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Biodegradability of quinoa stalks: The potential of quinoa stalks as a forage source or as biomass for energy production

Gökhan Filik

Department of Agricultural Biotechnology, Faculty of Agriculture, University of Kırşehir Ahi Evran, Bağbaşı Mah. Şehit Sahir Kurutluoğlu Cad. No: 100 Kırşehir, Turkey

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ABSTRACT

This study was carried out to determine the potential of quinoa stalks, left as waste in the fields after harvest, to be converted into roughage for animal feed or as biomass for energy production. The quinoa stalks were harvested from cultivated fields in Şanlıurfa, Turkey, and the biochemical and thermochemical potential conversion of the quinoa stalks to forage feed or biomass was then determined.

A chemical and basic element analysis of the quinoa stalks was carried out. In terms of animal feeding potential that involved the *in vitro* digestibility and metabolizable energy value. In terms of biomass potential, the syngas values and other gases: estimated methane (CH_4), biodegradability, total biogas production value and higher heating value, were also all determined.

According to ADL $^{DM\%}$ analysis value (46.49 ± 0.97) and calculated relative feed value (RFV, 71.09) results showed that quinoa stalks have a very poor potential as forage and cannot be regarded as roughage. However, with an energy value of 18.27 MJ/kg was determined that quinoa stalks could be used as an energy producing plant.

1. Introduction

Feed costs should be kept to a minimum to achieve an economically satisfactory production in modern animal husbandry. The increasing need to use agricultural land for urbanization, human nutrition and energy agriculture is met using that agricultural land for both concentrate feed and roughage production [1]. For this reason, researchers have started to cultivate products that can meet the nutritional needs of the modern age in marginal areas [2–4]. In addition, researches have focused on alternative energy sources due to the decreasing use of fossil fuel resources that increase global warming and contribute to the greenhouse effect. Agricultural products are generally produced for industrial production and nutrition, and the surplus – or waste – is used for energy production.

In recent years, the Food and Agriculture Organization (FAO) has been trying to expand the production of different grains that can provide more nutrition per unit area and can be cultivated under all kinds of farming conditions. For this purpose, the FAO encourages farmers to produce traditional products such as Amaranth, the African garden eggplant, Bambara groundnut, breadfruit cactus pear, cardoon, common buckwheat, fe'i bananas, finger millet, oca, moringa, quinoa, teff and yam bean [5]. Cereals such as amaranthus, common buckwheat, chia, finger millet, quinoa and teff are called pseudo or mother grains. In particular, these grains are selected as cereals of the month or year by the FAO and efforts are made to expand their cultivation [6–8]. The Andean region, inhabited by civilizations such as the Inca and Tiahuanaco, is considered to be the center of the above-mentioned pseudo grains.

Chenopodium quinoa Willd. can be grown in marginal, salty and arid soils. It is a plant with high adaptability to many diseases or pests; it is particularly used as a dietary product [9]. Quinoa, which is a C-3 plant that does not have photosynthetic adaptations to reduce photorespiration, grows up to 150 cm in length while hay yield is 431.85 kg/da [10]. Quinoa stalks are rich in xylan, cellulose and saponin [11]. Studies on quinoa have generally been in terms of cultivation, soil requirements, feed availability for plant physiological development stages or human nutrition [9,12–15]. However, there is no information on nutrient and basic element values, *in vitro* digestibility, energy value, syngas and other gases, estimated methane, biogas or biomass values of the quinoa stalks remaining in the field after harvest [11]. The ANKOM^{RF} Gas Production System developed by Ankom technology was used to determine the digestibility of quinoa stalks [16]. In addition, the gross energy value of quinoa stalks was determined using a bomb calorimeter. The present study was carried out to determine the efficacy of quinoa stalks as forage or as biomass in post-harvest fields.

E-mail address: gfilik@ahievran.edu.tr.

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2. Materials and method

Nutrient values and *in vitro* digestibility were analyzed in the Feed Biotechnology laboratory of the Agricultural Biotechnology Department in the Agriculture Faculty of Kırşehir Ahi Evran University. Elemental composition analysis was performed at the Central Research and Application laboratory of Kırşehir Ahi Evran University. The actual combustion energy value was determined by using high-pressure atmospheric combustion bombs at the Science and Technology Application and Research Center of Çanakkale Onsekiz Mart University.

2.1. Materials

2.1.1. Ethics and permission

The study complied with an ethics document taken from the Animal Experiments Local Ethics Committee of Kırşehir Ahi Evran University, dated and numbered 12/09/2018-17-2.

2.1.2. Feedstuff samples

Stalk samples of *Chenopodium quinoa* Willd. were taken from two different regions in the Şanlıurfa province in Turkey (37°N Latitude, 38 °E Longitude, at an altitude of 650 m above mean sea level). The collected stalks were dried in a ventilated drying oven at 65 °C for 48 h. The dried quinoa stalks were ground (Ultra-Centrifugal Mill ZM 200-Retsch) in a 1 mm sieve grinder before analysis.

2.1.3. Animal samples

Rumen fluid was taken from three Belgian Blue-Holstein hybrid cows of approximately 650 kg/LW which had been fed 40 concentrate/60 roughage at the age of 28 months in the slaughterhouse (Kırşehir Meat and Meat Products Food Marketing Industry and Trade Limited Company, Turkey). A thermos flask with hot pure water at 39.5 °C was emptied and the rumen fluids (200 ml of rumen liquid from each animal) was mixed, collected and poured into this empty thermos flask and taken to the laboratory in the thermos flask within 10 min.

2.2. Method

2.2.1. Chemical and elemental composition

The dry matter (DM), crude protein (CP) and ash contents of the quinoa stalks were determined according to the AOAC procedure [17] while the non-fiber carbohydrates (NFC), crude fiber (CF), neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin (ADL) values were analysed using ANKOM 200 Fiber Analyzer (ANKOM Technology Corp. Fairport, NY, USA) according to the method by Van Soest et al [18]. Ether extract (EE) procedure was carried out in ANKOM^{XT15} extraction system according to AOCS [19]. The calculations of total carbohydrates (TC) [20], hemicellulose (HCel), cellulose (Cel), nitrogen free extracts, and non-digestible carbohydrate (NFE; DC) contents were as follows;

$$\text{Total carbohydrates (TC) (g/kg DM)} = 100 - [\text{CP} + \text{EE} + \text{ash}] \quad (2.1)$$

$$\text{Hemicellulose (HCel)} = [\text{NDF\%} - \text{ADF\%}] \quad (2.2)$$

$$\text{Cellulose (Cel)} = [\text{ADF\%} - \text{ADL\%}] \quad (2.3)$$

$$\text{Nitrogen free extracts (NFE)} = [\text{DM} - (\text{CP} + \text{ash} + \text{EE} + \text{CF})] \quad (2.4)$$

$$\text{Non-digestible carbohydrate (NFC) (g/kg DM)} = 100 - [\text{NDF} + \text{CP} + \text{EE} + \text{ash}] \quad (2.5)$$

The sulfur (S) (ASTM D4239), carbon (C) (ASTM D5373), hydrogen (H) (ASTM D5373), nitrogen (N) (ASTM D5373) and oxygen (O) (ASTM D3176) values of the quinoa stalks were determined by using a Thermo Scientific FLASH 2000 HT Elemental Analyzer.

