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Seasonal incidence of invasive tomato leafminer, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) on tomato in Karnataka, India

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Abstract
The tomato leafminer, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) is a recently invaded pest to India and causing havoc in both open field tomatoes and in protected crops. Present study was conducted to understand the influence of weather parameters on the *Tuta absoluta* in open field and in polyhouse tomatoes in *Kharif,* 2015 and *Rabi,* 2015-16. Infestation level of *T. absoluta* both in *Kharif* and *Rabi* was low during first crop phenologic cycle. Then *T. absoluta* density increased with age of crop under both polyhouse and field condition. In both *Kharif* and *Rabi* seasons, the incidence of *T. absoluta* showed the positive correlation with the maximum temperature. The adult moth trap catches per trap per week showed positive correlation with the maximum temperature in both *Kharif* and *Rabi* seasons. Based on the results it is inferred that, management should be initiated in the early growth period itself to avoid build-up of the pest in the later phenological cycle of the crop.

Keywords: tomato leafminer, *Tuta absoluta,* seasonal incidence, weather parameters

Introduction

Large scale movement of materials such as vegetables, fruits, ornamentals, planting materials, seeds, packaging material *etc.,* between countries invites the danger of the accidental introduction of insect pests. The problems due to such invasions are innumerable. Such introduced pests exploit the conducive nature of environment for breeding and establishment in the absence of natural enemies.

In last 25 years, at least 10 species of insect and mite pests have invaded India. These includes, the American serpentine leafminer, *Liriomyza trifolii* (Burgess) in 1990-91, the coffee berryborer, *Hypothenemus hampei* (Ferrari) in 1990, the spiraling whitefly, *Aleurodicus dispersus* Russel in 1994, the coconut mite, *Aceria guerreronis* Keifer in 1998, the whitefly, *Bemisia tabaci* biotype B in 1999, the sapota seed borer, *Trymalitis margaritas* Meyrick (Tortricidae: Lepidoptera) in 2000, the eucalyptus gall wasp, *Leptocybe invasa* Fisher and La Salle in 2006, the papaya mealy bug *Paracoccus marginatus* Williams and Granara de Willink in 2008, south American tomato moth, *Tuta absoluta* (Meyrick) in 2014 and the western flower thrips, *Frankliniella occidentalis* (Pergande) in 2015. Increased international trade and the movement of plant materials have increased the risk of invasive alien pest species, threatening cultivation of crops globally.

In the aforesaid list, the tomato has been the victim of these invasions. At least four out of 10 affects the tomato crop directly or indirectly. Tomato is a premier vegetable crop round the year and one of the prominent eco-industrial crops of India generating sizeable employment. Now it is well known fact that the tomato leafminer, *T. absoluta* (Meyrick) is well established in south India. The pest is native to Peru, where it is a serious pest on solanaceous vegetables [1], hence also called South American tomato moth. Tomato leafminer or South American tomato leafminer or tomato pin worm, *T. absoluta* (Meyrick) (Lepidoptera: Gelechiidae) is a serious pest on tomato (*Lycopersicum esculentum*) cultivation in several countries in Latin America and Mediterranean basin [2]. The pest has been spreading fast and devastating tomato crop both in protected and open fields. It is a Neotropical oligophagous pest mainly on solanaceous crops. Its primary host is tomato although potato, brinjal, common bean and various wild solanaceous plants are also suitable hosts [3]. The main reason for the spread of this pest is through infested fruits and packing material. The aggressive nature of the pest, multivoltine character, short generation time, high biotic potential and increased resistance to insecticide use are the reasons for its key pest status in the new localities [4].

Explosive spread and dissemination of *T. absoluta* is mainly correlated with fruit import and further distribution [4]. One of the possible pathways for a long-distance dissemination of *T. absoluta* could be through packaging materials (boxes) from infested countries [5]. Since the initial detection, this has become the most serious pest causing severe damage to tomato in many areas [6]. Cost-benefit analysis showed that *T. absoluta* significantly increased costs of pest management, primarily because of increased use of insecticides [7]. In India, incidence of the tomato leaf miner, *T. absoluta* (Meyrick) (Lepidoptera: Gelechiidae) was recorded for the first time on tomato at the Indian Institute of Horticultural Research (IIHR), Hessaraghatta, Bengaluru, Karnataka, during the *Rabi* season of 2014 [1] and then from Pune [8] and then in Malnad and in Hyderabad - Karnataka region [9]. Although the exact route of entry to India is unknown.

