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Energetic properties of european Black Pine (*Pinus nigra* subsp. *nigra* var. *nigra* J.F. Arnold) wood in the Trieste area

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A Federico e Nora

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I am glad to have carried out this thesis work in the city where I was born and where I live.

I like to have given though a little contribute for better understanding black pine wood value in order to foster a cleaner and more sustainable use of our resources. But to realize this work I wasn't alone, that's why I specially thank all persons who have helped me in this work in particular my brother Lorenzo and the forest commander G. Milani for the work in the field, and A. Sgarbossa, M. Zanetti, D. Marini and A. Cardin for the labour analysis and special labour company. Nevertheless special thanks to Vitadello family for the special support and kindness given me along this time.

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Finally, I thank all you, family, scouts and friends, who are part of my little human community whom I have shared and have been sharing the beautiful play in which it has to be found out the best "forest management" in every-day life.

RIASSUNTO

In questi ultimi decenni il tema della sostenibilità energetica è stato al centro dell'attenzione di molti programmi politici di diversi paesi. Su questo tema anche gli stati membri dell'Unione Europea hanno accresciuto la loro attenzione promuovendo la produzione di energie rinnovabili tra cui un importante ruolo è svolto dalle biomasse.

Nella categoria delle biomasse rientrano principalmente prodotti legnosi che per la gran parte provengono dalla gestione delle risorse forestali. La qualità del legno in termini di fonte di energia, è rappresentata dal così detto *potere calorifico*, che è a sua volta correlato a variabili di crescita (riferiti alla pianta in piedi) e di qualità del combustibile (analizzati in laboratorio).

Alcune di queste variabili sono state valutate e analizzate su due popolazioni di pino nero della provincia di Trieste, cresciute su due suoli differenti. Una su suolo più povero e xerico (leptosols), l'altra su un suolo più ricco sia in acqua che in nutrienti (cambisols). In questi territori il pino nero in quanto pianta pioniera, ha svolto un ruolo importante fin dalla seconda metà XIX sec., quando fu usato per i primi impianti sperimentali.

Una volta raccolti i dati di campo e compiute le dovute analisi di laboratorio, lo studio ha analizzato la significatività statistica del confronto e della correlazione tra le variabili di crescita e di qualità del combustibile intra- e inter- popolamento.

Infine emerge che il potere calorifico valutato con l'indice FVI (*fuel vlue index*; Sotelo Montes, 2011) del legno di pino nero è superiore nei popolamenti cresciuti su suolo più povero e xerico (leptosols).

ABSTRACT

In last decades sustainable energy recruitment has occupied first page of many political agenda all over the world. High attention to this issues has been given by member states of European Union, which have been fostering increasing production of renewable energy sources (RES), such as biomass.

Major part of biomass utilized is represented by woody material, which is principally obtained from forest management. Wood quality as energy source is evaluated with its *heating value* and could depend on different variables which belong to growth- or fuel- variables.

Some of these variables are evaluated and analyzed on two population of european black pines grown on different soils of Trieste province. First on drier and poorer leptosols and second on more humid and nutrient rich cambisols. In Trieste's area black pine has been playing an important role as pioneer species since XIX century, when it was used for first plants.

Once field data are collected and labour analysis are computed, the survey investigate with statistical comparisons and correlations on growth- and fuel- variables between and within sample population.

Finally results bring out that heating value evaluated with index FVI (fuel value index; Sotelo Montes, 2011) of black pines is higher for individuals grown on drier and poorer soil (leptosols).

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1. INTRODUCTION

1.1 BLACK PINE IN THE TRIESTE AREA

Pinus nigra subsp. *nigra* var. *nigra* J.F. Arnold was the most used tree species in the past two centuries to recover over exploited land of the Trieste area. Thanks to its pioneer characteristics it was able to recover many lands spread over poor and dry Karst soils, degraded from long time of intensive pasture activities.

First tree plantation experiments were carried out in 1842. In XIX century intensive human activities (pasture and tree felling) combined with difficult climatic conditions had given cause of concern for land destruction (Bubola, 2006).

In 1859 forester Josef Koller observed that a particular pine species coming from Balcan regions was able to grow on difficult terrain and climatic conditions, so first experiment of black pine plantation was made in Basovizza suburb, but it didn't work (Bubola, 2006).

In 1870 Administrative Committee for Karst Reforestation was born; its purpose was to improve reforestation in the Municipalities over Karst plateu. In 1872, in Basovizza, was created a big nursery where trees were grown for 2-3 years before to be planted and, in the same time, a reforestation school was founded (Bubola, 2006).

In 1882 the Committee was substituted with the Commission for Karst Reforestation, financed by Trieste city and Austro-ungaric empire so that reforestation project took off involving local population as workers. Thank to 12 million of planted trees in that span of 40 years, Karst has now a luxuriant vegetation spread over a larger area respect to the original 18 black pine plants (Bubola, 2006).

