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Proximate Analysis, in Vitro Organic Matter Digestibility, and Energy Content of Common Guava (*Psidium guajava* L.) and Yellow, Strawberry Guava (*Psidium cattleianum* Var. *lucidum*) Tree Parts and Fruits as Potential Forage

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Supporting Information

ABSTRACT: The nutrient composition of common guava, *Psidium guajava* L., and strawberry guava (waiwi), *Psidium cattleianum* var. lucidum, tree parts and fruits was determined during three seasons for six locations in Hawaii to assess guava as a potential feed for cattle. All guava plant parts were higher ($p < 0.001$) in crude protein than waiwi, but there were no differences in the fiber and energy densities for bark, shoots, and branches. Guava leaves were higher in fiber and had lower energy densities ($p < 0.05$) than waiwi. Ripe and breaker stage fruits were lower ($p < 0.05$) in fiber, similar in protein (CP), and higher ($p < 0.05$) in energy density than immature fruits. Guava fruits were higher in CP ($p < 0.05$) and organic matter ($p < 0.001$) and lower in ash ($p < 0.001$) than waiwi fruits. The primary nutritional concern with guava is low in vitro organic matter digestibility as compared to tropical forage grasses; therefore, it is not recommended as a feedstock for livestock.

KEYWORDS: *common guava, Psidium guajava L., yellow, strawberry guava, Psidium cattleianum var. lucidum, nutrient content, IVOMD, energy values*

■ INTRODUCTION

Currently in Hawaii and other tropical and subtropical locations, it is common to see guava trees in yards, pastures, and low-land forests at elevations below 914 m (Figure 1A).[1] Native to tropical America, guava was introduced to Hawaii in approximately 1790.[1] Common guava, subsequently referred to as guava, is a fragrant fruit with green or yellow skin, typically 4−10 cm in diameter, with pink or white flesh (Figure 1B).[2] The appearance of strawberry guava fruit is the same as common guava, except its size is smaller, ranging from 2 to 4 cm in diameter. Guava is a shrub or small tree, growing to an average height of 3−5 m, but sometimes growing to as high as 9 m, with no tolerance for salty soils (Figure 1C).[2] Guava is native to southern Mexico[3] and Central America and has spread throughout the American tropics, Asia, Africa, and Pacific Islands.[2] Guava grows in all of the tropical and subtropical areas of the world, adapts to different climatic conditions but prefers dry climates,[4] and is known to be an invasive plant species in many parts of the world, especially the Pacific Islands,[2] including Hawaii. In Hawaii, it is common to see guava infest pastures to the extent of largely crowding out the local grasses on which livestock graze. The flowers of guava have white petals measuring up to 2 cm long with numerous stamens (Figure 1D).[4] Guava fruit weighs from 0.06 to 0.5 kg.[1] The time of ripening is traditionally from May to August.[1]

Depending on management practices and climatic conditions, the abundance of guava in pastures of the Big Island of Hawaii has been increasing. It has been observed that livestock grazing on such mixed pastures with guava often suffer from bladder stones, particularly in goats who commonly strip the bark off of the trunk, oftentimes killing the tree (personal communications with local veterinarians). Our reference search disclosed a dearth of literature to substantiate the nutritional value and impact on animal productivity of guava. The objectives of the study were to determine the nutrient concentrations of the fruit and tree parts of guava (*Psidium guajava* L.) and yellow, strawberry (*Psidium cattleianum* var. *lucidum)* guava (locally known as waiwi) and assess their potential value as a feed source for livestock.

■ MATERIALS AND METHODS

Fresh common guava tree parts including the bark, leaves, shoots, branches, and fruit (immature, breaker stage, and ripe) were collected off of 12 randomly selected trees at six sites during three seasons. All trees were determined to be physiologically mature based on the height of the tree and their fruit-bearing ability. The age of the trees at the time of harvesting varied between 4 and 6 years. The experiment was established using factorial randomized complete block design (RCBD) with six replications/blocks (sites, $n = 6$) and as source main effects and seasons ($n = 3$) as the secondary source of variation. Nutritional contents of guava were assessed accordingly: guava content × site, guava content × season, and guava content × site × season. The

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Figure 1. Common guava (*Psidium guajava* L.). (A) Tree, (B) fruit, (C) leaves, and (D) flowers.

12 trees sampled at each site were the same for the three season samplings. Detailed descriptions of the six collection sites (Kapapala Ranch, Mountain View, Panaewa near Hilo, Pepeekeo, Hawi, and Pololu Valley) on the Big Island of Hawaii (Figure 2) and the three seasons of collections [spring (March/April), summer (August), and winter (late December/early January)] are provided in Table 1.

Sample Collection. During guava harvests at each site and season, fresh bark (2 cm × 17 cm strips) was stripped off of the trunk and larger branches of 12 live trees using a drawknife. Fresh branches (1−1.5 cm width) of the same 12 trees were cut to a length of 2.5−7.6 cm using pruning shears or loppers. Fresh leaves and shoots were snipped or picked off of the 12 trees, and all samples were placed into separate paper bags; labeled by part, season, and site; weighed; and recorded.

