QUEENSLAND DEPARTMENT OF PRIMARY INDUSTRIES
DIVISION OF PLANT INDUSTRY BULLETIN No. 530

EFFECT OF DIFFERENT VARIETIES OF THE APPLE HOST ON THE DEVELOPMENT OF TETRANYCHUS URTICAE (KOCH)

By M. BENGSTON, M.Sc., Ph.D.

SUMMARY

The detached leaf culture technique used for the two-spotted mite (*Tetranychus urticae* (Koch)) on different apple varieties showed that the population growth potential was greatest on Delicious, followed in turn by Granny Smith, Jonathan and Gravenstein. This corresponds with the level of natural infestation in the field. This technique was proved to be a convenient method of assessing the resistance of apple varieties to *T. urticae*.

I. INTRODUCTION

It is commonly stated in literature that field populations of the two-spotted mite (*Tetranychus urticae* (Koch)) are generally higher on certain apple varieties than on others, but the reasons for this are not defined. In part, mite populations are influenced by the nature and timing of spray programmes applied to the several varieties. However, levels of field infestation could also reflect differences in natural resistance of the host variety to *T. urticae*. It is well known in the Stanthorpe district of Queensland also that differences of this kind occur among apple varieties.

A plant-breeding programme to develop new apple varieties is currently being conducted by the Department of Primary Industries at Applethorpe, in the Stanthorpe district. In this work large numbers of seedlings are raised but marketing considerations dictate that only a small number of varieties will be commercially exploited. Should direct genetic differences in resistance to *T. urticae* be shown, screening of potential new varieties for resistance to this mite could be important.

The general phenomenon of insect resistance of crop plants has been widely studied (Painter 1951), but no references to work involving *T. urticae* and apples could be located.

The current work therefore was undertaken using the detached leaf culture technique to compare the intrinsic rate of natural increase and related parameters for *T. urticae* on apple varieties. Commercial apple varieties of known field resistance to *T. urticae* were selected.

Fritzsche (1960) produced evidence that the susceptibility of some hosts, especially beans, to *T. urticae* infestation was related to the reducing sugar content of the leaves. Should such a simple relationship hold for apples, this would provide a rapid method for screening potential new apple varieties. Reducing sugar content was therefore determined for leaves of each apple variety investigated.

II. MATERIALS AND METHODS

Mite material.—Mites from a stock colony held at Applethorpe were used in this experiment. The females providing the necessary eggs were preconditioned on detached apple leaves at 25°C and 70% relative humidity under continuous illumination. Quiescent deuteronymphs used in the study of adult fecundity and longevity were preconditioned on bean plants under the same conditions.

Mite cages and observations.—Handling techniques and observations were the same as those described in previous work (Bengston 1969), except that all of the current work was carried out under continuous illumination at 29·5°C and high relative humidity (85–90%).

Apple varieties.—Four varieties of apples—Delicious, Granny Smith, Gravenstein and Jonathan—were used in this work. These constitute about 95% of the trees in commercial orchards in the Stanthorpe district.

Determination of reducing sugars.—Reducing sugars were determined on foliage from four bearing and four young non-bearing trees of each variety studied. Each foliage sample consisted of 10 fully expanded leaves. On bearing trees, leaves were taken from fruiting spurs at different positions on the tree. On young non-bearing trees, the leaves were taken from the middle section of the new season's growth.

Duplicate samples were taken on all occasions. One of these was for the determination of reducing sugars from the leaves and the other for the determination of percentage dry matter. Samples were placed in polythene bags immediately after picking. Fresh weights were taken as soon as practicable but always within 30 min of picking.

The fresh leaves were macerated in 100 ml of 80% ethanol for 2 min in a domestic-type blender. The sugars were separated by a sintered glass filter and washed with three rinses of approximately 50 ml of 80% ethanol, and the final volume was made up to 250 ml. The reducing sugars were determined according to the phenol-sulphuric acid method (Hodge and Hofreiter 1964).

An aliquot was diluted 20 to 1 with distilled water. Preliminary experiments showed that under these circumstances neither clarification nor dealcoholization was necessary. Determinations were therefore carried out on the diluted alcohol extract without further treatment.

III. RESULTS

Duration of immature stages.—Data on the time for development of immature mite stages are given as a range together with mean and standard error in Table 1.

TABLE 1

Duration of Immature Stages at 29·5°C and High Humidity (85–90%)

Variety	Stage	No. of Mites	Duration (days)	
			Range	Mean ± S.E.
Delicious	Egg	86	3·0– 4·0	3·31 ± 0·03
	Larva	82	1·5– 4·5	1·75 ± 0·05
	Protonymph	75	1·0– 3·5	1·68 ± 0·05
	Deuteronymph	71	1·0– 3·0	1·87 ± 0·04
	Total	71	7·5–10·5	8·54 ± 0·08
Granny Smith ..	Egg	77	3·0– 4·5	3·31 ± 0·04
	Larva	64	1·0– 4·0	1·99 ± 0·06
	Protonymph	60	1·0– 3·5	1·88 ± 0·06
	Deuteronymph	54	1·0– 4·0	2·09 ± 0·07
	Total	54	7·5–11·0	9·19 ± 0·12
Gravenstein ..	Egg	50	3·0– 4·0	3·25 ± 0·04
	Larva	35	1·5– 7·5	3·23 ± 0·28
	Protonymph	28	2·0– 3·0	2·30 ± 0·07
	Deuteronymph	26	1·5– 6·0	2·25 ± 0·17
	Total	26	8·5–14·5	10·81 ± 0·32
Jonathan	Egg	43	3·0– 4·5	3·28 ± 0·05
	Larva	37	1·5– 4·0	2·39 ± 0·10
	Protonymph	33	1·0– 3·0	1·88 ± 0·07
	Deuteronymph	29	1·0– 5·0	2·33 ± 0·18
	Total	29	7·5–13·0	9·76 ± 0·24

