# MOST-COMMON AGRICULTURAL RESIDUES IN VIETNAM AND IRELAND: CHARACTERIZATION SERVING FOR ENERGY PURPOSES

## PHÂN TÍCH ĐẶC TÍNH CÁC LOẠI PHỤ PHẨM NÔNG NGHIỆP PHỔ BIẾN NHẤT TẠI VIỆT NAM VÀ IRELAND PHỤC VỤ CHO MỤC ĐÍCH NĂNG LƯỢNG

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**ABSTRACT**

Agricultural residues in Vietnam and Ireland hold significant potential for diverse applications in various countries, especially for energy purposes. However, the main challenge lies in the incomplete understanding of the physico-chemical properties of these residues, which impacts their utilization and management processes. This study aimed to address this knowledge gap by providing a comprehensive and detailed database of the characteristics and compositions of the most commonly encountered agricultural residues in Vietnam and Ireland. The research encompassed the analysis of various aspects, including physical characteristics such as moisture content, bulk density, calorific value, volatile matter, fixed-carbon content, and ash content. Additionally, it delved into the elemental compositions, covering carbon (C), hydrogen (H), nitrogen (N), oxygen (O), and sulfur (S). The findings of this research serve as a foundational resource for the selection of appropriate utilization methods, recycling techniques, or effective management strategies for these agricultural residues.

***Keywords:*** *Agricultural residues, biomass, physico-chemical properties, proximate analysis, ultimate analysis.*

**TÓM TẮT**

Các phụ phẩm nông nghiệp tại Việt Nam và Ireland có tiềm năng đáng kể cho nhiều ứng dụng đa dạng tại nhiều quốc gia khác nhau, đặc biệt cho mục đích năng lượng. Tuy nhiên, thách thức chính nằm ở việc hiểu biết chưa đầy đủ về các đặc tính vật lý và hóa học của những phụ phẩm này, ảnh hưởng đến quá trình sử dụng và quản lý của chúng. Nghiên cứu này nhằm mục đích giải quyết khoảng trống kiến thức này bằng cách cung cấp một cơ sở dữ liệu đầy đủ và chi tiết về các đặc điểm và thành phần của những phụ phẩm nông nghiệp phổ biến nhất tại Việt Nam. Nghiên cứu này phân tích các đặc tính vật lý như độ ẩm, mật độ tổng, giá trị nhiệt lượng, chất bay hơi, hàm lượng cacbon cố định và hàm lượng tro. Ngoài ra, ~~các~~ thành phần các nguyên tố, bao gồm cacbon (C), hydro (H), nitơ (N), oxi (O) và lưu huỳnh (S) cũng được phân tích. Kết quả này sẽ phục vụ như một nguồn dữ liệu cơ bản cho việc lựa chọn các phương pháp sử dụng phù hợp, các kỹ thuật tái chế hoặc các chiến lược quản lý hiệu quả cho những phụ phẩm nông nghiệp này.

***Từ khóa:*** *Phụ phẩm nông nghiệp, sinh khối, đặc tính lý hóa, phân tích kỹ thuật, phân tích nguyên tố.*

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### 1. INTRODUCTION

Vietnam is well known for intensified crop production systems to address problems in food security. Nevertheless, these practices also lead to a huge amount of agricultural residues, estimated at 100 million tons annually [1]. Only about 40% of these residues are collected and used, mostly for traditional purposes such as direct burning for cooking, animal feed, or materials for some recycled products [2, 3]. Uncollected agricultural by-products are often burned or disposed of in the environment, causing serious health effects and environmental pollution [4]. Meanwhile, Ireland has a high biomass potential of meadows/pastures, waste residues, and agricultural residues, according to the 2021's report of International Energy Agency - IEA and Sustainable Energy Authority of Ireland - SEAI. With that source of by-products, Vietnam and Ireland have many suitable conditions to develop biomass energy to partially replace fossil fuels. Therefore, recycling of agricultural wastes for renewable energy is a priority for countries like Vietnam and Ireland.

The physico-chemical characteristics of agricultural residues exert both direct and indirect influences on the conversion process of this feedstock [5]. To address any potential disparities between the feedstock and chosen technology, pre-treatment processes can be employed, provided that the feedstock's characteristics are well understood. Consequently, various analytical techniques have been developed to assess the attributes of agricultural residues, with proximate analysis and ultimate analysis being the most commonly used methods.

