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Assessment of Energy Potential of Date Palm Residues in Khairpur District in Pakistan

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Assessment of Energy Potential of Date Palm Residues in Khairpur District in Pakistan

Abstract: This paper provides an assessment of energy potential of date palm residues; including leaflets, rachis, fruit pruning, and trunks in Khairpur district, Sindh, Pakistan. The 'yield formula method' has been used to estimate the generation and energy potential of these date palm residues. The potential of biomass date palm residues generated in Khairpur district is estimated to be 155 thousand tonnes per annum with 51% and 44% share of rachis and leaflets, respectively. The total potential of date palm residues from leaflets, rachis, fruit pruning, and trunks available for energy production is found to be 87 thousand tonnes per annum which is about 56% of the total generated residues. The experimentally measured heating values of the date palm residues ranges from 12.1 to 14.4 MJ/kg. The cumulative energy potential of date palm residues is found to be about 1.16 PJ with 68% and 26% share of date palm rachis and leaflets, respectively. The regression model analysis of the data outlines a linear relationship between annual dates production and corresponding total residues generation increases with an average of about 8.77% and 6.97% respectively. However, the residues available for energy production is annually increasing of about 3.68% and reaches to approximately 55% in next 15 years. It could potentially influence the energy production and utilization in the region.

Keywords: Biomass; Date palm residues; Energy potential; Khairpur district

1. Introduction

Biomass is one of the leading available renewable energy source of the earth. Its production and utilization is growing day by being renewable in nature and abundance availability [1]. It has a promising potential become a major source of the future energy supplies thereby reducing the fossil fuel dependency [2,3]. The biomass feedstocks are categorized as fuelwood (i.e. forest and plantation), animal dung, crop residues (i.e.

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agricultural crops and its residues like date palm, rice husk, cotton stalk, bagasse, wheat straw, maize stalk, etc.) [4,5]. Amongst these feedstocks, the date palm tree is an important biomass resource which is cultivated in arid and semi-arid regions. The date palm tree is abundantly cultivated in the several regions of world and in particular in the Middle East [6,7]. Figure 1 shows the date palm production data of top 09 countries for 2014. It is evident that Saudi Arabia is the chief producer of dates, producing about 1.24 million tons followed by Egypt, Iran, UAE, Pakistan, and Algeria. The Middle East and Africa, therefore, accounts for about 90% of world's total date production [8].

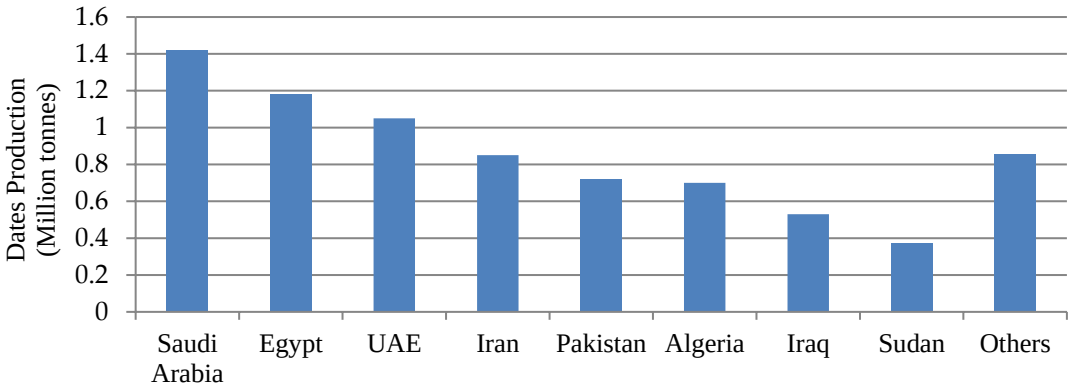

Figure 1. World's top dates producing countries-2014 [8]

Pakistan is being within the top ten date producing countries, produces 9% of the world's total dates. It is estimated that about 0.72 million tonnes of dates are annually produced in the country over an area of 90.1 thousand hectares. In this total production, the Sindh province has lion's share with approximately 48% of total dates produced here [9]. For the crop season 2016-2017, the production of dates of province Sindh has reached around 0.209 million tonnes, with approximately 85-90% of these produced in the in the Khairpur district [10, 11]. Khairpur district is located in the southeast region of Pakistan. The agrarian land of the district which is mostly cultivated to germinate the date palms. This cultivation contributes strongly to the district's economy.

The dates' cultivation also generates a significant quantity of agricultural residues, comprising of palm leaves, which can be separated into rachis and leaflets. Once cut and dried, these residues are a true asset to be used for energy production [12]. In general, a date palm tree produces almost 20 kg of dried leave residues per year [13]. The date palm trunk, which grows over several decades, the fruit stalk pruning and date stones produced from date palm fruit are potentially valuable biomass resources.

Various studies, reported in the literature, have investigated the use of date palm residues such as fruit stalks pruning and date stones for heat, electricity, syngas, and biodiesel production, as well as its other domestic applications [14]. Generally, the date palm residues are classified as date palm leaflets (DPL), fruit pruning (FP), trunk (DPT), and rachis (DPR). In order to evaluate associated energy content, various studies have examined the energy recovery from date palm residues through different techniques such as thermochemical, biochemical and extraction processes [15,16]. The potential use of date palm residues in combustion systems has also been investigated, specifically. El-may et al., have characterized the physicochemical properties and the combustion behaviour of five date palm residues including date palm leaflets, date palm rachis, date palm trunk, date stones, and fruit stalk prunings. These studies suggest that date stone is promising source for biofuel production with a high energy density (11.4 GJ/m^3) and low ash content (close to 1.2%) [17]. El-may et al., invested the production of agro-pellets from date palm rachis. This study had evaluated the performance of pellets as well as date stones (as received) during combustion tests in domestic pellets boiler. The obtained combustion efficiencies were close to 80%, which are highly promising. However, the CO and particulate matters emissions were higher in comparison to sawdust pellets. It is, therefore, suggested to modify the boiler

parameters such as air excess to relinquish the negative impacts of the pollutant emissions [14].

