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UNIVERSITY OF FLORIDA
AGRICULTURAL EXPERIMENT STATION, Lake City
WILMON NEWELL, Director
GAINESVILLE, FLORIDA

SOME ANALYTICAL STUDIES OF THE PERSIAN LIME

By S. J. Lynch

TECHNICAL BULLETIN

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GAINESVILLE, FLORIDA

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SOME ANALYTICAL STUDIES OF THE PERSIAN[1] LIME

By S. J. Lynch

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INTRODUCTION

The planting of Persian lime trees in Florida has expanded considerably in the past decade. A partial survey made in the Redlands fruit growing area of Dade County in April 1938 by Wolfe *(9)*[2] of 1,200 acres of lime plantings indicates that 85 percent of the plantings have been made since 1933. The survey was completed later in that year, showing a total of 1,505 acres, but the percentage of the total planted in any given year was practically the same as reported in the incomplete survey by Wolfe.

During this period of rapid expansion, and particularly in the last few years, a number of questions have arisen in connection with the Persian lime fruit and some of its characteristics. These were answered from time to time by a series of analyses, or a small experiment, as the particular subject warranted. The larger plantings of four and five years ago are coming into heavier production along with the increased production from the numerous topworked orange, tangerine and grapefruit trees in the central part of the state.[3] This should give a decided increase each year for several years to come in the quantity of limes picked for the market. The increase in production is causing an increased demand for reliable information about the Persian lime, and to meet this demand the results of a number of investigations have been compiled into this bulletin.

[1] *Citrus aurantifolia* Swingle. Also known as the Tahiti lime.

[2] Italic figures in parentheses refer to "LITERATURE CITED" in the back of this bulletin.

[3] It is estimated from fruit shipments that there is about the same acreage of lime trees, including both young groves and topworks, in the central portion of the state as in Dade County.

COMPARISON BETWEEN VARIOUS TYPES OF JUICE EXTRACTORS FOR LABORATORY ANALYSES

Numerous types of extractors are available for the removal of juice from acid fruits. Many of these types employ equipment of such size, and require so large a quantity of fruit, that they are impractical for the laboratory, home or drink counter. Many require peeled fruit which makes them impractical for tests requiring extensive samplings *(6)*. For laboratory work, and especially in a routine analysis in which it is desired to determine the percent juice of a lime or lemon, a reasonably fast, accurate and economical method is desirable. Three types of extractors, the hand reamer, power reamer and hand press (Fig. 1) are economical to operate, light in weight, handle fruit by individual halves, remove a very high percentage of the juice and seem to remove very little of the rind oil.

PRECISION OF THE EXTRACTORS

The precision of a juice extractor can be considered as the degree of uniformity of volumes of juice removed by the extractor from each of a series of similar fruit samples. The precision

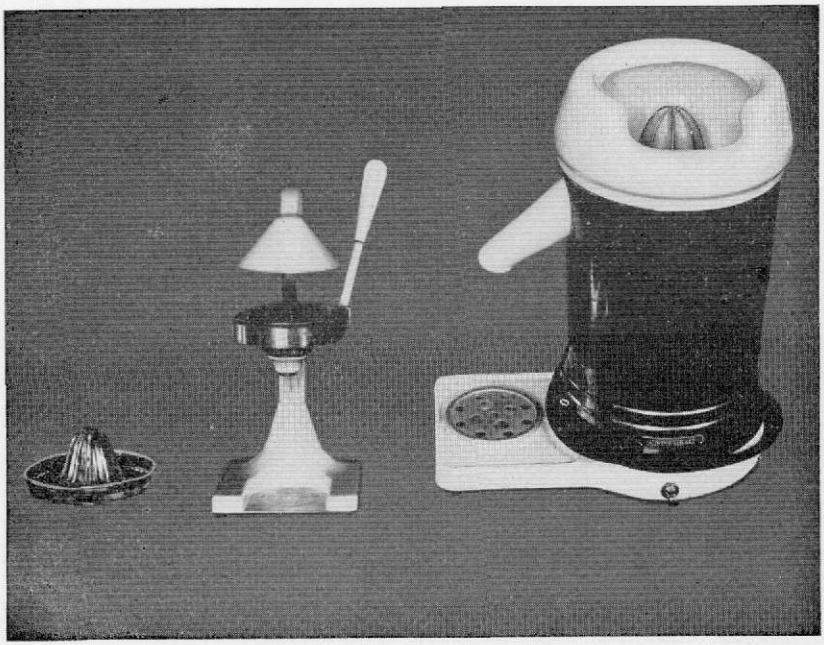

Fig. 1.—Three types of juice extractors. Left to right, hand reamer, hand press and power reamer.

of the three types of juice extractors was tested by observing the variations from the mean of pairs of identical samples. An insignificant difference in percent juice content by weight[4] between the blossom half and the stem half of Persian lime fruits was indicated in a series of preliminary analyses. The average juice content of the blossom half of 120 Persian limes divided into 20 fruit samples was 51.4 ± .74,[5] and of the stem half of the same fruits 50.5 ± .83 percent. To obtain two fruit samples of 20 half fruit each, the blossom halves of 10 fruits were added to the stem halves of 10 other fruits as one sample and the stem halves of the former 10 fruits were added to the blossom halves of the latter 10 fruits as the companion sample. All fruits were of approximately the same size and maturity from trees budded on rough lemon rootstock.

Table 1 shows a comparison of the precision of the three types of juice extractors. The error between paired samples is

[4]The term 'juice content' as hereafter used means percent juice based on the total weight of fruit.

[5]The figures in the bulletin representing means are in some instances followed by the sign ± and more figures. This value is the probable error of the mean and gives the range within which the chances are even that the true mean is found.

TABLE 1.—COMPARISON OF RECOVERY OF JUICE CONTENT OF IDENTICAL PAIRS OF SAMPLES OF PERSIAN LIMES.

