Nutritional Evaluation of the Jojoba Plant: Elemental Analysis of the Seed Meal

Seeds of the jojoba [*Simmondsia chinensis* (Link) Schneider] from various geographic sources were analyzed for their N, P, S, Cl, Na, K, Ca, Mg, Fe, and other trace elements of nutritional importance. Though the different sources were found to be significantly different in their trace elements, the seed meal compared favorably with feed rations for cows and chickens.

Jojoba [*Simmondsia chinensis* (Link) Schneider] is a dioecious shrub, native only to the Sonoran Desert of North America. It is the subject of intense agricultural research around the world since it is the only plant known which contains a unique oil consisting almost entirely of a mixture of the esters of eicosene and docosene acids and alcohols. Jojoba oil has a composition and structure very similar to that found in sperm whale oil, a valuable commodity no longer available in the United States. This oil comprises 50–60% by weight of the ripe seeds and is typically obtained commercially by applying mechanical pressure. The oil has excellent lubricating properties and is used extensively in the cosmetics industry. Numerous studies have been carried out characterizing and evaluating the potential of the oil (Knoepfler and Vix, 1958; U.S. Department of Commerce, 1975; Clarke and Yermanos, 1980).

The meal that is left after the oil is expressed also has excellent potential commercial value (U.S. Department of Commerce, 1975) and is already used on a limited basis as a livestock feed in Mexico. The dehulled, solvent-extracted meal is approximately 30% protein by weight (Verbiscar et al., 1980; Samac and Storey, 1981). The hulls themselves (often incuded in commercially expressed meal) contribute about 10% to the weight of the seeds and can significantly affect the value of the meal as a protein source, since the hulls are only about 7% protein (Verbiscar and Banigan, 1978).

The major problem with utilizing the meal as a feed source has been its toxicity. This is attributed by most workers to the presence of the cyanogenic compounds simmondsin and simmondsin 2′-ferulate. However, Storey (1980) and Samac et al. (1981) have also found that the meal contains a potent trypsin inhibitor which is destroyed by heat. In addition, if too much of the jojoba oil is left in the meal, it might be expected to act as a lubricant in the gut as well as preventing absorption of fat-soluble vitamins. Recently Verbiscar et al. (1981) reported a meal detoxification involving an ensilage process with lactobacilli that apprently eliminates most of the factors which contribute to the meal's toxicity in test animals.

In addition to the above work on detoxification, some studies have dealt with the nutritional value of the meal. Yermanos and Duncan (1976) and Verbiscar and Banigan (1978) have reported the carbohydrate, protein, and amino acid content of the seeds. They found the methionine was poor, but otherwise most of the essential amino acids were all about 1–2% of the meal. Storey (1980) and Samac et al. (1980, 1981) reported that the ratios of storage proteins, and thus the nutritional quality of the meal, varied with seeds of different ecotypes. A globulin fraction, termed jojobin, was found to be the major storage protein in jojoba seeds. This observation could explain the low methionine content reported by others.

This paper presents elemental composition data on several sources of wild jojoba seeds. Data on fiber, ash, and total caloric content are also included to make it possible to more accurately evaluate jojoba meal as a feed source to be blended with other feeds.

EXPERIMENTAL PROCEDURES

Seven different sources of wild jojoba seeds, covering all the major areas where jojoba occurs naturally (California, Arizona, and northern Mexico), were sampled. Individual seeds were analyzed so that estimates of appropriate sample sizes could be determined. The oil was expressed in a hand press and the resulting meal ashed overnight in a muffle furnace at 550 °C. Some meal samples were also solvent extracted before ashing to test for volatilization losses. No significant differences in elemental concentrations were found in the meal deoiled by either method. The furnace ash residue was digested in a Teflon Parr bomb at 150 °C for 1 h with 2 mL of HNO_3. the sample was subsequently diluted to 25 mL with distilled water before detection by flame atomic absorption and emission (Varian AA-275B). Simply dispersing the ash in dilute HNO_3 was also found to give satisfactory results, since all the metals determined here were readily soluble in the acid solution. However, the more rigorous bomb digestion was employed throughout this study. Sodium and potassium were determined by flame emission; the other metals were determined by flame atomic absorption. All standards were reagent grade, chosen for their stability and purity.