In these studies, the biochemical conversion processes for the valorisation of date palm residues were also tested. In particular, the bioethanol production from date palm feedstock was has also been examined in the literature. Fang et al. have also quantified the biodiesel production from date palm leaflets and rachis. These residues were subjected to hydrothermal pre-treatment for enzymatic conversion. The bioethanol obtained under optimal pre-treatment condition at 210°C/10 min through simultaneous scarification and fermentation process yielded 5.89 g/L to 18.05 g/L from the date palm leaflets and 7.59 g/L to 27.90 g/L from the date palm rachis [18]. Hassan et al. have also studied the biofuel production from the date palm waste in Saudi Arabia using the thermogravimetric technique. The experimental results from this study depicted that significant amount of biofuel can be produced from date palm waste, which can be effectively utilized for producing electricity and transport sector [19]. Lattieff [] examined the production of biogas from date palm residues. The biogas production tests were performed in a batch reactor (anaerobic digester), in this study, with different mixing ratios (weight of fruit waste/weight of water). These samples were subjected to anaerobic digestion at 37°C for mesophilic conditions and 55°C for thermophilic conditions. The results of this study revealed that at a 0.15 mixing ratio, the produced biogas was 182 L/kgVS and 133 L/kgVS at mesophilic conditions and thermophilic conditions, respectively [20].

The cultivation of the date palm crop has a significant role pertaining the socio-economic development in Khairpur district. The considerable quantity of date palm residues generated in Khairpur district are not at the moment efficiently used thus being

accumulated every year in the oasis lands. It is, therefore, urgently required to explore the energy potential of residues generated by date palms in the district.

It is evident that various studies, briefly discussed above, have investigated the different type of date palm residues, energy conversion technologies and its industrial applications. However, limited studies pertaining quantification of different date palm residues and their effective utilization as sources of energy are found in literature. Hence, this study aims to assess the potential of date palm residues, date palm rachis, trunk, fruit stalk pruning, and date palm leaflets in Khairpur, Sindh, Pakistan towards meeting the energy demand. In order to achieve the objectives of this study, first, the dates production and residues generation data is collected from the agriculture department followed by field survey analysis. Next, the heating values of each date palm residues are also estimated experimentally. Based on this, the bio-energy production potential from date palm residues is mathematically modelled with the availability data. Finally, the statistical analysis are undertaken to predict the dates production and date palm residues for a period of 15 years. This study is, therefore, significant and anticipated to be useful for the date palm tree producers, researchers and for renewable energy experts to identify the energy potential of date palm residues in different regions of the world.

2. Biomass Date Palm Residues

The date palm is known as “Phoenix dactylifera L,” in the botanical nomenclature. This term "Phoenix," meaning date palm, and "dactylifera" is derived from a Greek word "daktulos" meaning a finger. The stem of date palm tree is unbranched and is surrounded by old remaining leaves and palms. The trunk of the date palm is covered by several offshoots at the base of the tree. The average economic life of a date palm tree is about 40 to 80 years. However, some of these trees can live up to 150 years. The

average height of a mature date palm tree is about 20 to 23 meters. Figure 2 shows a date palm tree illustrating the different parts, namely date palm leaflets, rachis, trunk, and fruit stalk pruning.

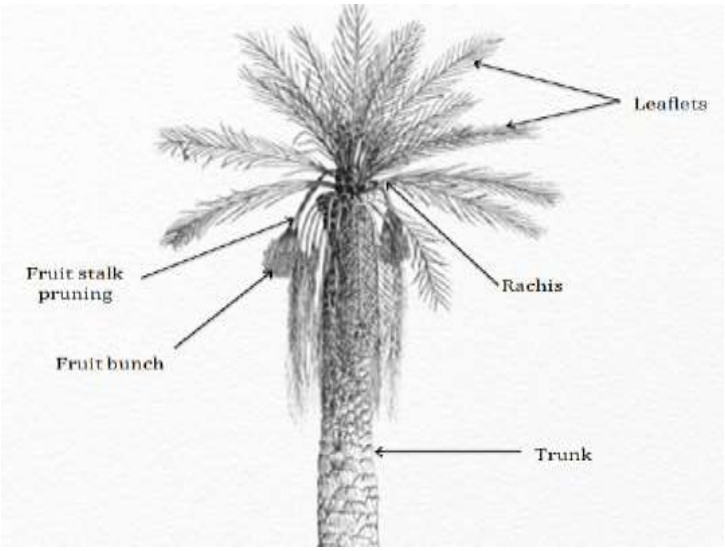

Figure 2. Date palm tree [7]

Following the date fruits cultivation, the tree parts are separated in different residues. An adult date palm tree has approximately 100 to 125 green palms with an annual formation of 10 to 26 new leaves [21,22]. Each year, some leaves become dry and their removal from the date palm tree is required. The date palm branches are composed of 46% of leaflets and 53.4% rachis [10]. The annual production of dry leaves from date palm tree is about 20 kg [23]. The mass of a single bunch of fruit pruning with date fruit is about 8 kg (18 pounds) [24]. On a dry basis, fruit pruning without date fruits has a weight of 0.4 to 0.5 kg. The average fruit stalk pruning in a tree is 11 to 15, and the average number of trees in an acre is 80 to 120 [25]. The approximate mass of the trunk of tree is estimated to be 60 kg per acre since minimum one or two trees expires annually in an acre, and new trees are planted [26]. The average weights of different date palm residues are given in Table 1.

Table 1. Average weight of date palm residues [7,23,24,26]

Type of Residue	Weight of Residue (R_{g_i})
Date palm leaflets (DPL)	9.2 kg/tree/year
Date palm rachis (DPR)	10.8 kg/tree/year
Fruit pruning (FP)	0.5 kg/tree/year
Date palm trunk (DPT)	60 kg/acre/year

The date palm residues are used to manufacture numerous industrial products such as composite panels, fibre as a construction material, lumber, particleboard, pulp and paper, wood cement and wood-plastic composites, biochar [27], biopolymers, adsorbents [28], and building insulating materials [29,30]. Moreover, date palm residues can be turned into briquettes, pellets, and cubes since it cannot be used easily in the original form due to r high moisture, irregular shape, size, and low bulk density [31,32,33,34].