No. Halves per Sample	Percent Juice by Weight		
	Sample A	Sample B	Error[1]
	With Hand Reamer		
20	43.3	44.3	2.28
20	46.3	46.6	0.65
20	38.9	40.6	4.28
20	40.3	39.5	2.01
20	40.9	41.1	0.49
	Average error		1.94 ± 0.46
	With Hand Press		
20	48.4	48.5	0.21
20	45.8	46.2	0.43
20	49.2	50.5	1.30
20	49.3	48.2	1.13
20	49.0	49.9	0.91
	Average error		0.80 ± 0.12
	With Power Reamer		
20	47.7	47.2	1.05
20	44.2	44.5	0.68
20	48.1	47.2	1.89
20	47.6	47.9	0.63
20	47.4	45.4	4.31
	Average error		1.71 ± 0.42

[1]The figure for error is arrived at by dividing the difference between juice content of Samples A and B by the mean juice content of the two samples.

not excessive for any of the samplings except in one pair using the hand reamer and one pair using the power reamer. The hand press, in this series of samplings, showed significantly less variation between paired samples than did either the hand reamer or the power reamer. The latter two were of about the same degree of precision.

EFFICIENCY OF THE EXTRACTORS

The efficiency or percentage of the total juice removed by an extractor is important. It is also important to know the degree of efficiency one type of extractor possesses in comparison with another. This latter makes it possible to compare data involving juice content with a truer perspective than when this differential factor is not taken into consideration. Table 2 is a comparison of juice removal from paired samples of Persian limes as extracted by the hand press and power reamer, the hand reamer and power reamer. The samples were prepared and paired as in the above tests for precision. The efficiency of the hand reamer and hand press are calculated on the basis of 100 percent as percentage of the efficiency of the power reamer. The power reamer does not remove 100 percent of the juice, but, as it

TABLE 2.—PERCENTAGE REMOVAL OF JUICE FROM PAIRED SAMPLES OF PERSIAN LIMES BY HAND PRESS COMPARED WITH THE POWER REAMER AND BY THE HAND REAMER COMPARED WITH THE POWER REAMER.

No. Halves per Sample	Percent Juice by Weight		Relative[1] Efficiency of Hand Press
	Power Reamer	Hand Press	
20	54.7	49.8	91.0
20	53.7	46.7	87.0
20	58.1	49.8	85.7
20	56.4	49.4	87.6
20	57.1	46.4	81.3
	Average relative efficiency		86.5 ± 1.04
	Percent Juice by Weight		Relative[1] Efficiency of Hand Reamer
	Power Reamer	Hand Reamer	
20	50.9	43.7	85.9
20	51.1	41.9	82.0
20	52.2	43.4	83.1
20	51.8	44.4	85.7
20	51.4	39.8	77.4
	Average relative efficiency		82.8 ± 0.94

[1]Efficiency was arrived at by considering the percent juice removed by the power reamer as 100 and expressing comparatively the juice removed by the other extractors as relative percentages of this figure.

removes a much greater percentage than the other extractors, in this case it is used as a standard. The percentage efficiency of the individual samples varies widely both for the hand press and for the hand reamer. This can be accounted for only in part by the error due to lack of precision of the extractors. The average efficiency of the hand press is significantly higher than the relative average efficiency of the hand reamer. Neither the hand reamer nor the hand press approaches the efficiency of the power reamer in juice removal. The efficiency in juice removal, the facility of operation and the speed with which samples can be handled by the power reamer make it the best of the three types tested for laboratory juice extraction.

The hand press, of a type shown in Fig. 1, would be desirable for juice extraction in the grove or packinghouse. It does not require electric current, is inexpensive, light to carry, easy to operate under trying conditions and will remove relative percentages of juice from each fruit. Because the hand press is not highly efficient in juice removal, the relative efficiency of any particular model should be established, using as a standard the juice removal efficiency of the power reamer. This will make possible a more accurate comparison between field and laboratory data.

METHODS OF ANALYSES

Methods of analyses of the Association of Official Agricultural Chemists *(1)* were used.

Juice Content.—The total weight of the sample was recorded in grams. In most instances more than one fruit or a single portion of a fruit were considered a sample, and in these instances the aggregate was treated as an individual sample. The juice was removed from the cut halves with the power reamer and strained through a 15-mesh wire sieve. The volume of the juice was recorded in milliliters. Specific gravity of the juice was obtained by conversion *(5)* of degrees Brix of the juice with correction for temperature. The juice content was calculated as percentage by weight of the sample of fresh fruit.

Acid.—The acid was determined as the total free acid by titration against tenth normal sodium hydroxide using phenolphthalein as an indicator. It is expressed in the tables as anhydrous citric acid calculated as percentage by weight of the extracted juice.

Soluble Solids.—The soluble solids were taken on the extracted juice, from which broken juice sacs and air bubbles were decanted after standing 15 minutes, with a hydrometer calibrated in degrees Brix. It is expressed as degrees Brix corrected for temperature.

CHANGES IN LIMES DURING A SHORT PERIOD OF STORAGE

Persian limes when picked from the tree and allowed to stand at ordinary room temperature have a tendency to lose their bright luster and turgidity. After 10 to 15 days they tend to take on a wrinkled appearance. To study the changes taking place in the juice content, percent acid and percent soluble solids of Persian limes during the first two weeks after being picked from the trees, a series of analyses was conducted. The fruit was picked from trees grafted on rough lemon rootstock. The maturity as judged from the external appearance of the fruit was uniform and all fruit were of about the same size. Seven lots of 20 fruit each were weighed, placed in separate four-quart baskets and stored at room temperature. The average daily mean temperature at the Experiment Station during the period from July 12 to July 24, 1938, was 78.5° F. Room temperature during this period approximated the outdoor temperature.

The first lot of 20 fruit was analyzed on the day of picking. The other six lots were weighed and analyzed, one lot after each two-day interval. Determinations were made of the juice content, percent acid and percent soluble solids.