Nitrogen was analyzed by the Kjeldahl method, phosphorus and iodine were analyzed by colorimetry, chloride was analyzed by argentiometric titration, and sulfur was analyzed by turbidimetric measurement of barium sulfate. Appropriate acid digestions were employed in each case to minimize volatilization losses. These were essentially standard methods described in the literature (Welcher, 1975). Similar results were obtained by utilizing an ion chromatograph (Dionex System 10) to measure the NO_3^-, PO_4^{3-}, and SO_4^{2-} obtained after digestion with sodium peroxide and dissolution in water. The free NO_3^-, PO_4^{3-}, SO_4^{2-}, and Cl^- were also measured on an aqueous extract of the meal. Fiber and ash were determined by standard AOAC (1930) methods, and the total calorie content was obtained by combustion of the meal in an oxygen bomb calorimeter.

RESULTS AND DISCUSSION

Table I presents the atomic absorption data for the metals from the various sources of jojoba seeds. From an analysis of variance, it was found that except for calcium, copper, and zinc, the sources of seed had significantly different (95% confidence level of the F test) variances for all the elements. This suggests that one should use caution when comparing the means of one source with another and that nonparametric methods of statistical analysis should be employed. Keeping this problem in mind, for every element at least one of the sources was found to be significantly different in its mean concentration when compared to the other sources. In all cases, the concentrations of the elements in the seed meal were well above the detection limits for the samples, except for iodine, molybdenum, and selenium, which were below the detection limits of 0.01, 0.2, and 0.5 ppm, respectively. Sodium, magnesium, manganese, and cobalt exhibited a positive correlation between the amount of seed coat present and

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Table I. Trace Metal Concentrations in Whole Jojoba Seeds

source	elements[a] K	Na	Mg	Ca	Fe	Mn	Zn	Cu	Ni	Co
Bakersfield, CA (0.67 g)[b]	7160	52	1170	269	27	16	14	11	4.7	0.4
Riverside, CA (0.45 g)	9660	143	1380	254	43	26	18	8	2.5	0.7
Phoenix, AZ (0.68 g)	6920	90	1440	493	41	22	17	11	3.7	0.7
Casa Grande, AZ (0.35 g)	5420	195	1550	389	73	22	18	16	3.8	1.0
Rancho Jojoba, AZ (0.57 g)	5700	155	1390	385	42	17	14	9	2.5	0.7
Hermisillo, Mexico (0.66 g)	5840	147	1220	368	59	18	10	7	2.4	0.5
Mexico (0.46 g)	5600	168	1690	446	34	24	24	6	6.9	0.7
means (0.55 g)	6610	136	1410	372	46	21	16	10	3.8	0.7
pooled SD	1390	51	230	137	18	4	7	5	1.8	0.2
detection limit	160	2	56	13	1	1	1	1	0.6	0.2
recommended sample size, no. of seeds	71	225	43	217	245	70	289	353	359	131

[a] Concentrations in ppm in the whole seed; based on five or more samples from each location. [b] Mean seed weight for each geographic source.

Table II. Nutrient Content of Various Feed Rations

nutrients	quantity/kg of dry matter: jojoba meal	dry[a] cow ration	starting[a] chicken ration
protein ($N \times 6.25$), g	270	85	220
energy, mcal	3.3	2.3	3.1
crude fiber, g	120	150	–[b]
ash, g	39	–	–
potassium, g	13.2	7.0	2.0
sodium, g	0.27	1.0	1.5
magnesium, g	2.8	0.8	0.5
calcium, g	0.74	3.4	10.0
iron, mg	92	100	80
manganese, mg	42	20	55
zinc, mg	32	40	50
copper, mg	20	10	4.0
cobalt, mg	1.4	0.1	–
molybdenum, mg	(<0.2)	(<6)	–
chlorine, g	3.0	1.5	2.2
sulfur, g	3.0	2.0	–
phosphorus, g	3.5	2.6	7.0
selenium, mg	(<0.5)	0.1	0.1
iodine, mg	(<0.01)	0.6	0.35

[a] Data from Siegmund and Fraser (1973). [b] No values given.

the concentrations observed. Thus, these elements showed significantly (95% confidence) greater concentrations in or on the surface of the seed coats when compared to those of their interior embryos. Therefore the seed volume will be important in sampling schemes for Na, Mg, Mn, and Co. Finally, on the basis of the pooled standard deviations for the various elements, the last line of Table I estimates the number of seeds needed to determine each element to within a precision of 5% at the 95% confidence level. With a mean seed weight of 0.55 g, samples of about 100 g of seed are recommended for trace element analyses. For the meal, sample sizes of 20 g or more should be sufficient.

