



## Production of solid biomass and investigation of optimum thermal properties

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### Abstract

The sustainability potential of global biomass for energy is widely recognized. The annual global primary production of biomass is equivalent to 4.500 EJ of solar energy captured each year. About 5% of this energy, or 225 EJ, should cover almost 50% of the world's total primary energy demand at present. The biomass energy in Turkey has a share of 13% in renewable energy sources. Trees with high energy potential and growth rate in Turkey are as follows; poplar, aspen, alder, pine, oak, ash, pine, larch, cedar and cypress. In this study, wild liquorice (*Astragalus*), great mullein (*Verbascum Thapsus*) and sunflower (*Helianthus annuus*) have been pelletized to search their burning behaviors according to other fuels. With this aim, plants have been mixed in specific amounts with the use of Taguchi Optimization Method to attain a pelletized fuel with maximum calories, low humidity and low ash. Among these values, the calorie was used as a base and the estimated optimum values for humidity and ash were calculated. The calculated optimum values were obtained as 4526.05 cal for caloric value, 6.93% for humidity and 2.92% for ash, respectively. These values provide that the pellet has low humidity and ash content, and that the calorie is at the same level with the agricultural wastes and more than the calorie of the prina, lignite, wood, sawdust, and animal and plant wastes which are going to be used as the fuel for the present tenements in Turkey.

*Keywords:* Solid biomass, pellets, briquette, wild liquorice, great mullein, sunflower, renewable

### 1. Introduction

Today, renewable energy to meet the needs of non-renewable (fossil) and renewable energy sources are used. Due to limited fossil fuel resources and environmental criteria, especially the world of science has accelerated efforts to find alternative renewable energy sources. One of them, particularly biomass energy, has great potential for biomass to be used.

Biomass has two greatest advantages, namely inexhaustibility and reducibility anywhere. Biomass, as other sources of energy for the greenhouse effect, does not cause environmental pollution, it only environmentally benefits renewable sources of energy. The European Union which had 5.75% share of biofuels in total energy in 2010, aims to have up to 20% share of biofuels by 2020. Identifying these targets, the Kyoto Protocol signed in 2012, plays an important role to achieve this aim [1]. Today, biomass energy, the fourth largest energy source, meets approximately 14% of the world's energy needs. Biomass energy is composed of 64% of wood and wood wastes, 24% of municipal solid wastes, 5%

of agricultural wastes and 5% of the landfill gases. 13% of renewable energy sources is biomass energy in Turkey. The economic value of energy forestry in Turkey is high and it is possible to take into account the fastest-growing indigenous tree species such as poplar, aspen, alder, pine, oak, ash, pine, larch, cedar and cypress. Among the eucalyptus trees with foreign origin that can be produced in Turkey, *Euramericana*, *Populus*, *Pinus pinaster*, *Acacia* species are listed as *Cynophilla*. Turkey's annual biomass potential is about 32 Mtoe and, its total available bioenergy potential is estimated to be approximately 17.2 Mtoe [2].

A research made investigation of some agricultural products grown in Turkey and they intended to use sweet sorghum as a power plant. Cotton, wheat, corn, sunflower and sugar beet waste can be considered as a source of biomass in Turkey. The total amount of these products is around 40-50 million tones. As it is an agricultural country, source of biomass can be easily obtained in Turkey. For example, the sweet sorghum plant as a biomass energy source, can be

grown 20 tons per hectare on the conditions of Turkey. The average lower heating values of biomass resources are ranged from 3100 to 3800 kcal/kg, and the maximum sulfur content of its is around 0.19%. Instead of lignite, the use of these wastes will provide significant reductions in SO<sub>2</sub> and CO<sub>2</sub> emissions [3].

Sweet sorghum plant that is used to obtain biomass energy were grown in Marmara Research Center. The briquetting works were carried out for burning of biomass in the systems of stove and grid, and the chemical composition of the combustion products were determined. In addition, the studies were performed by burning the fluidized bed of the biomass prepared by mixing with coal. For sorghum and agricultural wastes, thermal values were determined as 3400-4300 cal/g, the amount of sulfur and the ash content were determined to be 0.04 to 0.21% and 10.7% respectively [4]. In another study, it was determined that when biomass is used in boilers process, it has many economic, social and environmental benefits such as financial advantage, conservation of conventional fossil fuel resources, employment opportunities and CO<sub>2</sub> and NO<sub>x</sub> emissions reduction [5-6]. At the same time, attention is drawn to other environmental impacts of biomass such as consumption of land and water resources, soil erosion, loss of biodiversity and deforestation. The study entitled "Biomass combustion in fluidized bed boilers: Potential problems and remedies", presents the important issues concerned with biomass combustion in the small scale fluidized bed systems. Where, problems have been identified, mechanisms have been explained and solutions have been shown. In another study, the effect of temperature on transesterification of wood oil was investigated to find the optimum temperature of maximum biodiesel yield. The yield of the biodiesel produced in optimum conditions was obtained 96-98% [7]. In this study, the algae production techniques such as open, closed and hybrid systems, production costs, and algal energy conversions have been investigated.

Sunflower husk contains a high proportion of cellulose, and the sun flower that is used to make pellets has a higher calorie than the sunflower husk briquettes. However, during combustion, these pellets are low in absorbing air to prevent overheating and excessive amounts of smoke, and the average combustion efficiency of it is 62%. The ash content of briquettes made from stalks is 10% while its pellets made from the shell is 3.6% [8].

Tea wastes were briquetted at a hydraulic press at pressures ranging from 300-800 MPa and at various

temperatures ranging from 5 to 30 minutes. The experiments on the effects of briquetting pressure, density and moisture and compressive strength of briquettes were conducted in different experimental pressures. Optimum moisture content and compressive strength of tea waste samples were determined 15-18% and 36.2-37.1% MPa respectively. There are also studies investigating the effects of processing temperature and time on the briquette density [9].