JUICE, ACID, AND SOLUBLE SOLIDS

The data in Table 3 show that the loss in weight of the stored samples increased directly with the length of the storage period. The juice content, based on weight of the fruit at time of sampling, exhibited an increase which became larger as the fruit remained longer in storage. However, when the percentage of juice was based on the weight of the fruit on the day picked there was no appreciable increase or decrease, as the percent of juice remained fairly constant for all samples. There was probably an increase in the percentage of available juice removed by the reamer from the fruits as their time in storage lengthened. This could be due to the removal of more unbroken juice sacs by the reamer from fresh picked fruit than would be removed from fruits after a storage period when the juice sac

walls are more easily ruptured. The unbroken juice sacs would be caught on the sieve and although pressed by hand to remove most of the juice some would be discarded, their juice content being lost for the determination. The loss of weight of the fruit during the storage period was apparently partly from the juice sacs and partly from the peel and other fruit tissues.

TABLE 3.—VARIATIONS IN THE JUICE CONTENT, PERCENT ACID AND PERCENT SOLUBLE SOLIDS OF PERSIAN LIMES, WITH THE STORAGE PERIOD WHILE STORED AT ROOM TEMPERATURE.

			Percent Juice			
No. of Fruit in Sample	Days from Picking to Sampling	Percent Loss of Weight	Based on Original Weight	Based on Weight at Time of Sampling	Percent Acid	Degrees Brix
20	0		56.0	56.0		9.4
20	2	2.03	54.0	55.1	5.45	9.1
20	4	4.20	55.3	57.7	5.44	9.2
20	6	5.71	53.4	56.4	5.44	9.4
20	8	7.51	55.3	59.7	5.57	9.5
20	10	10.29	54.3	60.6	5.48	9.9
20	13	12.36	55.5	62.9	5.60	9.6

The acid content remained constant during the storage period as did also the solids-to-acid ratio. Since the principal ingredients of the juice, namely, acid, soluble solids and moisture, remained constant, and ade made from the juice at each sampling was of good flavor, it can be considered that there were no deleterious effects on the juice of the limes over this short storage period.

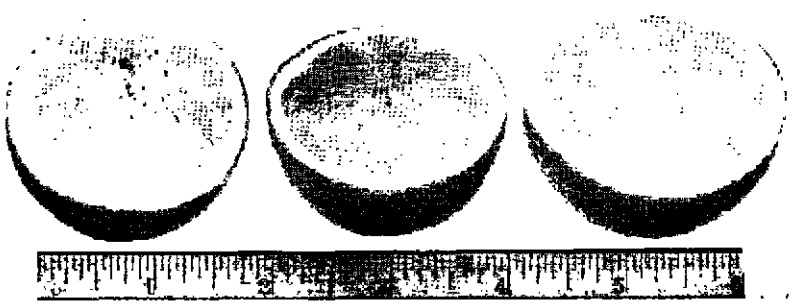

Fig. 2.—Severe ricing, left, and slight ricing, center, compared with no ricing, right. Persian lime fruits cut transversely and squeezed lightly by hand.

'RICING' OF JUICE SACS

An undesirable feature exhibited by all immature and some mature Persian lime fruits, when cut transversely and squeezed, is "ricing" (Fig. 2). The juice sacs, especially those near the cut surface, fail to break upon squeezing of the fruit, but, instead, are forced outward to a position almost vertical to the cut surface, giving the appearance of so many attached grains of rice. Gaddum *(3)* and numerous workers quoted by him demonstrated that there is a change in the pectic compounds during the growth period found in the locular and juice sac walls making up the pulp of oranges, lemons, grapefruit and kumquats. Gaddum *(3)* further states, citing from Sucharipa *(8)*, that "protopectins, which are the water insoluble, acid hydrolyzable parent substances of the pectins, are present in the cell-walls of plants, possibly in combination with cellulose. Normal ripening processes are accompanied by a gradual transition from the insoluble protopectins to the soluble pectins with a consequent decrease in cell-wall rigidity." The findings of these workers would indicate that one of the possible causes of ricing was the rigidity and toughness of the cell walls of the juice sacs, especially in immature fruit.

Observations indicate that immature Persian limes invariably show ricing, whereas fully mature fruit showing some yellow coloring in the peel exhibit this property to such a small degree as to be negligible. However, fruits 125 to 160 days of age (a large portion of the limes picked are in this age class) are quite variable in the amount of ricing exhibited. The amount of ricing at each sampling date was noted in the above described storage test. A moderate amount of ricing was general for all fruits on the day of picking, although there was considerable difference between fruits. Two days after picking the skin of the fruit had begun to soften somewhat and the degree of ricing was about half as great as that exhibited by the fresh fruit. There seemed to be a gradual decrease in amount of ricing on subsequent sampling dates until the tenth day after picking, when ricing had practically disappeared. The skin of the fruit at this time was quite soft and wrinkling was noticeable.

The loss of moisture by some of the tissues of the fruit, probably including the cells making up the walls of the juice sacs, would effect a general loss of turgidity in the fruit. During the maturing and ripening processes of the fruit the protopectins

are gradually changed over to the pectins with a consequent decrease in wall rigidity. Ricing in the fruit would tend to diminish under the influence of either or both of the above-mentioned causes. Thus, to satisfy the market demands for limes with easily extractable juice, fruit that is approaching maturity and has gone through some curing process such as storage, might well be the answer.

SPECIFIC GRAVITY OF LIME FRUITS IN RELATION TO THEIR JUICE CONTENT

The specific gravity of whole lime fruits can be determined easily without affecting their salability, either by volume displacement of the fruit in some liquid or by weighing under water. If the juice content of fruit could be correlated directly with the specific gravity of the fruit, a very simple means of grading limes into their respective ranges of juicensss would result. Toward this end determinations were made on groups of fruit in May and in November 1937 to establish either a negative or positive correlation between juice content and specific gravity. Wolfe *(9)*, in reporting the group of determinations listed below, stated that "except in rare cases of very dry or pithy fruit, no correlation showed between juiciness and specific gravity."