The results of statistical testing of the differences in time of development of the various individual stages—egg, larva, protonymph, deuteronymph—are given in Tables 2–5. Similar results on total immature development time for both sexes combined and also for males and females separately are given in Tables 6–9.

Two types of statistical analyses were carried out. In the first, the least significant differences between varieties were calculated, using lumped error within varieties. In the second, individual mean differences and standard errors were compared, using Student's t test. The general trends were the same in both types of analyses but some slight differences were apparent in the levels of significance. In most cases the variance differed among the varieties, so Student's t test was the more appropriate test. Both types are presented for comparison.

No differences were apparent in the time of development for eggs (Table 2) on the different varieties.

TABLE 2

DURATION OF EGG STAGE AT 29·5°C AND HIGH RELATIVE HUMIDITY (85–90%)

Variety	No. of Mites	Duration (days)	
		Range	Mean ± S.E.
1. Delicious	86	3·0–4·0	3·31 ± 0·03
2. Granny Smith ..	77	3·0–4·5	3·31 ± 0·04
3. Gravenstein ..	43	3·0–4·0	3·25 ± 0·04
4. Jonathan	50	3·0–4·5	3·28 ± 0·05

Comparison	t†	L.S.D.††	
		5%	1%
Delicious–Granny Smith ..	0·04	0·10	0·13
Delicious–Gravenstein ..	1·28	0·11	0·15
Delicious–Jonathan	0·56	0·12	0·16
Granny Smith–Gravenstein ..	1·09	0·12	0·15
Granny Smith–Jonathan ..	0·48	0·12	0·16
Gravenstein–Jonathan ..	0·44	0·13	0·17
	N.S.D.	N.S.D.	

† Student's t, calculated for differences between pairs of varieties.

†† Calculated using lumped error within varieties.

Time of development for larvae (Table 3) was affected to a considerable extent by the apple variety. Time of development was shortest on Delicious, and increased in turn for Granny Smith, Jonathan and Gravenstein. All differences were highly significant.

TABLE 3

DURATION OF LARVA STAGE AT 29·5°C AND HIGH RELATIVE HUMIDITY (85–90%)

Variety	No. of Mites	Duration (days)	
		Range	Mean ± S.E.
1. Delicious	82	1·5–4·5	1·75 ± 0·05
2. Granny Smith ..	64	1·0–4·0	1·99 ± 0·06
3. Gravenstein ..	35	1·5–7·5	3·23 ± 0·28
4. Jonathan	37	1·5–4·0	2·39 ± 0·10

TABLE 3—continued

DURATION OF LARVA STAGE AT 29·5°C AND HIGH RELATIVE HUMIDITY (85–90%)

Comparison	t†	L.S.D.††	
		5%	1%
Delicious–Granny Smith ..	3·05**	0·27	0·35
Delicious–Gravenstein ..	5·13**	0·32	0·43
Delicious–Jonathan	5·75**	0·32	0·42
Granny Smith–Gravenstein ..	4·24**	0·34	0·44
Granny Smith–Jonathan ..	3·35**	0·33	0·44
Gravenstein–Jonathan ..	2·77**	0·38	0·50
	$1 \ll 2 \ll 4 \ll 3$	$1, 2, 4 \ll 3$ $1 \ll 4;\ 2 < 4$	

† Student's t, calculated for differences between pairs of varieties.
†† Calculated using lumped error within varieties.

For protonymphs (Table 4) time of development was significantly shorter on Delicious than on the other three varieties. It was approximately equal on Granny Smith and Jonathan and was significantly less on these varieties than on Gravenstein.

TABLE 4

DURATION OF PROTONYMPH STAGE AT 29·5°C AND HIGH RELATIVE HUMIDITY (85–90%)

Variety	No. of Mites	Duration (days)	
		Range	Mean ± S.E.
1. Delicious	75	1·0–3·5	1·68 ± 0·05
2. Granny Smith ..	60	1·0–3·5	1·88 ± 0·06
3. Gravenstein ..	28	2·0–3·0	2·30 ± 0·07
4. Jonathan	33	1·0–3·0	1·88 ± 0·07

Comparison	t†	L.S.D.††	
		5%	1%
Delicious–Granny Smith ..	2·69**	0·14	0·19
Delicious–Gravenstein ..	7·32**	0·18	0·24
Delicious–Jonathan	2·28*	0·17	0·23
Granny Smith–Gravenstein ..	4·65**	0·19	0·25
Granny Smith–Jonathan ..	0·05	0·18	0·24
Gravenstein–Jonathan ..	4·23**	0·21	0·28
	$1,2,4 < 3$ $1 \ll 2,3;\ 1 < 4$	$1,2,4 \ll 3$ $1 \ll 2;\ 1 < 4$	

† Student's t, calculated for differences between pairs of varieties.