Anyway, with passage of time wood has lost its central importance as everyday use and industrial material so that all black pine plants have not been managing anymore. As a consequence pine trees grew up, generated new litter and played an important protection function for other vegetation and young trees of different and more valuable species such as oak (*Quercus pubescens* Willd.), hornbeam (*Ostrya carpinifolia* L.) and ash (*Fraxinus ornus* L.); but no attention has been given to this natural ecologic succession, so that such simplified ecosystems of black pine on dry Karst soil left on their own evolution process has been facing, in the last decades, with some typical problems as fire risk during hot summer and pine Processionary moth (*Thaumatopea pityocampa* Den. & Schiff.) pest diffusion throughout old or not much viable even-aged trees populations.

Nevertheless black pine plants have not only been totally ignored and a minimal use of these trees as wood for energy has been always maintaining, even if just with low felling rate and only for local use, respect to what it could be done in this situation.
Now with new European political programs to foster promotion in the use of biomass for energy including raw material like forest biomass as well as wood chips and wood pellets, their importance is growing in the economical picture for every member states. In this contest potential role of black pine wood of Trieste area was analyzed in this thesis study.

1.2 TRIESTE KARST AREA

The name Karst come from the Indo-European word Kar which means “rock, stone”. It perfectly describes the calcareous skeleton that 30 millions years ago emerged from the sea as consequence of the collision of a piece of earth coming from the African plate which moved against the Euroasiatic plate. Karst is an anticlinal N-W/S-E oriented and it spreads over an area divided between Italy, Slovenia and Croatia. The part in question is the Italian one. It spreads north-west until Isonzo’s alluvium, north-east until Vipacco’s syncline, south-east to the natural border of Rosandra valley, whereas south-west it dives into Adriatic sea. Karst of Trieste has a surface of 140 km^2 and it is divided between 5 municipalities: Duino-Aurisina, Monrupino, San Dorligo della Valle-Dolina, Sgonico and Trieste.
Karst geologic composition strongly influence land morphology and vegetational patterns. Main features of Karst’s calcareous rocks are linked to dissolving phenomena with rain water. It models morphologic aspect of rocks creating solution flutes, solution grooves, solution pan and, more in a wide view, entire morphology over Karst plateau because water leaching in the deep permeable soil with formation of depressions (*doline*), holes (*foibe*), caves and underground water flows.
Three principal rock types belong to Karst’s geology: *Flysch*, an alternation between sandy, clayey and calcareous sediments; *Marlstone*, grey, breakable, clayey-calcareous rocks; *Sandstone*, sedimentary rocks formed with cementation of siliceous, clayey and calcareous sands (Bubola, 2006).
Karst’s rocks were formed during Cretaceous between 110 and 65 million years ago (environment with tropical features) as result of calcareous and dolomitic deposition in the sea. Then, between 65 and 40 million of years ago (Paleocene-Eocene) coastal marine environments became gradually deeper. In the Eocene (around 45 million years ago) sea water became more cloudy because of terrigenous debris (sand, lime and clay) originated

from earth lifting on the northern side. Thereafter, submarine falls produced accumulation of sediments at the base of the continental slope. In the Oligocene (30 million of years ago), the area that actually is occupied by Karst begun to emerge as consequence of the alpine and dinaric orogenesis (Cucchi, 2009).

Vegetation in the Trieste Karst area is also influenced by different geologic composition and climate regime along shore and the inner Karst plateau. In fact, the environment change passing from Mediterranean climate and flysch geologic formation where soil is almost powerful, with presence of the B horizon (Cambisols), to a region with more continental climate over calcareous plateau where soil is definitely thin and also more exposed to the inconstant wind (Bora) able to blow till 180 km/h. In this area soil is less thick and C horizon is nearby the top (Leptosols).

Along the hilly coast strip, between the sea and the beginning of the Karst-plateau slope, is possible to find the so called *maquis* shrubland, dominated by holm oak (*Quercus ilex* L.) and from typical shrub species as bay (*Laurus nobilis* L.), asparagus (*Asparagus acutifolius* L.) or ivy (*Smilax aspera* L.). Over drier and steeper slopes aromatic plants (Sage, Rosemary, Thyme, Savory etc), dominate the landscape with the endemic euphorbia (*Euphorbia characias* subsp. *wulfenii* Hoppe ex W.D.J. Koch).

Going inside trough the continent, nearby reforested areas of black pine, thermophile broad-leave trees have been growing driving up the formation of the typical karsik brush dominated by thermophile oak (*Quercus pubescens* Willd.), black hornbeam (*Ostrya carpinifolia* L.) and ash (*Fraxinus ornus* L.), then wig tree (*Cotinus coggygria* L.) dominates the underwood. Deforested lands, that during time have been managed for pasture activities, are now represented from a bare landscape with thorny scrubs like juniper (*Juniperus communis* L.) and (*Prunus Spinosa* L.), while dry meadow of *Sesleria* sp. are coloured with endemic flowers like little widow (*Globularia cordifolia* L.) and karsik thistle (*Jurinea mollis* L.). Last typical environment of this plateau is the so called dolina-wood, that grows on the cooler side of these depressions. Here can be found the white hornbeam (*Carpinus betulus* L.) and some particular flower like green hellebore (*Helleborus odorus* Willd.) or coralline peony (*Peonia mascula* L.) (Bubola, 2006).