The specific gravity of the individual fruit was determined by weighing in air and under water. The fruit was then cut in half and the juice extracted by the hand press. The fruits tested were chosen at random from commercial pickings before the fruit had been graded at the packinghouse.

Statistical analysis *(6)* of the data of Table 4 indicates that there is no correlation between percent juice and specific gravity of the whole fruit of the Persian lime. The average juice content is higher for the fruit with a specific gravity above .990 than for those with a lower specific gravity, but there are too many wide variations from this average in each category to make this method of grading lime fruits worthy of consideration.

It was noted, in a few instances, that extremely dry or pithy fruit had an abnormally low specific gravity.

The variation of specific gravity among fruit with approximately the same juice content may be due in part to the hollow core, and cores of varying diameter which are found among the limes. The considerable difference in rind thickness found among fruit, even from the same tree, undoubtedly plays a part in the variation in specific gravity of the fruits.

In the light of these observations and tests it does not seem plausible to consider specific gravity of the whole fruit as a criterion of juiciness.

TABLE 4.—COMPARISON BETWEEN SPECIFIC GRAVITY AND JUICE CONTENT OF INDIVIDUAL PERSIAN LIMES.

Sampled 5/10/37		Sampled 11/15/37	
Specific Gravity	Percent Juice by Weight	Specific Gravity	Percent Juice by Weight
.930	43.1	.971	49.8
.954	51.7	.973	51.4
.955	39.7	.975	42.1
.956	45.2	.977	45.7
.963	50.9	.979	48.8
.969	53.2	.980	53.0
.975	47.5	.982	40.1
.978	50.2	.982	49.0
.979	54.4	.984	56.7
.980	47.3	.984	30.5
.984	49.3	.988	54.3
.985	51.0	.989	51.3
.986	51.2	.989	57.6
.987	50.3	.990	49.6
.989	49.1	.991	51.4
.989	49.5	.993	54.3
.990	50.3	.993	48.5
.991	46.1	.994	54.1
.992	48.8	.995	49.0
.998	51.4	.995	55.8
1.000	49.0	.995	54.6
		.995	48.4
		.997	52.9
		.998	55.1
		.998	54.8
		.999	74.9
		.999	47.2
		.999	48.6
		1.000	55.2
		1.002	57.0
		1.003	50.2
		1.003	52.9
		1.008	54.4
		1.009	50.5

MATURITY STUDIES

A problem which confronts the grower and shipper of Persian limes is determining at what stage in the maturity of the fruit it possesses the optimum juice and acid content. As a step toward answering this question, a limited analytical study was made of Persian limes at progressive stages of maturity for three seasons.

During the 1938 season fruits of approximate known age were tested from trees of different ages, all trees grafted on rough lemon rootstock. An extremely heavy drop of tagged

fruit reduced considerably the number of fruit available for sampling. The trees used in this test received no irrigation. As there were several periods throughout the season when the trees were suffering from drought, as indicated by leaf curl and slight loss of turgor of the fruit, it is probable that the fruits did not make their maximum growth. Furr and Taylor *(2)*, working in California, found that the final size of lemons was decreased markedly in plots which were irrigated only when the leaves began to roll, as compared to plots in which water was applied at such short intervals that the trees showed little or no water deficit.

In the 1939 season the samples were taken from trees eight years of age, grafted on five different rootstocks—willowleaf sour orange, rough lemon, sour orange, bittersweet orange and Cleopatra. In the 1940 season samples were taken from trees nine years of age, grafted on these five rootstocks and, in addition, from nine-year-old trees grafted on grapefruit rootstock. These trees were irrigated when evidence of drought was apparent but a heavy drop of tagged fruit was again experienced in 1939 and also in 1940.

PRELIMINARY FRUIT MATURITY TESTS DURING 1938 SEASON

The fruit for these preliminary tests was taken from trees of three different ages, four years, seven years, and 11 years, grafted on rough lemon rootstocks. Fruits from trees of each age were tested separately. The fruits selected for tagging (a white paperboard tag was attached to the pedicel of each fruit) were 41 mm. in diameter, as the bloom and fruit of smaller size were too scarce to allow tagging of sufficient fruits for analyses. In comparison of size with fruit from tagged blossoms, the 41 mm. fruit were estimated to be approximately 75 days from blossoming. The size of the fruit at tagging was determined with a wire ring.

Sampling began on an estimated 110 days from blossoming and was continued at approximately two-week intervals thereafter until the fruits began to turn yellow. Ten fruits were taken as a sample from both the seven-year-old and 11-year-old trees. The 10-fruit sample from the four-year-old trees was selected in part from each of three trees. The fruits were analyzed individually by the usual methods. The diameter of the fruit was taken with calipers at the place of greatest transverse section.

TABLE 5.—ANALYSES OF PERSIAN LIMES AT PROGRESSIVE STAGES OF MATURITY FROM TREES OF THREE DIFFERENT AGES DURING 1938 SEASON.

Date	Tree	Age of fruit	Weight in Grams			Diameter			Percent Juice			Percent Acid	Degrees Brix
			Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.		
6/20/38	4-year old	110 days	80.4	55.2	66.9	51	46	48	54.2	45.3	50.2	5.63	10.2
7/7/38	" "	127 "	101.7	63.5	81.3	56	48	52	58.6	45.0	51.8	5.53	9.8
7/18/38	" "	138 "	126.8	68.3	90.3	60	49	54	60.1	51.6	55.6	5.56	9.4
8/2/38	" "	153 "	125.8	80.9	100.3	66	50	56	63.2	50.1	55.0	5.58	9.0
8/16/38*	" "	167 "	143.7	98.8	115.8	63	55	59	61.4	38.9	54.2	5.92	9.5
6/20/38	7-year old	110 days	76.3	55.3	68.2	45	51	48	56.0	45.5	51.1	5.14	9.6
7/7/38	" "	127 "	101.2	76.0	85.9	57	50	53	56.1	50.8	53.6	5.30	9.4
7/18/38	" "	138 "	104.5	73.9	88.1	56	48	53	59.6	43.4	54.0	5.13	9.0
8/2/38	" "	153 "	120.0	92.1	108.4	59	54	57	63.9	46.2	56.6	5.14	8.6
8/16/38**	" "	167 "	125.4	100.3	112.0	61	55	58	67.4	55.3	62.5	5.09	8.5
6/20/38	11-year old	110 days	74.3	53.9	62.7	48	44	46	53.6	45.5	50.4	5.20	10.4
7/7/38	" "	127 "	88.1	63.0	78.1	53	47	51	54.0	45.5	50.2	4.99	10.0
7/18/38	" "	138 "	97.6	77.6	88.2	56	50	52	57.8	49.4	54.2	5.01	9.2
8/2/38	" "	153 "	121.2	80.2	95.2	61	52	55	62.6	53.2	55.9	4.94	9.1
8/16/38***	" "	167 "	105.5	98.3	101.9	54	54	54	60.0	56.0	58.0	5.07	8.3