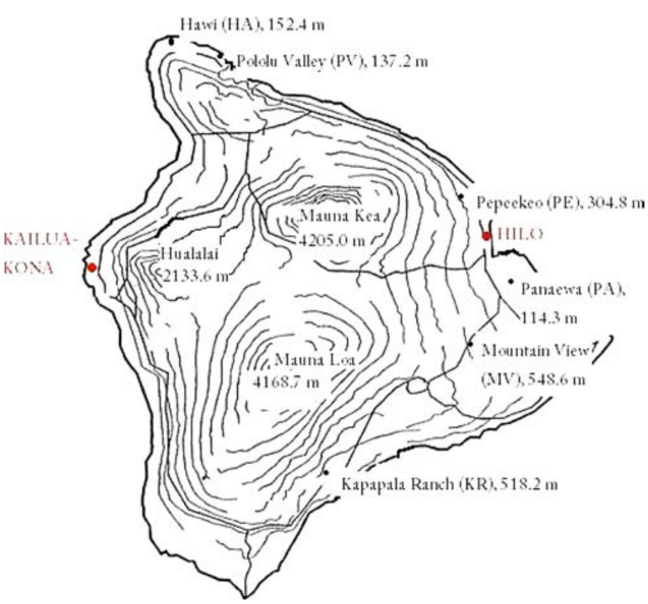

Figure 2. Big island of Hawaii elevation map: modification of the 2004 County of Hawaii Data Book.

Approximately 450−500 g (dry weight) of each component from the 12 trees was collected and composited from each site and season. The number of samplings varied depending on component because the weight of each vegetative part is different. Much more leaves and shoots were needed to comprise 500 g as compared to the bark and branches. A total of 15 shoots, 12 leaves, four strips of bark, and three pieces of branches were collected from each tree. The study resulted in a total of 18 individually composited samples for each vegetative part, separated by site and season, and a total of 72 trees sampled per season. In other words, one composite sample consisted of one vegetative part type for each site and each season. Following each harvest, the foliage samples were oven-dried in the labeled brown paper bags at 55−60 °C for 10 days in a laboratory oven to determine % dry matter (DM). Once the foliage was dried, the bark and branch samples were kept separate and first ground through a 4 mm stainless steel screen using a model 4 Thomas-Wiley laboratory mill (Thomas Scientific, Swedesboro, NJ) and then thoroughly mixed and ground through a 1 mm stainless steel screen using the same mill. All other sample types were ground directly after drying through a 1 mm stainless steel screen. All ground and mixed samples were packaged into appropriately sized Nasco Whirl-Pak plastic bags and labeled for storage.

Because of their close proximity to the common guava, samples of yellow, strawberry guava or waiwi tree parts were also collected from 12 trees for comparison to common guava at only the Mountain View and Pepeekeo sites during all three seasons of collection. Approximately 450−500 g (dry weight) of each component from the 12 trees was collected and composited from Mountain View and Pepeekeo. This resulted in six individually composited samples for each vegetative part, separated by site and season, and a total of 24 trees sampled per season. These samples underwent the same drying and grinding procedures as the common guava. Because yellow, strawberry guava, a different species, is often present in the pastures under study, it seemed important to gather comparative samples.

Both common guava and waiwi fruit samples were also collected when available during each of the three seasons. On the basis of color and firmness, all fruit samples were classified as either immature, breaker stage, or ripe. Because of the variance of fruit availability and level of fruit maturity during each season, sample numbers for each season varied as well. Once collected, the fruits were placed in plastic

Table 1. Elevation, Soil Type, and Seasonal Climatic Data (2010) of the Six Sampling Sites

site (abbreviation)	elevation (m)	soil series	annual precipitation (m)	season	average precipitation[a] (cm)	average temperature[a] (°C)	average solar radiation[a] ($kWh/m^2/day$)
Kapapala Ranch (KR)	518.2	Kapapala loam, Typic Haplustands	1.33[b]	spring	12.65	22.6	5.9
				summer	9.35	24.7	6.4
				winter	16.28	23.3	6.0
				mean	12.76	23.5	6.1
Mountain View (MV)	548.6	Keaukaha extremely rocky muck, Lithic Udifolists	2.54	spring	43.38	22.2	4.5
				summer	39.09	22.1	5.0
				winter	52.88	22.8	4.8
				mean	45.12	22.4	4.8
Panaewa (PA)	114.3	Papai extremely stony muck, typic Udifolists	2.54	spring	29.49	22.1	4.6
				summer	26.04	24.5	5.0
				winter	33.12	22.8	4.6
				mean	29.55	23.1	4.7
Pepeekeo (PE)	304.8	Kaiwiki silty clay loam, Acrudoxic Hydrudands	2.54	spring	34.19	22.1	4.6
				summer	29.34	24.5	5.0
				winter	36.42	22.8	4.6
				mean	33.32	23.1	4.7
Hawi (HA)	152.4	Hawi silty clay, Pachic Haplustolls	1.38	spring	12.98	26.5	5.6
				summer	10.80	25.8	6.3
				winter	14.25	24.1	5.7
				mean	12.68	25.5	5.9
Pololu Valley (PV)	137.2	Ainakea silty clay loam, Acrudoxic Hydric, Hapludands	1.69	spring	16.94	22.9	5.6
				summer	12.57	25.8	6.3
				winter	16.81	24.1	5.7
				mean	15.44	24.3	5.9
average across all sites	295.9		2.00	spring	24.94	23.1	5.1
				summer	21.21	24.6	5.7
				winter	28.30	23.3	5.2
				mean	24.82	23.7	5.3

[a]Precipitation, temperature, and solar radiation are averages of the 60 days prior to each harvest. [b]All climatic data are sourced from NOAA, NCDC, and the National Weather Service using weather stations within the closest proximity to the sampling sites.