The tomato leafminer can cause crop losses up to 100% and it is considered a key pest of greenhouse and open-field tomato [10]. Introduced populations are probably resistant to the various group of insecticides and basic studies like invasion dynamics, life history, and reproductive biology are need of the hour to provide the information for its management [9]. Geographical location may also influence the other aspects of biology, diversity of insects in tomato ecosystem, potential natural dispersal and resistance to insecticides [10]. Keeping in view the points discussed above, the present investigation was undertaken.

2. Materials and methods

A. Seasonal incidence of *T. absoluta* both in polyhouse and field condition: The study was carried out in farmer's field and in College of Agriculture, Shivamogga during *Kharif* and *Rabi* season of 2015-2016. The tomato variety JKTH811 was grown over an area of 100 m^2 and seedlings were transplanted with a spacing of 60×45 cm. All the recommended cultivation practices were followed during the period of investigation except plant protection measures. In olyhouse condition, net plot size was 100 m^2 whereas in field condition net plot size was 500m^2. Date of sowing and transplanting in *Kharif* 2015 was May 8th and June 9th, respectively. Date of sowing and transplanting in *Rabi* 2015-16 was August 28th and September 30th, respectively.

To calculate the number of larvae and mines of *T. absoluta*, in a selected field, four quadrates of 5 m^2 area was selected. Weekly sampling was done from two weeks after transplanting untill harvest (17 weeks). For recording leaf infestation, from each quadrate, five plants were randomly selected. In each selected plant, five leaflets were collected each from the top, middle and bottom, then individually packed in labeled plastic bags and then transported to the laboratory. During observation in the field, also looked for any natural enemy found feeding in different stages of *T. absoluta*. In laboratory, with the aid of binocular microscope, the observations on per cent leaf infestation, number of eggs per plant, number of mines per plant and number of larvae per plant were recorded at weekly intervals from June 16th to October 6th during *Kharif* season of 2015 and from October 6th of 2015 to January 26th of 2016. In both season per cent fruit infestation was also recorded during each picking. The eggs, larvae and pupae were maintained for a week to look for presence of any natural enemies.

***B.* Influence of weather parameters on the incidence of T. absoluta:** The observations on per cent leaf infestation, number of larvae per plant, number of eggs per plant and number of mines per plant (Y) were correlated with six weather parameters like total rainfall (X_1) in mm, maximum temperature (X_2), minimum temperature (X_3), morning relative humidity (X_4) taken at 8.30 AM, afternoon relative humidity (X_5) taken at 5.30 PM and sunshine hour (X_6) and multiple regression analysis was also performed with the same. The weekly meteorological data on weather parameters were collected from Gramin krishi mausam seva, ZAHRS and College of Agriculture, Navile, Shivamogga.

***C.* Monitoring of moths**: Moth population was monitored starting from transplanting using sex pheromone traps (PCI WOTA traps). Five traps were installed 0.5 m above ground level and adjusted to canopy height at weekly interval. Sex pheromone dispensers were renewed every four weeks and the number of moths captured per trap was recorded weekly during both *Kharif* and *Rabi* seasons of 2015-16.

3. Results and Discussion

A. Seasonal incidence of T. absoluta under polyhouse condition

(i) in Kharif 2015

The eggs of *T. absoluta* were first observed in June fourth week. The number of eggs varied from 1.40 to 9.60 eggs per plant from last week of June to second week of October. The maximum number of eggs per plant was noticed in second week of October. Leaf mining due to larval damage was observed from June fourth week and was varied from 1.20 to 14.80. Highest number of mines per plant was noticed in the second week of October. The mean number of eggs per plant was 4.72±3.02 whereas the mean number of mines per plant recorded was 9.44±5.42, respectively (Table 1).