Proximate analysis allows for the determination of the relative proportions of volatile matter, fixed carbon, and ash content within the biomass. This information proves invaluable for conversion technologies that operate at high temperatures, such as pyrolysis, gasification, and combustion [6, 7]. On the other hand, ultimate analysis provides insights into the relative proportions of individual elements, including C, H, O, N, and S [8]. In cases where the conversion of agricultural residues into high-end products necessitates precision, the data yielded by ultimate analysis becomes particularly valuable. While these techniques may have some interrelated aspects, their results serve distinct purposes and can be applied differently in practice.

Therefore, the comprehensive presentation of essential characteristics of agricultural residues through proximate and ultimate analysis can offer valuable insights for developers and researchers when conceptualizing, designing, and selecting suitable technologies. However, upon reviewing existing literature, it becomes evident that data pertaining to the characteristics of common agricultural residues in Vietnam and Ireland remain fragmented and incomplete.

Hence, this study embarked on an endeavor to initially provide a thorough characterization of a diverse array of agricultural residues prevalent in Vietnam and Ireland. These residues, readily abundant in both countries, also serve as significant sources of environmental pollution resulting from agricultural practices. Subsequently, the most suitable feedstock types were selected for steam gasification, thereby verifying their potential for producing high-quality syngas.

## 2. MATERIALS AND METHODS

### 2.1. Biomass collection

Different biomass feedstocks were collected across Vietnam and Ireland. These biomass types can be categorized as livestock wastes, post havesting wastes, and agro-industrial residues.

### 2.2 Characterization of biomass

The moisture content (M) of these samples was initially assessed in accordance with the ASTM E1756-08 standard. Subsequently, the samples underwent a cleaning process using distilled water to eliminate dust and impurities. They were then subjected to drying in a Memmert Oven (Model 800) at 105°C for a duration of 24 hours to eliminate any remaining moisture content. The bulk density was determined following the ASTM E873 - 82 standard.

Various analytical techniques were employed to thoroughly characterize the biomass feedstocks, including proximate analysis, ultimate analysis, and the determination of the higher heating value (HHV). Volatile matter (VM) and ash (A) contents were quantified in accordance with ASTM D 3175-07 and ASTM D 3174-04 standards, respectively. Fixed carbon (FC) was calculated using the formula: FC (% wt.) = 100 - V - A. HHV was determined using the Parr 6200 Calorimeter, following the NREL protocol.

Furthermore, the elemental composition, encompassing Carbon (C), Hydrogen (H), Nitrogen (N), Oxygen (O), and Sulfur (S), was determined using the PerkinElmer 2400 Series II Elemental Analyzer.

## 3. RESULTS AND DISCUSSIONS

### 3.1. Livestock wastes

#### *3.1.1. Livestock as a source of energy*

To meet the food demand of humanity, livestock farming has been expanded intensively over the decades, leading to the challenge of handling massive waste manure after treatment processes [9, 10]. Livestock waste leaves various environmental risks on water and the arable soil system as well as human heath due to heavy metals and pathogenic microorganisms in manure. The breakdown of livestock manure containing types of organic and inorganic contaminants, which are rich in carbon (C), nitrogen (N) and phosphorous (P), results in greenhouse gas emission and pollution to the land [11, 12]. Thus, the proper treatment and management of livestock manure are becoming an urgent matter of concern to the authorities recently.

One of the suggestions to taking advantage of livestock manure is to use conversion process for energy production. There are two conversion processes that are applied widely: biological process and thermochemical conversion process. For biological routes, the production of bioenergy are divided into 3 types: bioethanol production from fermentation, bio-hydrogen production from dark fermentation, and biogas production from anaerobic digestion [13]. In Europe, the livestock manure is commonly used as a feedstock for biogas production as a renewable energy source [14]. On the other hand, thermochemical conversion process is composed of three pathways: pyrolysis, gasification, and direct combustion [15]. The application of thermochemical conversion in treating livestock manure has piqued attention due to its potential of greenhouse gases reduction and power supplementation [16]. To consider the ability of the manure feedstock for energy conversion, some physico-chemical properties should be measured such as bulk density, proximate analysis, heating value ultimate analysis and biochemical analysis.