Ziploc bags and frozen. Following the freezing, the fruits were partially thawed, homogenized in a Hobart model 8145 food processor, then placed in stainless steel pans, and freeze-dried for 48 h using a Virtis VirTual 50 XL, 50 L condenser capacity, pilot lyophilizer (SP Scientific, Gardiner, NY) with a vacuum chamber total pressure and temperature equal to 1.3×10^{-1} mbar and −45 °C, respectively. The thermocouple probes located at sample level and underneath trays were used to control and monitor the sample temperature values. The sublimation heat was supplied by a heating plate located under the tray. During the second stage of drying, the samples reached a final temperature of about 35 °C. After they were dried, the fruits were ground using the Thomas-Wiley mill with a 1 mm stainless steel screen and then placed in Nasco Whirl-Pak plastic bags as previously described.

Nutrient Analysis of Tree Parts and Fruits. Following the collection, drying, and grinding of all samples, they were subsampled and sent to Dairy One Cooperative Inc. Forage Lab in Ithaca, NY, for basic proximate, forage fiber, and energy analysis. Analyses were performed by standard procedures.[5] Specific nutrients analyzed were percentages of moisture, DM, crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), and total digestible nutrients (TDN). Energy prediction equations for NE_l, NE_g, and NE_m (net energy for lactation, gain, and maintenance, respectively) were expressed as Mcal/kg. The Ohio State 1996 Summative energy equation was used for predicting TDN at maintenance levels (1 time or 1×), which is the sum of the digestible fiber, lipid, protein, and carbohydrate components of the sample. It was calculated based on ADF determined by using lignin solutions as in Association of Official Analytical Chemists (AOAC) 973.18 because TDN is precisely correlated to digestible energy (DE). Net energy predictions used the variable discount approach. NE_l values were predicted at 3 times (3×) maintenance and NE_m and NE_g at 2 times (2×) maintenance. The percent hemicellulose was estimated by difference (% NDF − % ADF). Samples were also sent to the University of Florida Forage Evaluation Support Laboratory (FESL) where in vitro organic matter digestibility (IVOMD) was performed by modification of the Tilley and Terry two-stage technique by Moore and Mott.[6] The source of rumen inoculum to determine IVOMD was from two fistulated Holstein donor cows fed a total mixed ration that included bermudagrass (*Cynodon dactylon*) hay. The ash was determined by ashing for at least 4 h at 500 °C. The organic matter (OM) was determined by the difference (% DM − % ash).

Statistical Analyses. Results of the nutritional composition of guava were analyzed using analysis of variance (ANOVA) in factorial RCBD with six replications/blocks (sites) and as source main effects and seasons as the secondary source of variation. Nutritional contents of guava were assessed accordingly: guava content × site, guava content × season, and guava content × site × season. Means were separated using protected least significant difference (LSD) at $p \leq 0.05$. Comparisons of the nutritional concentrations between guava and waiwi parts were made using *t* test analysis at a 0.05 level of significance. The variability from tree to tree was not investigated in this study. All statistical calculations were done using SAS statistical software version 9.1.3 (Cary, NC).

RESULTS AND DISCUSSION

Description of Sampling Sites. The elevation, soil series type, and seasonal climatic data during 2010 for each of the six sampling sites are presented in Table 1. The elevation of

Table 2. Mean (±SE) Proximate and Fiber Analysis for Common Guava Plant Parts[a]

		%					
guava plant part	n	DM	CP	Ash	ADF	NDF	hemicellulose
bark	18	40.5 ± 1.3 b	3.8 ± 0.1 d	11.8 ± 0.7 a	27.1 ± 1.1 d	33.2 ± 1.2 d	6.1 ± 0.5 b
branch	18	46.3 ± 0.9 a	2.9 ± 0.2 d	2.5 ± 0.1 d	66.5 ± 1.3 a	76.8 ± 0.8 a	10.3 ± 0.9 a
leaves	18	36.2 ± 1.2 c	12.9 ± 0.8 b	6.6 ± 0.3 b	26.6 ± 1.5 d	38.3 ± 2.6 d	11.7 ± 0.8 a
shoots	18	28.2 ± 0.8 d	16.8 ± 0.5 a	6.8 ± 0.2 b	27.4 ± 1.0 d	37.1 ± 0.8 d	9.7 ± 0.7 a
immature fruit	11	26.3 ± 1.3 d	7.3 ± 0.6 c	3.4 ± 0.2 c	55.4 ± 2.8 b	60.7 ± 2.5 b	5.3 ± 0.9 b
breaker stage fruit	5	15.3 ± 1.4 e	7.0 ± 0.8 c	3.5 ± 0.2 c	39.1 ± 3.6 c	44.9 ± 3.0 c	5.8 ± 0.7 b
ripe fruit	6	16.5 ± 2.1 e	5.9 ± 0.7 c	4.1 ± 0.2 c	38.7 ± 4.1 c	44.2 ± 3.9 c	5.6 ± 0.5 b

[a]All data are presented on a DM basis. n, number of common guava samples for each plant part across all sites and seasons. Means (±SE) within the same column followed by different letters differed significantly ($p < 0.05$).