In another study, it was studied "total non-methane volatile organic carbon" (NMTVOC) emissions created by burning of pellets prepared with MDF (medium density fiber) and the burning of pine shavings under laboratory conditions. The effects of corn starch used as a binder at a specific rate of %9 on TVOC emissions were investigated. Moreover, the combustion gas emissions such as CO, CO<sub>2</sub>, SO<sub>2</sub>, and NO<sub>x</sub> caused by burning pellets were investigated. As a result, the burning emissions of pellets resulted in higher rate of NMTVOC emissions than that of burning of pine pellets. In addition, the starch added to the MDF and pine shavings increased NMTVOC emissions. When MDF pellet is burnt, due to the nitrogenous chemicals contained in its composition, it caused higher NO<sub>x</sub> emissions than the natural pine pellets [10].

It was investigated the economy of its use as a biofuel switchgrass (*Panicum Virgatum*). Pelletizing of switchgrass is easier than the types of hard and soft-textured wood, and pelletizing has been found to have lower cost. One pellet machine (150 hp), while producing 6.9 to 10.9 tons of pellets from switchgrass per hour, can produce 3.1 tons of pellets from hard-textured woods; on the other hand 4.5 tons of pellets from soft-textured trees. They found out that the ash rate of switchgrass harvested in spring is 3-3.5%, the energy rate is 19.2 GJ / t and potassium and chlorine rate is low and the quality of biomass is high. They determined the energy value of switchgrass pellets to be 3% lower than the energy value of wood and 7% higher than wheat stem. In this study, they identified that more quality biomass is obtained from switchgrass grown in sandy soil and switchgrass to be more economical than the other types of wood [11].

In a article, it was investigated the burning behavior of pelletized wood dust taken from furniture factories, in fixed bed combustion system. Combustion experiments were conducted in a square cross-section block with a vertical placed camera, resistance wires and refractory bricks are placed in

this block. Experiments were performed for 873 K, 973 K and 1073 K oven initial temperatures and 7 mm, 9.6 mm and 12.5 mm pellets heights. It has been calculated that moisture rate is %5.11, ash rate is %0.93 and volatile matter rate is %75.71 and 18.64 MJ / kg caloric for wood dust pellets. As a result, it was determined that volatile matter and carbon combustion duration decreased with increasing oven

## 2. Pelletizing

The raw material is firstly dried, then it is turned into powder by grinding. Powdered material is compressed under high pressure 6-12 mm in diameter, and is turned into 10-30 mm long cylindrical particles. These particles are called pellets. Briquettes have larger size than pellets. Pellet can be produced from waste materials such as wood chips, bark, agricultural products, crops, vines, nuts, almonds, walnut shells, waste paper articles, stubs of corn, beet pulp, sunflower petals, dried beans, olive and cherry seeds. Pellets are formed under high pressure without addition of chemical binding materials. Chemical binders contain less moisture and have more calories than wood. Despite the negative effect of moisture on heating value of fuel pellet construction materials, it is allowed to contain less moisture. Thus, a more robust structure of pellets will be gained. Excessive moisture in the pellets will prevent the proper operation of the system by sticking between the wheels of the machine. In addition, a quantity of heat is released during process of producing pellet by compression without a chemical binding. Pellets are a flammable substance, so it must be cooled to prevent it from burning at the time of production. During the process of pellet production at least 3 separate processes are used. These processes are: grinding of woody waste materials into powder, drying them to include

## 3. Materials and methods

### 3.1. Geven (Astragalus)

Geven (Astragalus) is a plant legume group and a long-lived legume. There are 2000 known species of astragalus, and they grow in many areas. The leaves are arranged in the form of an ellipse along the branch. Their length varies from 5-100 cm depending on the type and their altitudes vary from 200 to 2700 m depending on their place. The glues obtained from Geven (Astragalus) are used in making marbling. These glues are also used in drug production. Geven

### 3.2. Mullein (Verbascum Thapsus)

There are about 200 species of Mullein (Verbascum

temperature and increased with the increase in the height of pellets. Furthermore it was identified that the rate of volatile matter combustion increased with increasing temperature while the carbon combustion rate decreased with increasing temperature. The ash of pellet formed around the pellet and sintered at low temperature during the combustion of biomass has been understood to be quite effective [12].

specific amount of moisture, flocculating and cooling them in pelletizing molds, then filling the finished products into tankers or packaging. Depending on the number of production equipment and processes used in the production, with the capacity of 4 tons / h, the initial investment cost of a factory is approximately \$ 3,000,000. On the other hand, there are small pelletizing machines with 200 kg production capacity per hour turning dry wood chips into pellets. Consequently, it is economic in terms of producing the pellets meeting the needs of the daily heating of carpenter shops [13].

The investments in the production of pellets have increased in European countries. The world's major countries that are producing wood pellet and their production capacity are as follows; Germany 2.4 million tons / year, Canada 2 million tons / year, the U.S. 1.8 million tons / year, Austria, Sweden, France and Russia about 1 million tons / year. The number of Pellet stoves and boilers used in Germany by 2015 is estimated to be 1,500,000. The number of pellet stove is used in Italy has reached 700,000 units and nearly 800,000 tons of pellets are consumed per year. Pellet imports have reached 300,000 tons a year in Italy. In Denmark, there are around 50,000 pellet stove, and are consumed about 800,000 tons per year.

(Astragalus) is grown in all kinds of soil conditions. Geven (Astragalus) is an important plant in terms of soil conservation and erosion prevention. Geven (Astragalus) grows in forest, steppe and mountain slopes of 300-2300 m elevations in the Central Aegean and the Taurus Mountains, 1300-3500 m elevations in Eastern Anatolia and Central Anatolia region of Turkey [14].

Thapsus). It has a quite large habitat. Mullein is a

plant which has length of 60-200 cm and a two-year life span. Mullein does not bloom in the first year. In the second year, from mid-summer to autumn, bright yellow flowers bloom abundantly. Among the people in Turkey it is also called "wool grass". In addition to

### 3.3. Binding

The sunflower (*Helianthus annuus*), a specie of sunflower family, is an agricultural plant with yellow flowers and is grown for its oil and seeds. Sunflower is one of the most important sources of vegetable oil in the world and our country. In parallel with the increasing population, our country's need for vegetable oil is increasing. The importance of

### 3.4. Taguchi method

Taguchi method is one of the most appropriate solutions to evaluate the experimental data. Taguchi Method takes into account all the effective parameters. Dr. Genichi Taguchi who is a Japanese scientist developed the standard tables that contain all the effects of factors, and consist of orthogonal arrays, and contains fewer repetitive calculations. There is a principle in selecting any of these statements. However, the number of factors, the factors and degrees of interactions between the factors are taken into account in the selection table [17]. The most appropriate combination of uncontrollable variables in any design is determined by the Taguchi Method. The adverse effects of the variables taken into account in design with the help of this method are minimized [18- 23].