* 5 fruit in sample
** 8 fruit in sample
***2 fruit in sample

VARIATION IN MATURITY OF FRUIT FROM TREES OF DIFFERENT AGES

The data of Table 5 show a consistent increase in the average weight of the fruits from all trees as the age of the fruit increased. The maximum and minimum columns indicate a wide variation in weight and also diameter among fruits of the same age. This difference in weight and diameter was evident throughout the growth period. The average weight and the average diameter of the fruit from the 11-year-old tree were slightly but consistently less during the season than those of the fruit from the four- and seven-year-old trees. This was probably due to the large crop on the 11-year-old tree, as compared with the moderate crops on the other trees. It has been observed that trees with heavy crops tend to produce smaller fruit than trees with moderate to light crops.

With few exceptions there was a gradual increase in juice content during the growth period for the fruit from trees of all ages. Also the juice content was quite similar for the fruit of the trees of all ages.

The percent acid in the juice from fruit from each age group remained constant throughout the period of sampling. As the juice content increased the total amount of acid in the individual fruit increased also. However, the fruit from the four-year-old trees contained from 7 to 17 percent more acid per gram of juice than fruit from the seven- and 11-year-old trees.

The soluble solids declined about 1 degree over the sampling period in fruit for all of the trees. This value was very similar for trees of all ages at any one sampling date.

Ade was made from the excess juice at time of sampling. The juice from all trees at the 110-day sampling had a distinct, bitter after-taste. At the 127-day sampling the fruit from the four- and seven-year-old trees made palatable ade, but that from the 11-year-old trees was slightly bitter. At the 138-day sampling the ade made from the fruit from the trees of all ages was excellent. Apparently the fruit reached maturity, as measured by palatability, satisfactory juice and acid content, in from 125 to 140 days from blossom opening.

FRUIT MATURITY INVESTIGATIONS OF 1939 AND 1940

The fruits for the investigations of 1939 and 1940 were of known age at each sampling. Ten flower clusters were tagged at the time of a heavy bloom on the test trees, which occurred in

May 1939 and in February 1940. One week later, after the petals had fallen and the first heavy drop of small fruit had occurred, small fruits, comparable to the 10 tagged samples, were tagged. This made it possible to know the age of the fruits at sampling time to within one or two days of their true age. In 1939 200 small fruits scattered over five trees were tagged on each rootstock. Twenty-four percent of the tagged fruit was recovered for sampling. In the 1940 season 1,000 small fruits were tagged on the same groups of trees on each rootstock but only 6 percent was recovered for sampling.

Samples of 10 fruits from each rootstock were collected at 114 days of age in 1939 and 100 days of age in 1940, with subsequent samples following at about two-week intervals until the fruit turned yellow or until no more fruit of known age was available.

VARIATION IN MATURITY OF FRUIT FROM TREES GROWN ON DIFFERENT ROOTSTOCKS

Results of these two seasons' investigations are given in Tables 6 and 7. The figures in Table 6 represent the average value of 10 fruits which were weighed, measured and juice extracted as one sample during the 1939 season. The figures in Table 7 for the 100- and 115-day age samplings were determined the same way, but the values for the 128-, 142-, 156- and 170-day old samplings represent the average of 10 fruits weighed, measured and juice extracted individually. The maximum and minimum values under each category are given. The acid and Brix values were determined upon the aggregate juice of each sampling. The data in both tables have been arranged under each rootstock according to the progressive age of the fruit for ease of comparison. The weight, diameter and length of the fruit on all rootstocks, with minor exceptions, increased as the fruit increased in age. This increase was accelerated during the first and last two weeks of the sampling period; namely, before the fruit was 114 to 115 days old and after it reached an age of 154 to 156 days. The maximum and minimum values in Table 7 show the great variation in weight and size between fruit at any one age. These wide variations were found in fruits on all the rootstocks tested.

Fruits grown on rough lemon rootstock were of greater weight and size than those grown on any of the other rootstocks. This held true throughout the sampling period. Fruits grown on

TABLE 6.—ANALYSES OF LIMES AT PROGRESSIVE STAGES OF MATURITY DURING 1939 FROM TREES GRAFTED ON FIVE DIFFERENT ROOTSTOCKS.