Table 1: Seasonal incidence of tomato leafminer during *Kharif* 2015 and *Rabi* 2015-16 in polyhouse condition

Season	Date	No. Eggs$	No. Mines ^	Leaf infestation#	No. Larvae *	Fruit infestation/plant (%)
Kharif, 2015	16/06/2015	0.00	0.00	0.00	0.00	-
	23/06/2015	0.00	0.00	0.00	0.00	-
	30/06/2015	1.40	1.20	4.74	0.60	-
	07/07/2015	1.60	2.80	12.56	4.00	-
	14/07/2015	1.60	4.20	19.59	4.20	-
	21/07/2015	3.20	9.80	20.16	4.80	-
	28/07/2015	3.40	10.00	25.37	5.40	-
	04/08/2015	4.60	12.20	27.00	8.40	-
	10/08/2015	5.40	12.40	27.75	9.00	10.00
	18/08/2015	5.60	12.60	31.62	9.20	14.99
	25/08/2015	6.40	12.80	35.65	11.80	26.43
	01/09/2015	6.60	12.60	36.24	11.80	36.95
	08/09/2015	7.60	12.80	37.57	13.20	36.98

	15/09/2015	7.60	13.60	40.07	13.20	54.40
	22/09/2015	7.80	13.80	42.39	13.40	57.98
	29/09/2015	7.80	14.80	57.10	14.00	79.83
	06/10/2015	9.60	14.80	60.75	16.40	97.51
Mean±SD		**4.72±3.02**	**9.44±5.42**	**28.15±17.66**	**8.20±5.31**	**46.12±29.19**
Rabi, 2015-16	06/10/2015	0.60	2.80	12.97	1.40	-
	13/10/2015	1.00	2.00	10.81	1.60	-
	20/10/2015	1.20	3.20	16.76	3.00	-
	27/10/2015	1.20	2.00	15.15	2.40	-
	03/11/2015	2.20	4.40	16.19	4.00	-
	10/11/2015	2.20	6.00	16.70	5.40	-
	17/11/2015	9.00	5.40	16.50	10.20	-
	24/11/2015	5.80	5.40	20.04	13.40	-
	01/12/2015	7.20	6.80	33.08	5.80	16.37
	08/12/2015	10.80	10.00	36.42	7.20	29.34
	15/12/2015	8.80	11.20	35.32	10.60	34.28
	22/12/2015	10.80	13.60	36.09	15.00	44.35
	29/12/2015	10.00	12.80	34.44	15.40	59.37
	05/01/2016	7.60	12.80	37.54	15.60	72.38
	12/01/2016	15.00	14.60	61.31	16.40	88.33
	19/01/2016	12.40	17.40	79.87	20.60	97.34
	26/01/2016	17.20	17.80	83.61	31.80	98.32
Mean±SD		7.24±5.21	8.72±5.39	33.11±22.46	10.58±8.12	60.01±30.75

$ - number of eggs per plant; **^** - number of mines per plant; **#**- per cent leaf infestation per plant; *****- number of larvae per plant

Leaf damage was noticed from June fourth week. From there, per cent leaf damage varied from 4.74 to 60.75 per cent up to the second week of October. The number of larvae per plant varied from 0.60 to 16.40 from June fourth week to the second week of October. Highest per cent leaf damage and the number of larvae per plant was recorded during the second week of October (60.75 and 16.40, respectively). The mean per cent leaf damage and mean number of larvae was 28.15±17.66 and 8.20±5.31, respectively (Table 1).

Fruiting was started from August third week of 2015. The fruit infestation was noticed right from the first week of fruiting stage *i.e.*, the third week of August which ranged from 10.00 to 97.51. The mean per cent fruit infestation was 46.12±29.19 (Table 1).

(ii) *in Rabi*, 2015-2016

The eggs were started noticing in the second week of October. From there, number of eggs per plant varied from 0.60 to 17.20 up to the fourth week of January 2016. Maximum number of eggs per plant was noticed in fourth week of January 2016. Leaf mining due to larval damage was observed in second week of October and was varied from 2.00 to 17.80. Maximum number of mines per plant was noticed in fourth week of January 2016. The mean number of eggs per plant and mines per plant was 7.24±5.21and 8.72±5.39, respectively (Table 1).

Leaf damage began in the second week of October. There onwards per cent leaf infestation was varied from 12.97 to 83.61 per cent up to fourth week of January 2016. The number of larvae per plant varied from 1.40 to 31.80. Highest per cent leaf damage and the total number of larvae per plant was recorded during fourth week of January 2016 (83.61 per cent and 31.80, respectively). The mean per cent leaf damage and mean number of larvae was 33.11±22.46 and 10.58±8.12, respectively (Table 1).

