A STUDY OF SAMPLE SIZE IN

MACADAMIA NUTS

(*MACADAMIA INTEGRIFOLIA*)

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We certify that we have read this thesis and that in our opinion it is satisfactory in scope and quality as a thesis for the degree of masters in horticulture.

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ABSTRACT

Replicated samples of 10, 20, 30, 40, and 50 in-shell macadamia nuts were set up to determine optimum sample size needed to determine the number of nuts necessary to obtain acceptably reliable values for percent grade 1 kernels, percent kernel, and average shell diameter. Average shell diameter was found to be most variable with an average coefficient of variation of 150 percent for the 5 sample sizes. A 30 nut sample was necessary for ±3 percent accuracy at the 95 percent probability level. The lowest average coefficient of variation found in the experiment was 2.4 percent for percent kernel. A 30 nut sample was required for accuracy of ±2 percent at the 95 percent probability level. The average coefficient of variation for percent grade 1 kernels was 7.3, and a 100 nut sample was required for accuracy of ±5 percent, at the 95 percent probability level.

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INTRODUCTION

The macadamia nut M. integrifolia (Maiden and Betche) is often considered to be the finest confectionary nut in the world because of its fine texture and excellent flavor (6). It was first introduced into Hawaii between 1882 and 1885 by William Purvis of Kukuihaele, Hawaii, and later in 1892 by E.W. Jordan and R.A. Jordan of Honolulu, Oahu (4). For a time, the earlier of the two introductions was not recognized as being the macadamia nut of commerce and was thought by Pope (13) to be the gympie nut, M. ternifolia. It has now been established however, that Purvis' introduction was the 'smooth-shell' macadamia nut, M. integrifolia (4, 23). The rough-shell macadamia, M. tetraphylla L. Johnson (23) was introduced sometime after the smooth-shell macadamia. It has been almost 100 years since these early introductions, and the predicted value of macadamia nuts in Hawaii was $7,481,000 in 1977 (20).

The smooth and rough-shell macadamia nuts are native to the eastern coastal rain forests of northern New South Wales and Southern Queensland in Australia (23). M. integrifolia was first discovered in the Moreton district along the Pine River near Brisbane in 1858 by Walter Hill (10), director of Brisbane Botanical Gardens, and Ferdinand Mueller, a government botanist from Victoria. Mueller described and named the species in the same year. The genus was named for Dr. John Macadam, then secretary of the Philosophical Institute of Victoria. The name given to the macadamia nut by the aborigines of Australia is 'Kindal Kindal'. The non-native population of Australia sometimes refer to it as the 'Australian nut' but in the world trade both species are generally called macadamia nuts (9).

In 1892, 1893 and 1894 the Board of Agriculture and Forestry of the

Hawaiian Government planted rough-shell, M. tetraphylla, trees in reforestation plantings on the slopes of the Tantalus section of Honolulu at about the 900 feet elevation (4,6,13). Six trees were planted, three of which were included in land set aside for the Hawaiian Agricultural Experiment Station established by the Hawaiian government in 1900 (4,13). Seed from these trees and the trees themselves were used in preliminary experiments by station personel (4,13).

Macadamia trees were planted primarily as ornamental trees between the years 1900-1915 and in a reforestation project by Honaka'a Sugar Company in 1916 (4,6,26). In 1918 to 1919, the Hawaii Agricultural Experiment Station distributed seedling macadamia nut trees to the coffee growers as a possible source of supplemental income. However, coffee prices during the 1920's were high and interest in growing macadamia nuts as a supplementary crop declined (4,6).

The macadamia nut industry began in 1922, when the Hawaiian Macadamia Nut Company was organized to produce and process macadamia nuts (6). Two orchards were planted by the company, one at Tantalus on Oahu at about 900 foot elevation , and the other at Keauhou, Hawaii, at 1800 feet. By 1934 these orchards of seedling smooth-shell macadamia nut trees constituted about 25 and 100 acres respectively (4,6). In 1924 Honoka'a Sugar Company planted a seedling orchard of smooth-shell macadamia trees. From that time, the smooth-shell species predominated in all seedling plantings in Hawaii to the virtual exclusion of the rough-shell species (22). This was mainly due to the quality of the processed roasted kernels. The processed smooth-shell kernels were superior, being light brown in color, crisp and tender in texture with a mild nutty flavor, while many of the rough-shell kernels turn dark after roasting and frequently develop off flavors (18).

The period from 1920 to 1940 saw many advances in the macadamia nut industry. In 1922, Pope began experimenting with vegatative propagation of the macadamia without notable success (13). More extensive experiments were performed in 1927 by Ralph Moltzau, a student research assistant; these were moderately successful in rooting shoot cuttings and air layers and some success was also achieved with inarches and grafts (13). He collected scions from a partially broken branch which had been naturally girdled. In 1937, Beaumont and Moltzau conducted experiments demonstrating the importance of carbohydrate accumulation in scions taken from girdled branches (2). Higher carbohydrate level in scion pieces proved effective in promoting a higher percentage of successful grafts.

In 1930, Pope, recognizing the tremendous seedling variation found in macadamia nut seedlings, began to select and multiply more vigorous and better-quality seedling trees by grafting (15). In 1932, a selection program with macadamias was initiated by Pope from seedling trees growing on Oahu. A number of preliminary selections were made and propagated for further study in test orchards as a part of the process of selecting clonal varieties (15).

In Australia, variation of seedling macadamia trees was not fully appreciated and individual trees were given names such as 'Comet', 'Pearl', 'Venus', 'Rough King', and 'Smooth Queen'. Seeds from these named trees were collected and sold at high prices. Seeds from those trees produced variable seedlings and the original trees given these names were eventually lost or forgotten (5).