#### *3.1.2. Physical properties and proximate analysis*

Some properties including volatile matter, ash content, and fixed-carbon content from proximate analysis of several manures are listed in Table 1. Important parameters related to the thermochemical conversion system as bulk density, moisture content, and heating value are also presented. Based on the results, to consider the characteristics of the manure for the energy conversion process, the types of manure need to be verified carefully due to their different proximate components. A high moisture content in all samples was detected, which is not advantageous for any energy conversion process. The moisture content of the manure could vary depending on the type, the weather condition, and collection position through the farming procedures, and collecting time. Thus, the manure collected in two different studies could have distinguished moisture due to the far different conditions of location [17, 18]. The livestock manure has a relatively high bulk density (> 400 kg $m^{-3}$), but high moisture content present in the manure leads to difficulties in the transport and usage of this type of feedstock [19].

Table 1. Proximate analysis of some manure

| | BD ($kgm^{-3}$) | M (wt%, ar.) | V (wt%, db.) | A (wt%, db.) | FC (wt%, db.) | HHV ($MJkg^{-1}$) |
|---|---|---|---|---|---|---|
| Cow dung bio-briquettes | 580 | 16.39 | 54.51 | 29.99 | 15.5 | 13.92 |
| Sheep manure | 450 | 18.30 | 66.11 | 20.11 | 13.78 | 11.98 |
| Goat manure | 470 | 17.75 | 53.84 | 33.71 | 12.45 | 11.20 |
| Poultry (chicken) manure | 490 | 22.50 | 77.65 | 17.01 | 5.34 | 13.59 |
| Poultry (egg-laying process) manure | 430 | 12.83 | 67.26 | 15.41 | 17.33 | 11.55 |
| Swine manure | 460 | 20.11 | 72.91 | 16.45 | 10.64 | 13.55 |
| Horse manure | 480 | 22.10 | 69.2 | 16.9 | 13.9 | 13.90 |
| Cow manure | 500 | 10.18 | 51.54 | 34.41 | 14.05 | 11.96 |
| Pig manure | 450 | 15.56 | 39.96 | 53.58 | 6.46 | 11.01 |

BD: Bulk density, M: Moisture, V: Volatile, A: Ash, FC: Fixed-carbon, HHV: Heating value

Also, high ash content (11.01 - 14.59%, dry basis) was also detected in all samples, suggesting that manure usually contains a large amount of mineral contents. This could bring some troubles when using manure as a source of energy, as some inorganic elements could inhibit the conversion rate, or block some part of the system after a certain time of usage [20, 21]. The heating value, or calorific value, is a specific quantity representing the heat energy released from the biomass during combustion [22]. The recorded heating value of livestock manure ranges from 11.01 to 13.92$MJkg^{-1}$. This heating rate is quite low compared to woody biomass (typically higher than 16$MJkg^{-1}$).

#### *3.1.3. Ultimate analysis*

Table 2 shows the ultimate analysis results of some types of manure. Based on the ultimate analysis, the heating value and quality of the energy product could be predicted [23]. The livestock manure usually contains 4 main elements: carbon (C), nitrogen (N), hydrogen (H), and Oxygen (O). The slight difference in the concentrations of C, H, and O in the biomass could affect the composition of energy product [5].

According to the results mentioned in Table 2, low C and H contents compared to woody biomass was detected in the manure. Moreover, significantly high content of N was also present in the collected samples. By determining the C/N atomic ratio, the nitrogen volatilization in the form of amonia, odors and maturation stage of the manure can be considered [24]. Following the listed studies, the calculated C/N ratio ranges from 8.1 to 18.0. With the C/N less than 20, the volatilization of ammonia and odors would enhance due to high temperature and basic pH [25].

Besides, the manure also obtains a small amount of other contents as phosphorus (P), sulfur (S) or potassium (K).