1.3 BIOMASS FOR ENERGY

Energy underlies the existence of societies and human activities. The way by which it is produced or how do energy production plants work, plays a fundamental role in the management of a country. Great importance must be given to both socio-economical and ecological aspects in order to fulfil a balanced and sustainable development.

In last decades member states has been giving more importance to two aspects of the energy issue: independency (in terms of energy recruitment) and reduction of pollution (particularly greenhouse gases-GHG, emissions). Both these two objectives could be reached fostering the production of energy coming from Renewable Energy Sources (RES). In fact, it is what has been made with specific programs developed by the European Commission (EU).

Among renewable energies, bioenergy comes from biological material using various transformation processes such as combustion, gasification, pirolysis or fermentation (AEBIOM, 2012).

Basic material that feeds bioenergy production is generally named biomass. Biomass originates from forest, agricultural and waste streams. Forest and wood-based industries produce wood and derived products (by-products or residues) which are the largest resource of solid biomass (AEBIOM, 2012).

Biomass is the fourth energy source of the world, after coal, oil and natural gas. It represents 14% of energy requirements of the planet (Parikka, 2004). Among biomasses for energy, wood is the principal element and it generally represents the highest amount of renewable energy consumed all over the world, its demand is increasing (FAO, 2011) and it is estimated that of the total domestic fuel wood needs, around 70% in the rural area and 35% in the urban areas are being met from fuel wood (Rai and Chakrabarti, 1996). In Europe it ranges from 97,46% in Estonia to just 12,87% in Cypro of total renewable energy consumed. Looking on a wider view, woody biomass is really important energy source in almost all developing countries. In Burkina Faso and Niger, nearly 90% of the harvested wood (19,2 million m^3 in 2005) is destined for fuelwood, and demand is increasing (Montes et al., 2009). Rural communities in the Sahelian and Sudanian ecozones of West Africa use many native tree species for fuelwood (Faye et al., 2011). As well in India the demand for firewood has grown faster than the supply, particularly in the eastern Himalayan region (Bhatt and Sachan, 2004). Generally wood plays an important role in terms of thermal energy production, and now, thank to implementation of cogeneration technologies, it plays an important role also in the field of electricity production.

Focusing on the European contest, last data about energy sources consumption are strictly related to the difficult economic situation, which began in 2007. Among a lot of legislative acts fostered by the Council and the European Parliament in order to overcome the crisis, one of the most important theme considered is the issue about energy supply. The so called Third

Legislative Package of the energy domain, adopted in July 2009, contains several regulations and directives aiming at improving the functioning of the European internal energy market, focusing more on the problem of electricity and gas.

Furthermore, in April 2009 a Directive (2009/28/EU) on the promotion of the use of RES was adopted. In May 2010 a recast of two other directives was adopted: the Directive (2010/30/EU) on indication by labelling and standard product information of the consumption of energy related resources and the Directive (2010/31/EU) on the energy performance of houses.

All these directives reflect the growing importance given to energy production efficiency. Already in 2008 an increase by 5,6% in the consumption of RES was recorded: they represent the fifth energy source for EU after oil, natural gas, solid fuels and nuclear energy. In the same year also a low increase of gas consumption (1,9%) was recorded, while oil and nuclear consumption remained stable. Instead solid fuels (fuelwood and charcoal are not comprised because they are renwable) showed a significant drop compared to previous year (-7%) (EU Annual report, 2011).

Currently the European Energy Outlook 2012, drown up by the European Agency for Biomasses (AEBIOM) brings out following important data related to biomasses; they represents (AEBIOM, 2012):

- 8,16% of the total final energy consumption in Europe in 2010. Total gross inland consumption of RES in EU27 was almost 152 Mtoe in 2010, from which 118,22 Mtoe was biomass;
- 12,90% of the total heat demand in Europe is covered with biomass. Heating with biomass represent more than 93% of all renewable heat production in Europe;
- Bioelectricity cover 16,85% of all the demand of electricity form RES in Europe. The cogeneration share was more than 63,59% of all electricity produced with solid biomass in 2010;
- The production of wood pellets in EU increased by 20,5% between 2008 and 2010, reaching 9,2 million tons in 2010. 3,2 million tons of pellet production with the ENplus quality certification in 2012;
- 13,2 Mtoe of biofuels consumed in the transport sector in Europe in 2010. Biofuel is the main biofuel in Europe transport with a 78% share of total consumption;

As a result of the EU polices, the bioenergy represents the major source among RES in Europe by accounting for 64% and by showing steady growth patterns across the different market segments. Moreover share of renewable energy is on rise, from 6% of total gross inland energy consumption in 2000 to 10% in 2010.

1.4 FUELWOOD PROPERTIES

As it is highlighted in the previous chapter, bioenergy plays an important role in the field of heat and energy production, and in this contest wood is the principal raw material utilized.
High amount of wood is used directly for heating production all over the world. Focusing on European situation, new type of woody material, such as wood chips and wood pellets, are becoming more important in the market both for energy efficiency and more convenient way to be conserved and transported.
There are several broad categories of combustion applications:

- heat for daily living use (stoves, few kW; and boilers, up to 500 kW); community applications including district heating which actually cover 10% of total heat demand in Europe; (Sims, 2004; AEBIOM 2012);
- industrial use for both process heat and electricity production (combined heat and power, CHP) in the pulp and paper and forest processing industries (Sims, 2004);
- the production of electricity (Sims, 2004).