In 1927, Act No. 37 of the Territorial Legislature exempted land used solely for culture and production of macadamia nuts from taxation for 5 years (13). This act encouraged the planting of macadamia nuts and indirectly led to the construction of a factory in Honolulu for cracking and processing macadamia nuts (21).

The macadamia industry developed rapidly during the early 1930's. In 1932 there were 423 acres of seedling trees (18) and by 1935 there were 800 acres containing 60,000 seedling trees (21). It was from these 60,000 seedling trees that selections were made in 1936, which later became the first 5 named varieties released in Hawaii in 1947 (21).

The first orchards of grafted trees were planted from 1938 to 1941. These were trial orchards of the Hawaii Agricultural Experiment Station designed to test clonal selections on Maui, Oahu, Kauai, and Hawaii (6). The Honoka'a Sugar Company also planted a large number of grafted trees in 1938 (26).

From 1939 to 1943, interest in macadamia growing decreased due to low prices paid to the growers for nuts. As a result, acreage dropped from 1,086 acres in 1938, to 607 acres in 1943 (6). Although acreage decreased during this period the nuts became more widely known and sought after, resulting in higher prices to growers and a subsequent increase in acreage of macadamias by 1945 (4).

In 1947, Storey announced the release of the first five named Hawaiian macadamia nut varieties; 'Keauhou', 'Kohala','Nuuanu', 'Kakea', and 'Pahau' (21). Their release stimulated increased planting of these varieties (4), primarily 'Keauhou' which in the past has been the most widely planted variety. In 1950 the estimated acreage in the state was 1,659 acres (4). In 1948, Castle and Cooke began planting a 1,000 acre macadamia orchard at Keaau on the island of Hawaii. This planting was completed in 1954 (4).

A limited amount of selection work has also been done in Australia. Most Australian selections have been made from trees in dooryard plantings and seedling orchards (10). Many macadamia trees in Australia have been planted as dooryard or ornamental nut trees with at least 20,000 trees planted in the Brisbane area alone (25). In 1949, the Hawaii Agricultural Experiment Station received scions of an Australian selection sent by Andrew Jademan of Southern Queensland. These scions, which were of a M. tetraphylla selection, were successfully grafted but the trees were slow to come into bearing and unproductive (24). In 1950 and 1951, H.F. Clements of the Hawaii Agricultural Experiment Station brought in another 6 selections (24). In 1951, 2 more M. integrifolia selections and one M. tetraphylla selection were brought into Hawaii. The late J.H. Beaumont sent back scions of 34 selections from Australia and by 1960, 21 of 54 selections from Australia had fruited. None of these introductions proved promising enough to be put into variety trials in Hawaii (24).

Two new Hawaiian varieties 'Wailua' and 'Ikaika' were released by Hamilton, Storey and Fukunaga in 1952 (3). In 1966, Hamilton and Ooka released another variety, 'Keaau'. 'Kau' released in 1973, became the ninth Hawaiian variety (6). The two newest varieties to be released by the Hawaii Agricultural Experiment Station were 'Mauka' and 'Makai'(7).

Since 1947 there have been more than 44 named clones named from Australia, California and Hawaii (5). There are at least 24 clones from Queensland, 8 from California and 12 from Hawaii. Of the 44 varieties 22 are smooth-shell, 7 are hybrids, and 15 are rough-shell. There is presently no rough-shell varieties grown commercially in Hawaii or elsewhere. The Australian varieties tested in Hawaii have been useful mainly as seed parents in breeding work (5).

The Hawaii Agricultural Experiment Station has selected more than 875 clones and tested them at various locations (5). Of these, the first 750 have been adequately tested. During the selection and testing process approximately 95,000 bearing seedlings have been evaluated. These have been reduced to 6 outstanding commercial cultivars. These are 'Keauhou', 'Kakea', 'Keaau', 'Kau', 'Mauka', and 'Makai'.

Improved clonal selections have resulted in an increase of at least 4 times the total yield of nuts per tree, 10 percent more kernel and 10 percent more grade 1 kernels as compared to original planted seedlings (5). This is approximately 6 times greater yield of marketable kernels than field run seedlings. A prediction made by R.A. Hamilton (5) based on the current variety testing program of the Hawaii Agricultural Experiment Station is that present production per tree can be increased by about 25 percent, percent kernel increased from 35 to 45 percent, and percent grade 1 kernels increased from 90 to at least 95 percent. If this can be realized it would lead to an increase in production of about 70 percent more grade 1 kernels per tree or per acre (5).

The introduction of improved clonal varieties into Hawaiian macadamia orchards led to increased planting. In 1943, 607 acres of macadamia nuts produced an income of $38,000. By 1961, 3,526 acres had been planted which produced a crop worth $602,000 to growers (6). The greatest increase in dollar value has been between the years of 1972 and 1977 (19, 20). In 1972 there were 9,250 acres of macadamia trees 5,000 of which were bearing and the crop was worth $3,055,000 (19). In 1977 the predicted value of macadamia nuts from 6,300 acres was $7,481,000, an increase of more than 100 percent over 1972 (20).

It is apparent that selection has greatly benefited the macadamia nut industry in Hawaii. In all of the selection work and analytical studies done on the macadamia, however, the optimum sample size for accurate determination of variables such as percent kernel, percentage of grade 1 kernels and average nut size has not been determined objectively.

In 1931, Ripperton used 2 pound samples (approximately 140 nuts) from seedling trees for his analysis of quality of nuts produced by individual trees (17). Later in 1938 he used 150 pound samples (10,500 nuts approximately) to determine quality of nuts from individual trees (18).

In 1937, J.H. Beaumont used 2 pound samples to determine the percentage kernel in nuts from seedling trees and 20 nut samples taken at random to determine other characteristics. He used regression analysis and standard error in analyzing nut characteristics (1).