In this method, the optimum conditions are determined after determining the main effects of each factor. The factor levels providing the optimum conditions will be determined with the help of this method. In short, the so-called ANOVA table is generated by the analysis of variance that is a statistical procedure. ANOVA table reveals us what factors must be controlled in the process, after determining the optimum conditions required to make the verification tests. The two different approaches in Taguchi analysis are preferred. The first approach is called the standard approach and the data are evaluated with the main effect and ANOVA analysis. The multi-parameter studies are made in the second approach and S / N (signal to noise ratio) ratios are used for the same steps [24]. Performance statistics are used in determining the parameters of the optimum levels.

The largest for the best;

In this case, the target value of y is infinite, and the

the Northern Hemisphere temperate regions, especially in the eastern part of Eurasia, it is widely grown. In our country, on roads, gardens, and the edges of fields are places where mullein can be seen [15].

sunflower is constantly increasing. Sunflower oil is the most consumed vegetable oil in our country and half of the required vegetable oil is imported from outside. Sunflower is grown mainly in dry conditions. Despite its wide range of adaptation ability, lack of plantations is due to having less revenue from a unit area [16].

signal / noise ratio is defined as follows:

$$SN_L = -10 \text{Log} \left[ \frac{1}{n} \sum_{n=1}^n \frac{1}{y^2} \right] \quad (1)$$

The minimum for the best:

In such conditions, the target value of variable y is zero and the signal / noise ratio is defined as;

$$SN_S = -10 \text{Log} \left[ \frac{1}{n} \sum_{n=1}^n y^2 \right] \quad (2)$$

Here, n shows the number of repeated experiments and y shows the value of performance. The goal of a process is to find the maximum value of SNL. Maximum SNL shows also the optimum value for the process. The purpose of a minimum value of the process should be chosen the maximum value of the expression of SNS. As it is well known, the maximum value of SNS refers to the optimal value of the process. Performance value that provides optimum working conditions can be written as in Taguchi method [24].

In Taguchi method, the performance value that provides optimum working conditions can be expressed by the following equation [24];

$$Y_i = \mu + X_i + e_i \quad (3)$$

and can be estimated with this equation. Where;  $Y_i$  shows the estimated performance value for Experiments,  $\mu$  shows the overall average of performance value,  $X_i$  shows the size of the total activity levels of the parameter used in the experiment, and,  $e_i$  shows the experimental error. If the test results are given as a percentage, the omega transformation of these values should be before the

use of (3.6) equality. According to the results of the conversion, omega ( $\Omega$ ) value provides the optimum conditions. The reverse conversion is done using the same equation [21].

$$\Omega(db) = -10 \text{Log} \left( \frac{1}{p} - 1 \right) \quad (4)$$

Here;  $\Omega$  (db), and p show respectively decibel value and the percent value obtained experimentally. The confidence interval must be determined using

### 3.5. Analysis of variance

The optimum conditions of pellet were determined by using analysis of variance. MINITAB package program was used for this purpose. The equations related to variance were used in the analysis.  $F_{\text{Experimental}}$  values were determined experimentally, and to determine the effective parameters, these

### 3.6. Method

In this study, the effects of the raw materials, mass, pressure, and the binder on the combustion characteristics of pellet were investigated. The obtained experimental results were evaluated by means of Taguchi Optimization Method. In this method, three trials were made and calculations were

### 3.7. Determination of the orthogonal experimental design

In this study, it was aimed to determine the optimum conditions of the pellet that contains the maximum calories, minimal ash, and the minimum humidity. In experiments, three-level and four-parameter  $L_9$  ( $3^4$ ) procedure that affects the caloric, moisture and ash value of the pellet was preferred. Analysis did not include the compound effects due to their negligible level. To observe the effects of parameters on the optimization criterion, performance values associated

### 3.8. Supply of raw materials and preparation

The raw materials were obtained from the dried plant stems in a mountainous northeast area of Erzurum. The raw materials were completely dried on ambient air as the first process, and then they were turned into powder by grinding mill. The rates of this powdered raw material were determined with the help of Taguchi Method, and then they were turned into pellets in a hydraulic press. Hydraulic press shown in Fig. 3.1-a works as manual and has a maximum of 15 tons of the compaction pressure. The application pressure ranges of the hydraulic press varies between 0-1, 0-2; and 0-5 tons. The steel press mold used in the pelletizing process is shown in Fig. 1-b. The steel

Equation (6). As a result, the validity of the model used of experimental studies and the estimated experimental error will be determined [19]. As is known, the prediction error is the difference between the observed p and the estimated p. Confidence interval (Se) for the estimated error is determined by the appropriate equations. If the prediction error is outside of these limits, this model used in the process is understood that is not appropriate [21].

values obtained from the experimental studies were compared with theoretical  $F_{\text{theoretical}}$  values taken from [21]. If  $F_{\text{Experimental}} > F_{\text{Theoretical}}$ , the parameter is effective on the system, otherwise the parameter is not effective.

made by using the two closest values. The heating value, moisture and ash ratios of the pellet were determined with the analysis of coal by using the standards of TS 438-1967, TS 330-1966 and 2678-1977. The S/N values (1) and (2).

with the values of calories, moisture and ash of the pellet were calculated. Performance statistics used in the calculation of calories, moisture and ash are respectively developed for the following situations; the calculation of calories 'the best of the biggest' (1), the calculation of moisture 'the best of the small' (2), and the calculation of ash in 'the best of the small' (2).

press mold that has three different diameters such as 0.5 cm, 1 cm and 1.5 cm was produced. The three different dimensions of the mold were used in pelletizing works, and 1 cm diameter mold was understood to be the most suitable for studies. As it is known, the pelletizing process is made of raw materials which have different masses, and the process of pressing pellets with other two molds cannot be fully realized. The pellets used in the analysis had 1 cm in diameter and 1 cm to 2.5 cm lengths. The pictures of the sawdust produced from raw materials and the pellets which were pressed of different pressures are shown in Fig. 1-c.