Fruiting was started from first week of December 2015. Fruit infestation was noticed right from first week of December. Fruit infestation ranged from 16.37 to 98.32. The mean per cent fruit infestation was 60.01±30.75 (Table 2). During *Rabi* season, the infestation of tomato plants in polyhouse condition was very high compared to field condition.

In *Kharif* 2015, the maximum number of leaf mines (14.80) was closely related to the density of *T. absoluta* larvae (16.40) during October. The maximum leaf infestation 60.75 per cent and the maximum number of 9.60 eggs were noticed in October. In *Rabi* 2015-16, the maximum number of leaf mines (17.80) was closely related to the density of *T. absoluta* larvae (31.80). The maximum leaf infestation 83.61 per cent and higher number of 17.20 eggs were noticed during January.

B. Seasonal incidence of T. absoluta under field condition (i) in Kharif 2015

The eggs were noticed in the second week of August up to the second week of October. Number of eggs per plant varied from 0.80 to 8.80. Maximum number of eggs per plant was noticed in the second week of October. The number of mines per plant varied from 0.20 to 13.20 and highest was observed in the third week of August. Highest number of mines per plant was noticed in second week of October. The mean number of eggs per plant and mines per plant was 1.64±2.36 and 2.10±3.71, respectively (Table 2).

Leaf damage was noticed from third week of August which varied from 1.60 to 9.79 per cent and continued up to second week of October. The number of larvae per plant was varied from 0.62 to 10.00. Maximum per cent leaf damage and number of larvae per plant was noticed during fourth week of September (9.79 and 10.00, respectively). The mean per cent leaf damage and mean number of larvae recorded was 2.72±3.81 and 1.73±3.02, respectively (Table 3). Fruiting was started from third week of August 2015. Fruit infestation was noticed from first week of September which ranged from 12.34 to 34.69. The mean per cent fruit infestation was 14.72±12.93 (Table 2). The moth catches were began in third week of June and continued up to first week of October. The number of moths varied from 1.00 to 10.50. Highest moth catches per trap per week was noticed in last week of September (10.50). Lowest moth catches per trap per week was recorded in June and July months (1.00). The mean moth catches per trap per week was 5.12±3.41 (Table 2).

In *Kharif* 2015, the maximum number of leaf mines (13.20) was close to the density of *T. absoluta* larvae (10.00) during September. The maximum leaf infestation of 9.79 per cent was noticed. The maximum number of eggs were noticed in

September (8.80). In *Kharif* season, when correlation was performed with maximum temperature and per cent plant infestation (r=0.383), number of eggs per plant (r=0.392), number of larvae per plant (r=0.340) and number of mines per plant (r=0.328) results showed positive correlation. Per cent fruit infestation per plant and maximum temperature when correlated, results showed the significant positive correlation (r= 0.569*). This shows that when the temperature is high infestation level also increases as reported by previous workers [14]. In *Kharif*, the positive correlation was also observed with minimum temperature among all parameters.

Table 2: Seasonal incidence of tomato leafminer during *Kharif* 2015 and *Rabi* 2015-16 in field condition