In 1962, Leverington working in Queensland, Australia, used 10 percent of the total crop of nuts per tree to determine variables including percent kernel, percent grade 1 and nut size. For advanced selections Leverington used the entire crop produced by the tree to determine nut and kernel characteristics.

Twenty to 25 nuts per tree have been considered an adequate sample for selection work in California (24). Hamilton and Ooka (8) used 100 nut samples in computing average nut size, percent kernel, nuts per pound and percent grade 1 kernels of the new variety 'Keaau' in 1966. Samples of twenty-five nuts have been used routinely since 1948 for determination of nut characteristics in the University of Hawaii Horticulture Department variety selection program. Radspinner in 1968, used samples of 50 nuts per tree in his study of percent grade 1 kernels, percent kernel, shell thickness and shell diameter (16).

It is evident that sample sizes used in determining the nut qualities of individual trees vary greatly. This experiment was designed to establish within an acceptable margin of error an optimum sample size for accurate determination of nut qualities from individual trees.

MATERIALS AND METHODS

An experiment was begun in September 1977 to determine the optimum sample size needed to accurately evaluate nut quality from individual trees within an acceptable margin of error. Three variables were studied: percentage kernel recovery, percentage grade 1 kernels, and average shell diameter. Bulk samples of about 400 mature nuts were gathered from the ground under 31 experimental trees during the period from September to December. Samples were collected at the Kona, Waiakea, Haleakala, Poamoho and Waimanalo branch stations of the Hawaii Agricultural Experiment Station and one additional sample from Brewer Orchards Inc. at Keaau, Hawaii.

Samples were collected and husked within 24 hours. They were then dried in a forced draft oven at 43^{o}C (110^{o} F) for seven days. Samples were identified by seedling selection number or name. Samples from individual trees will be referred to as treatments. Samples were sealed in a plastic bag, and the plastic bags placed in an airtight,.five gallon plastic container to maintain a constant moisture level in the nuts. Samples were kept in sealed containers in an air conditioned room at 70^{o} F until required data were taken.

Each treatment was divided randomly into five sample groups of 10, 20, 30, 40 and 50 nuts, each with two sub-samples. These two sub-samples were designated A and B, and data from each recorded separately. For example, there were two sub-sample groups of 10 nuts each for each treatment labeled 10A and 10B. The sample data were taken within 4 hours to minimize gain in weight due to absorption of moisture from the air.

Measurement of shell diameter was done for each individual nut by measuring along the suture-line extending from the micropyle to the funiculus and at a 90 angle to this suture-line. Both measurements were recorded separately, and averaged to provide the shell diameter data. A slide caliper was used for the measurements.

Individual sample groups were then weighed to the nearest tenth of a gram on a tri-beam balance and weights recorded. Each sample of nuts was carefully hand-cracked. Shells were discarded and the kernels weighed to the nearest tenth of a gram on the tri beam balance. Percent kernel recovery is determined by the following formula:

$$\frac{\text{wt. of kernels}}{\text{wt. of in-shell nuts}} \times 100 = \text{percent kernel} \qquad (1)$$

After the kernels were weighed, percent of grade 1 kernels was determined by floating the kernels in tap water. The number of floaters is determined by subtracting the number of kernels sinking in water (sinkers) from the total number of kernels. The number of floaters or grade 1 kernels was recorded for each sample. Percent of grade 1 kernels is determined by the following formula:

$$\frac{\text{no. of floaters}}{\text{total no. of kernels}} \times 100 = \text{percent grade 1 kernels} \qquad (2)$$

The data for all 31 treatments were analyzed in part on a Hewlet-Packard computer terminal. A one-way analysis of variance was used for the three variables.

Data for percent kernel and percent grade 1 were treated as 5 sample groups of 10,20,30,40 and 50 nuts from each of the 31 different trees sampled. There were 2 observations per treatment, coming from the A and B sub-samples of each sample, 10A and 10B for example. By this method the mean square for error provided an estimate of variance within the 31 treatments as well as an estimate of variance among sub-samples.

Shell diameter was treated differently than the other two variables since data was obtained from each individual nut, rather than from a group of nuts as in percent kernel and percent of grade 1 kernels. A one-way analysis of variance was carried out for each sample size group for each treatment. There were 2 sub-samples for each treatment with 10 to 50 observations each, depending upon sample size. Another analysis was carried out on average shell diameter for each sample group using a one-way analysis of variance of the 31 combined treatments.

From each computer printout, a coefficient of variation (CV) and confidence limits were determined from the standard deviation which is the square root of the mean square for error.

The coefficient of variation was determined by the following formula:

$$\frac{\sqrt{MSe}}{\bar{X}} \times 100 = \text{coefficient of variation} \qquad (3)$$

Where 'MSe' is the mean square for error and $\bar{X}$ is the mean for the sample.

The coefficient of variation was then plotted against sample size for percent kernel, percent of grade 1 kernels and average shell diameter. This graph provides an indication of the sample size at which variability levels off.

The coefficient of variation indicates the sample size at which variability stabilizes, but is not definitive enough to determine the optimum sample size for future selection work. For this reason, confidence limits were determined by the following equation:

$$D = t_\alpha \sqrt{\frac{s^2}{n}} \qquad (4)$$

Where D is the percent difference within which the mean ($\bar{X}$) will vary, t_α is students t with (n-1) df (df for the error term), s^2 is the variance or the mean square for error and n is sample size.

From the previous equation the D value can be determined for average shell diameter. Percent kernel, percent of grade 1 kernels and average shell diameter, however, present problems since the units consisted of 10, 20, 30, 40 and 50 nuts each. The true n is therefore calculated from the equation:

$$n = \frac{t_{\alpha}^{2} \; s^{2}}{D^{2}} \qquad (5)$$

where the symbols are the same as in equation (4).