2.2.2. In vitro digestibility

The *in vitro* digestibility of 200 mg of quinoa stalks ground with a 1 mm sieve – using the Ankom^{RF} Gas Production System (Ankom Technology, New York, USA) and modified rumen fluid/buffer solution prepared for the *in vitro* gas production technique reported by Menke and Steingass [21] – was weighed into a Schott flask and then incubated and shaken in a hot water bath at 39.5 °C. Carbon dioxide (CO_2) was added to the quinoa stalks weighed out in the Schott flask into vials with 20 ml of clean, cheesecloth-filtered rumen liquid and 80 ml of buffer solution until the formation of oxygen (O_2). A total of ten samples, eight of them containing the quinoa stalks, rumen fluid and buffer solution, and two of them containing only rumen fluid and buffer solution, were incubated in a 250 ml Schott flask that was preheated to 39.5 °C. The amount of gas produced was determined by measuring the internal pressure (P_{psi}) of the Schott flask from the gas produced by the digestion of quinoa stalks by the microorganisms in the rumen fluid during incubation. The microchip sensor in the Schott flask module sends the gas pressure values to a Gas Pressure Monitor V9.7.2.0 program every 5 min. The program is set to open the valve when the gas pressure generated in each module reaches 5 psi. The value for the total amount of gas produced was transferred to the computer program via wireless in real time. An Uninterruptible Power Supply (UPS) was used to prevent any power outage in the system. In case the wireless batteries in the module ran out, the modules were connected to the UPS by direct connection. The total amounts of gas produced in the Schott flasks in a continuously agitated water bath at 39.5 °C were measured at 3, 6, 9, 12, 24, 48, 72 and 96 h, respectively. The amount of gas produced was determined by calculating the total gas production (GP) resulting from the incubation of 200 mg of quinoa stalks. The means of the total gas values were corrected according to the average values of blind samples [22,23].

The organic matter digestibility (OMD, %), metabolic energy (ME, MJ/kg DM) and net energy lactation (NE_L, MJ/kg DM) values were calculated by using formulas 2.6, 2.7 and 2.8 to provide a chemical analysis and the total gas content results after 24 h incubation [21].

$$\text{OMD (\%)} = 15.38 + 0.8453\text{GP} + 0.0595\text{CP} + 0.0675\text{ash} \quad (2.6)$$

$$\text{ME (MJ/kg DM)} = 2.20 + 0.1357\text{GP} + 0.0057\text{CP} + 0.0002859\text{CP}^2 \quad (2.7)$$

$$\text{NE}_L\text{ (MJ/kg DM)} = 0.54 + 0.0959\text{GP} + 0.0038\text{CP} + 0.0001733\text{CP}^2 \quad (2.8)$$

2.2.3. Metabolizable energy and protein values

The digestible crude protein (DCP, %) [24] and total digestible nutrient (TDN, %) values [25], digestible energy (DE Mcal/kg) [26], metabolizable energy (ME Mcal/kg) [27], net energy-lactation (NE_L Mcal/lb) [28], net energy-maintenance (NE_M Mcal/lb) [28], net energy-gain (NE_G Mcal/lb) [28], net energy-maintenance (NE_m Mcal/kg) and net energy-gain (NE_g Mcal/kg) [29] of the quinoa stalks were all calculated using the following formulas:

$$\text{DCP (\%)} = \text{CP} * 0.908 - 3.77 \quad (2.9)$$

$$\text{TDN (\%)} = 50.41 + 1.04\text{ CP} - 0.07\text{CF} \quad (2.10)$$

$$\text{DE (Mcal/kg)} = 0.04409 * \text{TDN\%} \quad \text{(50\% TDN: 6.40 MJ/kg DM of ME)} \quad (2.11)$$

$$\text{ME (Mcal/kg)} = 0.82 * \text{DE} \quad (2.12)$$

$$\text{NE}_L\text{ (Mcal/lb)} = [\text{TDN\%} * 0.01114] - 0.054 \quad \text{(1 Mcal/lb} = 2.2046\text{ Mcal/kg)} \quad (2.13)$$

$$\text{NE}_M\text{ (Mcal/lb)} = [\text{TDN\%} * 0.01318] - 0.132 \quad \text{(1 Mcal/lb} = 2.2046\text{ Mcal/kg)} \quad (2.14)$$

$$\text{NE}_G\text{ (Mcal/lb)} = [\text{TDN\%} * 0.01318] - 0.459 \quad \text{(1 Mcal/lb} = 2.2046\text{ Mcal/kg)} \quad (2.15)$$

$$NE_m \text{ (Mcal/kg)} = 1.37\ ME - 0.138\ ME^2 + 0.0105\ ME^3 - 1.12 \quad (2.16)$$

$$NE_g \text{ (Mcal/kg)} = 1.42\ ME - 0.174\ ME^2 + 0.0122\ ME^3 - 1.65 \quad (2.17)$$

2.2.4. Relative feed value and relative forage quality

The dry matter intake (DMI) (Live Weight: LW, %), digestible dry matter (DDM), relative feed value (RFV) [30] and relative forage quality (RFQ) [31] values were calculated using the following formulas given below:

$$DDM\ (\%) = 88.9 - [0.779 * ADF\%] \quad (2.18)$$

$$DMI\ (\text{Live Weight: LW }\%) = 120/[NDF\%] \quad (2.19)$$

$$RFV = [DMD * DMI]/1.29 \quad (2.20)$$

For the determination of the quality of forage, The Hay Marketing Task Force of the American Forage and Grassland Council (AFGC) classification method was used, which is based on the use of the ADF and NDF values from the chemical analysis contents. According to the roughage classification method, the RFV value "V" (< 75) indicates poor quality to be rejected – (75–86) IV. Quality; (87–102), III. Quality; (103–124), II. Quality; (125–151) – while "prime" (> 151) refers to the best quality [32,33].

$$RFQ = [DMI * TDN]/1.23 \quad (2.21)$$

The relative forage quality (RFQ) is a method that makes it possible to estimate the quality of feed to be consumed according to the performance of animals fed with roughage. According to the RFQ method developed to determine roughage quality for dairy cattle, "140–160" Dairy, 1st trimester Dairy calf, "125–150" Dairy, last 200 days Heifer, 3 to 12 months Stocker cattle, "115–130" Heifer, 12 to 18 months Beef cow-calf and "100–200" Heifer are described as 18 to 24 months Dry cow [34,35].

2.2.5. Syngas and other gases, estimated CH_4 and biodegradability

Biomass products such as fuel, gases or chemicals from quinoa stalks are produced by biological and chemical reactions [36]. The oxygen (O_2), ozone (O_3), hydrogen (H_2), hydrogen sulfide (H_2S), carbon monoxide (CO), carbon dioxide (CO_2), methyl (CH_3), methane (CH_4), nitrous oxide (N_2O), ammonia (NH_3), ammonium (NH_4) and sulfur dioxide (SO_2) values were determined by substituting the values obtained by taking the basic element analysis (C, H, O, N and S) results divided by the atomic weights of the elements and dividing them by a coefficient that would most easily equal them to the number 1, and then substituting the values obtained in the molecular formulas. C, H, O, N and S are the values obtained by dividing the analysis results by atomic weights by multiplying any of them with a coefficient equal to 1. Determination of the theoretical methane production value (VT) and biodegradability value were calculated using the basic element analysis values and the following formulas [37,38]:

$$C_aH_bO_cN_d + [(4a - b - 2c + 3d)/4] * H_2O \rightarrow [(4a + b - 2c - 3d)/8] * CH_4 + [(4a - b + 2c + 3d)/8] * CO_2 + dNH_3 \quad (2.21)$$

Eq. (2.1)

$$VT\ (m^3\ CH_4/kg) = [(4a + b - 2c - 3d) \times 2.8]/[12a + b + 16c + 14d] \quad (2.22)$$

Biodegradability = The volatile carbon percentage (VC)/The theoretical methane production value (VT) * 100% (2.23)