In 2011 more than 1,5 Million pellet stoves are installed for heating purposes in Europe with the biggest market in Italy (over 1.100.000 units installed) (AEBIOM, 2012). Everyone of these systems listed above is more efficient if the wood fuel used has good characteristics in terms of heating value. Heating value is related with physical and chemical properties such as moisture content, ash content, density and composition of the woody material. In particular, related to moisture content, high attention has to be made during harvesting-comminution-delivering processes. Depending on which is the final desired product and where has to be delivered and whether raw material comes from a forest or from a plantation; different decisions will be taken about tree species, felling cycle, harvesting systems and machines utilized (Sims, 2004).
It's fundamental to keep in mind that heat produced with wood combustion comes from burning of gases that originate from the degradation of lingo-cellulosic elements (CHO polymers), so the higher the moisture content (both free water and bound water) the worse the heating power, due to the fact that lot of energy is dispersed to evaporate water instead of generating heat.

Wood is an igroscopic and anisotropic material mainly made of hydrocarbon molecules. Cellulose fibres, xiloglucans and extensine are the main constituents of the primary cell wall, while lignin, cutin, suberin and mineral salts are the basic constituents of secondary cell wall (Longo and Marziani, 2005). Different type of wood refers to different percentage content of their components and how they are spatially organized. All these aspects explain differences in wood energetic and physical properties.

Energetic power of wood is measured as the amount of thermal energy produced with combustion (in joules) for unit of mass (in kg) and its name is Calorific Value.

Calorific value is an important indicator of fuelwood quality: it depends on the chemical composition, moisture content and ash producing compounds in the wood (Montes et al. 2011). Many studies have been carried out in order to find out correlations between calorific value and tree growth properties or environmental variables (Montes et al., 2011; Montes et al., 2012; Kumar et al., 2010).

There are two types of calorific value: *gross calorific value* and *net calorific value*.

Gross calorific value (GCV) is the amount of heat [kJ/g] produced from the combustion of 1 kg of material, considering, in the product of the combustion, the water at a liquid status (15°C); whereas net calorific value (NCV) is the amount of heat [kJ/g] produced from the combustion of 1 kg of material, considering, in the product of the combustion, the water at a vapour status (100°C) (Giordano, 1980; Hellrigl, 2004).

So, values of NCV are always lower than that of GCV because NCV refers to fresh material, otherwise it must be also taken into account that the water produced from combustion doesn't come only from free or bound water in wood cells or cell-walls, but a certain amount comes from oxidation of hydrogen bound in the wood components. This amount is valuated with a mean value of 6% of the whole wood mass (Hellrigl, 2004).

Fuel wood index (*FVI*) is an important index used to evaluate heating value of different types of wood (Sotelo Montes, 2011): it is measured with a mathematical equation where it is directly proportional with density (*Den*) and net calorific value (*NCV*) and inversely proportional with ash content (*AC*) and moisture content (*MC*):

$$FVI = \frac{Den * NCV}{MC * AC}$$

1.4.1 Heating Value

GCV at constant volume is the absolute value of the specific energy of combustion, in joules, for unit mass of solid biofuel burned in oxygen in a calorimetric bomb under the conditions specified.

The products of combustion are assumed to consist of gaseous oxygen, nitrogen, carbon dioxide and sulphur dioxide, of liquid water (in equilibrium with its vapour) saturated with carbon dioxide under the conditions of the bomb reaction, and of solid ash, all at the reference temperature.

According to the UNI EN 14918 “Solid biofuels - Determination of calorific value” proposed by CEN – Comité Européen de Normalisation (European Committee for Standardisazion) GCV is obtained as follow: a weighed portion of the analysis sample of the solid biofuel is burned in high-pressure oxygen in a bomb calorimeter under specified conditions.

The effective heat capacity of the calorimeter is determined in calibration experiments by combustion of certified benzoic acid under similar conditions, accounted for in the certificate. The corrected increment of the temperature is established from observations depend on the type of calorimeter used. Water is added to the bomb initially to give a saturated vapour phase prior to combustion, thereby allowing all the water formed, from the hydrogen and moisture in the sample, to be regarded as liquid water.

The gross calorific value is calculated from the corrected temperature rise (change in calorimeter temperature cause solely by the processes taking place within the combustion bomb) and the effective heat capacity of the calorimeter, with allowances made for contributions from ignition energy, combustion of the fuses and for thermal effects from side reactions such as the formation of nitric acid. Furthermore, a correction is applied to gaseous sulphur dioxide, i.e. the required reaction product of sulphur in the biofuel. The corresponding energy effect between aqueous and gaseous hydrochloric acid can be neglected due to the usually low chlorine content of most biofuels (induce correction value low).