Table 2. Ultimate analysis of some manure

| | C (%) | H (%) | O (%) | N (%) | S (%) | Cl (%) |
|---|---|---|---|---|---|---|
| Cow dung bio-briquettes | 38.12 | 3.11 | 54.04 | 2.93 | 1.23 | 0.57 |
| Sheep manure | 33.15 | 4.61 | 58.5 | 2.9 | 0.63 | 0.21 |
| Goat manure | 34.83 | 5.13 | 56.32 | 2.39 | 1.11 | 0.22 |
| Poultry (chicken) manure | 33.29 | 5.74 | 58.18 | 1.85 | 0.51 | 0.43 |
| Poultry (egg-laying process) manure | 40.09 | 3.85 | 49.29 | 5.67 | 0.55 | 0.55 |
| Swine manure | 32.67 | 6.46 | 57.78 | 2.01 | 0.42 | 0.66 |
| Horse manure | 25.88 | 6.47 | 65.57 | 1.2 | 0.55 | 0.33 |
| Cow manure | 30.25 | 6.51 | 57.83 | 3.5 | 1.8 | 0.11 |
| Pig manure | 28.23 | 6.52 | 59.4 | 3.5 | 1.8 | 0.55 |

Hence, the use of manure as an energy source, as seen in some countryside locations, should be carefully considered.

### 3.2. Post harvesting wastes

#### *3.2.1. Post harvesting wastes as a source of energy*

Post harvesting wastes or crop residues are the primary waste from agriculture, which are released directly from the field level of agricultural production [26]. These residues could be used in food production for animal and also be value-added products. The lignocellulosic crop residues was reported to be generated about 4 million tons per year worldwide and 25% -35% of them are rice residues in tropical regions [27]. Most of the postharvest waste are decomposed or burned in the open air to eliminate their occupation in the agricultural area, which is causing the rise in the greenhouse gas emission and environmental pollution. Thus, this source of biomass needs to be treated properly to mitigate its effect on the environment as well as human health. It can be used for improving soil properties, compost, ethanol, bioethanol, and energy production [28, 29]. Same as the livestock manure, to use the post-havest agriculture waste for the energy generation, the thermochemical conversion process is applied. Therefore, the physicochemical properties of various biomass types from the crop residues are surveyed in recent years.

#### *3.2.2. Physical properties and proximate analysis*

Table 3. Proximate analysis of some post harvesting wastes

| | BD ($kgm^{-3}$) | M (wt%, ar.) | V (wt%, db.) | A (wt%, db.) | FC (wt%, db.) | HHV ($MJkg^{-1}$) |
|---|---|---|---|---|---|---|
| Herbal plant residue | 355 | 16.20 | 78.00 | 4.50 | 17.50 | 15.05 |
| Sugar cane plants residue | 426 | 36.20 | 78.0 | 1.2 | 20.8 | 16.5 |
| Rice straw | 110 | 4.2-6 | 71.6-92.8 | 8.2- 6.0 | 14.5 | 14.45-15.5 |
| Wheat straw | 130 | 4.4-8.4 | 74.4-92.7 | 7.2-12.8 | 17.3 | 17-18.9 |
| Corn stover | 320 | 5.3-7.4 | 86.5-96.8 | 4.2-6.3 | 16.9 | 16.2-16.5 |
| Barley straw | 140 | 5.8 | 76.2 | 5.3-9.8 | 19.79 | 16.42 |
| Oat straw | 123 | 5.38 | 74.48 | 5.39 | 19.53 | 14.3 |
| Rice husk | 180 | 5.6 | 66.94 | 14.35 | 13.11 | 17.19 |
| Wheat | 110 | 8.79 | 69.24 | 8.75 | 13.22 | 15.94 |
| Corn | 320 | 6.30 | 68.88 | 9.50 | 15.32 | 17.50 |
| Legumes | 160* | 7.02 | 70.67 | 6.17 | 16.14 | 15.91 |
| Sugarcane | 180* | 9.06 | 74.25 | 2.26 | 14.43 | 17.46 |
| Coconut husk | 74.0 | 5.43 | - | 3.95 | - | - |