Solving for n can be done depending on which value of D is used. For this experiment D values ranging from 1 to 10 percent were substituted along with the appropriate $t_{.05}$ and n values. Using this equation, a table can be made up listing percent D vs. sample size. This permits a choice of acceptable accuracy, plus and minus percent D. The n value indicates the sample size necessary to achieve the desired degree of accuracy.

RESULTS

A. Average Shell Diameter

Of the three characteristics studied average shell diameters were found fo be most variable. Coefficients of variation ranged from a high of 230 percent for the 10 nut sample to a low of 90 percent for the 40 nut sample. Table 1 contains coefficients of variation with their respective mean square for error values.

Table 1. Means for average shell diameter in inches, mean square for error, and coefficients of variation of macadamia nuts from 5 sample sizes.

Sample size	Mean Shell Diameter (inches)	Mean Square For Error	Coefficient Of Variation (Percent)
10 nuts	0.89	4.13	230.0
20 nuts	0.88	1.82	150.0
30 nuts	0.88	1.92	160.0
40 nuts	0.89	0.65	90.0
50 nuts	0.89	1.18	120.0

The n values for average shell diameter based on 31 treatments and 5 sample sizes are listed in table 2.

Table 2. Number of macadamia nut samples (n) required for determination of percent of average shell diameters at specific sample sizes and percent differences.

	Percent Difference								
Sample size	10	9	8	7	6	5	4	3	2
10 nuts	0.2	0.2	0.3	0.4	0.5	0.7	1.1	1.9	4.3
20 nuts	0.1	0.1	0.1	0.2	0.2	0.3	0.5	0.8	1.9
30 nuts	0.1	0.1	0.1	0.2	0.2	0.3	0.5	0.9	2.0
40 nuts	---	---	---	0.1	0.1	0.1	0.2	0.3	0.7
50 nuts	---	0.1	0.1	0.1	0.1	0.2	0.3	0.5	1.2

B. Percent of Grade 1 Kernels (floaters)

Coefficients of variation for percent of grade 1 kernels ranged from a high of 14.2 percent for the 10 nut sample to a low of 4.5 percent for the 50 nut sample. Table 3 contains coefficients of variation for the different sample groups.

Table 3. Average percent of grade 1 kernels, mean square for error, and coefficients of variation of macadamia nuts from 5 sample sizes.

Sample size	Average Percent Of Grade 1 Kernels	Mean Square For Error	Coefficient Of Variation (Percent)
10 nuts	88.5	157.26	14.2
20 nuts	90.5	37.80	6.8
30 nuts	90.6	19.69	4.9
40 nuts	89.8	32.49	6.3
50 nuts	90.8	16.48	4.5

N values for percent of grade 1 kernels are listed in table 4 with corresponding values for percent difference and sample size.

Table 4. Number of macadamia nut samples (n) required for determination of percent of grade 1 kernels at specific sample sizes and percent differences.

	Percent Difference								
Sample size	10	9	8	7	6	5	4	3	2
10 nuts	6.6	8.1	10.2	13.4	18.2	26.0	41.0	72.9	163.9
20 nuts	1.6	1.9	2.5	3.2	4.4	6.3	9.9	17.5	39.4
30 nuts	0.8	1.0	1.3	1.7	2.3	3.3	5.1	9.1	20.5
40 nuts	1.4	1.7	2.1	2.8	3.8	5.4	8.5	15.1	33.9
50 nuts	0.7	0.8	1.1	1.4	1.9	2.7	4.3	7.6	17.2

C. Percent Kernel

Percent kernel had the lowest coefficients of variation for the three variables studied. Coefficients of variation ranged from a high of 3.5 percent to a low of 1.2 percent. Table 5 lists coefficients of variation for 5 sample sizes.

Table 5. Average percent kernel, mean square for error and coefficients of variation of macadamia nuts from 5 sample sizes.

Sample size	Average Percent Kernel by Weight	Mean Square For Error	Coefficient Of Variation (Percent)
10 nuts	45.80	2.38	3.4
20 nuts	44.01	2.31	3.5
30 nuts	43.60	0.92	2.2
40 nuts	43.34	0.42	1.5
50 nuts	43.30	0.28	1.2

Table 6 lists the n values for percent kernel at different combinations of percent difference and sample size.

Table 6. Number of macadamia nut samples (n) required for determination of percent kernel at specific sample sizes and percent differences.

Sample size	Percent Difference 10	9	8	7	6	5	4	3	2
10 nuts	0.1	0.1	0.2	0.2	0.3	0.4	0.6	1.1	2.5
20 nuts	0.1	0.1	0.2	0.2	0.3	0.4	0.6	1.1	2.4
30 nuts	---	---	0.1	0.1	0.1	0.2	0.2	0.4	1.0
40 nuts	---	---	---	---	---	0.1	0.1	0.2	0.4
50 nuts	---	---	---	---	---	---	0.1	0.1	0.3

D. Shell Diameters of Individual Seedlings

The coefficient of variation for shell diameter was calculated for each individual seedling. Those seedlings having small coefficients of variation would have more uniform shell diameters. Seedlings with larger coefficients of variation would have more variable shell diameters, and would therefore be less desirable for commercial processing. Table 7 lists the average coefficient of variation for each seedling.

Table 7. Average coefficients of variation for shell diameter of 31 macadamia selections.