2.2.6. Total biogas production value

The total biogas production value is calculated by using the following formulas [38]: The quinoa stalks daily gas production value (G) was determined by multiplying the mean value of the specific gas yield (Gy) of the maize straw (410) by the 1/kg VS value. Since the quinoa stalks were similar to maize straw when milled, nutritional value analysis results determined in the present study was similar to those obtained by Werner et al. and García-Martínez et al. [39,40].

$$\text{Dry Matter (DM\%)} = 100 - \text{Moisture\%} \quad (2.24)$$

$$\text{Organic Matter (OM\%)} = DM\% - ash\% \quad (2.25)$$

Organic Dry Matter (ODM: VS) = Quinoa Stalks * DM% * OM% (t ODM/day) (2.26)

$$G\ (m^3\ gas/d) = VS * Gy \quad (2.27)$$

Total Biogas Production Value (TBP) (m^3 gas/d/decare) = G * Quinoa Stalks (kg per decare) (2.28)

2.2.7. Higher heating value

The biomass potential of quinoa stalks was determined by analyzing the moisture content (MC) percentage (International Organization for Standardization; ISO 589 (Met B2)), the ash percentage (ISO 1171), the volatile carbon or volatile matter percentage (VC; VM %) (ISO 562) and the fixed carbon percentage (FC, %) (ASTM D3172), using a Binder ED 53 Oven and Protherm (PLF 110/6) devices.

One of the most widely used methods for determining biomass potential is to estimate the higher heating value (HHV) with formulas. The higher heating value was calculated using the different HHV formulas in Table 2.1 using the results of Carbon (C), H (Hydrogen), O (Oxygen), N (Nitrogen), S (Sulphur), ash, L; ADL%, FC and VM; and VC analyzes.

The LECO AC-350 high-pressure atmospheric combustion bomb device was used to compare the estimated energy value with the formulas in Table 2.1 and the actual energy value of the quinoa stalks [38].

2.3. Statistical analysis

The mean and standard errors of the chemical analysis results of quinoa stalks were calculated from four readings. Basic element analysis was determined as the average of three readings. In vitro gas production values were calculated from eight readings. The mean of OMD, ME and NE_L values, and standard errors, were calculated after correcting the mean of two blind samples. Metabolic energy and protein values were calculated from the chemical analysis results corrected on a DM basis. The RFV and RFQ were calculated using the chemical analysis results. Syngas and other gas values and the estimated methane amount that can be released by burning plants were calculated with the basic element values. Total biogas production values and biomass values were calculated from the chemical analysis results. For the statistic of the data, Descriptives Variables was used for the descriptive statistical analysis. Mean and standard error (SE) values were calculated using the SPSS (17.0) ® statistical software program package [60].

3. Results

After harvesting quinoa plant seeds, a significant amount of stem remains in the field. Quinoa stalks are either harvested and thrown out of the field or driven into the field for soil preparation.

The chemical and elemental composition analysis results of the quinoa stalks (Table 3.1) and the findings reported by Salgado et al. [61] and Paniagua Bermejo et al. [62] were found to be in line with each other. Paniagua Bermejo et al. [62] has stated that the ADL, $^{DM\%}$ value is one of the most important factors that determined whether ruminant animals can utilize quinoa husk. In this study, the ADL, $^{DM\%}$ value was determined to be 46.49 ± 0.97 in quinoa stalks.

According to Table 3.2, 24-h OMD, ME and NE_L values, even quinoa stalks are found to be low when compared to poor quality roughages such as good quality alfalfa hay, low quality alfalfa hay, corn silage, grape pomace, common vetch, pea, birdsfoot trefoil, canola or drying

Table 2.1
Higher heating value formulas for quinoa stalks.

Higher Heating Value	Formulas	References	Formulas Number
HHV (kJ/kg)	349.1C + 1178.3H + 100.5S – 103.4O – 15.1N – 21.1ash	[36]	(2.29)
HHV (MJ/kg)	0.4373C - 1.6701	[41]	(2.30)
HHV (Btu/lb)	7527C + 11.479[1 - C]	[41]	(2.31)
HHV (Btu/lb)	188.0C - 131.5	[41]	(2.32)
HHV (MJ/kg)	−0.763 + 0.301C + 0.525H + 0.064O	[42]	(2.33)
HHV (MJ/kg)	(33.5C + 142.3H - 15.4O - 14.5 N)/100	[43]	(2.34)
HHV (MJ/kg)	0.3259C + 3.4597	[44]	(2.35)
HHV (MJ/kg)	0.196FC + 14.119	[45]	(2.36)
HHV (MJ/kg)	0.0979L + 16.292	[44]	(2.37)
HHV (MJ/kg)	167.2 – 1.449VM - 1.562FC - 1.846ash	[46]	(2.38)
HHV (MJ/kg)	−17.507 + 0.3985VM + 0.2875FC	[46]	(2.39)
HHV (MJ/kg)	22.3418 – 0.1136FC - 0.3982ash	[46]	(2.40)
HHV (MJ/kg)	10.982 + 0.1136VM - 0.2848ash	[46]	(2.41)
HHV (MJ/kg)	−18.37 – 0.8469FC - 1.1251ash + 4420/VM	[46]	(2.42)
HHV (MJ/kg)	44.336 + 0.286FC - 2394.7/VM	[46]	(2.43)
HHV (MJ/kg)	28.296 – 0.2887ash - 656.2/VM	[46]	(2.44)
HHV (MJ/kg)	18.297 – 0.4128ash + 35.8/FC	[46]	(2.45)
HHV (MJ/kg)	0.312FC + 0.1534VC	[47]	(2.46)
HHV (MJ/kg)	19.914 – 0.2324ash	[44]	(2.47)
HHV (MJ/kg)	−3.0368 + 0.2218VM + 0.2601FC	[44]	(2.48)
HHV (MJ/kg)	0.3536FC + 0.1559VM - 0.0078ash	[48]	(2.49)
HHV (MJ/kg)	0.3259C + 3.4597	[44]	(2.50)
HHV (MJ/kg)	−1.3675 + 0.3137C + 0.7009H + 0.0318O^{*b} O^{*b} = 100 – C – H – ash	[44]	(2.51)
HHV (kJ/kg)	3.55C^2 - 232C - 2230H + 51.2C - H + 131N + 20.600	[49]	(2.52)
HHV (MJ/kg)	0.3491C + 1.1783H + 0.1005S - 0.1034O - 0.0151N- 0.0211ash	[50]	(2.53)
HHV (kJ/kg)	354.3FC + 170.8VM	[51]	(2.54)
HHV (kJ/kg)	35.430 – 183.5VM - 354.3ash	[51]	(2.55)
HHV (MJ/kg)	−10.8141 + 0.3133[VM + FC]	[52]	(2.56)
HHV (MJ/kg)	−0.763 + 0.301C + 0.525H + 0.064O	[42]	(2.57)
HHV (MJ/kg)	0.4373C - 1.6701	[41]	(2.58)
HHV (MJ/kg)	0.1905VM + 0.2521FC	[53]	(2.59)
HHV (MJ/kg)	0.2949C + 0.8250H	[53]	(2.60)
HHV (MJ/kg)	0.196FC + 14.119	[43]	(2.61)
HHV (MJ/kg)	0.312FC + 0.1534VM	[43]	(2.62)
HHV (MJ/kg)	0.3516C + 1.16225H - 0.1109O + 0.0628 N + 0.10465S	[54]	(2.63)
HHV (MJ/kg)	0.341C + 1.322H - 0.12O-0.12N + 0.0686S - 0.0153ash	[55]	(2.64)
HHV (MJ/kg)	0.328C + 1.4306H - 0.0237 N + 0.0929S - (1 - ash/100)(40.11H/C) + 0.3466	[56]	(2.65)
HHV (MJ/kg)	0.0889L + 16.8218	[57]	(2.66)
HHV (MJ/kg)	0.0877L + 16.4951	[57]	(2.67)
HHV (MJ/kg)	32.3EE + 24.5L + 18.6Cell	[58]	(2.68)
HHV (MJ/kg)	14.3366 + 0.1228L + 0.1353EE	[59]	(2.69)

Table 3.1
Chemical and elemental composition of quinoa stalks.