NCV at constant volume/pressure is the absolute value of the specific energy of combustion, in joules, for unit mass of the biofuel burned in oxygen under conditions of constant volume/pressure and such that all the water of the reaction products remains as water vapour (at 0,1 MPa), the other products being as for the gross calorific value, all at the reference temperature (25°C).

The Net Calorific Value at constant volume and the net calorific value at constant pressure of the biofuel are obtained by calculation from the gross calorific value at constant volume determined on the analysis sample. The calculation of the net calorific value at constant volume requires information about the moisture and hydrogen contents of the analysis sample. In principle, the calculation of the net calorific value at constant pressure also requires information about the oxygen and nitrogen contents of the analysis sample.

1.4.2 Ash Content

According to the EN 14775:2009 “Solid Biofuels - Determination of ash content”, ash content on dry basis is defined as the mass of inorganic residue remaining after ignition of a fuel under specified conditions expressed as a percentage of the mass of the dry matter in the fuel. The ash content is determined by calculation from the mass of the residue remaining after the sample is heated in air under rigidly controlled conditions of time, sample weight and equipment specifications to a controlled temperature of (550 ± 10) °C.

As already verified in many studies the higher the ash content the lower is the calorific value (Kumar et al. 2010, Sotelo Montes et al., 2011). Except for oxygen, the major components of wood ash are calcium (Ca), potassium (K), magnesium (Mg), silicon (Si), aluminium (Al), iron (Fe) and phosphorus (P) (Stenari et al., 1999); then also micronutrients such as arsenic (As), barium (Ba), boron (B), cadmium (Cd), copper (Cu), chromium (Cr), silver (Ag), molybdenum (Mo), mercury (Hg), nickel (Ni), vanadium (V) and zinc (Zn) can be present (Booth et al. 1990). Instead, ash is generally very low in nitrogen (N) and sulphur (S) content because they are vaporised during combustion. Related to its rich composition, possibilities and risks related to ash recycling on forest soil have been deeply analyzed from Karltun et al. (2008) in terms of effects on pH, microbiological processes and tree physiology, morphology and biochemical status. An interesting result brought out is that ash has an alkaline reaction (liming effect) and when mixed with water the pH of the solution becomes high.

1.4.3 Particle Density

According to the EN 15150:2011 “Solid Biofuels – Determination of particle density”, particle density of compressed fuels such as pellets or briquettes is not an absolute value. As a consequence, the conditions for its determination have to be standardized to enable comparative determinations to be made.

Both mass and volume of an individual particle or a group of particles are determined. The volume is measured by determining the buoyancy in a liquid. This procedure follows the physical principle that the buoyancy of a body is equal to the weight of the displaced volume of a liquid. The apparent loss in weight between a measurement in air and a subsequent measurement in liquid marks its buoyancy. The volume of the sample body is calculated via the density of the applied liquid. Liquid applied is a mixture of water with low content of ions (distilled water) and a detergent known with the name of Triton-X which density value at 20 °C is 1,07 g/l. Presence of this detergent in the solution allows that air trapped in the wood pores is quickly removed before the wood begin to absorb water when samples are submerged.

Apparatus for pellet testing consist in a balance, which has sufficient accuracy to determine the weight to the nearest 0,0001 g, a transparent beaker glass of about 200 ml filling volume and a density determination rig which can be placed on the balance. The rig consists of a bridge which overstretches the weighing plate of the balance in order to prevent the balance from being loaded. The bridge is capable of carrying the beaker glass. Through a supporting frame with suspension rods a weighing dish ("submergence dish") is hung into the beaker glass (Figure 1.1) which is filled with liquid. The dish shall be able to accommodate at least four pellets at once. Both, the supporting frame and the submergence dish are directly loaded on the balance plate. The submergence apparatus (the dish and the suspension) can be removed for being loaded with pellets. Through the dish suspension, the submergence depth is always kept constant. The bottom of the submergence dish is perforated by openings which are smaller in diameter than the diameter of the pellets. This perforation allows the liquid to fill the dish from underneath when it is submerged. If sample material of low density shall be applied (below 1,0 g/cm^3) a modified suspension having an inverted submergence dish is required; this is to force the pellets underneath the liquid surface and prevent them from floating atop of the liquid. For the determination of the mass in air it is useful to use a combined test rig where an additional upper weighing dish is fixed to the suspension (Figure 1.1).

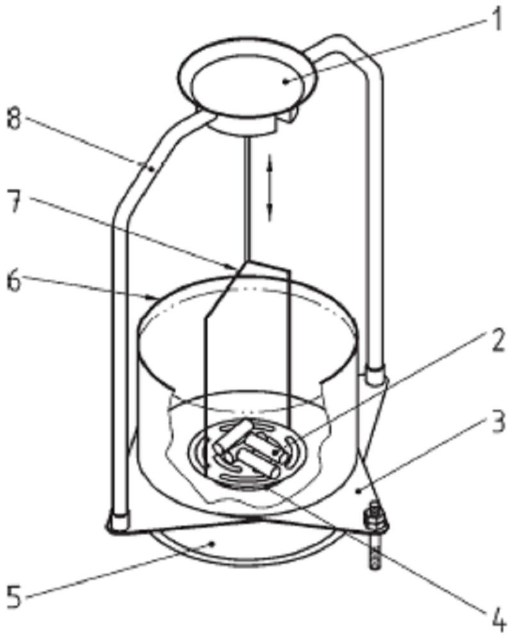

Figure 1.1 : Buoyancy determination rig on a balance (method for pellets) (EN 15150:2011)