†† Calculated using lumped error within varieties.

For deuteronymphs (Table 5) time of development was shorter on Delicious than on the other varieties and there were no statistically significant differences among Granny Smith, Gravenstein and Jonathan.

TABLE 5

DURATION OF DEUTERONYMPH STAGE AT 29·5°C AND HIGH RELATIVE HUMIDITY (85–90%)

Variety	No. of Mites	Duration (days)	
		Range	Mean ± S.E.
1. Delicious	71	1·0–3·0	1·87 ± 0·04
2. Granny Smith ..	54	1·0–4·0	2·09 ± 0·07
3. Gravenstein ..	26	1·5–6·0	2·25 ± 0·17
4. Jonathan	29	1·0–5·0	2·33 ± 0·18

Comparison	t†	L.S.D.††	
		5%	1%
Delicious–Granny Smith ..	2·71**	0·22	0·29
Delicious–Gravenstein ..	2·13*	0·28	0·37
Delicious–Jonathan	2·46**	0·27	0·36
Granny Smith–Gravenstein ..	0·85	0·29	0·39
Granny Smith–Jonathan ..	1·23	0·28	0·37
Gravenstein–Jonathan ..	0·31	0·33	0·44
	1≪2 1<4, 3	1≪3,4	

† Student's t, calculated for differences between pairs of varieties.

†† Calculated using lumped error within varieties.

Time for total immature development (Table 6) reflects the overall effects on the various stages. Time of development was shortest on Delicious, followed by in turn Granny Smith, Jonathan and Gravenstein. Statistically significant differences between all varieties were attained.

TABLE 6

DURATION OF TOTAL IMMATURE DEVELOPMENT AT 29·5°C AND HIGH RELATIVE HUMIDITY (85–90%)

Variety	No. of Mites	Duration (days)	
		Range	Mean ± S.E.
1. Delicious	71	7·5–10·5	8·54 ± 0·08
2. Granny Smith ..	54	7·5–11·0	9·19 ± 0·12
3. Gravenstein ..	26	8·5–14·5	10·81 ± 0·32
4. Jonathan	29	7·5–13·0	9·76 ± 0·24

TABLE 6—continued

DURATION OF TOTAL IMMATURE DEVELOPMENT AT 29·5°C AND HIGH RELATIVE HUMIDITY (85–90%)

Comparison	t†	L.S.D.†† 5%	L.S.D.†† 1%
Delicious–Granny Smith ..	4·61**	0·36	0·48
Delicious–Gravenstein ..	6·91**	0·46	0·61
Delicious–Jonathan	4·85**	0·44	0·59
Granny Smith–Gravenstein ..	4·79**	0·48	0·63
Granny Smith–Jonathan ..	2·16*	0·46	0·61
Gravenstein–Jonathan ..	2·63*	0·54	0·72
	$1 \ll 2 < 4 \ll 3$	$1 \ll 2 < 4 \ll 3$	

† Student's t, calculated for differences between pairs of varieties.

†† Calculated using lumped error within varieties.

Males developed more rapidly than females (Table 7). Data for each sex (Tables 8 and 9) show that the same trends relate to both males and females. The slight lessening of statistical significance between varieties for male individuals reflected smaller numbers of individuals. Data on the total immature development times for females (Table 9) are appropriate for use in calculation of the intrinsic rate of natural increase.

TABLE 7

DURATION OF TOTAL IMMATURE DEVELOPMENT OF MALES AND FEMALES AT 29·5°C AND HIGH RELATIVE HUMIDITY (85–90%)

Variety	Sex	No. of Mites	Duration (days) Range	Duration (days) Mean ± S.E.	t†
Delicious	Male	23	7·5– 9·0	7·96 ± 0·09	6·875**
	Female	48	7·5–10·5	8·81 ± 0·09	
Granny Smith	Male	25	7·5–11·0	8·94 ± 0·18	2·000
	Female	29	8·5–11·0	9·40 ± 0·14	
Gravenstein	Male	11	8·5–12·5	10·45 ± 0·38	1·005
	Female	15	9·0–14·5	11·07 ± 0·48	
Jonathan	Male	10	8·0–11·0	9·25 ± 0·30	1·779
	Female	19	7·5–13·0	10·03 ± 0·32	

† Student's t, calculated for differences between males and females.