The proximate analysis results of some crop residues are shown in Table 3. As can be seen, the composition of concerning biomass varies over a smaller range than that of the livestock manure. The bulk density of the postharvest wastes is only in the range of 74 and 426$kgm^{-3}$, while that of livestock manure is in the range of 580 and nearly 1000$kgm^{-3}$. However, the low bulk density condition is not highly recommended due to its consequences in difficulties of storage, transportation and energy conversion process. Same as in manure, depending on the type of the biomass, growth circumstances, harvesting time, storage and process conditions, moisture content varies in the wide range. The volatile matter of the samples was found much higher than that of manure (from 68.88 up to 96.8%), which is a huge advantage for thermochemical conversion due to the large energy released during lignocellulosic component decompositions. Besides, the lower ash content, higher fixed-carbon content, and higher heating value also prove that the postharvest waste biomass is more favorable for energy conversion processes. Moreover, the heterogeneity in this group of agricultural residues is much lower than that of manures.

#### *3.2.3. Ultimate analysis*

Table 4 provides the information of the elemental analysis of several post-harvest agriculture wastes. Based on the found data, C and O are still the main components constituting this type of biomass. In general, the C and O contents ranges from about 32 to 51%, while N and H account for approximately 1 and 5% in average, respectively. It can be seen that the N content in the crop residue biomass is generally lower than in the livestock manure. This can be explained by the higher amount of ammonia in manure than in the other common biomass. Besides, most of the mentioned post harvesting wastes also contains an insignificant amount of S (smaller than 0.5%). The results suggest that using this type of biomass feedstock reduces the risk of $NO_x$ and/$SO_x$ emission.

Table 4. Elemental analysis of some post harvesting wastes in the literature (dry basis)

| | Carbon (%) | Nitrogen (%) | Hydrogen (%) | Sulfur (%) | Oxygen and others (%) |
|---|---|---|---|---|---|
| Sugar cane plants residue | 40.0 | 1.6 | 6.1 | 0.3* | 52.0 |
| Rice straw | 34.0-41.5 | 0.2-0.8 | 4.6-6.7 | 0.1-0.2 | 32.8-41.2 |
| Wheat straw | 41.7-46.7 | 0.4-0.5 | 5.1-6.3 | 0.1-0.3 | 34.1-51.4 |
| Corn stover | 35.2-45.8 | 0.3-0.8 | 5.4-6.3 | 0.1-0.3 | 43.4-45.7 |
| Barley straw | 40.4 | 0.7 | 6.2 | 0.13 | 43.6 |
| Oat straw | 48.8 | 0.5 | 6.0 | 0.08 | 44.6 |
| Rice | 38.80 | 0.25 | 5.46 | 0.36 | 40.65 |
| Wheat | 42.20 | 0.06 | 5.57 | 0.36 | 38.64 |
| Corn | 40.66 | 0.22 | 5.59 | 0.42 | 39.80 |
| Legumes | 40.49 | 1.13 | 5.72 | 0.12 | 41.62 |
| Sugarcane | 45.38 | 0.41 | 5.92 | 0.16 | 43.73 |
| Coffee residue | 52.45 | 2.07 | 6.49 | <0.1 | 38.99 |

### 3.3. Argo-industrial residues

#### *3.3.1. Argo-industrial residues as a source of energy*

Differing from post-harvest wastes, argo-industrial residues are secondary wastes generated during/after industrial processing of agricultural crops or animal products [30]. The argo-industrial residues comprise of multiples plant-based biomass, such as husk, peels, shells, seeds, bagasse, spent coffee, spent grains, etc. and some animal products as feathers and whey [31]. Argo-industrial wastes are major contributors to the consequences of environmental problems and economic losses due to their uncontrolled disposal. Thus, the processing of this biomass type for sustainable and bioenergy production is currently of particular concern for the development of the circular economy [32]. In fact, argo-industrial wastes have been studied by some different valorization pathways for several applications as bio-refineries, biofuels, thermal energy, biodegradable material and bio-compounds [33]. The fuel values for energy conversion of the argo-industrial wastes are also identified by proximate, ultimate and biochemical analysis.

#### *3.3.2. Physico-chemical properties*

Table 5 illustrates the compositions of some argo-industrial wastes measured by proximate and ultimate analysis. Based on the data, the proximate properties of the argo-industrial residues are also dependent on the type of biomass as well as the condition of preparation. The bulk density of some biomass found in the literature ranges only from 14.74 to 263kgm$^{-3}$. In general, most of the biomass in this group have high content of volatiles (> 62.10%), which could be the reason for the high calorific value (up to 24.14MJkg$^{-1}$ with grape marc). Except for the sawdust and rice straw, most argo-industrial residues contain very low ash amount (< 5%).