Date	Rootstock	Age of Fruit (days)	Average Weight (grams)	Average Diameter (mm)	Percent Juice	Degrees Brix	Percent Acid
9/15/39	Willowleaf Sour orange	114	72.1	49	49.1	10.1	5.60
9/29/39	"	128	70.1	49	55.6	9.9	5.60
10/12/39	"	140	78.0	50	60.0	9.9	5.62
10/26/39	"	154	89.2	55	62.3	9.9	5.81
11/6/39	"	165	116.3	59	63.0	9.4	5.68
9/15/39	Rough lemon	114	72.5	49	49.4	9.2	5.59
9/29/39	" "	128	87.1	52	59.5	8.8	5.47
10/12/39	" "	140	96.1	54	60.4	9.0	5.41
10/26/39	" "	154	120.7	59	59.6	8.6	5.57
9/15/39	Sour orange	114	76.0	50	56.1	10.0	5.86
9/29/39	" "	128	83.7	51	58.4	9.9	5.56
10/12/39	" "	140	85.5	52	63.2	10.1	5.54
10/26/39	" "	154	98.0	55	63.3	9.2	5.54
9/15/39	Bittersweet	114	69.4	48	53.2	9.7	5.43
9/29/39	"	128	79.1	51	57.9	10.0	5.38
10/12/39	"	140	94.8	52	61.4	9.9	5.40
10/26/39	"	154	109.1	57	63.8	9.5	5.41
11/6/39	"	165	121.8	59	63.5	9.4	5.59
9/15/39	Cleopatra	114	64.6	47	53.1	9.6	5.22
9/29/39	"	128	74.3	49	60.0	9.5	5.34
10/12/39	"	140	87.0	51	60.5	9.4	5.59

grapefruit, Cleopatra, bittersweet, sour orange and willowleaf sour orange stock were similar in weight and size at any particular age, except in 1939, when those grown on bittersweet were slightly heavier and larger than fruits from the other four. Fruits of the same age group were larger and heavier on all rootstocks in the 1939 tests than in 1940. The difference in fruit size was due, to a considerable extent, to difference in size of crop. There was a heavy crop on the trees while the 1940 test fruits were maturing but only a light crop on the trees while the 1939 test fruits were maturing. The period from 128 days to 156 days in the life of the fruit showed the least acceleration in change of fruit size or weight. It is fruit of this age group that is picked for shipment. Older fruit, although it increases somewhat in size and weight, suffers the loss of some of the bright green color, often turning a greenish yellow to yellow. Stylar-end breakdown is quite prevalent in these lighter colored fruits.

The juice content in the fruit increased with maturity. It was very similar for the fruit from the different rootstocks, with a few exceptions, at any of the sampling periods. The increase in juice content was most rapid up to the 128-day age, and was very gradual from the 128-day to 154-day age. After the 154- to 156-day period, the juice content, with minor exceptions, became either stationary or decreased slightly. At the sampling periods in the 1940 season when the fruits were analyzed individually, a substantial difference in juice content was found between those containing the maximum and those containing the minimum percentages in a sample[6]. There was, however, no correlation between these differences and the age of the fruit or the rootstock on which grown.

There was generally a higher percentage of juice in the fruits sampled in 1939 than in those sampled in 1940. This may have been due in part to the smaller number of fruits on the tree during the 1939 season in contrast to the heavy summer crop on the tree while the 1940 samples were taken. Also during the growth and maturity of the fruits sampled in 1939 rainfall was plentiful, 52.57 inches of rain being recorded for the five months prior to maturity, whereas in 1940 only 25.60 inches of rain was recorded during the same comparable period.

The percent acid was not influenced either by the rootstock or by the age of the fruit as represented in the samples. It is of interest to note that the percent acid was higher in general during 1939, a wet season, than during 1940. The soluble solids in the juice were not influenced by the rootstock on which the fruit was grown. The age of the fruit, however, seemed to have a slight influence. The soluble solids declined about 2 degrees from the time the fruit was 100 days old until it was 170 days old. Approximately half of this decrease, as observed during the 1940 season, occurred between the ages of 110 days and 115 days. The fruits within the 128- to 156-day age group contained, with a few exceptions, a uniform soluble solids content. The soluble solids during the 1939 season were slightly lower than during the 1940 season.

These analytical studies with limes indicated that there was no differential influence upon their juice content, percent acid

[6]Where the wide differences appeared, they were due in almost every case to either a single fruit being excessively high or low in juice content, or to two fruits, one moderately high and one moderately low in juice content.

TABLE 7.—ANALYSES OF LIMES AT PROGRESSIVE STAGES OF MATURITY DURING 1940 FROM TREES GRAFTED ON SIX DIFFERENT ROOTSTOCKS.