TABLE 8

DURATION OF TOTAL IMMATURE DEVELOPMENT FOR MALES AT 29·5°C AND HIGH RELATIVE HUMIDITY (85–90%)

Variety	No. of Mites	Duration (days)	
		Range	Mean ± S.E.
1. Delicious	23	7·5– 9·0	7·96 ± 0·09
2. Granny Smith ..	25	7·5–11·0	8·94 ± 0·18
3. Gravenstein ..	11	8·5–12·5	10·46 ± 0·38
4. Jonathan	10	8·0–11·0	9·25 ± 0·30

Comparison	t†	L.S.D.††	
		5%	1%
Delicious–Granny Smith ..	4·88**	0·49	0·66
Delicious–Gravenstein ..	6·43**	0·63	0·83
Delicious–Jonathan	4·13**	0·65	0·86
Granny Smith–Gravenstein ..	3·61**	0·62	0·82
Granny Smith–Jonathan ..	0·88	0·64	0·85
Gravenstein–Jonathan ..	2·49*	0·75	0·99
	$1 \ll 2,4,3$ $2 \ll 3$; $4 < 3$	$1 \ll 2$, $4 \ll 3$	

† Student's t, calculated for differences between pairs of varieties.

†† Calculated using lumped error within varieties.

TABLE 9

DURATION OF TOTAL IMMATURE DEVELOPMENT FOR FEMALES AT 29·5°C AND HIGH RELATIVE HUMIDITY (85–90%)

Variety	No. of Mites	Duration (days)	
		Range	Mean ± S.E.
1. Delicious ..	48	7·5–10·5	8·81 ± 0·09
2. Granny Smith ..	29	8·5–11·0	9·40 ± 0·14
3. Gravenstein ..	15	9·0–14·5	11·07 ± 0·48
4. Jonathan	19	7·5–13·0	10·03 ± 0·32

TABLE 9—continued

DURATION OF TOTAL IMMATURE DEVELOPMENT FOR FEMALES AT 29·5°C AND HIGH RELATIVE HUMIDITY (85–90%)

Comparison	t†	L.S.D.†† 5%	L.S.D.†† 1%
Delicious–Granny Smith ..	3·55**	0·48	0·64
Delicious–Gravenstein ..	4·64**	0·61	0·80
Delicious–Jonathan	3·70**	0·56	0·74
Granny Smith–Gravenstein ..	3·36**	0·65	0·87
Granny Smith–Jonathan ..	1·82	0·61	0·80
Gravenstein–Jonathan ..	1·82	0·71	0·94
	$1 \ll 2,4, 3$ $2 \ll 3$	$1, 2, 4 \ll 3$ $1 \ll 4; 2 < 4; 1 < 2$	

† Student's t, calculated for differences between pairs of varieties.

†† Calculated using lumped error within varieties.

Survival of immature stages.—Survival was highest on Granny Smith, followed by Delicious, Jonathan and Gravenstein in that order, but differences were slight and no statistical testing was warranted. These data are given in Table 10.

TABLE 10

MORTALITY AND SURVIVAL OF IMMATURE STAGES AT 29·5°C AND HIGH RELATIVE HUMIDITY (85–90%)

Variety	Stage	No. of Mites	No. Dead	Mortality (%)	Survival (accumul.)
Delicious	Egg	93	7	7·5	·925
	Larva	84	2	2·4	·903
	Protonymph	75	0	0·0	·903
	Deuteronymph	72	1	1·4	·890
Granny Smith	Egg	80	3	3·8	·963
	Larva	66	2	3·0	·933
	Protonymph	60	0	0·0	·933
	Deuteronymph	54	0	0·0	·933
Gravenstein	Egg	51	1	2·0	·980
	Larva	36	1	2·8	·953
	Protonymph	31	3	9·7	·861
	Deuteronymph	27	1	3·7	·829
Jonathan	Egg	46	3	6·5	·935
	Larva	39	2	5·1	·887
	Protonymph	34	1	2·9	·861
	Deuteronymph	29	0	0·0	·861

Total fecundity.—Results indicate that, with respect to total fecundity, varieties were ranked in the descending order Delicious, Jonathan, Granny Smith and Gravenstein. Data on total fecundity of females are given in Table 11.

TABLE 11

TOTAL FECUNDITY OF FEMALES AT 29·5°C AND HIGH RELATIVE HUMIDITY (85–90%)

Variety	No. of Mites	No. of Eggs per Female	
		Range	Mean ± S.E.
1. Delicious	29	0–73	40·93 ± 3·12
2. Granny Smith ..	24	0–60	26·75 ± 3·67
3. Gravenstein ..	26	0–48	21·00 ± 3·24
4. Jonathan	26	0–84	34·19 ± 4·50

Comparison	t†	L.S.D.††	
		5%	1%
Delicious–Granny Smith ..	2·95**	10·23	13·54
Delicious–Gravenstein ..	4·43**	10·02	13·26
Delicious–Jonathan	1·23	10·02	13·26
Granny Smith–Gravenstein ..	1·17	10·50	13·89
Granny Smith–Jonathan ..	1·28	10·50	13·89
Gravenstein–Jonathan ..	2·38*	10·29	13·61
	$1 \ll 2, 3$ $4 < 3$	$1 \ll 2, 3$ $4 < 3$	

† Student's t, calculated for differences between pairs of varieties.

†† Calculated using lumped error within varieties.

Statistical testing established that total fecundity was significantly greater on Delicious than on Granny Smith and Gravenstein, but was not significantly greater than on Jonathan. In turn, fecundity was significantly greater on Jonathan than on Gravenstein, but was not significantly greater than on Granny Smith.