Seedlings	Average Coefficient Of Variation	Seedlings	Average Coefficient Of Variation
1. Kona 729	3.94	17. Kona 814	6.04
2. Poamoho 660	4.76	18. Kona 841	6.06
3. Kona 828	5.12	19. Kona 826	6.08
4. Kona 788	5.32	20. Waiakea 818	6.21
5. Kona 806	5.34	21. Kona 842	6.28
6. Haleakala 294	5.40	22. Kona 806	6.34
7. Kona 762	5.52	23. Kona 812	6.50
8. Kona 819	5.62	24. Kona 783	6.60
9. Waimanalo 790	5.78	25. Kona 803	6.60
10. Kona 843	5.78	26. Kona 833	6.68
11. Kona 834	5.82	27. Kona 831	6.78
12. Kona 836	5.86	28. Poamoho 778	6.80
13. Waikea 816	5.88	29. Kona 847	7.02
14. Kona 344	5.90	30. Keaau 866	7.56
15. Kona 695	5.96	31. Kona 809	7.76
16. Kona 814	5.96		

The mean coefficient of variation for the 31 seedlings listed in table 7 is 6.04. The standard deviation for the seedlings is 0.77. Seedlings 1-3 have coefficients of variation less than 1 standard deviation away from the mean coefficient of variation. Seedlings 4-28 lie within 1 standard deviation plus or minus the mean. Seedlings 4-17 are less than or equal to the mean. Three seedlings, 29-31 are more than 1 standard deviation greater than the mean.

E. Average Percent Kernel and Average Percent of Grade 1 Kernels For 31 macadamia seedlings.

The average percent kernel and average percent grade 1 kernels for individual macadamia seedlings is listed in table 8.

Table 8. Average percent kernel and average percent of grade 1 kernels for 31 macadamia seedlings.

Seedlings	Average Percent Kernel	Seedlings	Average Percent Grade 1 Kernels
1. Kona 729	36.0	1. Waiakea 818	68.1
2. Kona 762	37.6	2. Kona 836	72.3
3. Kona 834	38.2	3. Kona 826	73.2
4. Kona 803	38.7	4. Kona 841	80.7
5. Kona 807	41.1	5. Kona 803	81.1
6. Kona 847	41.1	6. Kona 833	84.7
7. Keaau 866	41.2	7. Keaau 866	84.8
8. Kona 836	41.2	8. Kona 809	85.8
9. Kona 783	41.4	9. Kona 831	85.9
10. Waimanalo 790	41.5	10. Kona 842	87.8
11. Kona 831	42.6	11. Kona 729	88.9
12. Haleakala 294	42.8	12. Kona 807	90.3
13. Kona 842	42.8	13. Kona 843	91.4
14. Kona 812	43.4	14. Kona 814	91.6
15. Kona 344	43.7	15. Kona 812	91.7
16. Kona 833	43.7	16. Kona 783	91.8
17. Kona 695	43.8	17. Kona 834	93.5
18. Waiakea 818	44.2	18. Waiakea 816	93.8
19. Kona 814	44.8	19. Kona 847	94.0
20. Kona 819	45.3	20. Haleakala 294	94.1
21. Kona 788	45.8	21. Kona 819	94.2
22. Kona 826	46.4	22. Kona 788	95.5
23. Kona 841	46.7	23. Kona 828	95.8
24. Kona 660	47.5	24. Kona 806	95.9
25. Poamoho 660	47.6	25. Poamoho 778	96.5
26. Kona 828	47.6	26. Kona 660	97.0
27. Kona 843	47.8	27. Waimanalo 790	97.1
28. Kona 806	49.0	28. Kona 762	97.1
29. Waiakea 816	49.4	29. Kona 695	97.2
30. Poamoho 778	49.7	30. Poamoho 660	99.4
31. Kona 809	52.5	31. Kona 344	99.5

The mean percent kernel for the 31 seedlings listed in table 8 is 44.0. The standard deviation for the seedlings is 3.9 percent. Seedlings 1-4 have average percent kernels less than 1 standard deviation from the mean percent kernel. Seedlings 5-27 lie within 1 standard deviation plus or minus the mean. Seedlings 28-31 are more than 1 standard deviation greater than the mean.

The mean percent of grade 1 kernels for the 31 seedlings listed in table 8 is 90 percent. The standard deviation for the seedlings is 8.1 percent. Seedlings 1-6 have average percent of grade 1 kernels that are less than 1 standard deviation away from the mean percent grade 1 kernel. Seedlings 7-29 lie within 1 standard deviation plus or minus the mean. Two seedlings, 30-31, are more than 1 standard deviation greater than the mean.

DISCUSSION

A. Average Shell Diameter

The coefficients of variation of average shell diameter showed the greatest variation (see figures 1 and 2). Since average shell diameters are small, relatively small variances in average diameters produced relatively large coefficients of variation.

There is a difference of 30 percent between the coefficients of variation for the 30 and 50 nut sample sizes. Coefficients of variation of the 20 and 30 nut samples differ by 10 percent. The coefficient of variation for the 40 nut sample size group is lower than the others, differing by 30 percent from the 50 nut sample.

The n values for shell diameter (table 2) are slightly higher than those for percent kernel (table 6). The n value of the 30 nut sample from table 6 at ± 2 percent is 1.0, and from table 2 it is 2.0. The reason for this small difference in n values despite their coefficients of variation being drastically different is because of differences in their respective mean square for error values. The mean square for error of average shell diameter is about twice that for percent kernel. In equation 3, it appears that the n value should be double since the mean square for error is twice the size, the difference value of ± 2 percent is the same and 't' is constant.

Like the coefficients of variation, the n values agree closely in the 20 and 30 nut samples, differing by 0.1 at ± 3 and ± 2 percent. The 40 and 50 nut samples are also in close agreement differing by 0.1 at ± 5 and ± 4 percent, 0.2 at ± 3 percent and 0.5 at ± 2 percent.