Date	Rootstock	No. Fruit in Sample	Age of Fruit (days)	Weight of Fruit (grams)			Percent Juice			Diameter (mm.)			Length (mm.)			Percent Acid	Degrees Brix
				Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.		
5/20/40	Willowleaf sour orange	10	100	26.7	—	—	21.7	—	—	25.	—	—	32	—	—	5.50	12.7
6/4/40	Willowleaf sour orange	10	115	39.1	—	—	32.0	—	—	40	—	—	46	—	—	6.06	10.0
6/17/40	Willowleaf sour orange	10	128	48.5	62.0	37.0	43.0	50.0	37.8	43	47	39	48	54	43	6.09	10.2
7/1/40	Willowleaf sour orange	10	142	51.0	58.0	39.0	45.1	50.0	38.5	44	47	41	49	52	43	5.52	9.9
7/15/40	Willowleaf sour orange	10	156	59.0	78.0	38.0	46.3	50.7	38.2	46	50	39	51	57	41	5.67	10.2
7/29/40	Willowleaf sour orange	10	170	74.0	123.0	46.0	47.0	53.8	40.7	50	57	44	54	70	44	5.94	10.1
5/20/40	Rough lemon	9	100	39.2	—	—	26.7	—	—	27	—	—	33	—	—	5.81	11.9
6/4/40	Rough lemon	10	115	59.8	—	—	39.0	—	—	47	—	—	51	—	—	6.26	10.0
6/17/40	Rough lemon	10	128	64.6	106.0	39.0	41.8	47.2	26.8	47	56	39	52	63	44	5.71	10.0
7/1/40	Rough lemon	10	142	73.0	107.0	51.0	47.8	54.9	43.4	49	57	43	55	62	47	5.58	10.0
7/15/40	Rough lemon	10	156	79.0	113.0	57.0	49.6	52.5	46.8	51	59	46	55	62	49	5.79	9.7
7/29/40	Rough lemon	5	170	109.0	127.0	94.0	51.5	53.0	49.7	58	62	55	62	67	57	5.80	9.4
5/20/40	Sour orange	10	100	19.3	—	—	16.4	—	—	20	—	—	27	—	—	5.58	13.0
6/4/40	Sour orange	10	115	47.8	—	—	34.7	—	—	43	—	—	49	—	—	6.35	11.2
6/17/40	Sour orange	10	128	55.1	70.0	43.0	44.1	46.3	38.6	45	48	43	51	58	44	6.27	11.1
7/1/40	Sour orange	10	142	61.0	88.0	35.0	44.3	48.2	34.3	46	52	39	53	64	42	6.04	10.7
7/15/40	Sour orange	10	156	65.0	82.0	53.0	47.0	50.8	43.1	47	54	42	52	58	48	6.01	10.4
7/29/40	Sour orange	10	170	79.0	97.0	54.0	49.4	54.0	45.5	51	57	44	57	61	55	6.30	10.3
5/20/40	Bittersweet	10	100	26.1	—	—	18.1	—	—	21	—	—	31	—	—	5.60	11.7
6/4/40	Bittersweet	10	115	45.4	—	—	34.8	—	—	42	—	—	48	—	—	6.09	10.6
6/17/40	Bittersweet	10	128	49.8	61.0	39.0	42.7	47.2	34.1	43	45	39	50	54	48	6.30	10.5
7/1/40	Bittersweet	10	142	60.0	82.0	44.0	43.7	49.4	38.4	46	50	42	51	59	45	5.81	10.1
7/15/40	Bittersweet	10	156	63.0	81.0	53.0	47.7	51.4	43.8	47	52	44	53	60	49	5.94	10.2
7/29/40	Bittersweet	8	170	58.0	70.0	52.0	46.3	50.5	37.0	46	50	44	52	56	48	5.71	9.9
5/20/40	Grapefruit	10	100	25.0	—	—	23.1	—	—	21	—	—	32	—	—	6.32	12.5
6/4/40	Grapefruit	10	115	50.1	—	—	37.3	—	—	43	—	—	51	—	—	6.48	10.3
6/17/40	Grapefruit	10	128	50.0	69.0	34.0	43.6	48.9	28.9	44	47	39	50	59	44	6.42	10.1
7/1/40	Grapefruit	10	142	65.0	75.0	48.0	45.5	52.0	39.2	47	50	42	54	56	48	6.27	10.1
7/15/40	Grapefruit	10	156	58.0	78.0	42.0	45.7	51.3	35.8	46	50	41	50	59	45	6.14	10.5
7/29/40	Grapefruit	8	170	65.0	88.0	51.0	45.6	54.5	45.2	48	54	43	54	59	47	6.03	10.2
5/20/40	Cleopatra	10	100	28.1	—	—	22.6	—	—	22	—	—	32	—	—	7.66	14.1
6/4/40	Cleopatra	10	115	52.1	—	—	34.2	—	—	44	—	—	51	—	—	6.82	11.9
6/17/40	Cleopatra	10	128	59.3	65.0	48.0	42.6	47.4	36.9	46	49	41	54	57	52	6.55	11.1
7/1/40	Cleopatra	10	142	67.0	83.0	47.0	44.5	51.3	42.1	47	52	40	55	60	51	6.14	10.6
7/15/40	Cleopatra	10	156	65.0	83.0	50.0	46.7	52.1	33.3	47	52	43	54	59	49	6.03	10.6
7/29/40	Cleopatra	9	170	77.0	109.0	43.0	45.6	50.9	37.4	50	56	41	57	65	42	5.78	10.2

and percent soluble solids by the rootstocks on which they were grown. However, limes grown on rough lemon rootstock were of greater weight and size than those grown on any of the other rootstocks tested. In the light of these observations the selection of desirable rootstocks for limes should be judged on the production of small to medium-sized fruit, heavy bearing habits, resistance to disease and drought, congeniality of the graft union, adaptability to the soil, and type of tree growth resulting.

SEASONAL VARIATION IN JUICE AND ACID CONTENT OF TOP GRADE LIMES

The investigation of seasonal variation in juice and acid content of Persian limes was carried out during the 1938 season *(4)*. The object of the analyses was to determine the quality, in regard to juice and acid content, of the top grade limes shipped from the Redland district. The tolerance for defects allowed for top grade limes were not uniform for the four packinghouses from which the samples were obtained. However, the top grade from each of the packinghouses was similar enough in quality to be considered a single grade for the purposes of this series of analyses.

Samples were taken every two weeks, on Monday and Tuesday, since these were the heavier picking and shipping days. A sample consisted of 20 first grade fruits from a packinghouse. The fruit chosen was of average size for that particular picking. As many groves were represented by each sample as there were different lots of fruit in the packinghouse. Since all of the houses were not shipping every time samples were taken, the total number of fruits analyzed each time varied from 40 to 80.

The fruits were weighed and the juice was extracted and measured individually, as previously described. Specific gravity and percent acid were determined from the aggregate juice of the fruits from each packinghouse.

The 1938 shipping season for Persian limes from the Redland area extended from June through December. During this period 16 samples were taken at two-week intervals. The weight, juice content, and percent acid of the fruit from each of the four packinghouses were quite similar and the data of all four are combined, for brevity of presentation, into Table 8. The data under the headings "Average weight of fruit" and "Average percent juice" represent an average of the individual fruits sampled

on that day. The data under "Average percent acid" represent an average of the acid content of the samples taken on that day.

The weight and diameter of the fruit increased as the season progressed, larger and heavier fruit being picked during November and December. Probably the heavier crops on the trees during the summer months tended to keep down the size. Also the tendency of the grower to lighten the heavy crop on the tree by picking the limes before they had reached a maximum size accounted for the smaller average size being marketed during the summer. Both the minimum and maximum weight fruits in a sample were smaller during the summer months than during the fall and winter months.