Longevity.—Longevity was greatest on Delicious and this was statistically greater than on Gravenstein and Granny Smith. Varieties were ranked in the descending order Delicious, Jonathan, Gravenstein and Granny Smith, but differences between Gravenstein and Granny Smith were negligible. Length of life for adult females is given in Table 12.

TABLE 12

LONGEVITY OF ADULT FEMALES AT 29·5°C AND HIGH RELATIVE HUMIDITY (85–90%)

Variety	No. of Mites	Duration (days)	
		Range	Mean ± S.E.
1. Delicious . .	29	12–32	20·00 ± 1·10
2. Granny Smith . .	24	3–31	15·42 ± 1·47
3. Gravenstein . .	26	1–29	15·96 ± 1·68
4. Jonathan . .	26	2–29	17·85 ± 1·58

Comparison	t†	L.S.D.††	
		5%	1%
Delicious–Granny Smith . .	2·50*	4·08	5·40
Delicious–Gravenstein . .	2·02*	4·00	5·29
Delicious–Jonathan . .	1·12	4·00	5·29
Granny Smith–Gravenstein . .	<1·00	4·19	5·54
Granny Smith–Jonathan . .	1·13	4·19	5·54
Gravenstein–Jonathan . .	<1·00	4·10	5·43
	1 > 2, 3	1 > 2, 3	

† Student's t, calculated for differences between pairs of varieties.
†† Calculated using lumped error within varieties.

Life—fecundity tables.—m_x values were greatest for Delicious, followed in turn by Granny Smith, Jonathan and Gravenstein. Values for each variety are given in Tables 13–16.

TABLE 13

LONGEVITY (l_x), AGE-SPECIFIC FECUNDITY (m_x), NET REPRODUCTION RATE (R_0), INTRINSIC RATE OF NATURAL INCREASE (r_m), AND MEAN GENERATION TIME (T) FOR *T. urticae* Delicious apples 29·5°C and high relative humidity (85–90%)

Adult Age (days)	Pivotal Age (x)	Adult l_x	Adjusted l_x	m_x	$l_x m_x$
1	9·31	1·00	0·89	0·08	0·07
2	10·31	1·00	0·89	1·34	1·19
3	11·31	1·00	0·89	1·79	1·60
4	12·31	1·00	0·89	1·71	1·52
5	13·31	1·00	0·89	2·05	1·83
6	14·31	1·00	0·89	2·27	2·02
7	15·31	1·00	0·89	2·27	2·02
8	16·31	1·00	0·89	1·58	1·40
9	17·31	1·00	0·89	1·73	1·54
10	18·31	1·00	0·89	1·38	1·23
11	19·31	1·00	0·89	1·05	0·94
12	20·31	1·00	0·89	0·62	0·55
13	21·31	0·90	0·80	1·00	0·80
14	22·31	0·86	0·77	0·83	0·63
15	23·31	0·79	0·68	0·52	0·37
16	24·31	0·76	0·68	0·36	0·25
17	25·31	0·59	0·52	0·74	0·38
18	26·31	0·55	0·49	0·25	0·12
19	27·31	0·52	0·46	0·40	0·18
20	28·31	0·48	0·43	0·18	0·08
21	29·31	0·45	0·40	0·08	0·03
22	30·31	0·38	0·34	0·23	0·08
23	31·31	0·34	0·31	0·20	0·06
24	32·31	0·31	0·28	0·00	0·00
25	33·31	0·31	0·28	0·00	0·00
26	34·31	0·28	0·25	0·00	0·00
27	35·31	0·21	0·18	0·00	0·00
28	36·31	0·14	0·12	0·00	0·00
29	37·31	0·03	0·03	0·00	0·00
30	38·31	0·03	0·03	0·00	0·00
31	39·31	0·03	0·03	0·00	0·00
32	40·31	0·03	0·03	0·00	0·00
33	41·31	0·00	0·00	0·00	0·00

$R_0 = \Sigma l_x m_x = 18{\cdot}88$
$r_m = 0{\cdot}199$
$T = 14{\cdot}76$

TABLE 14

LONGEVITY (l_x), AGE-SPECIFIC FECUNDITY (m_x), NET REPRODUCTION RATE (R_o), INTRINSIC RATE OF NATURAL INCREASE (r_m), AND MEAN GENERATION TIME (T) FOR *T. urticae*

Granny Smith apples 29·5°C and high relative humidity (85–90%)