3. Biomass Date Palm residues in Khairpur Mir's

The district Khairpur Mir's is located in the north of Sindh province. It is the twelfth largest city of the province covering an area of 15,910 km^2 with latitude 27.533 and longitude 68.767 as shown in Figure 3 [35]. The population of the district was 2.12 million in 2015 with more than 70% of its population living in rural areas [26]. Khairpur is well known for the harvesting of large quantities of dates every year due to its favourable climate. The dates referred as the golden fruit of the district and in the Sindhi language are known as "Khark," whereas in the Urdu language it is called as "Khajoor". The date palm of Khairpur district is considered as one of the cash crops and therefore termed as the largest dates producing district both in the province and at country.

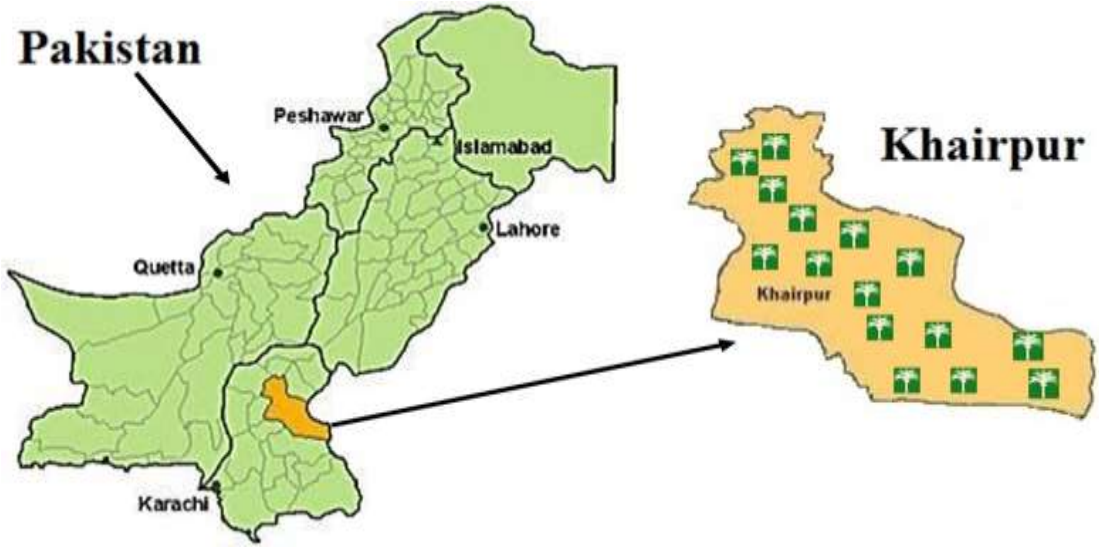

Figure 3. The location of district Khairpur in Sindh, Pakistan [35].

It is pertinent to mention that due to growing demand both locally and abroad, the cultivators have also increased the production of dates. Figure 4 illustrate the cultivation area of date palm production for Khairpur district specifically.

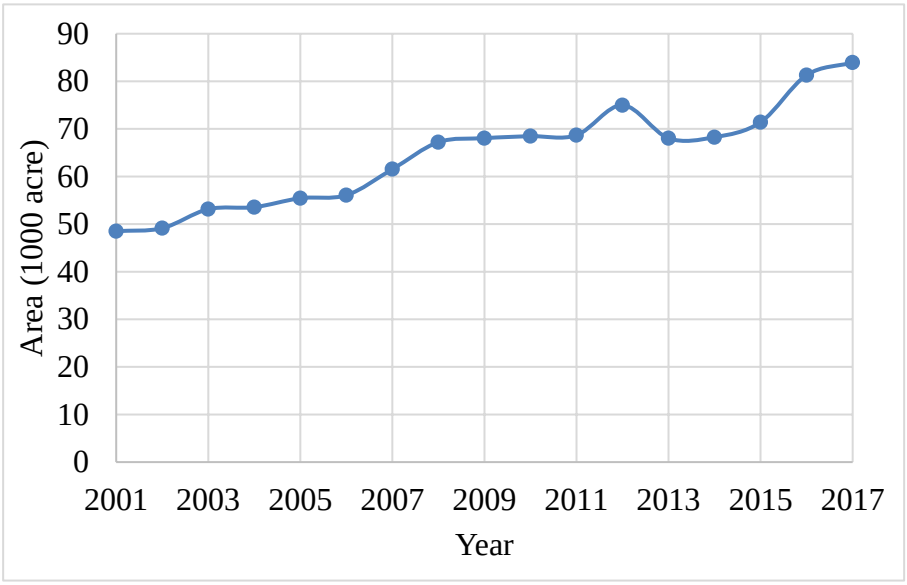

Figure 4. Annual production of dates in landed area of Khairpur [10].

This date palm production, which covers an area of 83.96 thousand acre in the district Khairpur [10], is also a source of important quantities of residues such as date palm leaflets, date palm rachis, fruit stalk pruning, and trunk.

4. Assessment of Energy Potentials of Date Palm Residues

4.1 Field Survey

A field survey was conducted to quantify the availability of date palm residues in the study area, Khairpur district, which has eight sub-administrative units (Talukas). Among them, date palm is mostly cultivated in six Talukas namely Khairpur (27.520N, 68.760E), Kot Diji (27.340N, 68.710E), Gambat (27.350N, 68.510E), Kingri (27.600N, 68.570E), Sobho Dero (27.300N, 68.390E), and Faiz Ganj (26.740N, 68.470E), [36]. These six units were selected for the field survey in this study. The flow chart of this study field survey is shown in Figure 5. At each of these sites, 20 participants were involved in the field survey. During the field survey, cultivators were asked about various applications of different residues of date palm trees as given in Table 2. Additionally, cultivators were asked about the quantity of the date palm residues, which were not utilised and discarded. The information gathered in the field survey is duly analysed and discussed in the results section of this study. Based on these results, the suitable utilisation of date palm residues for the commercial applications is also proposed. However, the kindly findings from the gather data and relevant analysis pertained the evaluation of the energy potential estimation of the quantified residues.