Table 3. Mean (±SE) Predicted Energy Values, OM, and IVOMD of Various Common Guava Plant Parts[a]

			Mcal/kg			%	
guava plant part	n	TDN (%)	NE_l	NE_m	NE_g	OM	IVOMD
bark	18	66.1 ± 0.39 c	1.54 ± 0.02 bc	1.51 ± 0.02 bc	0.88 ± 0.02 bc	88.2 ± 0.7 d	20.0 ± 1.1 d
branch	18	52.6 ± 0.22 e	0.71 ± 0.03 e	0.95 ± 0.01 e	0.40 ± 0.01 e	97.5 ± 0.1 a	7.3 ± 0.8 f
leaves	18	63.2 ± 0.7 d	1.51 ± 0.05 d	1.39 ± 0.03 cd	0.82 ± 0.03 d	93.4 ± 0.3 c	16.4 ± 0.7 e
shoots	18	63.6 ± 0.26 cd	1.54 ± 0.01 bc	1.32 ± 0.01 d	0.88 ± 0.01 bc	93.3 ± 0.2 c	17.5 ± 0.6 de
immature fruit	11	68.1 ± 0.72 b	1.61 ± 0.02 b	1.52 ± 0.03 b	0.93 ± 0.03 b	96.6 ± 0.2 b	23.7 ± 2.1 c
breaker stage fruit	5	72.6 ± 0.87 a	1.71 ± 0.02 a	1.70 ± 0.04 a	1.08 ± 0.03 a	96.5 ± 0.4 b	43.5 ± 0.9 b
ripe fruit	6	72.7 ± 1.15 a	1.72 ± 0.03 a	1.71 ± 0.05 a	1.09 ± 0.04 a	95.9 ± 0.3 b	52.5 ± 2.2 a

[a]All data are presented on a DM basis. n, number of common guava samples for each plant part across all sites and seasons. Means (±SE) within the same column followed by different letters differed significantly ($p < 0.05$).

Mountain View is the highest and Panaewa the lowest with an average of 295.9 m. The soil series type varied with each site. The annual precipitation at three of the sites (Mountain View, Panaewa, and Pepeekeo) was the same (2.54 m) with Kapapala Ranch having the lowest. The average annual precipitation across all six sites was 2 m. Mountain View had the highest average precipitation of the 60 days prior to each harvest with Kapapala Ranch and Hawi having the lowest; however, all six sites had lower rainfall in the summer and higher in the winter seasons. Table 1 also depicts Hawi as having the highest temperatures and Mountain View the lowest. The average solar radiation was the highest in the summer as expected and similar for the spring and winter seasons for all sites, which is inversely related to precipitation. The overall mean temperature and solar radiation were 23.7 °C and 5.3 kWh/m^2/day, respectively. The DM, CP, ADF, NDF, TDN, OM, ash, hemicellulose, NE_l, NE_m, NE_g, and IVOMD were acquired in this study and are available in Tables 2−7.

Nutrient Composition of Guava Plant Parts and Fruits. The nutrient composition and predicted energy values of the plant parts and fruits of guava are presented in Tables 2 and 3. For CP, the shoots were the highest ($p < 0.05$), and the bark and branches were the lowest. The ADF and NDF were highest ($p < 0.05$) in the branches and lowest in the shoots, leaves, and bark. The immature fruits were significantly higher ($p < 0.05$) in ADF as compared to the ripe and breaker stage fruits and significantly higher ($p < 0.05$) in fiber than the bark, leaves, and shoots. The high fiber levels (ADF and NDF) of the immature fruit as compared to the ripe and breaker stage fruit are a probable reflection of the thickness of the epicarp as compared to the pericarp (mesocarp and endocarp). Medina and Pagano[7] found similar DM and CP values where guava fruit pulp had a low content of carbohydrates (13.2%), fats (0.53%), and proteins (0.88%; 5.83% DM basis) and a high water content of 84.9% (15.1% DM). Another study showed that for every 100 g of fruit, guava has 36−50 kcal, 77−86 g of moisture, 2.8−5.5 g of crude fiber, 0.43−0.7 g of ash, 9.1−17 mg of calcium, and 17.8−30 mg of phosphorus.[8] When evaluating and comparing fruit wastes like guava, papaya (*Carica papaya*), mango (*Mangifera indica*), and mango fruit pulp waste, for small ruminants, papaya had the highest CP (14.8%) and mango fruit pulp waste had the lowest (4.6%), while guava fruit waste had the highest NDF and lignin content.[9] Waiwi protein values are significantly ($p < 0.001$) lower than that of guava.