B. Percent of Grade 1 Kernels

The 10 nut sample of percent of grade 1 kernels showed the greatest

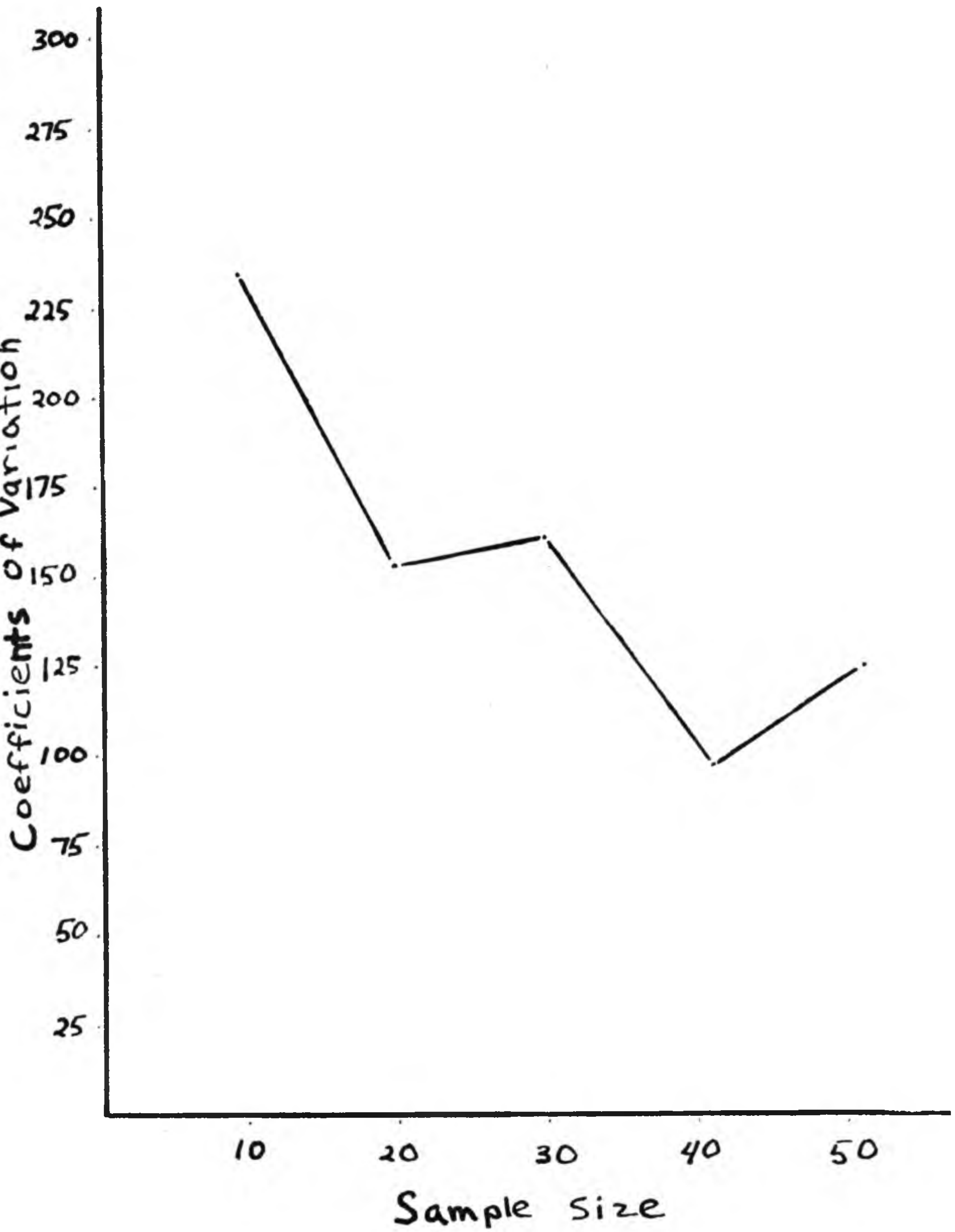

Figure 1. The relationship between coefficients of variation and sample size for average shell diameter.