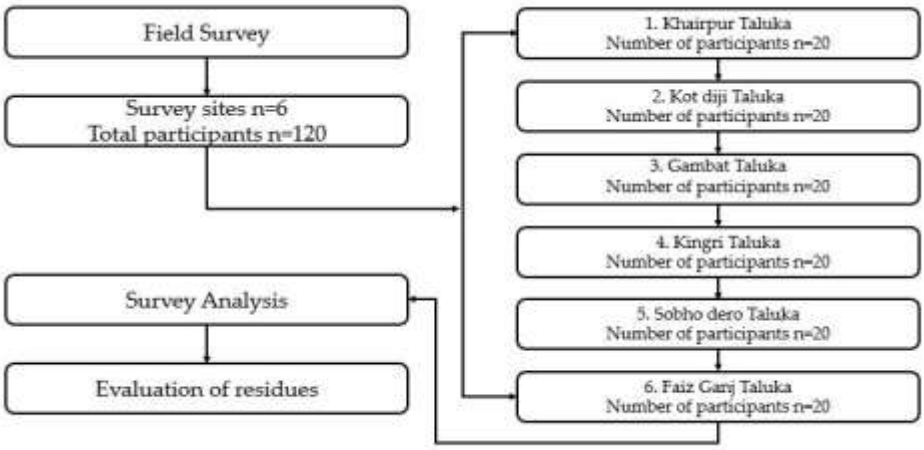

Figure 5: Field survey flow chart

Table 2. Applications of different date palm residues

Type of Residue	Applications
Date Palm leaflets	Baskets, crate, carpets, fan, food covers, etc.
Date palm rachis	Timber, wood, furniture, mats, paper, or fuel, etc.
Fruit pruning	Cages, trays, vases, cords, twine, etc.
Date palm trunk	Poles, beams, girders, etc.

Following sections provides detailed description related to energy content estimation from the date palm residue considered in this study.

4.2. Estimation Methods

4.2.1. Sample Preparation

Different samples (i.e., leaflets, rachis, fruit pruning, and trunk) of date palm residues were gathered from six different talukas' of Khairpur district. Two samples of each residue with a weight 10 gram from each site were collected. The collected leaflets were separated from the rachis manually. In order to reduce the moisture content, all the

samples were dried in the natural environment for 2-3 days. Finally, to develop a homogenous product for analysis, all the samples were pulverised manually by hammering into the particles each measure less than 2 mm. Later, after sieving, a 1-gram weight of each samples was prepared for the experimental test.

4.2.2. Heating Value Measurement

Heating values or calorific values of date palm residues were determined experimentally. The prepared samples of date palm residues were analysed using a Gallan Kamp Ballistic Bomb Calorimeter based on ASTM standards. The four samples of date palm residues date palm leaflets, rachis, fruit pruning and trunk were tested, and the results were obtained in terms of temperature, and finally, their heating values were estimated using ASTM guidelines.

4.2.3. Total Residues (RTi)

The total residue can be estimated by multiplying the total number of trees in an acre (N) with the date palm land area (A) and residues generated (R_{g_i}) by these trees. The mathematical relationship used to find the total date palm residues of Khairpur district is given as under:

$$R_{T_i} = \sum_{i}^{n} A.N.R_{g_i} \quad (1)$$

where,

RTi = Total residues generated of (i) type residue, tonnes

A = landed area of (i) residues type, acres

Rgi = Residues generated per tree (i) type residue, kg/ tree

N = Number of trees in an acre (100 trees per acre)

4.2.4. Residues available for energy production (RAi)

The residues available for energy production are further estimated using following equation [37]:

$$R_{A_I} = \sum_{I=1}^{N} R_{T_I} . AF_I \quad (2)$$

where,

RAi = Total residues available of (i) type residue for energy production, tonnes

RTi = Total residues generated of (i) type residue, tonnes

AFi = Availability factor of (i) type residues in percentage

4.2.5. Energy Potential (Ep)

The energy potential of date palm residues is calculated using following relationship [37]:

$$E_P = \sum_{I=1}^{N} R_{AI} . H_I \quad (3)$$

where,

Ep = Total energy content in the residue, MJ/year.

RAi = Total residues are available for the energy of (i) type residue, tonnes/year.

Hi = Heating value of (i) type residue, MJ/kg.

n = Number of residue type.

4.3. Forecasting energy potential of date palm residues

This study employed linear regression and developed model to forecast the dates production and date palm residue generation in next 15 years in the study area. The linear trend model of the study is defined as following mathematical relationship [38, 39],

$$Y_I = A_0 + B(X_I) \quad (4)$$

Where Yi is the predicted residue production in i period (i=1, in 2010), A_0 is intercept of the model, B is the slope of the model or annual production change obtained by OLS (ordinary least square regression) method, and X_i is dates production in i period [40].

A statistical linear regression model is also used to evaluate the impact of the dates production on residues generations and predicts the residues production for next 15 years [39, 41]. The model is validated by analyzing the model fit between the actual (available data) and predicted values and model coefficients i.e. R-square value, which determine how well model explains the production of dates, and corresponding residues production and p-value, which should be lower than 0.05 and standard error.

5. Results and Discussion

The total potential of date palm residues generated by date palm trees available in Khairpur is estimated using Eq. (1) and is shown in Figure 6. The values of residues generated per tree are taken from Table 1. The theoretical potential of biomass date palm residues generated in Khairpur is estimated to be 155,000 tonnes per annum. The estimation indicates that date palm rachis is available in large quantities (79.3 thousand tonnes) followed by date palm leaflets (67.5 thousand tonnes), trunk (4.4 thousand tonnes) and fruit pruning (3.4 thousand tonnes). Figure 6 shows that the date palm rachis and leaflets are the main residues comprising of 51% and 44% of total residues respectively.