In Table 3, the predicted energy values (TDN, NE_l, NE_m, and NE_g) were highest ($p < 0.05$) for the ripe and breaker stage fruits, followed by the immature fruit, bark, shoots, leaves, and branches as the lowest. The TDN and fiber values of waiwi are similar to guava. The guava values are similar to NRC published values for forages and lower quality roughages commonly fed to domestic ruminants[10,11] and are also very similar to TDN values of tropical grasses grown in Hawaii. The ripe fruits were highest ($p < 0.05$) in IVOMD, and the branches were the lowest. When compared to the predicted energy values, the IVOMDs are very low. The reason for this is possibly due to natural antioxidants or antimicrobial compounds such as tannins, oxalates, or other compounds inhibiting microbial digestibility. Carpenter and DuPonte[12] found that the digestibilities ranged from 30.5% for red ginger (*Alpinia purpurata*) leaves to 94.1% for hibiscus (*Hibiscus cameronii*) after investigating the chemical composition and in vitro digestibility of tropical browse plants. These values are considerably higher than guava plant parts. It has been reported from a study in Hawaii that increased concentrations of calcium or oxalates in guava tree bark may induce calculogenic minerals to accumulate, causing uroliths with a calcium or oxalate base to form uroliths and potential penile obstruction in male goats.[13] These factors and compounds were not analyzed in this study and could have made an impact on digestibility. Previous work

Table 4. Mean Nutrient Composition and *t* Test between the Foliage Characteristics of Common Guava vs Waiwi[a]

	bark			leaves			shoots			branches		
	Guava	Waiwi		Guava	Waiwi		Guava	Waiwi		Guava	Waiwi	
n	18	6	Pr > *t*	18	6	Pr > *t*	18	6	Pr > *t*	18	6	Pr > *t*
nutrient variable												
DM (%)	40.52	42.52	NS	36.23	34.51	NS	28.20	25.10	NS	46.33	50.01	**
CP (%)	3.83	2.40	***	12.94	7.92	***	16.80	9.30	***	2.89	1.97	***
OM (%)	88.17	92.98	***	93.42	91.95	*	93.25	92.73	NS	97.50	98.23	***
ash (%)	11.83	7.02	***	6.58	8.05	*	6.75	7.27	NS	2.50	1.77	***
ADF (%)	27.13	30.00	NS	26.55	24.25	NS	27.40	24.10	NS	66.48	65.10	NS
NDF (%)	33.23	39.65	NS	38.28	33.07	*	37.10	32.20	NS	76.76	77.00	NS
hemicellulose (%)	6.09	9.65	NS	11.73	8.82	**	9.70	8.20	NS	10.28	11.90	NS
TDN (%)	66.06	63.17	NS	63.17	64.83	*	63.60	65.00	NS	52.56	52.67	NS
NE_l (Mcal/kg)	1.54	1.46	NS	1.51	1.54	*	1.54	1.54	NS	0.71	0.68	NS
NE_m (Mcal/kg)	1.51	1.39	NS	1.39	1.46	*	1.32	1.54	NS	0.95	0.95	NS
NE_g (Mcal/kg)	0.88	0.79	NS	0.82	0.88	*	0.88	0.88	NS	0.40	0.40	NS
IVOMD (%)	20.03	22.83	NS	16.36	18.95	NS	17.52	20.57	*	7.34	7.42	NS

[a]all data presented on a DM basis. *n*, number of samples for each plant part. Means followed by *, **, and *** are significantly different at $p < 0.05$, 0.01, and 0.001, respectively. Means followed by NS are not significantly different. The number of each plant part for guava is 18 and for waiwi is 6.

found that the seeds of the fruit when evaluated by dry weight contain 14% oil, with 15% proteins and 13% starch;[14] and phenolic and flavonoid compounds,[15] with some isolated compounds being cytotoxic.[16] In the bark of guava, there is 12−30% of tannin,[14] resin, and calcium oxalate crystals.[17] The roots have tannins as well, along with leucocyanidins, sterols, gallic acid, carbohydrates, and salts.[18] All tree parts including the roots, bark, stems, and leaves largely contain tannic acid.[19]

While referring to data from the National Research Council (1981) presented in Jurgens,[20,21] the daily nutrient requirements of livestock vary with stage of growth, stage of development, and whether they are pregnant or lactating. On the basis of the CP and TDN requirements of sheep and beef cattle,[20,21] the leaves and shoots of guava would meet nutrient requirements for the various phases of the life cycle. If these animals were to consume a significant portion of the branches, then the CP and TDN may be limiting.

Comparison of the Nutrient Composition of the Foliage Characteristics of Guava versus Waiwi. The nutrient compositions of bark, leaves, shoots, and branches for both guava and waiwi are presented in Table 4. For all plant parts, CP was significantly higher for guava than the waiwi ($p < 0.001$). The protein ranking for guava and waiwi is consistent with shoots being the highest followed by leaves, bark, and branches. Although the ADF of plant parts did not differ, the NDF of guava leaves was greater than that of waiwi leaves ($p < 0.05$). Waiwi leaves were significantly higher in TDN than guava leaves ($p < 0.05$). The IVOMDs of waiwi shoots were significantly higher than guava shoots ($p < 0.05$). Bark, leaves, and branches did not differ between guava and waiwi for NDF, the various predicted energy values, and IVOMD.