Parameters	Mean + SE	Parameters	Mean + SE
OM*, $^{DM\%}$	91.50 ± 0.15	EE, $^{DM\%}$	1.33 ± 0.08
Moisture, $^{DM\%}$	2.27 ± 0.19	NFE*, $^{DM\%}$	41.73 ± 2.29
ash, $^{DM\%}$	8.50 ± 0.04	NFC*, $^{DM\%}$	17.23 ± 0.79
CP, $^{DM\%}$	4.93 ± 1.15	TC, $^{DM\%}$	86.72 ± 0.87
CF, $^{DM\%}$	42.62 ± 1.20	C, %	43.16 ± 0.01
ADF, $^{DM\%}$	50.06 ± 0.32	H, %	5.44 ± 0.01
NDF, $^{DM\%}$	69.49 ± 0.08	S, %	0.11 ± 0.01
ADL, $^{DM\%}$	46.49 ± 0.97	O, %	36.30 ± 0.01
HCel*, $^{DM\%}$	19.43 ± 0.40	N, %	4.22 ± 0.01
Cel*, $^{DM\%}$	3.57 ± 0.65	C/N	10.22 ± 0.01

*Calculated values, DM: Dry matter, OM: Organic matter = [DM – ash].

citrus pulp [63–65]. The metabolizable energy value results calculated by using the chemical analysis results of the quinoa stalks are given in Table 3.3.

The results of $NE_{M,\ m}$ and $NE_{G,\ g}$ (Mcal/kg) calculated by using formulas reported by Schroeder [28] and Garrett's [29] were found to be similar. The Abaş et al. [66] NE_L value – calculated from the 24-h *in vitro* degradability values of 12 different feeds – was determined to be 8.30 MJ/kg^{DM} in corn, 8.25 MJ/kg^{DM} in wheat, 7.84 MJ/kg^{DM} in barley, 7.55 MJ/kg^{DM} in oat, 7.03 MJ/kg^{DM} in dairy cattle feed, 6.65 MJ/kg^{DM} in beef cattle feed, 6.38 MJ/kg^{DM} in wheat bran, 5.27 MJ/kg^{DM} in sunflower meal, 5.20 MJ/kg^{DM} in alfalfa hay, 4.21 MJ/kg^{DM} in vetch hay, 3.78 MJ/kg^{DM} in grass hay and 2.67 MJ/kg^{DM} in wheat straw, which are the highest values to the quinoa stalks. The RFV and RFQ values calculated by using ADF$^{DM\%}$ and NDF$^{DM\%}$ were given in Table 3.4.

According to the RFV calculated from the nutrient analysis results of the quinoa stalks, the worst grade is 5, which is below the $<$ 75 Level. According to the RFV values, which take into account ADL$^{DM\%}$ content, quinoa stalks should not be used as a source of roughage. According to the RFQ value, which was developed to detail the quality of feed in all roughage, quinoa stalks are not good enough to be evaluated, especially for dairy cattle feed. Apart from 431.85 kg of hay yield per decare [10], waste quinoa stalks without economic value are generally considered a problem for farmers.

When quinoa stalks are considered as biomass, the potential amounts of syngas and other gases are very important. Biological and thermological breakdown occurs as a result of potential gases that increase global warming and contribute to the greenhouse effect [61]. For this reason, the amount of gases generated when burned, and the estimated amount of CH_4 and biodegradability values that can arise when used for ruminant animals, are given in Table 3.5.

Biogas production from plants is most commonly done using biodegraders. Quinoa stalks are an important raw material for biodegrading microorganisms used in biogas production with high lignin content [52]. By using quinoa stalks in biogas production, raw material

Table 3.2
OMD, ME, NE_L calculated from the total amount of gas produced by 96-h incubation.

Parameters/Hours	GP (ml/200 mg ^{DM})	OMD (%)	ME (MJ/kg ^{DM})	NE_L (MJ/kg ^{DM})
	Mean + SE	Mean ± SE	Mean + SE	Mean + SE
3	7.26 ± 0.14	22.33 ± 0.11	3.22 ± 0.02	1.26 ± 0.01
6	8.88 ± 0.32	23.70 ± 0.27	3.44 ± 0.04	1.41 ± 0.03
9	9.51 ± 0.68	24.23 ± 0.57	3.52 ± 0.09	1.48 ± 0.06
12	9.96 ± 0.95	24.61 ± 0.80	3.58 ± 0.13	1.52 ± 0.09
24	13.88 ± 0.90	27.93 ± 0.76	4.12 ± 0.12	1.89 ± 0.09
48	21.19 ± 1.44	34.10 ± 1.22	5.11 ± 0.20	2.59 ± 0.14
72	24.16 ± 1.08	36.62 ± 0.91	5.51 ± 0.15	2.88 ± 0.10
96	24.97 ± 0.99	37.30 ± 0.84	5.62 ± 0.13	2.96 ± 0.10

Table 3.3
Metabolizable energy values calculated by using chemical analysis results of quinoa stalks.

Parameters	DCP (%)	TDN (Mcal/kg)	DE (Mcal/kg)
Mean + SE	1.36 ± 0.76	1.67 ± 0.78	2.41 ± 0.03
Parameters	**ME (Mcal/kg)**	**NE_L (Mcal/kg)***	**NE_M (Mcal/kg)***
Mean + SE	1.97 ± 0.03	1.22 ± 0.01	1.29 ± 0.01
Parameters	**NE_G (Mcal/kg)***	**NE_m (Mcal/kg)**	**NE_g (Mcal/kg)**
Mean + SE	0.55 ± 0.01	1.11 ± 0.03	0.54 ± 0.03

*1 Mcal/lb = 2.2046 Mcal/kg.

Table 3.4
Relative feed value and relative forage quality of quinoa stalks.

Parameters	DMI (%)	DDM (LW %)	RFV	RFQ
Mean + SE	1.81 ± 0.00	51.92 ± 0.25	71.09 ± 0.26	78.34 ± 1.21

Table 3.5
Syngas and other gases, estimated CH_4, biodegradability of quinoa stalks.

Parameters	Unit	Quantity	Parameters	Unit	Quantity
O_2*	m^3/kg	15.02	CH_4 *	m^3/kg	83.96
O_3*	m^3/kg	22.54	NH_3 *	m^3/kg	55.03
H_2*	m^3/kg	36.02	N_2O*	m^3/kg	9.51
H_2S*	m^3/kg	72.06	NH_4 *	m^3/kg	73.05
CO*	m^3/kg	19.42	SO_2 *	m^3/kg	15.04
CO_2*	m^3/kg	26.93	Estimated CH_4	m^3 CH_4/kg	0.45
CH_3*	m^3/kg	65.95	Biodegradability	%	207.29

*Calculated value: C, H, O, N and S are the values obtained by dividing the analysis results by atomic weights by multiplying any of them with a coefficient equal to 1.

Table 3.6
Total biogas production value of quinoa stalks.