It was also observed during study that date palm residues are also used for the development of various products available in the markets. However, the quantity of date palm residues used for these commercial applications is not sufficiently reported in the literature. Therefore, in the field survey the quantification of the date palm residues exploitation for commercial use was also investigated. In this context, it was established following survey that large amount of date palm residues is used for commercial

applications. Despite date palm residues used for various commercial applications, there is a huge amount of residues available for energy applications. Table 3 provides the approximate percentage values of different date palm residues utilization for energy production, It is also revealed from survey results that date palm fruit pruning and date palm rachis residues are available in large quantities for energy production due to their fewer commercial applications. This amount of residue is estimated by using Eq. (2). The estimated potential of different date palm residues (i.e., total residues and residues available for energy) is shown in Figure 6. The total potential of biomass date palm residues available in Khairpur district for energy production is estimated to be 87,000 tonnes per annum.

Table 3. Date palm residues available for energy production

Type of Residue	Used for other applications (%)	Available for useful energy production (%)	Availability Factor (AF)
Date palm leaflets (DPL)	65-70	30-35	0.325
Date palm rachis (DPR)	20-30	70-80	0.75
Fruit pruning (FP)	10-20	80-90	0.85
Date palm trunk (DPT)	40-50	50-60	0.55

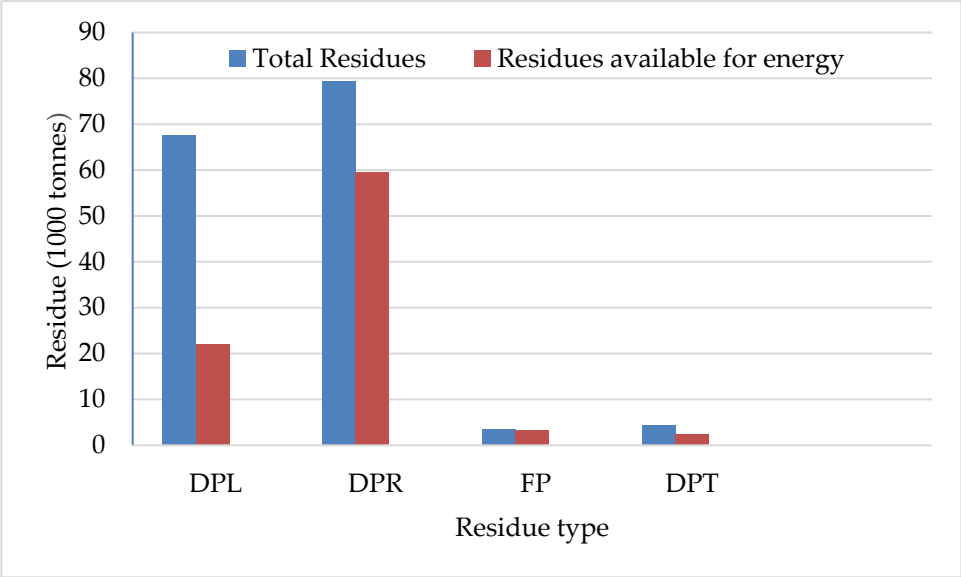

Figure 6. Total residue available in Khairpur district

The heating values of the different date palm residues were subsequently measured. The recorded values ranged between 12.1 to 14.4 MJ/kg. Table 4 provides the average lower heating values of the date palm residues. The fruit pruning had a high heating value of 14.4 MJ/kg compared to the other residues, i.e., leaflets 13.7 MJ/kg, rachis 13.3 MJ/kg and trunk 12.1 MJ/kg. These values are in the same order of magnitude as of other biomass resources, such as wood pellets, wood chips and solid waste [42]. Although, the obtained heating value of fruit pruning is high, the estimated potential of fruit pruning is not significant due to the low availability in Khairpur. The date palm trunks, however, have a lower heating values due to high moisture and ash contents. The date palm leaflets and date palm rachis are also the residues available in bulk quantities and having optimum heating values. Therefore, leaflets and rachis could be the main source of the bioenergy production in Khairpur district.

Table 4. Lower Heating values of date palm residues

Type of Residues	Low Heating Value

	(MJ/kg)
Date palm leaflets	13.7
Date palm rachis	13.3
Fruit pruning	14.4
Date palm trunk	12.1

The energy potential of date palm residues available in Khairpur district has been estimated using Eq. (3). As such, the cumulative energy potential of date palm residues in has been found to be 1.16 PJ. The date palm rachis has the highest energy potential, which is estimated to be 791.5 TJ, while the percentage of date palm leaflets, fruit pruning, and date palm trunk in total energy potential of date palm residues are 26%, 4%, and 2%, respectively as shown in Figure 7. These date palm residues particularly date palm rachis and leaflets can be used efficiently for cooking, heating and other purposes in the rural areas to reduce the deforestation and environmental degradation as well as create employment opportunities.