Adult Age (days)	Pivotal Age (x)	Adult l_x	Adjusted l_x	m_x	$l_x m_x$
1	9·90	1·00	0·93	0·00	0·00
2	10·90	1·00	0·93	0·99	0·92
3	11·90	1·00	0·93	1·45	1·35
4	12·90	0·96	0·89	1·47	1·32
5	13·90	0·92	0·86	1·97	1·69
6	14·90	0·88	0·82	1·38	1·13
7	15·90	0·83	0·78	1·80	1·40
8	16·90	0·79	0·74	1·48	1·09
9	17·90	0·79	0·74	1·00	0·74
10	18·90	0·79	0·74	1·04	0·77
11	19·90	0·79	0·74	1·19	0·88
12	20·90	0·75	0·70	0·57	0·40
13	21·90	0·67	0·62	0·68	0·42
14	22·90	0·58	0·54	0·53	0·29
15	23·90	0·54	0·51	0·46	0·23
16	24·90	0·50	0·47	0·19	0·09
17	25·90	0·50	0·47	0·08	0·04
18	26·90	0·37	0·35	0·17	0·06
19	27·90	0·33	0·31	0·19	0·06
20	28·90	0·33	0·31	0·13	0·04
21	29·90	0·25	0·23	0·17	0·04
22	30·90	0·25	0·23	0·00	0·00
23	31·90	0·25	0·23	0·00	0·00
24	32·90	0·04	0·04	0·00	0·00
25	33·90	0·04	0·04	0·00	0·00
26	34·90	0·04	0·04	0·00	0·00
27	35·90	0·04	0·04	0·00	0·00
28	36·90	0·04	0·04	0·00	0·00
29	37·90	0·04	0·04	0·00	0·00
30	38·90	0·04	0·04	0·00	0·00
31	39·90	0·04	0·04	0·00	0·00
32	40·90	0·00	0·00	0·00	0·00

$R_o = \Sigma l_x m_x = 12{\cdot}95$

$r_m = 0{\cdot}170$

$T = 15{\cdot}06$

TABLE 15

LONGEVITY (l_x), AGE-SPECIFIC FECUNDITY (m_x), NET REPRODUCTION RATE (R_o), INTRINSIC RATE OF NATURAL INCREASE (r_m), AND MEAN GENERATION TIME (T) FOR *T. urticae*

Gravenstein apples 29·5°C and high relative humidity (85–90%)

Adult Age (days)	Pivotal Age (x)	Adult l_x	Adjusted l_x	m_x	$l_x m_x$
1	11·57	1·00	0·83	0·02	0·02
2	12·57	0·96	0·80	0·91	0·73
3	13·57	0·88	0·73	1·50	1·10
4	14·57	0·81	0·67	1·72	1·15
5	15·57	0·81	0·67	1·50	1·00
6	16·57	0·81	0·67	0·84	0·56
7	17·57	0·81	0·67	1·27	0·85
8	18·57	0·81	0·67	0·82	0·55
9	19·57	0·77	0·64	0·88	0·56
10	20·57	0·77	0·64	0·58	0·37
11	21·57	0·73	0·61	0·35	0·21
12	22·57	0·73	0·61	0·57	0·34
13	23·57	0·73	0·61	0·64	0·39
14	24·57	0·73	0·61	0·48	0·29
15	25·57	0·65	0·54	0·34	0·19
16	26·57	0·62	0·51	0·35	0·18
17	27·57	0·46	0·38	0·50	0·19
18	28·57	0·46	0·38	0·35	0·13
19	29·57	0·42	0·35	0·25	0·09
20	30·57	0·38	0·32	0·00	0·00
21	31·57	0·35	0·29	0·10	0·03
22	32·57	0·31	0·26	0·00	0·00
23	33·57	0·27	0·22	0·00	0·00
24	34·57	0·23	0·19	0·00	0·00
25	35·57	0·15	0·13	0·10	0·01
26	36·57	0·12	0·10	0·00	0·00
27	37·57	0·08	0·06	0·00	0·00
28	38·57	0·08	0·06	0·00	0·00
29	39·57	0·04	0·03	0·00	0·00
30	40·57	0·00	0·00	0·00	0·00

$R_o = \Sigma l_x m_x = 8{\cdot}95$

$r_m = 0{\cdot}130$

$T = 16{\cdot}86$

TABLE 16

LONGEVITY (l_x), AGE-SPECIFIC FECUNDITY (m_x), NET REPRODUCTION RATE (R_o), INTRINSIC RATE OF NATURAL INCREASE (r_m), AND MEAN GENERATION TIME (T) FOR *T. urticae*

Jonathan apples 29·5°C and high relative humidity (85–90%)

Adult Age (days)	Pivotal Age (x)	Adult l_x	Adjusted l_x	m_x	$l_x m_x$
1	10·53	1·00	0·86	0·06	0·05
2	11·53	1·00	0·86	0·95	0·82
3	12·53	0·96	0·83	1·30	1·08
4	13·53	0·96	0·83	1·58	1·31
5	14·53	0·92	0·79	2·11	1·68
6	15·53	0·92	0·79	1·20	0·95
7	16·53	0·92	0·79	1·61	1·28
8	17·53	0·88	0·76	1·60	1·22
9	18·53	0·88	0·76	1·60	1·22
10	19·53	0·85	0·73	1·66	1·21
11	20·53	0·84	0·73	1·06	0·77
12	21·53	0·77	0·66	0·85	0·57
13	22·53	0·73	0·63	0·80	0·51
14	23·53	0·73	0·63	0·95	0·60
15	24·53	0·73	0·63	0·67	0·42
16	25·53	0·62	0·53	0·47	0·25
17	26·53	0·50	0·43	0·73	0·31
18	27·53	0·42	0·36	0·59	0·22
19	28·53	0·38	0·33	0·45	0·15
20	29·53	0·35	0·30	0·17	0·05
21	30·53	0·35	0·30	0·22	0·07
22	31·53	0·35	0·30	0·17	0·05
23	32·53	0·31	0·26	0·38	0·10
24	33·53	0·31	0·26	0·12	0·03
25	34·53	0·31	0·26	0·19	0·05
26	35·53	0·27	0·23	0·00	0·00
27	36·53	0·27	0·23	0·07	0·02
28	37·53	0·19	0·17	0·00	0·00
29	38·53	0·08	0·07	0·25	0·02
30	39·53	0·04	0·03	0·00	0·00
31	40·53	0·00	0·00	0·00	0·00