Parameters	Unit	Quantity
Daily Gas Production (G)	(m^3 gas/kg/day)	0.37
Total Biogas Production Value (TBP)	(m^3 gas/decare/day)	158.33
Diesel Fuel	(m^3 gas/L/day)	95.00
Electric	(m^3 gas/kWh/day)	950.00

m^3 biogas: equivalent to 0.6 L diesel fuel or 6 kWh electrical energy FNR [67].

is provided for biogas production, which is an alternative energy source, as well as good waste management. In addition, when the quinoa stalk is burned as biogas, it will release gas (syngas) that will produce less greenhouse gas effect than gasoline and/or diesel. The daily gas production and total gas production values in the quinoa stalks are given in Table 3.6.

When the daily gas production efficiency resulting from the biodegradation of quinoa stalks is calculated for 1 decare of land, the amount of energy that can be generated is 95 m^3 gas/L/day in diesel fuel terms and 950 m^3 gas/kWh/day in electrical energy terms. The energy value of quinoa stalks, according to the classification in the FNR [67] biogas catalog, has an electrical energy close to a 1000 kW_{el} classification for a model VIII energy plant. According to this value, for biogas production, all the quinoa stalks can be evaluated and used for energy production. The results of the analysis to determine the biomass potential separately to the biogas value of the quinoa stalks are given in Table 3.7.

Table 3.7
Energy value of quinoa stalks.

Parameters	MC%	VC;VM%	FC%	Bomb Calori Meter Result (MJ/kg)
Quinoa stalks	7.92	93.68	94.20	18.27

Higher heating value is generally calculated to determine the energy level. The HHV of biodiesel is generally between 39 and 41 MJ/kg [68]. A lot of literature and a limited number of formulas have been used in calculations related to biomass. In particular, few publications give estimated and actual analysis values for quinoa stalks [69,70]. In this study, the energy value of quinoa stalks was measured by bomb calorimeter and determined to be 18.27 MJ/kg.

The HHV's for the quinoa stalks calculated using the existing formulas, and the results obtained using the bomb calorimeter analyzer, were different (Table 3.7 and 3.8). Specific HHV formulas are needed to determine the energy value for each plant that may be used as an energy source.

4. Discussions

Ruminant animals prefer to consume young plants or shoots of trees. Lignization level extremely high in the quinoa stalks. The RFV and RFQ values indicated that the quinoa stalks cannot be used as forage source in ruminant diets [32–35]. Quinoa stalks may be considered for animal feed when roughage production is limited by time. As a result of the *in vitro* digestibility analysis conducted to determine the extent to which quinoa stalks can meet the needs of the animal, it was found that quinoa stalks did not have sufficient NFC and CP% content to feed the rumen microorganisms, and therefore quinoa stalks were not good enough to be poor quality forage such as low quality alfalfa hay, grape pomace or drying citrus pulp [63–65]. However, while $NE_{M,\ m}$ and $NE_{G,\ g}$ (Mcal/kg) values calculated using the formulas of Schroeder [28] and Garrett [29] show similar values, Spanghero et al. [71] – NE_L value 30-h *in vitro* degradability calculated from 10 different roughage feeds – was determined to be 9.80 MJ/kg^{DM} in distillers grains, 6.77 MJ/kg^{DM} in soyhulls, 6.08 MJ/kg^{DM} in wheat bran, 5.54 MJ/kg^{DM} in corn silage, 4.00 MJ/kg^{DM} in alfalfa dehydrated, 3.90 MJ/kg^{DM} in meadow hay, 3.20 MJ/kg^{DM} in alfalfa hay, 2.90 MJ/kg^{DM} in corn cob and 2.03 MJ/kg^{DM} in ryegrass hay, which are the highest values to the quinoa stalks. In addition, NE_L value of quinoa stalks were higher than 0.77 MJ/kg^{DM} in wheat straw. Since quinoa stalks have been reported to have a lignocellulosic structure [11] and a plant energy availability values as high as 46.49 ± 0.97 $ADL^{\%DM}$ was determined in the present study, it

Table 3.8
Higher heating value calculated with different formulas of quinoa stalks.

References	HHV Formula Numbers	Unit	Results	Converted MJ/kg
[36]	(2.29)	kJ/kg	17486.62	17.49
[41]	(2.30)	MJ/kg	17.20	–
[41]	(2.31)	Btu/lb	324390.38	754.53
[41]	(2.32)	Btu/lb	7982.81	18.57
[42]	(2.33)	MJ/kg	17.41	–
[43]	(2.34)	MJ/kg	15.99	–
[44]	(2.35)	MJ/kg	17.53	–
[45]	(2.36)	MJ/kg	32.58	–
[44]	(2.37)	MJ/kg	20.84	–
[46]	(2.38)	MJ/kg	−131.37	–
[46]	(2.39)	MJ/kg	46.91	–
[46]	(2.40)	MJ/kg	9.22	–
[46]	(2.41)	MJ/kg	19.20	–
[46]	(2.42)	MJ/kg	−60.53	–
[46]	(2.43)	MJ/kg	45.71	–
[46]	(2.44)	MJ/kg	18.84	–
[46]	(2.45)	MJ/kg	15.17	–
[47]	(2.46)	MJ/kg	43.76	–
[44]	(2.47)	MJ/kg	17.94	–
[44]	(2.48)	MJ/kg	42.24	–
[48]	(2.49)	MJ/kg	47.85	–
[44]	(2.50)	MJ/kg	17.53	–
[44]	(2.51)	MJ/kg	15.98	–
[49]	(2.52)	kJ/kg	7827.18	7.83
[50]	(2.53)	MJ/kg	17.49	–
[51]	(2.54)	kJ/kg	49375.60	49.38
[51]	(2.55)	kJ/kg	−20165.66	20.17
[52]	(2.56)	MJ/kg	48.05	–
[42]	(2.57)	MJ/kg	17.41	–
[41]	(2.58)	MJ/kg	17.20	–
[53]	(2.59)	MJ/kg	41.59	–
[53]	(2.60)	MJ/kg	17.22	–
[43]	(2.61)	MJ/kg	32.58	–
[43]	(2.62)	MJ/kg	43.76	–
[54]	(2.63)	MJ/kg	30.91	–
[55]	(2.64)	MJ/kg	16.92	–
[56]	(2.65)	MJ/kg	17.57	–
[57]	(2.66)	MJ/kg	20.95	–
[57]	(2.67)	MJ/kg	20.57	–
[58]	(2.68)	MJ/kg	12.48	–
[59]	(2.69)	MJ/kg	20.23	–

was thought that the waste parts of this plant, compared to being used as a feed, has a higher potential to be used as a biomass. Lignocellulosic structure is one of the most important factors that reduce the animal's feed intake and feed conversion ratio. Furthermore, according to the results, the $ADL^{\%DM}$ value of the quinoa stalks was at a level that prevents the animal to benefit from feed intake and feed conversion ratio whereas it was a significant value in terms of biomass [72,73].

In addition, it is seen from the calculations of ME, NE_L (MJ/kg DM, 24h), DCP, TDN, DE, ME, NE_m and NE_g (Mcal/kg), NE_L, NE_M and NE_G (Mcal/kg) which were found to be 4.12, 1.89, 1.36, 1.67, 2.41, 1.97, 1.11 and 0.54, 1.22, 1.29 and 0.55, respectively, that important energy potential exists. Üke [10] reported that quinoa yields 431.85 kg of hay per decare, although there is still great potential for energy to be metabolized for animal nutrition that can be realized by grazing before flowering. The FAO [74] called quinoa a *Mother Grain*, due to its rich content. Although quinoa stalks have a rich nutrient composition (cellulose, saponins, xylan), they have been evaluated in very few areas. Furthermore, quinoa stalks with a rich cellulose content are used in biomass production, in pesticide and herbicide production because of their saponin content, and in nanocomposites, hydrogels and bioplastics during the recycling of polymers because of their xylan content [11].