Season	Date	No. Eggs$	No. Mines ^	Leaf infestation#	No. Larvae *	Fruit infestation/plant (%)	Pheromone trap catches per trap per week @
Kharif, 2015	16/06/2015	0.00	0.00	0.00	0.00	-	1.50
	23/06/2015	0.00	0.00	0.00	0.00	-	1.00
	30/06/2015	0.00	0.00	0.00	0.00	-	2.00
	07/07/2015	0.00	0.00	0.00	0.00	-	1.00
	14/07/2015	0.00	0.00	0.00	0.00	-	1.00
	21/07/2015	0.00	0.00	0.00	0.00	-	2.00
	28/07/2015	0.00	0.00	0.00	0.00	-	3.00
	04/08/2015	0.00	0.00	0.00	0.00	-	3.50
	10/08/2015	0.80	0.00	0.00	0.00	0.00	7.50
	18/08/2015	1.20	0.20	1.60	0.60	0.00	6.00
	25/08/2015	1.60	0.40	0.77	0.80	0.00	7.50
	01/09/2015	1.60	2.00	3.32	1.40	12.34	6.50
	08/09/2015	2.80	3.00	5.47	2.20	15.76	9.50
	15/09/2015	3.00	3.20	6.58	2.80	17.97	7.50
	22/09/2015	8.80	13.20	9.79	10.00	22.39	10.00
	29/09/2015	3.40	4.20	9.21	8.40	29.34	10.50
	06/10/2015	4.60	8.80	9.52	3.20	34.69	7.00
Mean±SD		1.64±2.36	2.10±3.71	2.72±3.81	1.73±3.02	14.72±12.93	5.12±3.41
Rabi, 2015-16	06/10/2015	0.00	0.00	0.00	0.00	-	9.00
	13/10/2015	0.60	1.20	2.77	0.40	-	8.50
	20/10/2015	0.80	1.60	5.00	0.80	-	9.50
	27/10/2015	1.20	2.00	5.63	1.00	-	10.50
	03/11/2015	1.60	3.20	10.29	0.80	-	12.50
	10/11/2015	2.20	1.80	8.07	1.80	-	10.00
	17/11/2015	2.40	2.20	8.07	3.00	-	6.50
	24/11/2015	1.80	3.00	7.82	2.60	-	12.50
	01/12/2015	1.80	3.80	4.99	2.80	13.34	10.00
	08/12/2015	2.00	4.00	9.81	2.80	17.63	10.50
	15/12/2015	1.20	4.20	13.30	3.80	19.29	15.50
	22/12/2015	1.40	4.60	14.43	3.00	21.37	14.00
	29/12/2015	2.00	5.20	15.26	4.80	25.38	12.50
	05/01/2016	3.00	5.80	16.95	8.40	27.39	17.00
	12/01/2016	4.40	6.40	17.97	12.40	33.39	12.00
	19/01/2016	6.00	7.80	19.62	13.40	42.34	13.50
	26/01/2016	13.4	10.00	23.55	15.80	44.37	14.50
Mean±SD		2.69±3.10	3.93±2.56	10.80±6.47	4.56±4.89	27.16±10.87	11.68±2.73

$- number of eggs per plant; ^ - number of mines per plant; #- per cent leaf infestation per plant;*- number of larvae per plant;@- average of five traps per week

Perusal of Table 2 indicated that *Rabi* (2015-16) season had the higher incidence than *Kharif* 2015. And also, perusal of Table 3 indicated not much significant influence of weather parameters on the *T. absoluta* damage and as well as population. Among the weather parameters, minimum temperature and afternoon humidity had significant influence than other parameters. Overall, it means to say that crop phenology had much influence on *T. absoluta* population than weather parameters.

C. Influence of weather parameters on the incidence of T. absoluta

Correlation and regression analysis indicated that the weather parameters had significant influence on the incidence of T. absoluta in Rabi season than in the Kharif season. The results revealed that correlation coefficient between weather parameters and per cent leaf damage showed significant negative correlation with minimum temperature(r = -0.821*) in Rabi whereas it was non-significant in Kharif (r=0.409). Among the variables, Afternoon relative humidity had significant negative influence on the plant infestation (r=-0.807), total number of larvae per plant (r=-0.832), total number of eggs per plant (r=-0.814), Total number of mines per plant (r=-0.868), fruit infestation percentage (r=-0.813) and as a result on the pheromone catches (r=-0.583). The sunshine hour had significant positive influence on the pheromone trap catches in both the seasons (r=0.534 in Kharif and r=0.523 in Rabi) (Table 3). Most of the other weather parameters had non-significant correlation on the incidence of the pest.

Multiple linear regression analysis indicated the weather parameters influenced the infestation in Rabi rather than in Kharif. In Rabi, when the plant infestation was subjected to Multiple linear regression analysis with the weather parameters, the equation obtained was $Y= 41.944 +0.047 X_1+0.417 X_2-1.674X_3+0.073X_4 -0.246 X_5-0.586$

X_6+2.630, with an R^2 value of 0.89, which implied that 89 per cent of total variation in per cent leaf damage could be explained by above six weather parameters. Similarly, an R^2 value of 0.81, 0.82, 0.90, 097 and 0.79 was obtained with respect to total number of larvae per plant, total number of eggs per plant, Total number of mines per plant, fruit infestation percentage and on the pheromone catches, respectively (Table 3). However, in Kharif, the co-efficient of determination values were lesser indicating not much significant influence of weather parameters on the *T. absoluta* infestation. This could be due to the lesser variation observed among the weather parameters in the season.