In Table II, the mean values for the deoiled jojoba meal analyzed are compared with the requirements for feed sources for dry cow and starting chicken rations as reported by Siegmund and Fraser (1973). Concentrations given in Table I for the whole seeds were used to calculate the expected deoiled meal concentration based on the average value of 50% oil found in the seeds. As noted earlier, the protein content is quite high (3.2 times that needed for a dry cow ration). Only 0.05% of the total nitrogen present was found to be free nitrate. For the major metal elements, sodium and calcium are about 4 times lower in the meal than in the cow ration, while magnesium and potassium are about a factor of 2 higher. Among the trace elements, cobalt shows the greatest difference, being quite high compared to that of the cow ration. Otherwise the jojoba meal compares quite favorably, and it should not be necessary to supplement it with large amounts of minerals when it is used as a feed source.

The values for nitrogen, sulfur, and phosphorus agree with the values of 5.04%, 0.47%, and 0.32%, repectively, reported by other workers (Wells, 1955). About 10% of the sulfur and 10% of the phosphorus are present as SO_4^{2-} and PO_4^{3-}. Essentially all the chlorine is present as free Cl^-. Ash and fiber both compare favorably with values of $4.0 \pm 0.8\%$ and $12.2 \pm 3.4\%$ reported by Verbiscar et al. (1980). Previous workers (Wells, 1955) have noted the ash weight depends upon whether volatile organics are present. Therefore, if the oil is not completely removed before ashing, some of the ash may be lost. This would be a problem if sulfur were analyzed in the ash rather than by employing an acid digestion on the meal.

CONCLUSIONS

On the basis of this analysis of the elements, the analyses of Yermanos and Duncan (1976), Verbiscar and Banigan (1978), and Samac et al. (1981) on proteins and amino acids, and work reported by Verbiscar et al. (1980) to eliminate indigestibility or toxicity problems, it is clear that jojoba meal is a potentially valuable animal feed source.

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LITERATURE CITED

AOAC "Methods of Analysis"; AOAC: Washington, DC, 1930.
Clarke, J.; Yermanos, D. M. *J. Am. Oil Chem. Soc.* **1980**, *57*, 176.
Knoepfler, N. B.; Vix, H. L. *J. Agric. Food Chem.* **1958**, *6*, 118.
Samac, D. A.; Lovejoy, C. V.; Sage, R. F.; Storey, R. *Jojoba Happenings* **1980**, *33*, 11.
Samac, D. A.; Lovejoy, C. V.; Storey, R. *Plant Physiol.* **1981**, *67S*, 460.
Samac, D. A.; Storey, R. *Plant Physiol.* **1981**, in press.

Siegmund, O. H.; Fraser, C. M., Eds. "Merck Veterinary Manual", 4th ed.; Merck and Co., Inc.: Rahway, NJ, 1973; pp 1198, 1302.
Storey, R. *Plant Physiol.* **1980**, *65S*, 628.
U.S. Department of Commerce *U.S. NTIS, PB Rep.* **1975**, *May, PB-253-126.*
Verbiscar, A. J.; Banigan, T. F. *J. Agric. Food Chem.* **1978**, *26*, 1456.
Verbiscar, A. J.; Banigan, T. F.; Weber, C. W.; Reid, B. L.; Swingle, R. S.; Trei, J. E.; Nelson, E. A. *J. Agric. Food Chem.* **1981**, *29*, 296.
Verbiscar, A. J.; Banigan, T. F.; Weber, C. W.; Reid, B. L.; Trei, J. E.; Nelson, E. A.; Raffauf, R. F.; Kosersky, D. *J. Agric. Food Chem.* **1980**, *28*, 571.
Welcher, F., Ed. "Standard Methods of Chemical Analysis"; Krieger: New York, 1975.
Wells, F. B. *Cereal Chem.* **1955**, *32*, 157.
Yermanos, D. M.; Duncan, C. *J. Am. Oil Chem. Soc.* **1976**, *53*, 80.