Comparison of the Nutrient Composition of All Fruits versus Immature Fruits for Both Guava and Waiwi. The mean nutrient composition and *t* test between the fruit characteristics of guava versus waiwi are presented in Table 5. Although there were no significant differences in ADF and NDF, the CP of guava for both all fruit and immature fruit categories were significantly higher ($p < 0.05$) than waiwi. The predicted energy values and IVOMD did not differ significantly among fruits. It should be noted that for the all fruit category, 50% of guava was immature and 80% of the waiwi was immature as well. A study evaluating the nutritional value of cull papaya fruit for monogastric animals was used for comparison to all guava and waiwi fruits and guava and waiwi immature fruits. The ADF and NDF for cull papaya fruit were 17.1 and 14.2%, respectively, lower than guava and waiwi fruit; however, the CP for cull papaya fruit was 11.2%, higher than guava and waiwi fruit.[22]

Table 5. Mean Nutrient Composition and *t* Test between the Fruit Characteristics of Common Guava vs Waiwi[a]

	all fruit			immature fruit		
	Guava	Waiwi		Guava	Waiwi	
	$n = 22$	$n = 5$	Pr > *t*	$n = 11$	$n = 4$	Pr > *t*
DM (%)	21.14	22.72	NS	26.34	23.60	NS
CP (%)	6.83	5.30	*	7.25	5.70	*
OM (%)	96.39	95.24	***	96.60	95.28	**
ash (%)	3.61	4.76	***	3.40	4.73	**
ADF (%)	47.14	49.52	NS	55.40	52.00	NS
NDF (%)	52.65	58.20	NS	60.74	61.65	NS
hemicellulose (%)	5.51	8.68	NS	5.34	9.65	**
TDN (%)	70.36	69.00	NS	68.09	68.00	NS
NE_l (Mcal/kg)	1.65	1.61	NS	1.61	1.59	NS
NE_m (Mcal/kg)	1.61	1.54	NS	1.52	1.50	NS
NE_g (Mcal/kg)	0.99	0.95	NS	0.93	0.90	NS
IVOMD (%)	36.03	34.92	NS	23.66	29.73	NS

[a]All data are presented on a DM basis. Means followed by *, **, and *** are significantly different at $p < 0.05$, 0.01, and 0.001, respectively. Means followed by NS are not significantly different. *n*, number of samples for each guava fruit type across all sites and seasons.

Comparison of the Guava Nutrient Composition for the Six Sites. The proximate composition, IVOMD, and predicted energy values across all guava plant parts and seasons for each site are presented in Table 6. The % DM for guava plant parts at the Hawi site were higher ($p < 0.05$) than Kapapala Ranch, Mountain View, Panaewa, Pepeekeo, and Pololu Valley, which could have been attributed to the soil characteristics of Hawi being silty clay. Any correlation of the DM value with the elevation and seasonal variation of the sites and seasons was not evident. The CP at Panaewa was higher than Hawi and Kapapala Ranch, with Mountain View and

Table 6. Mean (±SE) Proximate Composition, IVOMD, and Predicted Energy Values Across Common Guava Plant Part Samples for Each Site[a]

	site					
	Hawi	Kapapala	Mt. View	Panaewa	Pepeekeo	Pololu
sites	n = 12	n = 12	n = 12	n = 12	n = 12	n = 12
DM (%)	41.20 ± 2.59 a	37.94 ± 2.84 b	36.80 ± 1.81 b	37.08 ± 2.47 b	37.91 ± 2.16 b	36.01 ± 2.05 b
CP (%)	8.58 ± 1.69 bc	9.13 ± 1.95 b	9.47 ± 1.90 ab	10.09 ± 2.07 a	8.00 ± 1.50 c	9.39 ± 1.86 ab
ADF (%)	34.04 ± 5.15 b	38.74 ± 5.27 a	38.26 ± 5.20 a	36.20 ± 5.68 ab	37.26 ± 5.07 a	36.85 ± 5.76 a
NDF (%)	44.36 ± 4.99 b	47.66 ± 5.49 a	47.19 ± 5.34 a	45.29 ± 5.93 ab	47.38 ± 5.11 a	46.22 ± 5.88 ab
hemicellulose (%)	10.32 ± 1.10 a	8.92 ± 1.15 a	8.93 ± 1.01 a	9.09 ± 1.01 a	10.12 ± 1.02 a	9.37 ± 1.15 a
OM (%)	92.72 ± 1.13 cd	91.99 ± 1.17 d	93.80 ± 1.10 b	92.14 ± 1.44 d	94.76 ± 0.64 a	93.11 ± 0.80 bc
ash (%)	7.28 ± 1.13 ab	8.01 ± 1.17 a	6.20 ± 1.10 c	7.86 ± 1.44 a	5.24 ± 0.64 d	6.89 ± 0.80 bc
TDN (%)	61.62 ± 1.39 a	60.67 ± 1.57 b	60.92 ± 1.48 ab	61.58 ± 1.72 a	60.58 ± 1.46 b	61.17 ± 1.62 ab
NE_L (Mcal/kg)	1.354 ± 0.09 a	1.271 ± 0.11 b	1.289 ± 0.10 b	1.310 ± 0.11 ab	1.289 ± 0.10 b	1.279 ± 0.12 b
NE_M (Mcal/kg)	1.332 ± 0.06 a	1.289 ± 0.07 b	1.289 ± 0.06 b	1.319 ± 0.07 ab	1.289 ± 0.06 b	1.310 ± 0.07 ab
NE_G (Mcal/kg)	0.750 ± 0.05 a	0.716 ± 0.06 b	0.720 ± 0.06 ab	0.741 ± 0.07 ab	0.713 ± 0.06 b	0.730 ± 0.07 ab
IVOMD (%)	15.27 ± 1.48 a	15.29 ± 1.91 a	15.81 ± 1.63 a	16.33 ± 2.17 a	14.16 ± 1.50 a	15.00 ± 1.71 a

