Under 35% relative humidity practically one hundred per cent of the moths emerged from the short cycle larvae, at most of the temperatures. In fact the only exception was at a constant temperature of 75° F. Generally about half of the total moths emerged from long cycle larvae if the relative humidity had been 100% during the cocoon period; about one-third if it had been 70%; and nil with 35% relative humidity, except 7.7% at 75° F. This indicates that the larvae of the oriental fruit moth, in areas where low relative humidity prevails during late summer and early fall largely emerge as moths and not go into hibernation. If the conditions are dry very few larvae enter into diapause or complete it successfully. A smaller number of moths emerge in the following spring on the return of favourable conditions. On the other hand, a substantially larger number of larvae may enter diapause and complete it successfully, if the relative humidity to which they are exposed during the cocoon period is high enough. The latter adaptation ensures greater survival of this species in regions where high humidity prevails in late summer and fall. Thus the present geographic distribution of the oriental fruit moth appears to be largely governed by the relative humidity prevailing from July to November, the period when larvae enter diapause. In humid areas G. molesta is far more abundant than in the drier regions. This difference is explained here by the influence of relative humidity on its development and on the successful completion of larval diapause.

The optimum range of temperature for egg laying was 75° to 85° F. The moths laid eggs when kept in darkness but the total number of eggs laid was less. The females emerging from the hibernating material laid very few eggs as compared to those from the short cycle larvae. The fecundity of moths emerging from material at low humidities was lower than that of those with preimaginal life under high humidities. Moths emerging from material grown at an ordinary room temperature of 70-80^{o} F., laid 74.5 eggs per female during the period September 24th to October 15, 1950. In the months of November, 1950, to April, 1951, the average per female varied from 3.3 to 9.6 eggs in the laboratory. During May, 1951, the average increased to 57.1 eggs and to 65.4 eggs during June, 1951. There was wide fluctuation in the average number of eggs laid per female for different periods during the year in the laboratory, where temperature conditions were almost the same throughout the year. It appears that moths of successive generations even though fed on the same food lay varying numbers of eggs.

Meteorological data for the years 1948 to 1950 for three typical stations in the United States of America have been compared with those of three places in Pakistan. There is little likelihood of the oriental fruit moth getting established in places where low humidity prevails during summer and fall as the pest develops best under high humidities of 80-90%. The probability of this insect becoming at least a minor pest in places like Parachinar, (Pakistan) where the maximum temperature seldom goes above 98^{o} F. and the relative humidity is often around 50-60%, is rather high. It is, therefore, necessary on the part of the plant quarantine organizations of Pakistan and India to continue to adopt strict measures in order to check the introduction of the oriental fruit moth into those countries.

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