The $ADL^{\%DM}$ content of quinoa stalks is not sufficient for biogas production by themselves. Combustion is a reaction in which basic elements such as C, H, S, O and N play a role. In the production of biogas, the first stage needs to be carried out by yeast or enzymatic fermentation, in other words, by biochemical sources. The second stage, carried out after combustion, is pyrolysis, gasification and liquefaction by thermochemical sources. The gases produced during all these stages are syngas and greenhouse gases.

Alarcon et al. [70] found that 0.28% CO_2 gas was produced as a result of combustion of quinoa pellets. In contrast to the present study, quinoa stalks had a lower CO_2 emission rate. It was calculated that the combustion of quinoa stalks resulted in 26.93 m^3/kg of CO_2 release. In his study, Basu [36] classified different fuel sources in terms of the C/N ratio and O percentage, which were similar to the C/N ratio and O percentage of peat and quinoa stalks (10 and 35, and 10.22 and 36.30, respectively). While biochemical and thermochemical processes are carried out in the biogas production stages, it is not required to convert the sulfur (quinoa stalks, 0.11%) to H_2S in the combustion chamber. The most important problem here is that sulfuric acid is poisonous as a gas and can damage the biogas production plant. The sulfur content of the raw materials used in biogas production facilities should be low. In recent years, research has focused on alternative energy sources due to the decrease in fossil fuel resources and the global warming and greenhouse effect of the gases emitted by the combustion of fossil fuels. Quinoa stalks can be both an alternative energy raw material for biogas production and have a reduced negative impact on the environment compared to fossil fuels [61]. Quinoa stalks have an electrical energy close to the 1000 kW_{el} classification for model VIII energy plants in the biogas catalog according to FNR [67]. This result shows that all the quinoa stalks can be used to deliver energy during biogas production. Marais [69] determined an HHV for raw quinoa of 16.96 MJ/kg using formula 2.51 and 15.19 MJ/kg in the analysis using the bomb calorimeter. In this study, the quinoa stalks were determined to produce 15.98 MJ/kg in the calculation using the formula in 2.51 and 18.27 MJ/kg in the calculation using the bomb calorimeter. Paniagua Bermejo et al. [62] were determined that HHV for quinoa husk, was 15.41 MJ/kg. Alarcon et al. [70] determined the energy value of quinoa pellets burned in the combustion chamber to be 299.2 GJ/T. Fomsgaard et al. [75] determined that the HHV for Amaranthus, a plant like quinoa, was 4.4 MJ/kg. Viglasky et al. [76] determined the HHV for Amaranthus to be 16.17 MJ/kg. No formula has been identified to determine the HHV of quinoa stalks. With the exception of some energy crops, there is generally no HHV. For this reason, the calculated HHV for quinoa stalks uses the most commonly used formulas and is given in Table 3.8.

5. Conclusions

It was determined that the stalks of the quinoa, which have very important nutrients for human nutrition, have no value in terms of animal nutrition. Besides that, quinoa stalks can be used as an intermediate energy plant. In addition, energy calculation formulas are needed for plants with high potential to be energy plants, such as amaranth, the African garden eggplant, Bambara groundnut, breadfruit cactus pear, cardoon, common buckwheat, fe'i bananas, finger millet, oca, moringa, quinoa, teff and yam bean.

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Declaration of Competing Interest

There are no conflicts of interest to declare.