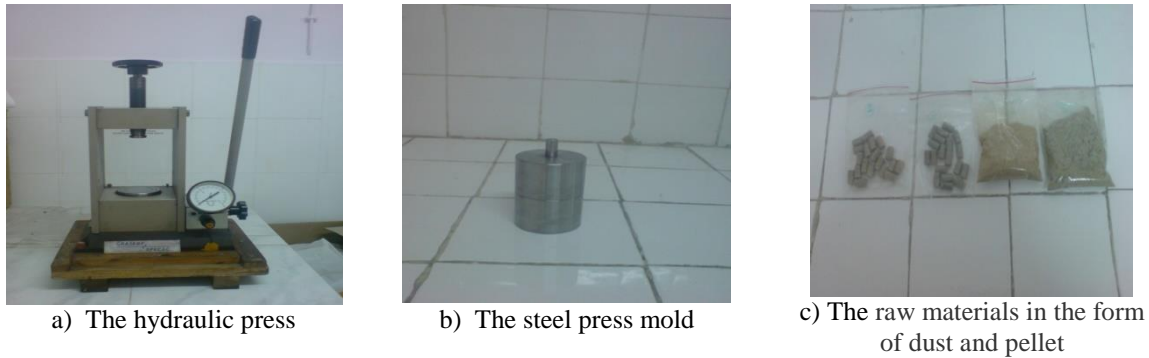


Fig. 1. The raw materials, the hydraulic press and the steel press mold.

**4. Research findings**

**4.1. Moisture determination**

The moisture determination of the pellets that were prepared according to orthogonal experimental plan and compatible with the TS 690-2002 were made. The average values of marginal parameters ( $Y_m$ ) were calculated by the equality (5) depending on the amount of moisture, and these values are given in Table 1. The graphs that are shown from Fig. 2 to Fig. 5, are drawn for the level of the parameter data obtained from the  $Y_m$ .

$$Y_m = \sum_{j=1}^n \frac{x_{ij}}{n} \tag{5}$$

where  $x_{ij}$  expresses the percent amount of parameters on the level of  $i$ ,  $n$  the number of test on the level of  $i$ ,  $i$  the level of parameter, and  $j$  the number of experiments on the level of  $i$ .

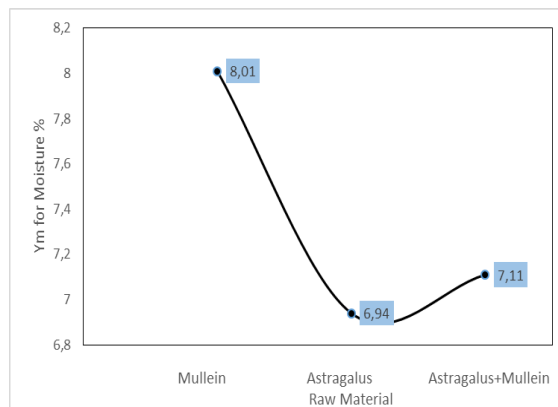


Fig. 2. Effect of raw material on the moisture

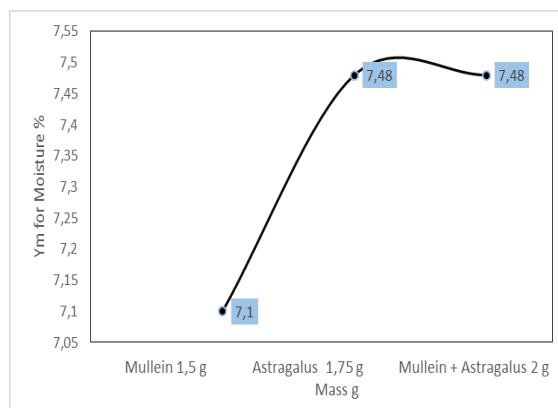


Fig. 3. Effect of the mass on the moisture

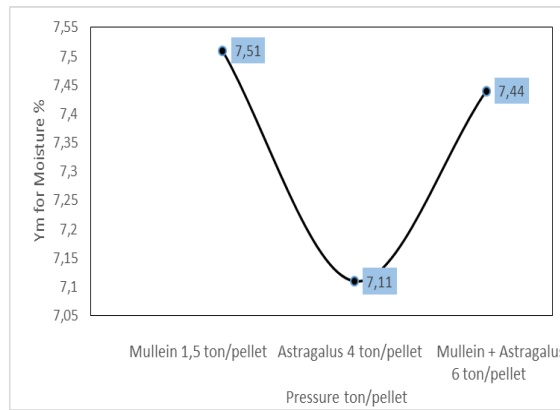


Fig. 4. Effect of the pressure on the moisture

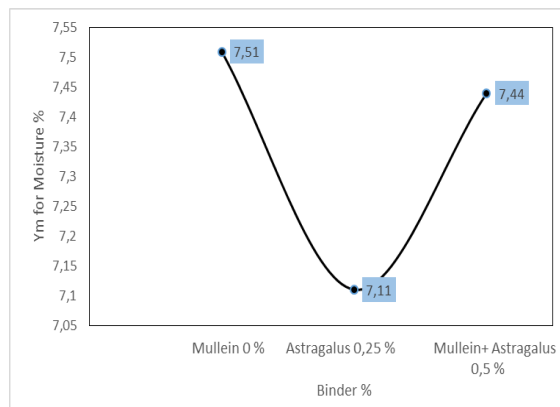


Fig. 5. Effect of the binder on the moisture

**4.2. Determination of ash**

Ash determination was carried out according to TS 330-1966 for pellets prepared according to the orthogonal experimental plan. For the three experiments, the amount of ash calculated as a percentage and the two closest values are given in

Table 2. The parameters related to the marginal means were obtained by using  $Y_m$  data. The graphs of the levels of these parameters drawn are shown in the Figs. 6, 7, 8 and 9.