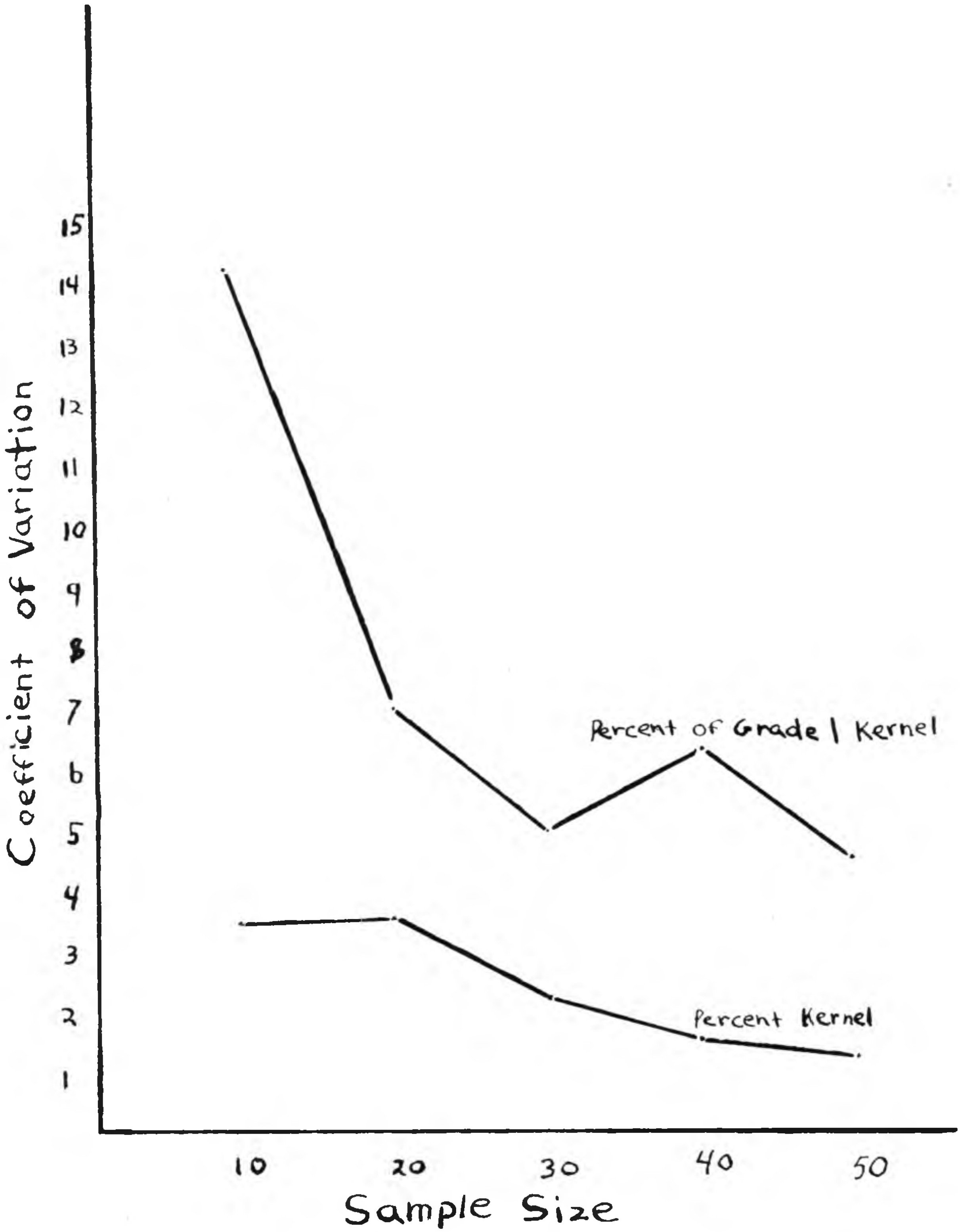

Figure 2. The relationship between coefficients of variation and sample size for percent grade 1 kernels and percent kernel.

variation for this characteristic. There was a reduction of 7.4 percent (see figure 2) between the 10 and 20 nut samples. Variation decreased between the 20 and 50 sample sizes. There was a reduction of 2.3 percent in coefficient of variation between samples 20 and 50. The decrease in coefficient of variation was not consistent. The 40 nut sample appears to be a chance variation since all samples were selected at random. Although the 40 nut sample has a slightly higher coefficient of variation than the 30 and 50 nut samples, it follows a general trend by having a lower coefficient of variation than the 10 and 20 nut samples.

N values and the coefficients of variation for percent of grade 1 kernels show similar variation. A difference value of 5 percent has an n value of 26.0 for a 10 nut sample and 2.7 for a 50 nut sample. Again, the 40 nut sample is higher than the 30 nut and 50 nut sample. 135 nuts (2.7 x 50 nuts) are required for accuracy of 5 percent difference, and 860 nuts (17.2 x 50 nuts) are required for accuracy of 2 percent difference. These numbers again emphasize the variability fo percent of grade 1 kernels.

Figure 3 compares more accurately the 5 samples for the total number of nuts required to achieve the accuracy of a certain percent difference. The graphs show that the accuracy of the 20, 30 and 50 nut samples is very similar. A 100 nut sample differs by approximately 0.7 percent between the 30 and 50 nut samples and 1.0 percent between the 20 and 30 nut samples. The accuracy of the various sample sizes is closer for the 130 nut sample than for the 100 nut sample. The 30 nut sample differs by 0.6 percent and 0.7 percent from the 50 and 20 nut samples, respectively.