[a]All data are presented on a DM basis. n, number of common guava samples for each site across all plant parts and seasons. Means (±SE) within the same row followed by different letters differed significantly ($p < 0.05$).

Table 7. Mean (±SE) Proximate Composition IVOMD and Predicted Energy Values Across All Common Guava Parts and Sites for Each Season[a]

	vegetative parts only			fruits only		
season	spring	summer	winter	spring	summer	winter
	n = 24	n = 24	n = 24	n = 10	n = 8	n = 4
DM (%)	38.10 ± 1.76 a	39.70 ± 1.56 a	35.70 ± 1.53 b	22.02 ± 3.14 a	21.60 ± 2.29 a	18.02 ± 1.50 a
CP (%)	9.63 ± 1.32 a	8.23 ± 1.19 b	9.46 ± 1.31 a	7.24 ± 0.70 a	6.56 ± 0.54 a	5.73 ± 0.87 a
ADF (%)	34.26 ± 3.40 b	34.65 ± 3.72 b	41.77 ± 3.82 a	42.66 ± 4.60 a	52.39 ± 3.34 a	46.25 ± 2.83 a
NDF (%)	46.03 ± 3.58 b	44.75 ± 4.06 b	48.26 ± 3.68 a	49.79 ± 4.82 a	57.05 ± 3.48 a	51.55 ± 2.57 a
hemicellulose (%)	11.78 ± 0.55 a	10.11 ± 0.53 b	6.49 ± 0.69 c	7.13 ± 0.88 a	4.66 ± 0.73 a	5.30 ± 0.30 a
OM (%)	93.42 ± 0.69 a	93.18 ± 0.75 ab	92.66 ± 0.86 b	96.09 ± 0.32 b	96.59 ± 0.21 ab	96.73 ± 0.19 a
ash (%)	6.58 ± 0.69 b	6.82 ± 0.75 ab	7.34 ± 0.86 a	3.91 ± 0.32 a	3.41 ± 0.21 ab	3.28 ± 0.19 b
TDN (%)	61.13 ± 1.03 ab	61.54 ± 1.14 a	60.63 ± 1.04 b	71.20 ± 1.35 a	69.13 ± 0.95 a	70.75 ± 0.75 a
NE_L (Mcal/kg)	1.32 ± 0.07 a	1.31 ± 0.08 a	1.27 ± 0.07 b	1.68 ± 0.03 a	1.63 ± 0.02 a	1.67 ± 0.02 a
NE_M (Mcal/kg)	1.31 ± 0.04 ab	1.32 ± 0.05 a	1.28 ± 0.04 b	1.64 ± 0.06 a	1.56 ± 0.04 a	1.62 ± 0.03 a
NE_G (Mcal/kg)	0.73 ± 0.04 a	0.75 ± 0.04 a	0.70 ± 0.04 b	1.03 ± 0.05 a	0.96 ± 0.04 a	1.02 ± 0.03 a
IVOMD (%)	17.80 ± 1.06 a	15.02 ± 1.23 b	13.11 ± 1.15 c	37.12 ± 5.60 ab	31.14 ± 4.70 b	43.10 ± 3.10 a

[a]All data are presented on a DM basis. n, number of common guava samples for each site across all plant parts. Means (±SE) within the same row followed by different letters differed significantly ($p < 0.05$).

Pololu Valley not being different than these, and Pepeekeo was lower than all other sites ($p < 0.05$). The ADFs of the Kapapala Ranch, Mountain View, Pepeekeo, and Pololu Valley sites were higher ($p < 0.05$) than Hawi, and Panaewa was not different from any of the other sites. The NDFs at Kapapala Ranch, Mountain View, and Pepeekeo were higher ($p < 0.05$) than Hawi, and Panaewa and Pololu Valley were not different from the other sites. The TDNs at Hawi and Panaewa were higher than Kapapala Ranch and Pepeekeo ($p < 0.05$). These nutrient components were not positively correlated with any of the seasonal characteristics of the sites and variations between seasons. It seems likely that maybe the soil types and their pH and fertility of each site could have a greater influence on the nutrient composition than elevation, rainfall, temperature, and solar radiation.