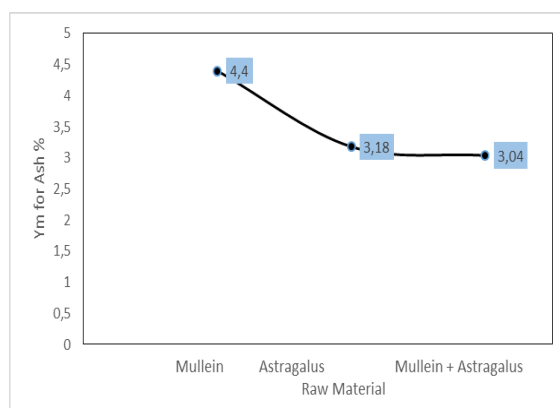


Fig. 6. Effect of the raw material on the ash

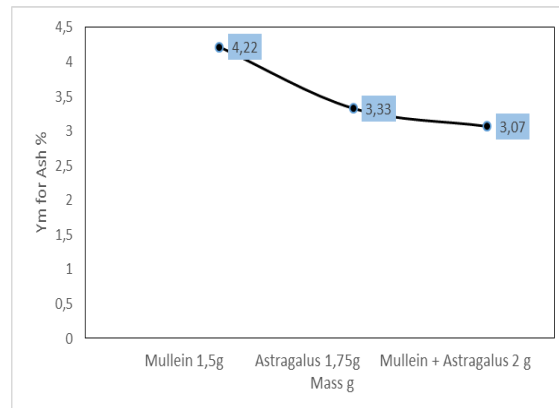


Fig. 7. Effect of the mass on the ash

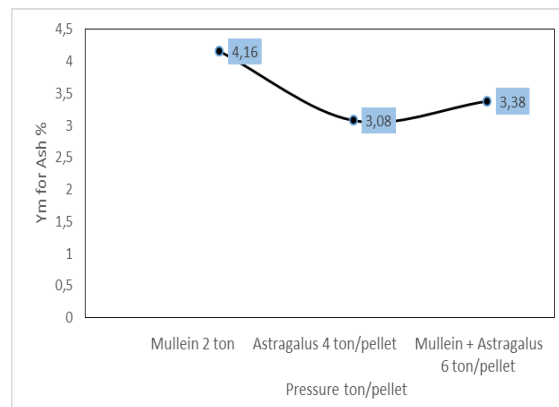


Fig. 8. Effect of the pressure on the ash

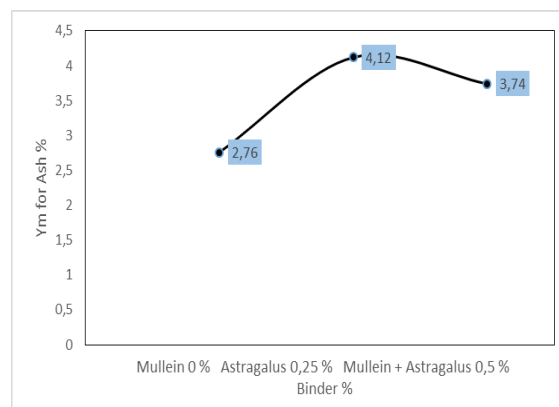


Fig. 9. Effect of the binder on the ash

#### 4.3. Determination of calories

The determination of the heat value was carried out according to TS 2678-1977 for pellets prepared according to the orthogonal experimental plan. For three experiments, the amount of calories was calculated and the two closest values are given in Table3. The marginal mean values of parameters

( $Y_m$ ) were calculated by equation (5) depending on the amount of calories. The parameters related to the marginal means were obtained by using  $Y_m$  data. The graphs for the levels of these parameters drawn are shown in the Figs. 10, 11, 12, and 13.