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Ascorbic Acid Content of Some Tropical Fruit Products Determined by High-Performance Liquid Chromatography

Some guava, mango, papaya, and orange products were analyzed for ascorbic acid by using high-performance liquid chromatography. Many of the products contained relatively low levels as compared with those of fresh fruit. Extraction procedures using methanol–water were compared with those using methanol–6% metaphosphoric acid, and the latter more completely extracted ascorbic acid. Canned orange shells were devoid of ascorbic acid. It may have been removed by extraction during a debittering process.

Fruit and vegetables are the major dietary sources for ascorbic acid in humans, and many fresh tropical and subtropical fruit are particularly rich in this vitamin (Nagy and Shaw, 1980). Retention of ascorbic acid in products from fruit processed in high volume, such as citrus, is well documented (Ting, 1977). However, retention of ascorbic acid in products from other tropical fruit processed in relatively small volume has received much less study, even though many tropical fruits are widely consumed as fresh fruit (Nagy and Shaw, 1980). With increasing concern for the nutritional content in foods and potential increasing development and marketing of processed products from tropical fruit, there is need for basic information on a principal vitamin, ascorbic acid, in processed tropical fruit products.

Processed products from tropical fruit such as guavas, mangos, and papayas have been studied for storage stability, and in some cases ascorbic acid retention has been monitored. Ascorbic acid retention in stored canned guavas was increased by addition of citric acid to increase acidity and sucrose to increase Brix (Gauhar and Durrani, 1972). A canned guava puree concentrate retained 65% of the original ascorbic acid after 5 months at −18 °C, but virtually all ascorbic acid was lost after 1 month at 7 °C (Brekke et al., 1970). Frozen and unfrozen bottled guava juices retained >70% of their ascorbic acid after 11 months (Orr and Miller, 1954). Freeze-dried and drum-dried mango powders were prepared that contained >86% of the original ascorbic acid, but several workers showed that in canned mango pulp ascorbic acid retention was poor during storage at room temperature (Lakshminarayana, 1980). Papaya puree with an initial ascorbic acid content of 50–90 mg/100 g has been prepared in both the canned and frozen forms. Heat treatment used during the process can reduce the ascorbic acid level in the canned product (de Arriola et al., 1980). Papaya puree concentrate and freeze-dried papaya each contained 15–20% less ascorbic acid than the fresh material. No studies on loss of ascorbic acid during storage of papaya products have been documented (de Arriola et al., 1980).

Table I. Ascorbic Acid (AA) Content of Some Tropical Fruit Products

product	ascorbic acid,[a] mg/100 g	% U.S. RDA[b]
guava		
shells[c]	6.0	
shells	13.8	30
shells + 6.8 mg % AA	21.3	
shells + 1000 mg % AA[c]	724	
shells + 1000 mg % AA	826	
paste	1.7	4
marmalade	1.7	4
jelly[d]	40.6	90
jelly[e]	2.9	6
mango		
slices	7.5	15
marmalade	7.9	20
papaya chunks (green)	0.6	2
orange		
shells	N[f]	
syrup from shells	0.1	0.2

[a] Average of two values determined on duplicate 50-g samples. [b] Based on a 100-g serving and a recommended U.S. RDA of 45 mg (Ting, 1977). [c] Ascorbic acid extracted with methanol-water instead of the methanol-6% HPO_3 solution. [d] Guava juice listed as the first ingredient. [e] Guava juice listed as the second ingredient. [f] N = not detected at a level of 0.075 mg % or greater.

These previous studies have provided little information for the consumer about the levels of ascorbic acid in processed products from tropical fruit reported to be good sources of this vitamin in the fresh state. We studied ascorbic acid levels in guava, mango, and papaya products available to the consumer as determined by high-performance liquid chromatography (HPLC). In addition, we studied the ascorbic acid content in a specialty citrus