The graph shows that the accuracy of a 100 nut sample is similar

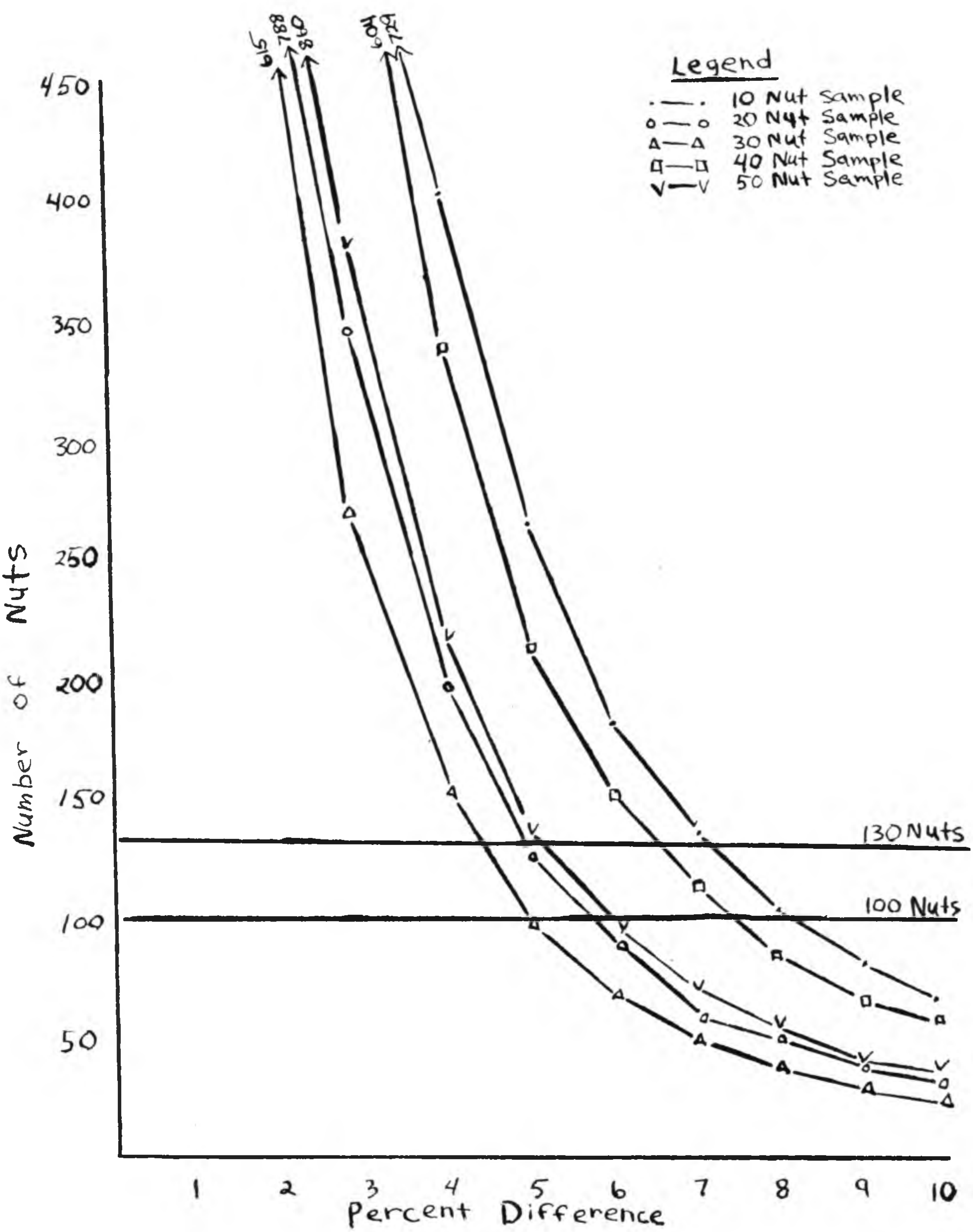

Figure 3. The relationship between number of nuts per sample (n x sample size) and percent difference for five sample sizes for percent of grade 1 kernels.

whether it is taken as 2-50 nut samples, 3-30 nut samples or 5-20 nut samples. The reason for this is the similarity of the 20, 30, and 50 nut samples as discussed earlier.

C. Percent Kernel

The variability of percent kernel is less than that of other characteristics (see figures 1 and 2). The variability of the 10 and 20 nut sample sizes is very similar with coefficients of variation of 3.4 and 3.5, respectively (see table 5).

Between the 20 and 30 nut samples there is a drop in coefficient of variation of 1.3 percent (see table 5). From the 30 to 50 nut sample sizes there is a steadily decreasing change in the coefficient of variation of 0.7 percent between 30 and 40 nuts and 0.3 percent from 40 to 50 nuts. It is apparent that the coefficients of variation which are relatively low in samples of 10 and 20 nuts are even lower in samples of 30, 40, and 50 nuts.

Table 6 shows the amount of variabliliy and increased accuracy of n values for percent kernel compared with n values for percent of grade 1 kernels (table 4). The n value of 5 percent difference (table 4) is 2.7 for the 50 nut sample while the corresponding value is less than 0.1 percent (table 6). N values for the 10 and 20 nut samples (table 6) agree closely except for the 2 percent level where they differ by 0.1 percent.

The coefficients of variation for the 30, 40, and 50 nut samples show a steady decrease in n values for these sample sizes (table 6). At 2 percent and 30 nuts, the n value is 1, at 40 it is 0.4 and 0.3 for the 50 nut sample size. The increased effect of sample size between the 40 and 50 nut sample size is only 0.1 while between 30 and 50 it is 0.6.

These n values suggest a leveling off as sample size increases from 40 to 50 nuts.

SUMMARY AND CONCLUSIONS

Overall variance was found to be the greatest in average shell diameter. However, large samples are not required for accurate determination of this characteristic in seedling selections. Average shell diameter and percent kernel both require the same sample size of 30 nuts each. This has been determined from the coefficients of variation from table 1. Variation seems to stabilize beginning with the 30 nut sample for both characteristics.

For average shell diameter the 30 nut sample size provides an accuracy of 3 percent. By using the mean from table 1 for the 30 nut sample, there is a 95 percent probability that the true mean will be within the range shown below:

$$0.88 \pm (0.88 \times 0.03)$$

or

$$0.86 \text{ to } 0.92$$

Their difference is ± 0.027 inches.

For percent kernel, 30 nut samples provide an accuracy of about 2 percent. Taking the mean for the 30 nut sample size from table 5 and using a 2 percent difference, there is a 95 percent probability that the true mean will be within the range shown below:

$$43.60 \pm (43.60 \times 0.02)$$

or

$$42.73 \text{ to } 44.47$$

The difference in this example is ± 0.87, which is less than 2 percent kernel.

Percent of grade 1 kernels was more variable than the other two characteristics. Although the 50 nut sample had the lowest coefficient of variation, the increase in coefficient of variation at the 40 nut sample suggests that variation has not stabilized completely at that point. The general trend, however, was that of decreasing variance as the sample size increased from 10 to 50 nuts. Figure 3 shows that the 20, 30, and 50 nut samples agree closely at a difference of 5 percent. The 5 percent level of difference appears to be the best choice for determining percent of grade 1 kernels in future selection work. At the 5 percent difference, with the mean for a 50 nut sample (table 3) there is a 95 percent probability that the true mean will lie within the range shown below:

$$90.84 \pm (0.05 \times 90.84)$$

or

$$86.30 \text{ to } 95.38$$

The actual difference here is ± 4.54 percent of grade 1 kernels, or a tatal variation of 9.08 percent.

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