The data show that the average juice content for the season was consistently 50 percent or better except for one picking in June and one in December, at which times the juice content fell a fraction of a percent below 50. There were two periods during the season when the juice content was highest. The first was during August and early September, when the average juice content ranged from 57 to 59 percent, and the other from the middle of October to the middle of December, with an average juice content of from 55 to 58 percent. It is of interest to note here that during the month preceding each of these peaks the rainfall was excessive. During July there was almost 10 inches and from September 15 to October 15 there was a little over seven inches of rainfall. The minimum juice content of an individual fruit dropped as low as 29.4 percent in one instance, but the minimum average for the season was 40.3 percent. Thus, if even the driest limes were selected they still contained only about 15 percentage points less juice than the average fruit shipped. The maximum juice content remained about 65 percent with a few minor exceptions. In all cases the fruits containing the minimum and those containing the maximum juice content were but a small portion of any sample.

The average juice content for the entire season was 54.6 percent, the lowest sampling being 49.4 percent and the highest 59.0 percent.

The acid content of the juice averaged 5.65 percent by weight for the season, with individual samplings varying very little from this figure.

The quality of the limes in juice content and percent acid was very satisfactory for the fruit from all packinghouses. The smaller size of the fruit during the summer months was a de-

TABLE 8.—THE WEIGHT, PERCENT JUICE, AND PERCENT ACID OF LIMES FROM FOUR PACKINGHOUSES IN THE REDLAND DISTRICT SAMPLED AT TWO-WEEK INTERVALS DURING THE 1938 SEASON.

Date	No. of Fruit	Weight of Fruit (Grams)			Percent Juice			Percent Acid
		Min.	Max.	Avg.	Min.	Max.	Avg.	Avg.
6/14/38	40	59.2	92.5	73.6	42.0	54.9	49.6	5.83
6/28/38	60	53.3	119.6	74.8	37.0	60.4	50.5	5.40
7/12/38	60	54.4	120.0	75.9	47.9	62.0	54.0	5.55
7/25/38	60	61.6	118.9	93.2	40.0	66.0	54.4	5.37
8/9/38	60	65.2	117.9	84.2	42.7	65.5	57.8	5.59
8/23/38	60	59.2	119.3	85.3	33.9	84.8	57.1	5.57
9/2/38	60	69.9	127.4	96.5	46.7	67.7	59.0	5.93
9/20/38	40	53.4	116.2	85.3	29.4	64.8	53.1	5.51
10/4/38	60	63.5	135.1	93.6	37.9	65.3	50.3	5.83
10/18/38	38	60.5	139.1	93.2	46.9	65.5	57.3	5.59
11/1/38	60	59.9	153.4	102.3	38.7	67.8	57.4	5.52
11/15/38	60	74.5	130.0	104.3	38.3	63.2	55.3	5.55
11/29/38	40	70.0	155.2	105.0	45.4	67.3	58.0	5.45
12/13/38	40	77.5	179.0	118.5	45.9	73.5	57.0	5.62
12/28/38	40	66.1	145.4	96.2	38.5	60.6	49.4	6.13
1/10/39	80	61.6	158.0	100.0	33.9	63.7	52.8	5.93
Average		63.1	132.9	92.6	40.3	65.8	54.6	5.65

sirable feature, since the larger sizes command a lower price during the peak months of the season. The months of heaviest pickings are from June through September. During the fall, winter and early spring months, when only small quantities of fruit are harvested, fruit size has very little effect upon prices. As there was no correlation between fruit size and juice content, and as the percent acid remained consistent for the season, a plausible harvesting program would be one wherein fruit of smaller size but satisfactory juice content and flavor would be picked during the summer months; during the months of light production and less discrimination against large size, the fruit can be allowed to remain longer on the trees, attain a larger size and thus increase the yield.

SUMMARY

Persian lime fruits from trees grown on five rootstocks were analyzed over three seasons for variations in juice content, percent acid and percent soluble solids as affected by storage and maturity, and the relation of juice content to specific gravity of the fruit as well as seasonal variation of juice and acid content of top grade limes were studied.

Three types of juice extractors, a power reamer, hand reamer and hand press, were tested for efficiency and precision in juice removal from lime fruits and for adaptability to laboratory analyses.

The power reamer, due to its efficiency in juice removal, facility of operation, and speed with which samples can be handled, was the best type of laboratory juice extractor. The hand press, of the type tested, was adaptable to juice extraction in the grove or packinghouse. The hand reamer proved impractical for either laboratory or field analyses.

Loss in weight by the fruit during a short storage period at room temperature was apparently partly from juice sacs and partly from the peel and other fruit tissues. The actual juice content as removed by the power reamer remained constant. The degree of ricing of the juice sacs was materially reduced by a short storage or curing period.

No correlation was found between specific gravity of the whole lime fruit and its percent juice content by weight.

Fruit analyzed from trees of different ages (4 years, 7 years, and 11 years), all on rough lemon rootstock, showed wide variation in weight and size for the same age fruit throughout the growth period. Juice content increased gradually during the growth period and was quite similar for the fruit from trees of different ages. Percent acid in the juice remained constant during the growth period, but fruit from the younger trees showed a greater percentage of acid. Soluble solids of the juice declined slightly and similarly during the sampling period in fruit from the trees of the three different ages. The fruit reached maturity, as measured by palatability and satisfactory juice and acid contents, in from 125 to 140 days from blossoming.

Fruit analyzed from trees grafted on different rootstocks (rough lemon, grapefruit, Cleopatra, bittersweet, sour orange and willowleaf sour orange) during the growth period of the fruit indicated: that fruits grown on rough lemon rootstock were of greatest weight and size throughout the growth period sampled, while fruits grown on the other rootstocks were generally of similar weight and size at any particular age sampled; that there is a general difference in fruit weight and size in different years; that the juice content of the fruit increased with maturity and was similar for the fruit from the different rootstocks at each sampling period; that after the 154- to 156-day age period, the juice content became either stationary or decreased slightly; that the percent acid content of the juice was not influenced either by the rootstock or by the age of the fruit as represented in the samples; that soluble solids content of the juice was not influenced by the rootstocks tested.

Very satisfactory juice and acid content was observed in top grade limes from four packinghouses throughout the 1938 season.

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