In both *Kharif* and *Rabi* seasons, no natural enemy was found feeding on any stage of *T. absoluta* both in field and polyhouse condition. However, in many countries, predators such as, *Dicyphus* spp., *Nesidiocoris tenuis* (Reuter) (Hemiptera: Miridae), *Orius* spp. (Hemiptera: Anthocoridae), *Chrysoperla carnea* species group (Neuroptera: Chrysopidae) have been reported [11]. Similarly, various parasitoids belong to family Braconidae, Ichneumonidae, Chalcididae and Eulopidae of Hymenoptera has been reported [11]. However, during the period of investigation no natural enemy was recovered. This may be due to many reasons. It is assumed that natural enemies in the newly invaded areas need time to get adapted to and control the exotic species effectively. This may be due to the fact that native antagonists need to adjust their behavior and/or physiology to be able to successfully develop on the exotic prey/host. For these reasons, natural enemy complexes on invaders may perform initially low predation or parasitism [11, 12]).

In both the seasons, the infestation level was low during first phenologic cycle as reported previously [13]. At the end of crop cycle due to temperature rising and continuous availability of food, *T. absoluta* density goes on increasing. These results agreed with the earlier reports [14, 15]. Likewise, several other studies showed that the density of *T. absoluta* showed initially a slow increase, but a rapid increase in subsequent periods [7, 15-17].

4. Conclusions

Minimum Temperature and afternoon relative humidity had a significant negative influence and their decrease lead to increase in infestation level. It was more evident in Rabi season than in Kharif season. Not much influence of weather parameters on the indigence was observed during Kharif season. It indicates that crop phenology had much influence on *T. absoluta* population than weather parameters. Based on the results it is inferred that, management should be initiated in the early growth period itself to avoid build-up of the pest in the later phenological cycle of the crop.

Table 3: Correlation coefficient (r) and coefficient of determination (R^2) between weather parameters and incidence of tomato leaf miner during *Kharif* 2015 and *Rabi* 2015-16 in field condition

Particulars	Correlation coefficient ('r' value)						Coefficient of determination (R^2)
	Total rainfall (mm) (X_1)	Temperature (^{0}C)		Relative humidity (%)		Sunshine (hours/day) (X_6)	
		Maximum (X_2)	Minimum (X_3)	I (X_4)	II (X_5)		
***Kharif* 2015**							
Plant infestation (%)	0.041	0.383	0.409	-0.466	-0.173	0.267	0.327
Total number of larvae/plant	0.080	0.340	0.373	-0.467	0.004	0.273	0.324
Total number of eggs/plant	-0.119	0.392	0.377	-0.498*	-0.109	0.331	0.309
Total number of mines/plant	0.045	0.328	0.364	-0.464	-0.028	0.269	0.300
Fruit infestation/plant@ (%)	0.182	-0.252	-0.122	-0.170	0.065	-0.364	0.341
Pheromone trap catches per week	-0.008	0.569*	0.653*	-0.616*	-0.166	0.534*	0.574
***Rabi* 2015-16**							
Plant infestation (%)	-0.228	0.284	-0.821*	-0.319	-0.807*	0.365	0.894
Total number of larvae/plant	-0.267	0.262	-0.644*	-0.383	-0.832*	0.285	0.814
Total number of eggs/plant	-0.171	0.273	-0.545*	-0.412	-0.814*	0.174	0.822
Total number of mines/plant	-0.240	0.408	-0.779*	-0.384	-0.868*	0.473	0.900
Fruit infestation/plant@ (%)	0.215	0.246	-0.403	-0.368	-0.813*	-0.149	0.976
Pheromone trap catches per week	-0.184	0.418	-0.768*	-0.216	-0.583*	0.523*	0.792

N = 17; *Significance at p = 0.05; Table r value at p=0.05 is 0.482; @N=9; *Significance at p = 0.05; Table r value at p=0.05 is 0.755

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