Key

1 weighing dish (weighing in air)

2 pellets

3 bridge

4 perforated submergence dish (weighing in water)

5 weighing plate (balance)

6 beaker glass

7 dish suspension

8 supporting frame

1.4.4 Moisture Content

According to the EN 14774-3:2009 "Solid Biofuels – Determination of moisture content-Oven dry method – Part 3 : Moisture in general analysis sample", the analysis sample of biofuel is dried at a temperature of (105 °C ± 2) °C and the moisture content is calculated from the loss of mass of the test sample. In this method moisture content is reported on an *as analyzed basis*.

1.5 AIMS

Black pine has historically led the restoration of degraded environments in Trieste area, preparing better conditions for other species. Increasing knowledge of its fuel and growth properties can help decision makers to manage pine utilization as biomass resource in terms of heating value related to different environmental sites or age or part of the plants.

As a consequence, the main goal of this thesis is to evaluate the fuel properties of black pines located in the Trieste area. As explained in the introduction this area is characterized by two principal different geologic environments: Karst plateau with soil type belonging to *leptosols* and flysch low land with soil type belonging to *cambisols* (according to FAO soil classification, 2006).

Other important environmental variables are linked to them: the former is more exposed to wind flow, has a lower mean temperature (a difference of 1-2°C) and higher amount of rainfall; while the latter is more protected from wind, has higher temperature and lower rainfall amount.

2. MATERIALS AND METHODS

Pinus nigra subsp. *nigra* var. *nigra* J.F. Arnold was the target of this thesis study.
Data for growth properties analysis and samples for fuel-wood properties tests have been collected in the two sample areas with the same methodology and the same instruments.

2.1 STUDY LAYOUT

Data and samples' increments were collected during last two weeks of October 2012 with fair weather conditions. Samples' tests were carried out during November and December 2012 in the Biofuel laboratory (ABC laboratory) of the Land, Environment, Agricolture and Forestry Department of Padua University.
The main analysis of this study focuses on black pine's growth and fuel properties. In particular, it highlights presence of significance variations of these properties between two sites and if there are significant correlation among these properties within and between sites.
Data's collection and analysis methodology are deeply described in the following chapters.
In Table 1.1 are reported all fuel and growth variables used in this study to characterize pines' morphology and fuel properties in two different sample areas.
Two sample areas were chosen according to the two principal different soil condition of Trieste (leptosols and cambisols).

Table 1.1 : Growth- and fuel- variables analyzed on black pine's sample coming from two different sample areas of the Trieste province

Variable	Unit	Name
UpBD	cm	Upper Bark Diameter
UnBD	cm	Under Bark Diameter
BaTh	cm	Bark Thickness
h	m	Height
GCVd	MJ/kg	Gross Calorific Value on dry Basis
NCVd	MJ/kg	Net Calorific Value on dry Basis
AC	%	Ash Content
MC	%	Moisture Content
Den	g/cm^3	Density
FVI	-	Fuel Value Index

2.2 COLLECTION OF DATA

All data collected in the field are reported in the ANNEX I. In both sample areas 4 trees for each diameter class of 25, 30, 35, 40 cm have been chosen, therefore a whole amount of 16 trees per sample area. Trees had to be viable, without defects nor infections and not placed on a particular site (such as the bottom of depressions or over rocky blocks).