$$R_o = \Sigma l_x m_x = 14{\cdot}98$$
$$r_m = 0{\cdot}163$$
$$T = 16{\cdot}61$$

Net reproduction rate (R_o).—Values for the net reproduction rate ($R_o = \Sigma l_x m_x$) were calculated for each variety. Results are given in Table 17. With respect to net reproduction rate, varieties were ranked in the ascending order Gravenstein, Granny Smith, Jonathan and Delicious. The Gravenstein variety allowed a net reproduction rate less than half that for Delicious.

TABLE 17

NET REPRODUCTION RATE (R_0) AT 29·5°C AND HIGH RELATIVE HUMIDITY (85–90%)

Variety	Net Reproduction Rate (R_O)
Delicious	18·88
Granny Smith	12·95
Gravenstein	8·95
Jonathan	14·98

Intrinsic rate of natural increase and related parameters.—Summaries of the effect of variety on intrinsic rate of natural increase (r_m), mean generation time (T), finite capacity for increase (λ) and doubling time (D) in days are given in Table 18. The intrinsic rate of natural increase (r_m) was smallest on Gravenstein, followed by Jonathan, Granny Smith and Delicious in that order. The mean generation time (T) conformed exactly to the reverse order. Finite capacity for increase (λ) and doubling time (D) are derived from r_m and merely present the same information in alternative form.

TABLE 18

INTRINSIC RATE OF NATURAL INCREASE (r_m), MEAN GENERATION TIME (T), FINITE CAPACITY FOR INCREASE (λ), AND DOUBLING TIME (D) FOR *T. urticae* AT 29·5°C AND HIGH RELATIVE HUMIDITY (85–90%)

Variety	Intrinsic Rate of Natural Increase (r_m) per day	Mean Generation Time (T) (days)	Finite Capacity for Increase (λ) per day	Doubling Time (D) (days)
Delicious	0·199	14·76	1·22	3·48
Granny Smith	0·170	15·06	1·07	4·08
Gravenstein	0·130	16·86	1·04	5·33
Jonathan	0·163	16·61	1·18	4·25

Capacity for increase (r_c).—Values for the capacity for increase (r_c) (Laughlin 1965) for the various varieties, together with the cohort generation time (T_c) and r_c as a percentage of the intrinsic rate of increase (r_m), are given in Table 19. Values for r_c were all slightly less than the corresponding r_m values. The relative order of the varieties was exactly the same—Gravenstein, Jonathan, Granny Smith and Delicious.

TABLE 19

CAPACITY FOR INCREASE (r_c), COHORT GENERATION TIME (T_c) AND THE INTRINSIC RATE OF NATURAL INCREASE (r_m) AS A PERCENTAGE OF r_c FOR *T. urticae* AT 29·5°C AND HIGH RELATIVE HUMIDITY (85–90%)

Variety	Capacity for Increase (r_c)	Cohort Generation Time (T_c)	r_m as Percentage of r_c
Delicious	0·186	15·81	107·0
Granny Smith	0·161	15·90	105·6
Gravenstein	0·121	18·07	107·4
Jonathan	0·154	17·53	105·8

Reducing sugar content.—Data on reducing sugar content of leaves from bearing trees and young non-bearing trees are given in Table 20. Differences between varieties and the young versus bearing trees were quite small and scarcely exceeded that due to sampling error.

TABLE 20

REDUCING SUGAR CONTENT OF APPLE LEAVES OF VARIOUS VARIETIES

Variety	Milligrams Reducing Sugar per gram Dry Weight	
	Young Trees	Bearing Trees
Delicious	195·3	193·4
Granny Smith	202·6	184·9
Gravenstein	205·3	190·6
Jonathan	208·3	204·8

IV. DISCUSSION

Duration of immature stages.—The effect of different apple varieties was not apparent during the egg stage but it became obvious during the later immature stages. The trends between varieties were remarkably consistent during the various stages. Using rate of development as a criterion of host resistance of the several varieties as hosts of *T. urticae,* the varieties clearly were ranked in the descending order, Gravenstein, Jonathan, Granny Smith and Delicious.

Survival of immature stages.—Survival of immature stages was quite high on all varieties and there were no real differences between them. Differences were noted in the general appearance of mites feeding on the different varieties and these possibly reflected differences in resistance. Mites feeding on Gravenstein and Jonathan varieties tended to be pale in colour but the phenomenon was not investigated further.

Total fecundity.—Data on mean total fecundity showed that varieties ranked for resistance to the mite were in the descending order Gravenstein, Granny Smith, Jonathan and Delicious. This reversed the order of Jonathan and Granny Smith determined according to the time of immature development, but the difference between Jonathan and Granny Smith was not statistically significant.