Seasonal Differences for Both Guava Vegetative Parts and Fruits. The mean proximate composition, IVOMD, and predicted energy values across sites and parts for each season are presented in Table 7. Because crop maturity is majorly impacted by weather conditions and consistent stages of maturity at varying seasons may bring about diverse forage quality, vegetative parts were gathered only from physiologically mature trees. The CP for the vegetative parts collected in the spring and winter was significantly higher ($p < 0.05$) than that of the summer. CP generally has increased nutritional quality following the growth spurt after the winter precipitation, followed by a slow decline.[23] The winter ADF and NDF for vegetative parts were significantly higher ($p < 0.05$) than the vegetative parts of spring and summer. Some browses have varying nutritional values at different seasons. White bursage (*Ambrosia dumosa*), for instance, has greater nutrient value than other browse species in the spring and less nutritious than others in the fall.[23] Forage in deserts fluctuates seasonally with nutrient quality being greatest in late winter and spring and lowest in fall and early winter.[23] The IVOMDs for the common guava vegetative parts collected in the spring were significantly higher ($p < 0.05$) than those collected in the summer, which were significantly higher ($p < 0.05$) than those collected in the winter, while the fruits only collected in the winter were significantly higher ($p < 0.05$) than those collected in the summer. Hanley and Brady[23] found digestibilities for white bursage, desert-thorn (*Lycium pallidum*), and foothills paloverde (*Parkinsonia microphylla*) were 39.8, 35.3, and 51.4%, respectively. The IVOMDs of the guava vegetative parts are considerably lower than the digestibility findings of Hanley and Brady. The IVOMDs of the guava fruit are similar to the digestibility of white bursage, desert-thorn, and foothills paloverde; however, the summer fruits are lower at 31.1%. According to George et al.,[24] forage may be of high nutrient content in the early growing season; however, increased water content within the forage can cause incomplete nutrient extraction by the rumen because of increased rate of passages. In general, with progression of the growing season, factors such as CP decrease, and factors such as fiber increase as the plant matures.[24] Variations in nutritional content follow changes in phenology.[23]

There are variations documented during transition of grazing of sheep, goats, and cattle, specifically during transitions of activity in the dry season,[25] or from more high-nutrient to low-nutrient status of seedlings.[26] Other documented variations include favoring of herbaceous species during rainy season versus woody species favored during dry seasons.[27] In this study, limited variations were seen in the plant and fruit nutrient density between seasons. This is obviously due to narrow climatic variations between each season; therefore, differences in animal consumption and performance might be influenced more by plant characteristics and factors influencing grazing behavior.

Observations of highly managed, low elevation grazing systems of Hawaii where guava is present (density of guava varies greatly with site and season and is normally quite low) comprises a relatively small proportion of the animals' consumption (personal communications with local ranchers). If there is evidence of intense guava tree parts being grazed, then this is an indication of limited forage availability. Although guava shoots and leaves would be acceptable sources of forage because of their CP and TDN values, which are comparable to Hawaiian pasture grasses, the IVOMDs are very low. In addition to the nutrient density of the diet, other contributing factors influencing animal consumption and grazing behavior are plant availability and physical characteristics. While it is usually expected that IVOMDs would be inversely correlated with NDF concentration, both of these forage quality indicators were low in the present study for guava plant parts and fruit. Contributing factors for low IVOMDs when NDF is also low may include natural antioxidants or antimicrobial compounds such as tannins, oxalates, and phenolic and flavonoid compounds that could inhibit digestibility. Because this study did not address these factors, further work should be done to verify their potential impact on guava IVOMD. Pen feeding studies are recommended to appreciate situations where animals are forced to consume large amounts of guava because of limited forage availability. In addition, the presence of antimicrobial factors could limit digestibility of pasture grasses, which would exacerbate the lack of nutrient availability and health of the animals. Because of the low protein content of waiwi plant parts and fruits, it may not be as high in quality as guava.

Conclusively, the primary nutritional concern with guava is low IVOMD as compared to tropical forage grasses; therefore, it is not recommended as a sole source or predominant feedstock for livestock. Even though livestock like cattle, sheep, and goats are observed to feed on guava in Hawaii, the results of this study do not support guava as having nutritional usefulness. Animals, however, specifically goats, have been observed to strip the bark circumference off the tree trunk, thus killing the tree. This may be a useful method to control the pest species.

■ ASSOCIATED CONTENT

Ⓢ Supporting Information

Table of nutrient composition of common Hawaiian pasture grasses and fruit byproducts. This material is available free of charge via the Internet at http://pubs.acs.org.

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■ ABBREVIATIONS USED

DM, dry matter; CP, crude protein; ADF, acid detergent fiber; NDF, neutral detergent fiber; TDN, total digestible nutrients; OM, organic matter; IVOMD, in vitro organic matter digestibility; NE_l, net energy for lactation; NE_m, net energy for maintenance; NE_g, net energy for gain; DE, digestible energy

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