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References

[1] Dengiz O, Demirağ Turan İ. Uzaktan Algılama ve Coğrafi Bilgi Sistem Teknikleri Kullanılarak Arazi Örtüsü/Arazi Kullanımı Zamansal Değişimin Belirlenmesi: Samsun Merkez İlçesi Örneği (1984-2011). (In Turkish: Determination of Temporal Change Land Use/Land Cover Using Remote Sensing and Geographic Information System Techniques the Central District of Samsun (1984-2011)) Türkiye Tarımsal Araştırmalar Dergisi, 2014; 1(1), 78–90. DOI:10.19159/tutad.45474. https://dx.doi.org/10.19159/tutad.45474.
[2] Jacobsen SE, Mujica A, Jensen CR. The resistance of quinoa (*Chenopodium quinoa* Willd.) to adverse abiotic factors. Food Rev. Int 2003;19(1–2):99–109. https://doi.org/10.1081/FRI-120018872.
[3] Schahbazian N, Kamkar B, Iran-Nejad H. Evaluation of amaranth production possibility in arid and semi-arid regions of Iran. Asian J Plant Sci 2006;5:580–5. https://doi.org/10.3923/ajps.2006.580.585.
[4] Alemayehu FR, Bendevis MA, Jacobsen SE. The potential for utilizing the seed crop amaranth (*Amaranthus* spp.) in East Africa as an alternative crop to support food security and climate change mitigation. J Agron Crop Sci 2015;201(5):321–9. https://doi.org/10.1111/jac.12108.
[5] FAO (Food and Agriculture Organization of the United Nations). Traditional Crops. http://www.fao.org/traditional-crops/en/; 2019; [accessed 23 February 2019].
[6] Muñoz Jáuregui AM. Año Internacional de la Quinua. Revista de la Sociedad Química del Perú 2013;79(1):1–2.
[7] Civaner AG, Filik G. Hayvan Beslemede Horozibiği'nin (Amaranthus spp.) Önemi. Yem Magazine. Year/Number: 23/72. Page: 47-51 (In Turksih: Importance of Amaranthus spp. In Animal Nutrition. http://www.yem.org.tr/DosyaMerkezi/Dergi/yem%20magazin%20sayı%2072/yemmag_72.pdf 2015; [accessed 23 february 2019].
[8] FAO (Food and Agriculture Organization of the United Nations). Proposal for an International Year of Millets. COUNCIL Hundred and Sixtieth Session. Rome, 3-7 December 2018; http://www.fao.org/traditional-crops/en/; 2018; [accessed 23 february 2019].
[9] Üner Ö, Açık M, Özdem A, Kuşcu MC, Civaner AG, Filik G. İnsan beslenmesinde kinoa (Chenopodium quinoa Willd.)'nin önemi. (In Turkish: Importance of Chenopodium quinoa Willd. In human nutrition.) XI. National Student of Animal Science Congress Abstract Book Page: 72 | 29-30.04.2015 http://zoofed.cu.edu.tr/tr/belgeler/2015-Dicle%20Üniversitesi.pdf 2015; [accessed 23 february 2019].
[10] Üke Ö. Effects of harvest times on herbage yield and quality of quinoa and teff plants [M.sc thesis]; 2016. Erciyes University, Institute of Natural and Applied Sciences, Field Crops Department, p. 36.
[11] Gil-Ramirez A, Salas-Veizaga DM, Grey C, Karlsson EN, Rodriguez-Meizoso I, Linares-Pastén JA. Integrated process for sequential extraction of saponins, xylan and cellulose from quinoa stalks (Chenopodium quinoa Willd.). Ind Crop Prod 2018;121:54–65. https://doi.org/10.1016/j.indcrop.2018.04.074.
[12] Brady K, Ho CT, Rosen RT, Sang S, Karwe MV. Effects of processing on the nutraceutical profile of quinoa. Food Chem 2007;100(3):1209–16. https://doi.org/10.1016/j.foodchem.2005.12.001.
[13] Tan M, Yöndem Z. İnsan ve Hayvan Beslenmesinde Yeni Bir Bitki: Kinoa (Chenopodium quinoa Willd.) (In Turkish: A New Crop for Human and Animal Nutrition: Quinoa (Chenopodium quinoa Willd.). Alınteri Zirai Bilimler Dergisi 2013;25(2):62–6.
[14] Kaya ÇI, Yazar A, Sezen SM. SALTMED model performance on simulation of soil moisture and crop yield for quinoa irrigated using different irrigation systems, irrigation strategies and water qualities in Turkey. Agric Agric Sci Procedia 2015;4:108–18. https://doi.org/10.1016/j.aaspro.2015.03.013.
[15] Üke Ö, Kale H, Kaplan M, Kamalak A. Effects of maturity stages on hay yield and quality, gas and methane production of quinoa (Chenopodium quinoa Willd.). KSU J Nat Sci 2017;20(1):42–6. https://doi.org/10.18016/ksujns.51209.
[16] ANKOM. Ankom RF Gas Production System Manuel Handbook. 2018; Available at https://www.ankom.com/sites/default/files/document-files/RF_Manual.pdf Revision Date: 16/11/18, [accessed 28 June 2019].
[17] AOAC. Official Procedure. Official methods of analysis of AOAC. International 17th edition; Gaithersburg, MD, USA 242 Association of Analytical Communities; 2000.
[18] Van Soest PV, Robertson JB, Lewis BA. Methods for dietary fiber, neutral detergent fiber, and non-starch polysaccharides in relation to animal nutrition. J Dairy Sci 1991;74(10):3583–97. https://doi.org/10.3168/jds.S0022-0302(91)78551-2.
[19] AOCS. Official Procedure. Approved procedure Am 5-04, rapid determination of oil/fat utilizing high temperature solvent extraction. Urbana, IL: American Oil Chemists' Society; 2005.
[20] Sniffen CJ, O'connor JD, Van Soest PJ, Fox DG, Russell JB. A net carbohydrate and protein system for evaluating cattle diets: II. Carbohydrate and protein availability. J Anim Sci 1992;70(11):3562–77. https://doi.org/10.2527/1992.70113562x.
[21] Menke KH, Steingass H. Estimation of the energetic feed value obtained from chemical analysis and in vitro gas production using rumen fluid. Anim Res Devel 1988;28:7–55.
[22] Cornou C, Storm IMD, Hindrichsen IK, Worgan H, Bakewell E, Ruiz DRY, et al. A ring test of a wireless in vitro gas production system. Anim Prod Sci. 2013;53(6):585–92. https://doi.org/10.1071/AN12091.
[23] Erdem F. Determination the digestibility of Juncus acutus by in-vitro gas production and its effect on ruminal cellulolytic bacteria by real-time PCR methods [Ph.D. thesis]; 2014. Ondokuz Mayis University, Health Sciences Institute, Animal Feeding and Nutrition Diseases Department. Samsun-Turkey.
[24] Schroeder JW. Interpreting forage analysis (AS1080). North Dakota State University, Fargo, ND 58105; 1994. https://library.ndsu.edu/ir/bitstream/handle/10365/9133/AS-1080-1994.pdf?sequence=2 [accessed 23 february 2019].
[25] Heeney MW. Estimating digestibility of livestock feedstuffs. Service in action; no. 1. 605; 1978. https://mountainscholar.org/bitstream/handle/10217/182521/AEXT_ucsu206221605.pdf?sequence=1&isAllowed=y [accessed 23 february 2019].
[26] NRC (National Research Council). Nutrient requirements of dairy cattle. Washington, D.C.: National Academy of Science; 2001; 381p.
[27] Moe PW, Flatt WP, Tyrell HF. Net energy value of feeds for lactation. J Dairy Sci 1972;55(7):945–58. https://doi.org/10.3168/jds.S0022-0302(72)85601-7.
[28] Schroeder JW. Quality Forage: Interpreting Composition and Determining Market Value (AS1251); 2004. https://www.ag.ndsu.edu/publications/livestock/quality-forage-series-interpreting-composition-and-determining-market-value [accessed 23 february 2019].
[29] Garrett WN. Energy utilization by growing cattle as determined in 72 comparative slaughter experiments. Energy metabolism. Studies in the agricultural and food sciences; 1980: pp. 3–7 ref.8.
[30] Rohweder DA, Barnes RF, Jorgensen N. Proposed hay grading standards based on laboratory analyses for evaluating quality. J Anim Sci 1978;47(3):747–59. https://doi.org/10.2527/jas1978.473747x.
[31] Undersander D, Moore JE. Relative forage quality. Focus Forage 2002;4(5):1–2.
[32] Linn JG, Martin NP. Forage quality analyses and interpretation. Vet Clin North Am Food Anim Pract 1991;7(2):509–23.
[33] Kiliç U, Abdiwali MA. Alternatif Kaba Yem Kaynağı Olarak Şarapçılık Endüstrisi Üzüm Atıklarının İn Vitro Gerçek Sindirilebilirlikleri ve Nispi Yem Değerlerinin Belirlenmesi. (In Turkish: Determination of In Vitro True Digestibilities and Relative Feed Values of Wine Industry Grape Residues as Alternative Feed Source). Kafkas Univ Vet Fak Derg 2016;22(6). https://doi.org/10.9775/kvfd.2016.15617.
[34] Undersander D. The new Relative Forage Quality Index concept and use. World's Forage Superbowl Contest, UWEX. 2003.
[35] Jeranyama P, Garcia AD. Understanding Relative Feed Value (RFV) and Relative Forage Quality (RFQ). Extension Extra. Paper 2004; 352. http://openprairie.sdstate.edu/extension_extra/352.
[36] Basu P. Biomass Gasification and Pyrolysis: Practical Design and Theory. Academic Press; 2010.
[37] Lin J, Zuo J, Gan L, Li P, Liu F, Wang K, et al. Effects of mixture ratio on anaerobic co-digestion with fruit and vegetable waste and food waste of China. J Environ Sci 2011;23(8):1403–8. https://doi.org/10.1016/S1001-0742(10)60572-4.
[38] Gül A. Sebze ve Meyve Atıklarının Biyogaz Üretim Potansiyelinin Belirlenmesi [In Turkish: Biogas Production Potential Determination of Fruit and Vegetable Wastes] [M.Sc thesis]; Gazi University, Graduate School of Natural and Applied Sciences, Department of Environmental Sciences; 2014. p. 87.
[39] Werner U, Stöhr U, Hees N. Biogas plants in animal husbandry. Deutsches Zentrum für Entwicklungstechnologien-GATE 1989.
[40] García-Martínez A, Albarrán-Portillo B, Castelán-Ortega OA, Espinoza-Ortega A, Arriaga-Jordán CM. Urea treated maize straw for small-scale dairy systems in the highlands of Central Mexico. Trop Anim Health Prod 2009;41(7):1487–94. https://doi.org/10.1007/s11250-009-9337-4.
[41] Tillman DA. Wood as an energy resource. New York: Elsevier, Academic Press; 2012.
[42] Jenkins BM, Ebeling JM. Correlation of physical and chemical properties of terrestrial biomass with conversion. Symposium Papers – Energy from Biomass and Wastes. Inst of Gas Technology; 1985. p. 371–403.
[43] Demirbaş A. Calculation of higher heating values of biomass fuels. Fuel 1997;76:431–4. https://doi.org/10.1016/S0016-2361(97)85520-2.
[44] Sheng C, Azevedo JLT. Estimating the higher heating value of biomass fuels from basic analysis data. Biomass Bioenergy 2005;28(5):499–507. https://doi.org/10.1016/j.biombioe.2004.11.008.
[45] Acar S, Ayanoglu A, Demirbas A. Determination of higher heating values (HHVs) of biomass fuels. Fuel 2012;3:1–3.
[46] Özyuğuran A, Yaman S. Prediction of calorific value of biomass from proximate analysis. Energy Procedia 2017;107:130–6. https://doi.org/10.1016/j.egypro.2016.12.149.
[47] Baley RT, Blankenhorn PR. Calorific and porosity development in carbonized wood. Wood Sci 1984;15:19–28.
[48] Parikh J, Channiwala SA, Ghosal GK. A correlation for calculating HHV from proximate analysis of solid fuels. Fuel 2005;84(5):487–94. https://doi.org/10.1016/j.fuel.2004.10.010.
[49] Friedl A, Padouvas E, Rotter H, Varmuza K. Prediction of heating values of biomass fuel from elemental composition. Anal Chim Acta 2005;544(1–2):191–8. https://doi.org/10.1016/j.aca.2005.01.041.
[50] Channiwala SA, Parikh PP. A unified correlation for estimating HHV of solid, liquid and gaseous fuels. Fuel 2002;81(8):1051–63. https://doi.org/10.1016/S0016-2361(01)00131-4.
[51] Cordero T, Marquez F, Rodriguez-Mirasol J, Rodriguez JJ. Predicting heating values of lignocellulosics and carbonaceous materials from proximate analysis. Fuel 2001;80(11):1567–71. https://doi.org/10.1016/S0016-2361(01)00034-5.
[52] Jiménez L, González F. Study of the physical and chemical properties of lignocellulosic residues with a view to the production of fuels. Fuel 1991;70(8):947–50. https://doi.org/10.1016/0016-2361(91)90049-G.
[53] Yin CY. Prediction of higher heating values of biomass from proximate and ultimate