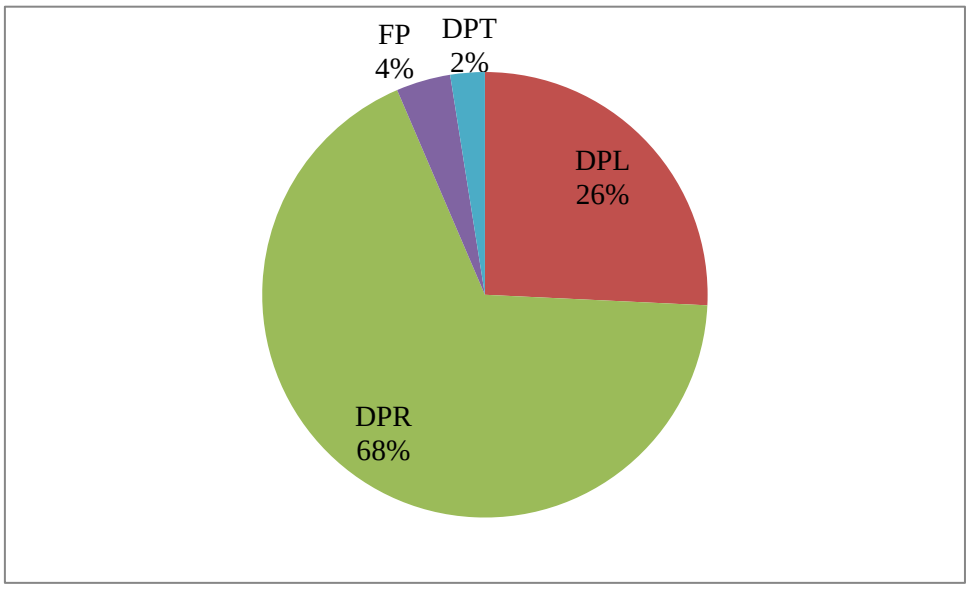

Figure 7. Percentage of date palm residues in total estimated energy

potential

As discussed earlier, a linear regression model has been used in this study to predict the trend between dates production and the residues generation. The regression approach has been applied for the available data for the period from 2001 to 2017 and further analysed for next fifteen years. In order to forecast the dates production and residues production, initially linear regression model is developed from landed area of date palm. The model is then fitted with actual area as shown in Figure 8. The model intercept and slope are given in Table 5. Further, this model has also been used to predict the dates production and residue production from 2018 to 2032. Thus, analysis of model results reveals that the dates production growth will increase linearly for the next 15 years as shown in Figure 8. The R-square value of the model is 0.903 (Table 5) which delineates that the production of dates and corresponding residues production will increase significantly in next 15 years. The dates production model accounts 8.77% as an average increase in production for each predicted year. This may have inferred that as the cultivation of dates increases each year. However, the standard error and p-value are found much less than 3.407 and nearly zero, so the analysis of model coefficients reveals that the model is statistically significant.

Table 5: Computed parameters of Linear Regression model

Parameter	**Value**
Intercept (α)	46.62
Slope (β)	1.99
R square	0.903
Standard Error	3.407
P-value	3.99×10^{-14}
Observations	17

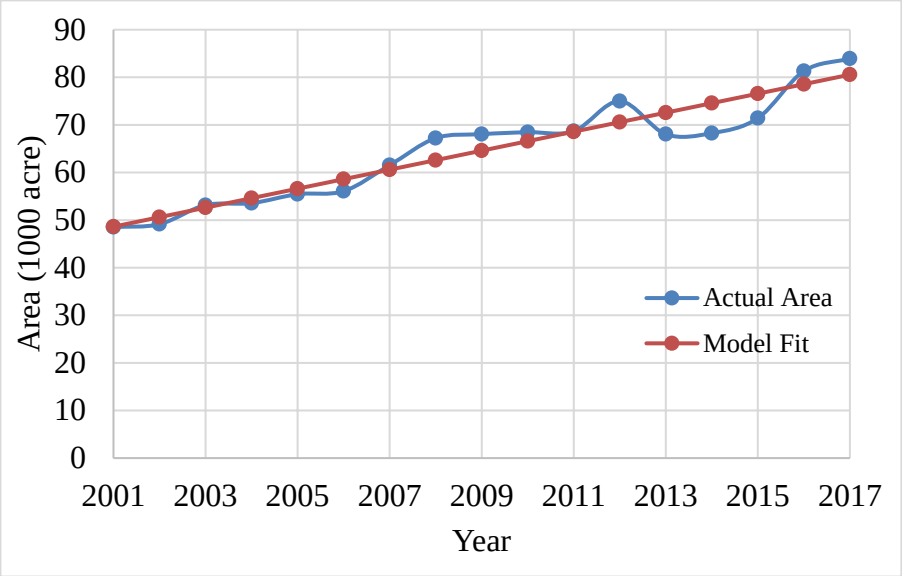

Figure 8: Model fit of area and actual area in acre

In similar fashion, the trend model is developed for the total date palm residues and residues available for energy production. This model results reveal that the residues production is directly proportional to the dates production. As the dates production increases, the residues production also increases. Thus, the residues production model predicts that total date palm residues production will increase at an average growth rate of about 7% per annum. However, residues available for energy production will increase at an average growth rate of about 3.68% per annum. These results are significant as they provide a linear trend in production growth of date palm crop cultivation and residue harnessing. Hence, the total date palm residue production model and residues available for energy conversion has a linear growth relationship as shown in Figure 9. In both of these models, the production may be attributed to the climate conditions, the fertility of land or the availability of water or maybe the use of effective scientific methods for the cultivation.

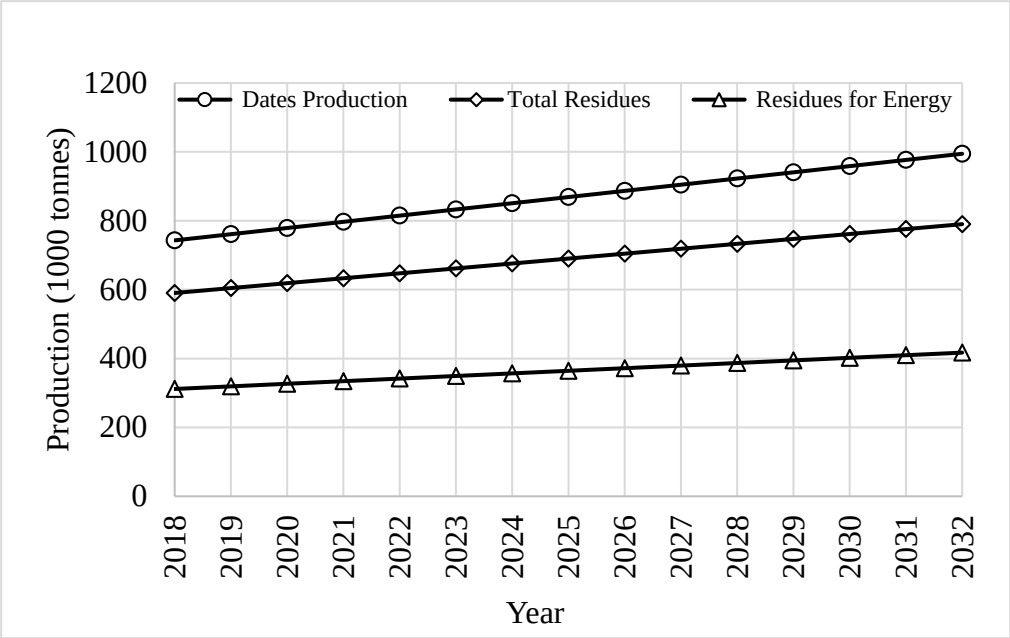

Figure 9: Model forecast of dates production, total residues production and residues available for energy from period 2018-2032