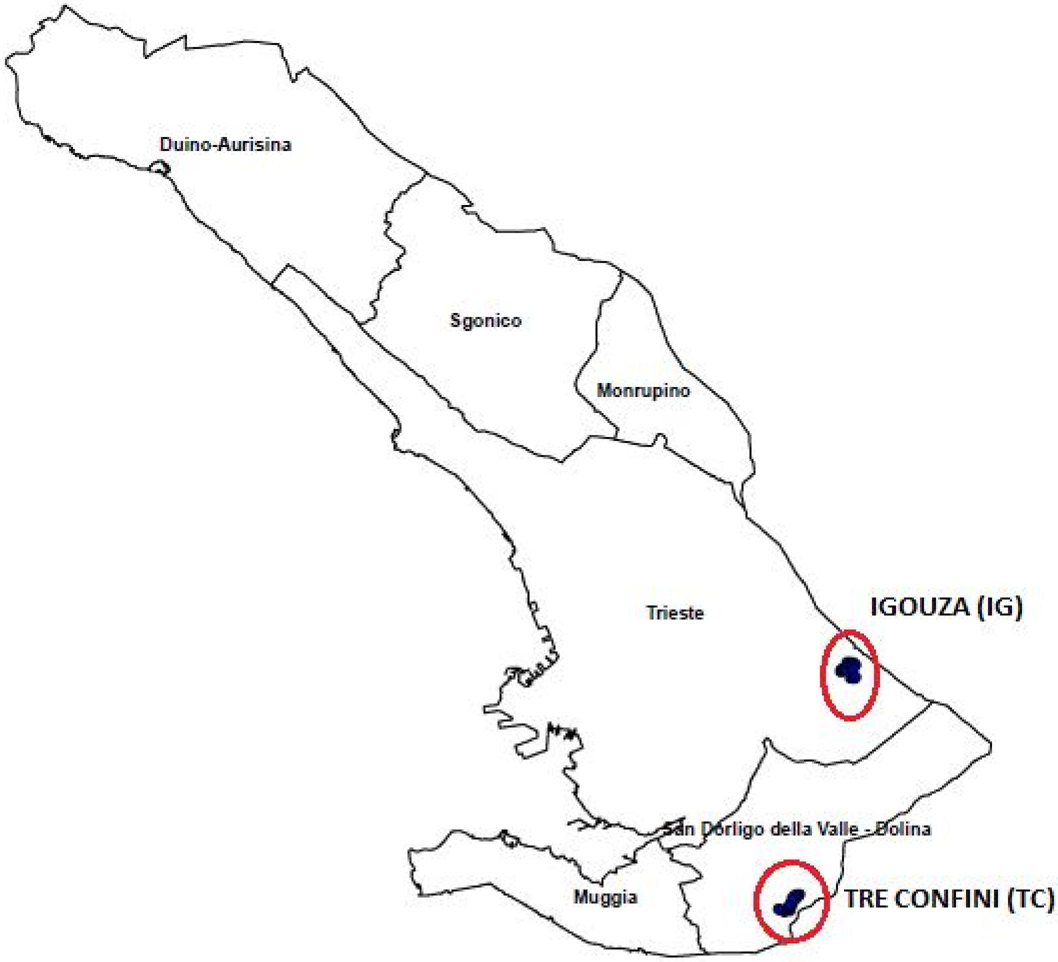

Figure 2.1 : Two sample areas of Igouza (IG) and Tre Confini (TC) in the Trieste province. Blue points represents GPS position of trees in the two areas.

For each tree, under bark diameter (*UnBD*) and upper bark diameter (*UpBD*) were recorded using a diameter tape, bark thickness (*BaTh*) was recorded using a small rule; trees' height (*h*) and terrain slope were recorded with a SUUNTO clisimeter; age of the trees was determined counting the rings of a wood core extracted from the bottom of the stem with a Pressler's borer. Finally elevation and geographic position were recorded with a hand field GPS device (GARMIN 60 CSx).

At the same time samples of bark (BA), branches (BR) and wood (W) have been collected in nylon bags, properly signed afterwards. Pieces of bark were taken at the height of 1,30 m on two opposite sites of the tree's diameter, so later was possible to measure the under bark diameter. Because of the technical difficulty of reaching the insertion height of the branches, dead residues of branches left on the ground from last thinning were taken as sample.

This action has to be taken in to account because of alteration processes due to fungi degradation: they alter original wood composition and heating value of branches. Of course it represents a constant error that doesn't influence analysis within site. Diversely when two sites are compared as the time of last thinning is not known.

Finally 4 wood cores were bored on the 4 exposition sides (N, S, E, W) on the base of the stem using a Pressler's borer. Extraction of 4 cores from the 4 different cardinal points excludes the possibility that asymmetric growth of the stems (with consequent asymmetric distribution of compression wood) may influence fuel variables' values that will be analyzed, such as gross calorific value.

Such kind of sampling for density analysis represent a less invasive and more fast method respect the traditional one which require a wood disc 2 cm thick (UNI EN 14150). Nevertheless its significance of acceptable representativeness has still to be verified by ongoing studies.

Trees of the same sample area had to be at least 50 m far each other.

2.2.1 Studied area "Igouza Wood"

Igouza wood is located over a flat plane on the Karst plateau in the municipality of Basovizza. Mean elevation is about 388,8 m a.s.l, mean temperature is 11°C (Jen. 1,5°C ; Jul. 20,6°C), and mean rainfall reach 1.239 mm (Meteorological station of Basovizza).

This forest is the result of the reforestation project begun at the end of the XIX century and then carried on. The major part of the trees has an age around 70-80 years, but there are some exceptions that are almost hundred-year-old, some groups of 50-60 years old and also new young individuals spread around from the original plantation area. As a consequence age's standard deviation of this site is quite high (± 15,08; Table 2.1).

New black pine individuals are able to spread around and win competition against other species thanks to their pioneer behaviour, in fact calcareous subsoil is just a few centimetres deep in the ground; soil is classified as Leptosols.