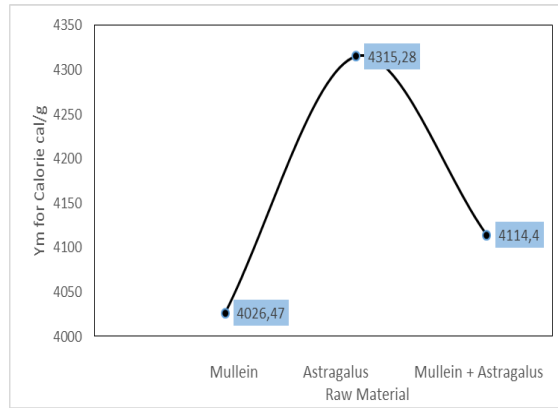


Fig. 10. Effect of the raw material on the calorie

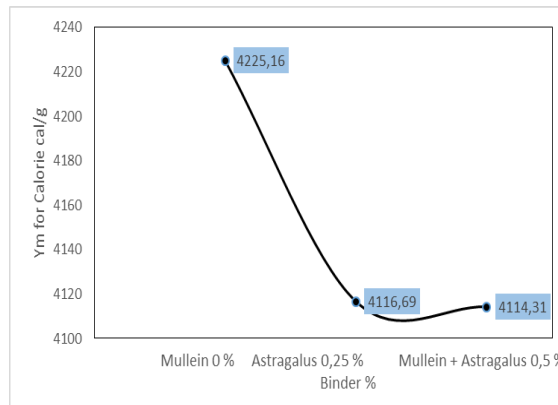


Fig. 11. Effect of the mass on the calorie

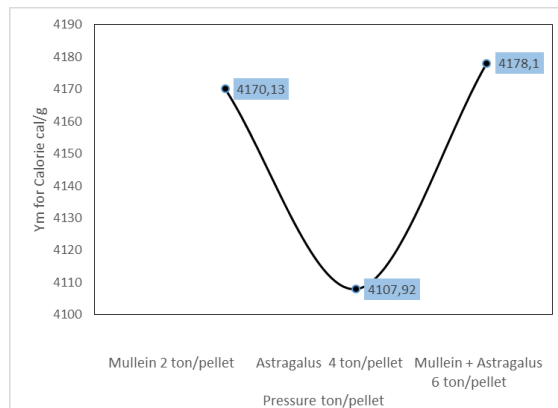


Fig. 12. Effect of the pressure on the calorie

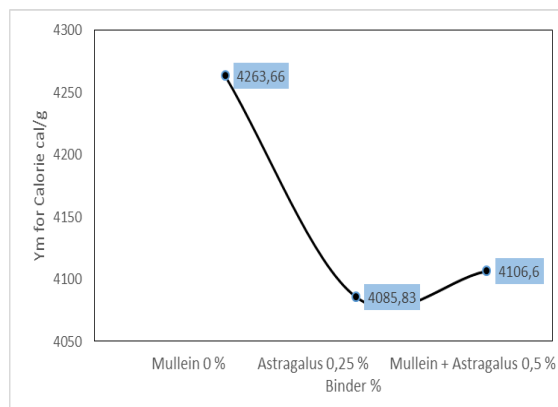


Fig. 13. Effect of the binder on the calorie1

Table 1. Variance Analysis for Moisture

Parameters	The degrees of freedom (SD <sub>i</sub> )	The sum of squares (SS <sub>i</sub> )	The mean of square (MS <sub>i</sub> )	F	Efficiency (%)	Efficiency
A Raw Material	2	3,933	1,967	867,61	65,68	Effect
B Mass	2	0,553	0,276	121,88	9,16	Effect
C Pressure	2	0,932	0,466	205,69	15,51	Effect
D Binder	2	0,543	0,272	119,81	9,00	Effect
Error	9	0,020	0,002			
Sum	17	5,982				

$$F_{(2,9),0,95} = 4,26 \quad F_{(2,9),0,99} = 8,02$$

Table 2. Variance Analysis for Ash

Parameters	The degrees of freedom (SD <sub>i</sub> )	The sum of squares (SS <sub>i</sub> )	The mean of square (MS <sub>i</sub> )	F	Efficiency (%)	Efficiency
A Raw Material	2	6,715	3,358	1894,57	32,36	Effect
B Mass	2	4,377	2,189	1234,92	21,09	Effect
C Pressure	2	3,757	1,879	1060,05	18,10	Effect
D Binder	2	5,874	2,937	1657,27	28,31	Effect
Error	9	0,016	0,002			
Sum	17	20,740				

$$F_{(2,9),0,95} = 4,26 \quad F_{(2,9),0,99} = 8,02$$

## 5. Discussion and conclusion

### 5.1. The effects on performance statistics of the parameters for moisture

According to the results of the experiment, when the marginal mean values of plotted graphs for moisture shown in the Figs. 2-5 are carefully examined it will be understood that the most effective parameter related to moisture is raw material. The applied pressure in the production of pellet, the moisture of binder and the mass of pellet does not have much effect on the moisture of pellet. The moisture amount of raw materials can be reduced by drying. As a result, the combustion quality of pellet is improved. SN<sub>S</sub> equation that is shown in equation (2) is used in

determining the levels of parameter to minimize the pellet containing moisture. These performance statistic values which minimize the amount of moisture contained in the pellet are shown in Table 4. In addition, the graphs from Fig. 14 to Fig. 17 were drawn for the same results. The graphs which show the correlation between the performance statistics and the levels of the parameters are drawn. The numerical value of the maximum points in each graph indicates the best value of the parameter.

Table 3. Variance Analysis for Calories

Parameters	The degrees of freedom (SD <sub>i</sub> )	The sum of squares (SS <sub>i</sub> )	The mean of square (MS <sub>i</sub> )	F	Efficiency (%)	Efficiency
A Raw Material	2	263003	131501	41,37	54,51	Effect
B Mass	2	48118	24059	7,57	8,87	No Effect
C Pressure	2	17718	8859	2,49	2,41	Effect
D Binder	2	113387	56693	17,84	22,73	Effect
Error	9	28607	3179			
Sum	17	470832				

$$F_{(2,9),0,95} = 4,26 \quad F_{(2,9),0,99} = 8,02$$

When we examine graphs connected with the performance statistics, the levels of parameter that

made maximum the mean performance statistics were obtained respectively as follows; given as raw

materials (2nd level), mass 1.5 g (1st level), pressure 2 tons (1st level) and 0.25 g binder (2nd level). At the optimum conditions, while the estimated value of moisture is 6.13%, the experimental value of moisture is 6.10%. It is understood that the effect of the mullein on the SN is very low and has more the effect of geven and geven-mullein on the SN as shown in Figure 14. Here, it is understood that the moisture content for mullein is high, and is low for

geven. As shown in Figure 15, it is observed that the moisture increased with the increase in the amount of substance depending on raw materials. On the other hand, when Figure 16 is examined, it is seen that the amount of moisture increased firstly with increasing pressure, then falls again. Figure 17 shows that the amount of moisture increase firstly with the use of binder, and decreases again later. The best values obtained for the parameters are given in Table 4.

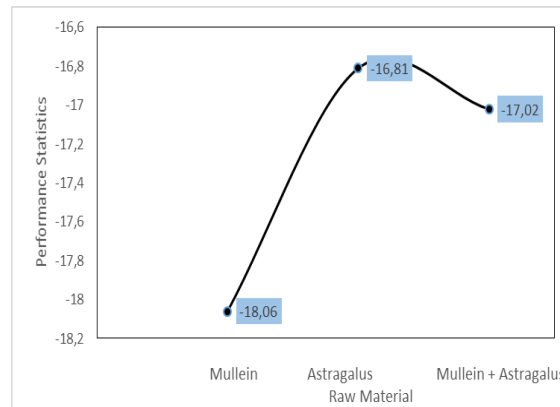


Fig. 14. The effect of the raw material on the performance Statistics for Moisture