The results of this study suggest that date palm residue production is significantly dependent on dates production. Thus, the annual growth in cultivation of date palm could potentially increases the residues generation. In addition, there could also be a significant improvement in yield through agronomic practices or adopting the proper yield harnessing approaches. The predicted relationship evident from the linear regression analysis strongly influnce the date palm residue production and the corresponding energy production. The forecasting model of this study, as such, suggest annual increase in dates production to be about 3.68% and average generation of date palm residues for producing energy may raise up to around 55% by the year 2032. As such, following the linear regression model trend, it is safe to conclude that Khairpur district of Pakistan would generate ample amount of date palm residues, which could be used for the cooking and heating purposes.

The finding of this study are relevant to continuous efforts being undertaken to identify new biomass resources as alternative to wood fuel for meeting the energy demand in the developing countries generally and in Arabian Peninsula, Africa, and Pakistan specifically where date palm is cultivated in large quantities. However, most of literature so far generally focused the industrial uses of date palm residues rather than for energy related application [34,36,42,43, 44]. Therefore, this study lays a foundation towards evaluating the date palm residues potential for energy production in Pakistan as well as in other date palm producing countries.

6. Conclusion

The use of date palm biomass resources could ensure the availability of sustainable energy supplies in future as this study demonstrates using the rural areas of Khairpur district as a case study. The four types of date palm residues, namely; date palm leaflets, rachis, fruit pruning and trunk, were surveyed in the study area and found suitable for energy production. The theoretical potential of biomass date palm residues in Khairpur is estimated to be 155,000 tonnes per annum with 51% and 44% of major share of rachis and leaflets respectively. The heating values of residues range from 12.1 to 14.4 MJ/kg. Alongside other competitive commercial applications of the date palm residues, about 87,000 tonnes per year of residue is estimated to be available in Khairpur district as a source of biomass energy. The leaflets and rachis are the main residues available for with maximum potential for energy recovery. The overall potential of date palm residues for energy recovery has been estimated to be 1.16 PJ. Further, the statistical analysis delineated that annual increase in dates production shall rise at 3.68% and average production of date palm residues would be around 55% during the year 2032. As such, these date palm residues could be efficiently used for cooking and heating purposes in rural areas of Pakistan. It is, therefore, concluded from this study that date

palm residues could be significant source for clean energy to meet the growing demand in the date palm producing countries.

Nomenclature	
GOP	government of Pakistan
DPL	date palm leaflets
DPR	date palm rachis
DPT	date palm trunk
FP	fruit pruning
TCS	traditional cookstoves
ICS	improved cookstoves
GHG	greenhouse gas emissions
IAP	indoor air pollution
R_{T_i}	total residues generated of (i) type residue, tonnes
A	landed area of (i) residues type, acres
N	the number of trees in an acre (100 trees per acre)
R_{g_i}	residues generated per tree (i) type residue, kg/ tree
R_{Ai}	total residues available of (i) type residue, tonnes
AF_i	availability factor of (i) type residues in percentage %
E_p	total energy content in the residue, MJ/year.
H_i	the heating value of (i) type residue, MJ/kg.
n	number of residue type

References

[1] Manos B, Partalidou M, Fantozzi F, et al. Agro-energy districts contributing to environmental and social sustainability in rural areas: Evaluation of a local public-private partnership scheme in Greece. Renew and Sustain Energy Rev. 2014; 29: 85-95.

[2] Harijan K, Uqaili MA. Potential of Biomass Conservation Through Dissemination of Efficient Cook Stoves in Pakistan. APCBEE Procedia. 2013; 5: 358 – 362.

[3] Uqaili MA, Harijan K, Memon MD, et al. Controlling the indoor air pollution due to biomass consumption in the rural household sector of Pakistan. Proceedings of International Conference on Environmental Management. Jawaharlal Nehru Technical University, Hyderabad, India. 2005.

[4] Ayamga EA, Kemausuor F, Addo A. Technical analysis of crop residue biomass energy in an agricultural region of Ghana. Resources. Conservation and Recycling. 2015; 96: 51–60.

[5] Organization for Economic Co-operation and Development. World energy outlook: 2006.

[6] Saafi EB, Trigui M, Thabet R, et al. Common date palm in Tunisia: chemical composition of pulp and pits, International Journal of Food Science & Technology. 2008; 43: 2033-2037.

[7] El-may Y, Jeguirim M, Dorge S, et al. Study On the Thermal Behavior of Different Date Palm Residues: Characterization and Devolatilization Kinetics Under Inert and Oxidative Atmospheres, Energy. 2012; 44: 700-709.

[8] Nuts and dried fruits. Global Statistical Review: 2014;15: 1-54.

[9] Memon NI, Noonari S, Kalwar AM, et al. Performance of Date Palm Production under Contract Farming in Khairpur Sindh Pakistan. Journal of Biology, Agriculture, and Healthcare. 2015; 5: 19-27.

[10] GOS, Department of Agriculture Extension, Hyderabad, Sindh, Pakistan, 2017.

[11] Department of Agricultural extension, Sindh, Pakistan. 2016.

[12] El-may Y, Jeguirim M, Dorge S, et al. Evaluation of Date Palm Residues Combustion in Fixed Bed Laboratory Reactor: A Comparison with Sawdust Behavior. Renewable Energy. 2014; 62: 209-215.

[13] Al-Omari SAB. Experimental investigation on the combustion and heat transfer characteristics in a furnace with unconventional biomass fuels (date stones and palm stalks). Energy Conversion and Management. 2006; 47: 778-790.