analyses. Fuel 2011;90(3):1128–32. https://doi.org/10.1016/j.fuel.2010.11.031.
[54] Annamalai K, Sweeten JM, Ramalingam SC. Technical notes: estimation of gross heating values of biomass fuels. Trans ASAE 1987;30(4):1205–8. https://doi.org/10.13031/2013.30545.
[55] IGT (Institute of Gas Technology). Coal conversion systems technical data book. Available from NTIS, Springfield, VA; 1978.
[56] Graboski M, Bain RL. Properties of biomass relevant to gasification. A Survey of Biomass Gasification, 1979; 2, 21–65.
[57] Demirbaş A. Relationships between lignin contents and heating values of biomass. Energy Convers Manage 2001;42(2):183–8. https://doi.org/10.1016/S0196-8904(00)00050-9.
[58] Rhén C. Chemical composition and gross calorific value of the above-ground biomass components of young picea abies. Scand J Forest Res 2004;19(1):72–81. https://doi.org/10.1080/02827580310019185.
[59] Telmo C, Lousada J. The explained variation by lignin and extractive contents on higher heating value of wood. Biomass Bioenergy 2011;35(5):1663–7. https://doi.org/10.1016/j.biombioe.2010.12.038.
[60] SPSSWIN. SPSS Statistics 17.0 release 17.0.0 (Aug 23, 2008) for Windows. WinWrap Basic, Copyright 1993-2007 Polar Engineering and Consulting; 2007. http://www.winwrap.com/.
[61] Salgado MAH, Tarelho LA, Matos A, Robaina M, Narváez R, Peralta ME. Thermoeconomic analysis of integrated production of biochar and process heat from quinoa and lupin residual biomass. Energy Policy 2018;114:332–41. https://doi.org/10.1016/j.enpol.2017.12.014.
[62] Paniagua Bermejo S, Prado-Guerra A, García Pérez AI, Calvo Prieto LF. Study of quinoa plant residues as a way to produce energy through thermogravimetric analysis and indexes estimation. Renewable Energy 2020;;146:2224–33. https://doi.org/10.1016/j.renene.2019.08.056.
[63] Güngör T, Başalan M, Aydoğan İ. The determination of nutrient contents and metabolizable energy levels of some roughages produced in Kirikkale region. Ankara Univ Vet Fak 2008;55:111–5.
[64] Canbolat Ö, Kara H, Filya İ. Comparison of in vitro gas production, metabolizable energy, organic matter digestibility and microbial protein production of some legume hays. Agric Faculty J Uludağ Univ 2013;27(2):71–82.
[65] Filik G, Kutlu HR. Determination of nutrient values in drying citrus pulp with alternative drying methods. Black Sea J Agric 2018;1(1):11–4.
[66] Abaş İ, Özpinar H, Kutay HC, Kahraman R, Eseceli H. Determination of the metabolizable energy (ME) and net energy lactation (NEL) contents of some feeds in the Marmara region by in vitro gas technique. Turkish J Vet Anim Sci 2005;29(3):751–7.
[67] FNR (Fachagentur Nachwachsende Rohstoffe e.V.). Guide to biogas from production to use; 2012. https://mediathek.fnr.de/media/downloadable/files/samples/g/u/guide_biogas_engl_2012.pdf [accessed 23 february 2019].
[68] Monisha J, Harish A, Sushma R, Krishna Murthy TP, Blessy BM, Ananda S. Biodiesel: a review. Int J Eng Res Appl 2013;3(6):902–12.
[69] Marais HB. Effect of operating parameters on bio-products obtained from the liquefaction of Quinoa lignocellulose materials; 2017. (Doctoral dissertation, North-West University (South Africa), Potchefstroom Campus).
[70] Alarcon M, Santos C, Cevallos M, Eyzaguirre R, Ponce S. Study of the mechanical and energetic properties of pellets produce from agricultural biomass of quinoa, beans, oat, cattail and wheat. Waste Biomass Valori 2017;8(8):2881–8. https://doi.org/10.1007/s12649-017-9983-0.
[71] Spanghero M, Berzaghi P, Fortina R, Masoero F, Rapetti L, Zanfi C, et al. Precision and accuracy of in vitro digestion of neutral detergent fiber and predicted net energy of lactation content of fibrous feeds. J Dairy Sci 2010;93(10):4855–9. https://doi.org/10.3168/jds.2010-3098.
[72] Reeves JB. Lignin composition and in vitro digestibility of feeds. J Anim Sci 1985;60(1):316–22. https://doi.org/10.2527/jas1985.601316x.
[73] Alaru M, Kukk L, Olt J, Menind A, Lauk R, Vollmer E, et al. Lignin content and briquette quality of different fibre hemp plant types and energy sunflower. Field Crops Res 2011;124(3):332–9. https://doi.org/10.1016/j.fcr.2011.06.024.
[74] FAO (Food and Agriculture Organization of the United Nations). Quinoa: An ancient crop to contribute to world food security. Regional Office for Latin America and the Caribbean Book; 2011; http://www.fao.org/3/aq287e/aq287e.pdf [accessed 23 February 2019].
[75] Fomsgaard IS, Añon MC, Barba de la Rosa AP, Christophersen C, Dusek K, Délano-Frier J, Espinoza Pérez J, Fonseca A, Janovská D, Kudsk P, Labouriau RS, Lacayo Romero ML, Martínez N, Matus F, Matusová K, Mathiassen SK, Noellemeyer EJ, Pedersen HA, Stavelikova H, Steffensen SK, de Troiani RM, Taberner A. Adding Value to Holy Grain: Providing the Key Tools for the Exploitation of Amaranth - the Protein-rich Grain of the Aztecs. Results from a Joint European – Latin American Research Project. Department of Integrated Pest Management; 2010. Aarhus University, Faculty of Agricultural Sciences, Denmark. ISBN 978-87-91949-62-3. 79 pp.
[76] Viglasky J, Andrejcak I, Huska J, Suchomel J. Amaranth (Amaranthus L.) is a potential source of raw material for biofuels production. Agron Res 2009;7(2):865–73.