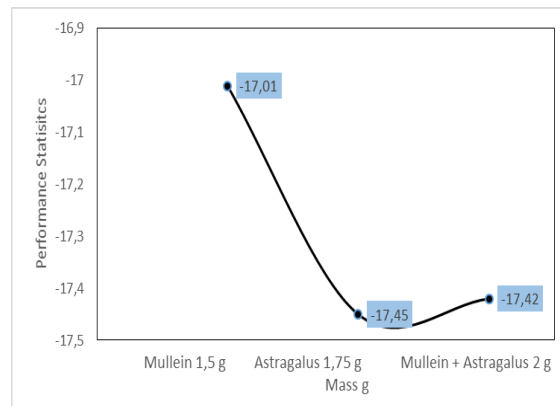


Fig. 15. The effect of the mass on the performance Statistics for Moisture

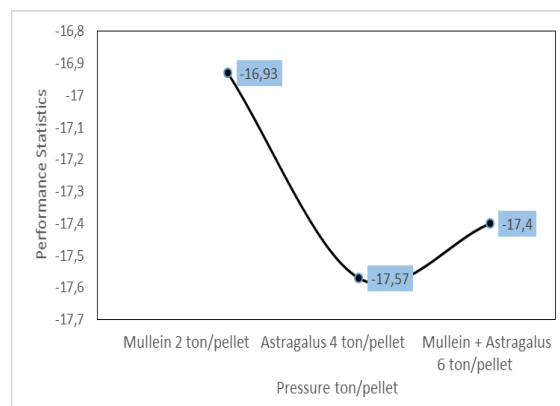


Fig. 16. The effect of the pressure on the performance Statistics for Moisture

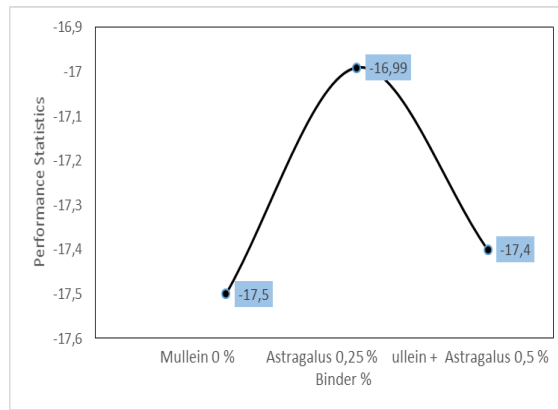


Fig. 17. The effect of the binder on the performance Statistics for Moisture

Table 4. Optimum Operating Conditions for Moisture, Observed and Predicted Values

Parameters	Level	Value
A Raw material	2	<b>Astragalus</b>
B Mass (gr)	1	<b>1,5</b>
C Pressure (ton)	1	<b>2</b>
D Binder (gr)	2	<b>0,25</b>
Observed value (%) Moisture		<b>6,10</b>
Predicted value (%) Moisture		<b>6,13</b>
Confidence interval (%) Moisture		<b>5,99 - 6,27</b>

**5.2. The effects of parameters on performance statistics for ash**

According to the results of the experiment for ash, all the parameters have effect on ash. These results will be also understood when the mean marginal graphics plotted for ash as shown in the Figs. 6-9 are examined. The formulation of  $SN_S$  in equation 2 is used in order to determine the parameter levels that minimize the amount of ash in pellet. The performance statistics values obtained for moisture are given in Table 4, and the graphics about these results are shown in the Figs. 14-17. The best values of parameters have been found as follows; as a raw

material mullein-geven (level 3), mass 2.0 grams (level 3), pressure of 4 tons (level 2) and a binder zero (level 1). Both the estimated value for the optimum conditions and the obtained value for experimental studies have been found to be 1.33%.

When Figs. 17-21 are examined, it can be seen that ash levels of raw material and mass parameters increased with the increasing performance, pressure was first increased and then decreased, binder was decreased and then increased.

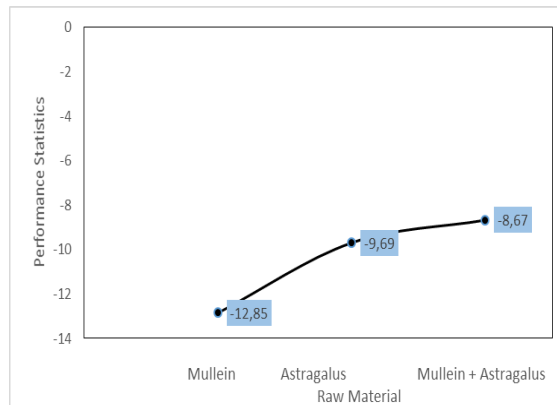


Fig. 18. The Effect of Raw Material on Performance Statistics for Ash

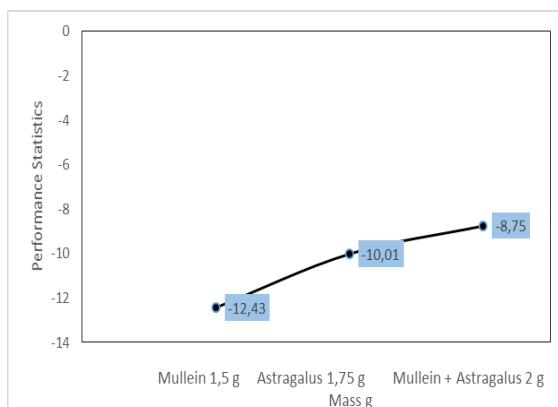


Fig. 19. The Effect of Mass on Performance Statistics for Ash

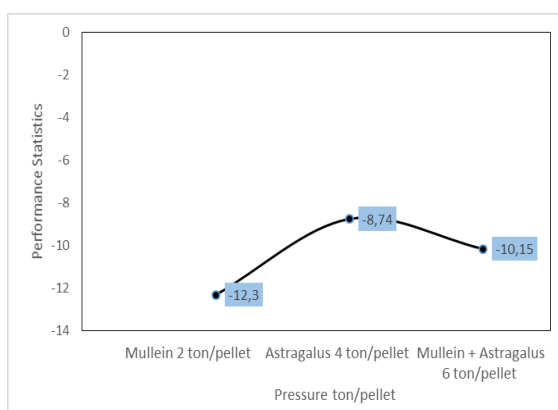


Fig. 20. The Effect of Pressure on Performance Statistics for Ash

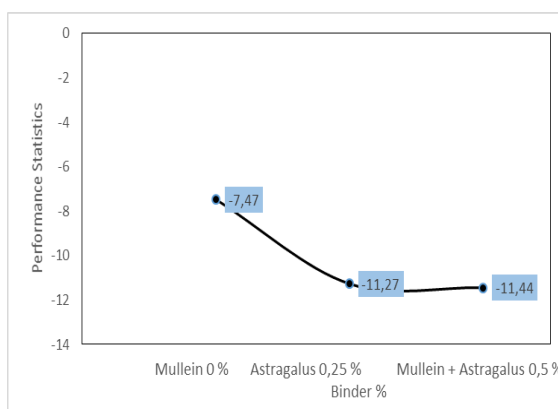


Fig. 21. The Effect of Binder on Performance Statistics for Ash

### 5.3. Effects on the performance statistics of the parameters for calorie

According to the results of the experiment, the most effective parameter on the calories is the raw materials, then binding. The amount of the binder with the level of raw material is important to obtain high-calorie pellets. The parameter levels making pellet calories maximum were found by using the (1) SNL equation. When examining graphics in the Figs 22-25, it is understood that the performance of calories increases firstly with the changing of raw materials, then decreases. The maximum point is reached for given at the 2nd level. The mass is reached initially to maximum point and at the 1st

level (1,5 g). The performance of calories increases firstly with the increase of the mass, then remains constant. The performance of calories decreases firstly and then increases depending on the pressure, and there are two maximum points that are close to each other in the graphics.