[14] El-may Y, Trouvé G, Jeguirim M, et al. Energy Recovery of Date Palm Residues in a Domestic Pellet Boiler. Fuel Processing Technology. 2013; 112: 12–18.

[15] El-may Y, Jeguirim M, Trouvé G, et al. Kinetic analysis of thermal decomposition of date palm residues using Coats–Redfern method. Energy Sources. Part A: Recovery, Utilization, And Environmental Effects. 2016; 38(8): 1117–1124.

[16] Chandrasekaran M, Ali HB. Valorization of date palm (Phoenix dactylifera) fruit processing by-products and wastes using bioprocess technology – Review, Saudi Journal of Biological Sciences. 2013; 20: 105–120.

[17] El-may Y, Jeguirim M, Dorge S, et al. Experimental investigation on gaseous emissions from the combustion of date palm residues in laboratory scale furnace. Bioresource Technology. 2013; 131: 94–100.

[18] Fang C, Schmidt EJ, Cybulska I, et al. Hydrothermal Pretreatment of Date Palm (Phoenix dactylifera L.) Leaflets and Rachis to Enhance Enzymatic Digestibility and Bioethanol Potential. Bio.Med. Research International. Hindawi Publishing Corporation. Article ID 216454. 2015; 1-13.

[19] Hussain A, Farooq A, Bassyouni MI, et al. Pyrolysis of Saudi Arabian Date Palm Waste: A Viable Option for Converting Waste into Wealth, Life Science Journal 2014; 11(12); 667-671.

[20] Lattieff FA. A study of biogas production from date palm fruit wastes. Journal of Cleaner Production. 2016; 139:1191-1195.

[21] Zaid A. Food and Agriculture Organization of the United Nations. Date and Palm Cultivation: FAO: Rome. 1999.

[22] Haimour NM, Emeish S. Utilization of date stones for production of activated carbon using phosphoric acid. Waste Management. 2006; 26: 651–660.

[23] Sait HH, Hussain A, Salema AA, et al. Pyrolysis and Combustion Kinetics of Date Palm Biomass Using Thermogravimetric Analysis. Biores Tech. 2012; 118: 382–389.

[24] Date Palm plant. Encyclopedia Britannica: Available at (http://www.britannica.com/EBchecked/topic/152224/date-palm)

[25] Date Palm Research Institute (DPRI). Shah Abdul Latif University Khairpur Mir's, Sindh, Pakistan: 2016.

[26] Dr. Bhanbhro FI. PPHI, NGO: District Khairpur Mir's, Sindh, Pakistan: 2015.

[27] Nasser RA, Salem MZM, Hiziroglu S, et al. Chemical Analysis of Different Parts of Date Palm (Phoenix dactylifera L.) Using Ultimate, Proximate and

Thermo-Gravimetric Techniques for Energy Production. Energies. 2016; 9:374: 1-14.

[28] Bchini H, Hsayoui S, Aloui S. Management of organic matter and composting of dry palms in the oasis environment. Annals of INRAT. 2002; 75: 299-312.

[29] El-Morsy MMS. Studies on the rachis of Egyptian date palm leaves for hardboard production. Fibre Science and Technology. 1980; 13: 317-321.

[30] Khiari R, Mhenni MF, Belgacem MN, et al. Chemical composition and pulping of date palm rachis and posidonia oceanice a comparison with other wood and non-wood fibre sources. Biores Tech. 2010; 101: 775-780.

[31] Eissa AHA, Alghannam ARO. Study on Some Mechanical and Chemical Properties of Agro Residual Briquettes Produced from Date Palm Fronds, Review. International Journal of Science and Qualitative Analysis. 2018; 4 (2): 42-59.

[32] Bendahou A, Dfresne A, Kaddami H, et al. Isolation and structural characterization of hemicelluloses from the palm of Phoenix dactylifera L. Carbohydrate Polymers. 2007; 68: 601-608.

[33] Belala Z, Jeguirim M, Belhachemi M, et al. Biosorption of copper from aqueous solutions by date stones and palm-trees waste. Environmental Chemistry Letters. 2011; 9: 65-69.

[34] Nasser RA, An evaluation of the use of midribs from common date palm cultivars grown in Saudi Arabia for energy production. Bio Resources. 2014; 9(3): 4343-4357.

[35] Jatoi MA, Markhand Z, Solangi N. Dates in Sindh: facts and figures, Proceedings. The International Dates Seminar. Date Palm Research Institute, Shah Abdul Latif University, Khairpur, Pakistan. 2009; 59-71.

[36] GOS. Khairpur district. accessed on 13.06.2018: Available at http://www.khairpur.gos.pk/.

[37] Hiloidhari M, Das D, Baruah DC. Bioenergy Potential from Crop Residue Biomass in India. Renew and Sustain Energy Rev. 2014; 32: 504–512.

[38] Calderini DF, Slafer GA. Changes in yield and yield stability in wheat during the 20th century. Field Crops Research.1998; 57: 335–347.

[39] Bentsen NS, Felby C, Thorsen BJ. Agricultural residue production and potentials for energy and materials services. Progress in Energy and Combustion Science. 2014; 40: 59-73.

[40] Sellam V, Poovammal E. Prediction of Crop Yield using Regression Analysis, Indian Journal of Science and Technology. 2016; 9(38): 1-5.

[41] Lecerf R, Ceglar A, Lozano RL, et al. Assessing the information in crop model and meteorological indicators to forecast crop yield over Europe. Agricultural Systems. 2018: 1-12.

[42] Jeguirim M, Chouchène A, Réguillon AF, et al. A new valorization strategy of olive mill wastewater: impregnation on sawdust and combustion. Resources, Conservation and Recycling. 2012; 59: 4-8.

[43] El-Hadrami A, Al-Khayri JM. The Socioeconomic and traditional importance of date palm. Emirates Journal of Food and Agriculture. 2012; 24(5): 371-385.

[44] El-Juhany LI. Degradation of Date Palm Trees and Date Production in Arab Countries: Causes and Potential Rehabilitation. Australian Journal of Basic and Applied Sciences. 2010; 4(8): 3998-4010.