Table 5. Proximate analysis of some argo-industrial residues

| | BD (kgm$^{-3}$) | M (wt%, ar.) | V (wt%, db.) | A (wt%, db.) | FC (wt%, db.) | HHV (MJkg$^{-1}$) |
|---|---|---|---|---|---|---|
| Food/vegetable waste | 14.74 | 1.84 | 78.86 | 1.75 | 18.59 | 17.55 |
| Tomato peel | 12.60 | 1.67 | 79.50 | 1.67 | 18.35 | 19.07 |
| Peach pit | 63.19 | 2.22 | 90.21 | 0.84 | 8.99 | 20.09 |
| Marc | 43.1 | 80.50 | 86.52 | 1.81 | 11.67 | 24.14 |
| Stalk | 24.3 | 5.70 | 84.8 | 1.30 | 13.90 | 21.77 |
| Sawdust | 90.1 | 8.38 | 69.21 | 8.81 | 21.98 | 22.58 |
| Rice straw | 91.2 | 7.70 | 66.77 | 10.16 | 23.07 | 19.10 |
| Coffee husk | 260 | 5.30 | 86.31 | 1.90 | 11.79 | 22.65 |
| Macadamia nut shell | 408 | 5.6 | 82.98 | 0.70 | 16.32 | 18.61 |
| Sugarcane bagasse | 97 | 12.5 | 82.55 | 1.05 | 16.40 | 14.36 |
| Cotton stalks | 70 | 15.1 | 78.50 | 2.40 | 19.1 | 19.80 |
| Olive solid waste | 225 | 30.1 | 62.10 | 2.8 | 34.6 | 21.60 |

### *3.3.3. Ultimate properties*

Table 6 illustrates the compositions of some argo-industrial wastes measured by ultimate analysis. For the elemental compositions, C, H, and O are still three main constituents, however, S content accounts for a slightly higher proportion than other two biomass groups. The S content in coffee husk is up to 43.7%, which indicates that this residue is not suitable for thermal conversion process.

Table 6. Ultimate analysis of some argo-industrial residues (dry basis)

| | Carbon (%) | Nitrogen (%) | Hydrogen (%) | Sulfur (%) | Oxygen and others (%) |
|---|---|---|---|---|---|
| Food/vegetable waste | 46.5 | 2.4 | 4.3 | 0.1 | 42.8 |
| Tomato peel | 58.38 | 1.49 | 7.72 | - | 30.60 |
| Peach pit | 53.01 | 2.32 | 5.90 | 1.88 | 36.89 |
| Marc | 52.91 | 5.41 | 5.93 | 5.34 | 30.41 |
| Stalk | 46.14 | 6.37 | 5.74 | 4.21 | 37.54 |
| Sawdust | 54.71 | 4.20 | 5.80 | 2.28 | 33.01 |
| Rice straw | 43.85 | 0.25 | 4.75 | - | 51.15 |
| Coffee husk | 47.50 | - | 6.40 | 43.7 | - |
| Macadamia nut shell | 49.1 | 0.30 | 5.75 | - | 43.0 |
| Sugarcane bagasse | 46.01 | 0.12 | 6.38 | - | 47.44 |
| Cotton stalks | 41.44 | 1.43 | 5.84 | 0.17 | 46.44 |
| Olive solid waste | 52.1 | 1.4 | 6.7 | <0.3 | 41.2 |

## 4. CONCLUSIONS AND RECOMMENDATIONS

This study focused on characterizing the common biomass residues found in Vietnam and Ireland. The considerable heterogeneity observed in the physico-chemical properties of various agricultural residues presents both opportunities and challenges. Characterizing biomass in this manner provides valuable insights for researchers and engineers seeking to optimize energy conversion processes like combustion, gasification, and pyrolysis. Furthermore, this characterization aids in the identification of potential contaminants and the selection of optimal strategies for handling and storing biomass. In summary, the thorough characterization of biomass plays a pivotal role in the development of sustainable energy solutions and the enhancement of biomass conversion process efficiency.

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