The performance of calories decreases firstly and then increases slightly depending on the binding, and there are two maximum points that are close to each other in the graphics. At the 1st level that the binding is not used, the maximum point is reached.

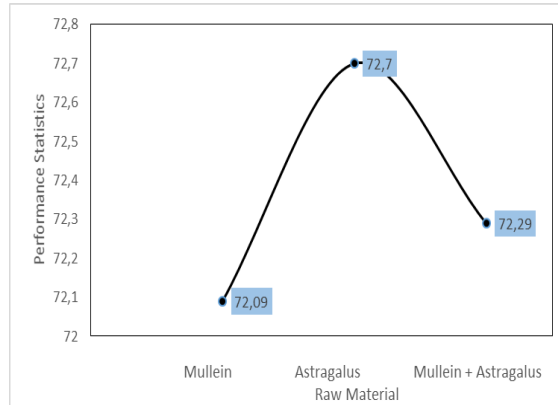


Fig. 22. Effect of raw material on performance statistic for calorie

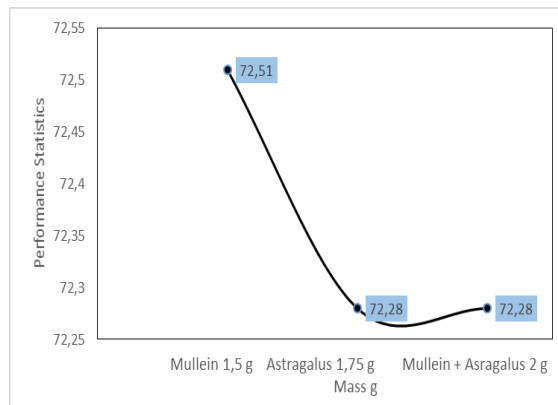


Fig. 23. Effect of mass on performance statistic for calorie

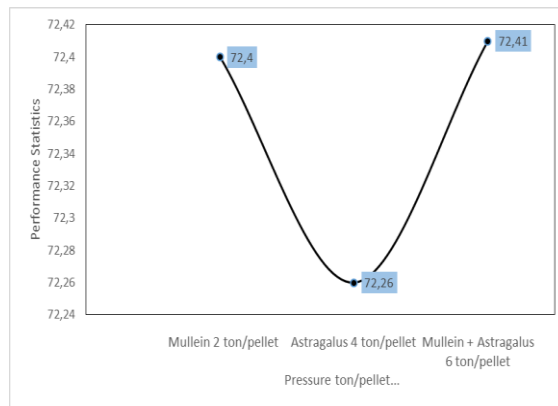


Fig. 24. Effect of pressure on performance statistic for calorie

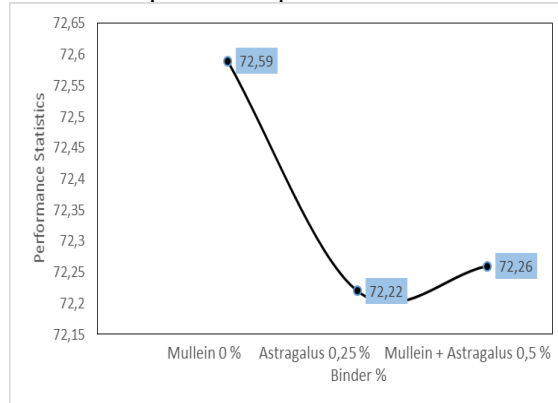


Fig. 26. Effect of binding on performance statistic for calorie

## 6. Conclusions

In this study, the determination of the optimum conditions that have the minimum moisture, the minimum ash, and the maximum calories was investigated for the pellets formed according to the Taguchi method. According to the results obtained for pellets; for moisture A2, B1, C1, D2, for ash A3, B3, C2, D1, for calories, A2, B1, C3, D1 and A2, B1, C1, D1 are determined as optimum conditions. If the results obtained for moisture, ash, and calories are taken into account, given (Astragalus) plant seems to be more effective for the raw materials shown with the parameter A. To make pellet more massive than the pellets which have level 1 and 1.5 g mass it is not appropriate for the mass shown with the parameter B. In the three analysis performed for the pressure indicated by the parameter C different levels were obtained. To use a binding with level 1 at the pellets has been found to give better results for the binding shown by the parameter D.

In this study, as there are two optimum values for the calories, the estimated optimum values of both moisture and ash were calculated. According to the calculations, the values corresponding to the first of

the optimum conditions for calories are; 4526.05 calories, moisture 6.93% and 2.92% ash, the values corresponding to the second of the optimum conditions for calories are; 4518.07 calories, 6.53% moisture and 3.7% ash. Here, due to the moisture and ash values of optimum conditions are less than 1%, here, values that correspond to the two optimum conditions can also be used. The low ash content and the higher calories show that combustion is complete. For this study, optimum conditions, containing 4526.05 calories 6.93% moisture and 2.92% ash values were selected. According to the results obtained on the basis of experimental data, it was understood that the moisture and ash content of pellets is low, pellets calories are more than other fuels such as pomace, lignite, wood, sawdust, animal and plant residues and pellets were determined to have the same values of calories of the agricultural wastes. In light of the evaluations, the creation of new jobs and diversifying its sources of biomass energy, energy crops in areas unsuitable for agriculture in Turkey and these plants seem to be able to use pellets as fuel in the heating industry.

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