Longevity.—The mean length of life for adult females was a variable criterion and the only statistically significant differences indicated that longevity tended to be greater on Delicious than the other varieties.

Life-fecundity tables.—Maximum age-specific fecundity (m_x) values for the several varieties were ranked in the same order as total fecundity—Delicious, Jonathan and Granny Smith and Gravenstein.

Net reproduction rate.—The net reproduction rates obtained for each variety reflect the combined effects of survival and fecundity. Varieties were ranked in the same order as that for total fecundity.

Intrinsic rate of natural increase.—The values for the intrinsic rate of natural increase calculated for the several varieties suggested that population increase should be least rapid on Gravenstein, Jonathan, Granny Smith and Delicious, in that order. This ranking is the same as that calculated for the rate of immature development and reflects the direct influence on this parameter on the intrinsic rate of natural increase. The net reproduction rate, which is related by the factor .og R_o, has much less influence. Thus although the net reproduction rate was greater on Jonathan than on Granny Smith, the more rapid development on Granny Smith meant that the intrinsic rate of natural increase was greater on Granny Smith than on Jonathan.

Capacity for increase.—Values calculated for the capacity for increase were all relatively close to those for the intrinsic rate of natural increase. Furthermore, the fact that they were all approximately the same percentage smaller than r_m meant that exactly the same trends were obtained.

Reducing sugar content.—Results from the determination of reducing sugar content were of no value for host resistance determination because of the lack of differences between varieties. The presence of a simple correlation of tissue analysis with resistance to *T. urticae* would simplify many investigations. Values obtained for apples in the current work were much higher than those obtained by Fritzsche (1960) for bean, calla and tomato, even after allowance was made for fresh weight/dry weight conversion. It seems that the simple correlation found by Fritzsche for beans is not likely to apply to apples.

General.—Field populations of *T. urticae* on apple orchards are influenced by orchard practice in addition to considerable differences in host resistance, as proved in the current work.

The Gravenstein and Jonathan varieties are susceptible to the fungus disease powdery mildew (*Podosphaera leucotricha* (Ell. and Ev.) Salm.) and a special spray schedule is normally applied. A typical schedule would comprise a pink tip application of lime sulphur followed by several cover sprays of either binapacryl, dinocap or sulphur. All these materials appreciably depress populations of *T. urticae.* For this reason populations would be expected to be lower on Gravenstein and Jonathan than on Granny Smith and Delicious.

These varieties mature fruit at different times. Trees are sprayed for control of codling moth (*Cydia pomonella* (L.)) and Queensland fruit fly (*Strumeta tryoni* (Frogg.)) until fruit is harvested (Bengston 1960). Late-maturing varieties therefore receive more applications of the modern organic insecticides and this means that predators are eliminated for a longer period. Harvest dates for the varieties are given in Table 21. This shows that Delicious are harvested earlier than Granny Smith.

TABLE 21

TIME OF HARVEST FOR VARIOUS APPLE VARIETIES IN THE STANTHORPE DISTRICT OF QUEENSLAND

Variety	Time of Harvesting
Gravenstein	January
Jonathan	Early February to late March
Delicious	February to March
Granny Smith	Mid March to mid May

Consideration of these cultural factors would suggest that the level of field populations on the varieties in ascending order should be Gravenstein, Jonathan, Delicious and Granny Smith. These varieties, however, comprise 95% of the total apple plantings in the Stanthorpe district of Queensland. According to field data on *T. urticae* populations, the varieties ranked in the ascending order, Gravenstein, Jonathan, Granny Smith and Delicious, the populations being much greater on Delicious than on the remaining varieties (Bengston 1960).

The difference between these two rankings is the relative positions of Delicious and Granny Smith. Differences due to the number of spray applications, however, are outweighed by differences in varietal resistance as shown by the intrinsic rate of natural increase. Measurement of the intrinsic rate of natural increase on detached leaves is therefore a satisfactory method for screening apple varieties for resistance to *T. urticae.*

REFERENCES

BENGSTON, M. (1960).—How to control major pests of apples and pears in the Granite Belt. *Qd agric. J.* 86:102-7.

BENGSTON, M. (1969).—Effect of various temperatures and relative humidities on the population growth potential of *Tetranychus urticae* (Koch). *Bull. Div. Pl. Ind. Qd Dep. Prim. Indus* No. 497.

FRITZSCHE, R. (1960).—Morphologische, biologische, und physiologische Variabilitaet und ihre Bedeutung fuer die Epidemiologie und Bekampfung von *Tetranychus urticae* Koch. *Biol. Zbl.* 79:521-76.

HODGE, J. E., and HOFREITER, B. T. (1962).—In "Methods in Carbohydrate Chemistry". (Ed. Whistler *et al.*) Vol. 1:388-9. (Academic Press: New York).

LAUGHLIN, R. (1965).—Capacity for increase: a useful population statistic. *J. Anim. Ecol.* 34:77-91.

PAINTER, R. H. (1951).—"Insect Resistance in Crop Plants". (Macmillan: New York).

(Received for publication August 20, 1969)

The author is an officer of Entomology Branch, Queensland Department of Primary Industries, and is stationed at Brisbane.