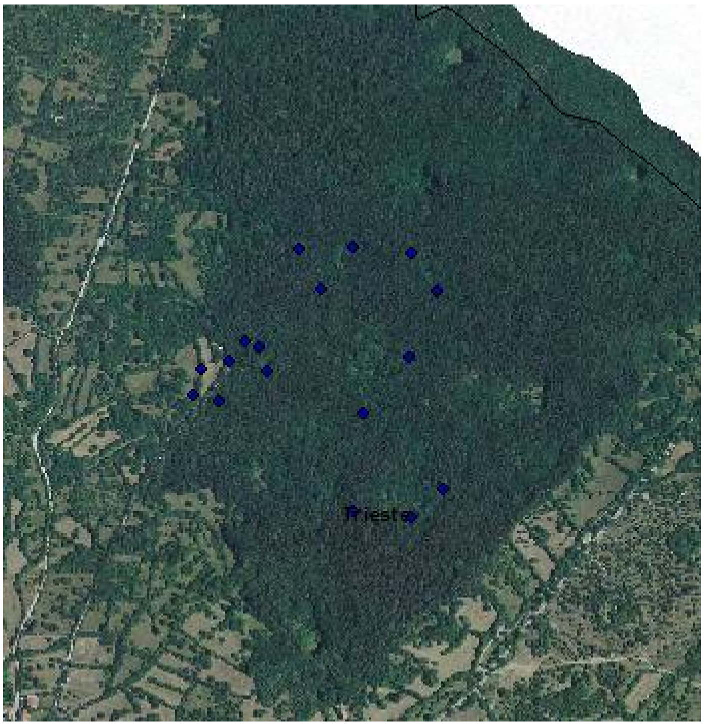

Figure 2.2 : GPS points of trees in Igouza wood

2.2.2 Studied area “Tre Confini Wood”

The wood named “Tre Confini” refers to a surface of 15,48 ha in the San Dorligo della Valle-Dolina municipality and is placed on a gentle slope (average: 20.6°) north oriented (azimuth:22°N) with a medium elevation of 175 m a.s.l. Climate data detected from the nearest meteorological station of “Trieste Porto” give mean temperature values of 14,5 °C (Jen. 3°C ; Jul. 24°C) and mean rainfall values of 1.025 mm.

The forest is principally composed from black pines (*Pinus nigra* J.F. Arnold) and oak (*Quercus pubescens* Willd.) forest. The former occupies 85% (13 ha) of the land. Medium age of pine trees is 56 years old, with a lower deviation respect Igouza’s trees (± 7,63; Table 2.1). It is a plantation realized after the Second World War: in the 50’s.

From a geologic point of view subsoil belongs to paleozoic flysch group, whereas soil is classified as Cambisols.

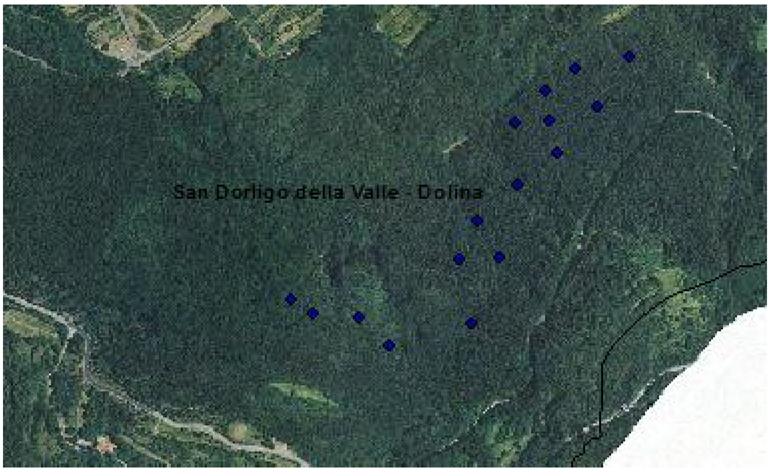

Figure 2.3 : GPS points of trees in Tre Confini wood

2.3 GROWTH PROPERTIES

Under bark and upper bark diameter values were recorded determining bark thickness' value too. This could be an index of site conditions: higher cork's thickness means that the plant has to overcome more difficult conditions like colder temperature, and less water availability. Instead, height is an index of the soil fertility (Susmel, 1956). Finally age, related to other parameters, can give indications of limiting factors along time.

In Table 2.1 are reported mean values and standard deviations of growth properties analyzed on the 16 sample-trees of the Igouza wood and Tre Confini wood.

Table 2.1 : Mean and Std. DV of growth variables in Igouza (IG) and Tre Confini (TC) test sites wood

		Igouza (IG)		Tre Confini (TC)	
Variable	*Unit*	*mean*	*std. Dev.*	*mean*	*std. Dev*
UnBD	cm	27,67	5,01	28,53	4,80
UpBD	cm	32,71	6,21	32,44	5,15
BaTh	cm	2,43	0,60	1,99	0,42
h	m	15,71	2,22	16,38	1,72
Age	y	73,50	15,08	56,44	7,63

2.4 FUEL PROPERTIES

Calorific value (*CV*) and ash content (*AC*) were analyzed for all sample collected while density (*Den*) and fuel value index (*FVI*) only for wood cores.

Sample preparation was managed concerning normative UNI EN 14780:2011 indications.

Combined samples were left in labour for two weeks in a nylon bag with holes to ensure air changing, so avoiding high humidity in the bag with consequent fungi proliferation that could alter the material.

Thereafter their size was comminuted using a cutting mill (RETSCH) for the preparation of the general analysis sample material (< 1mm).

General analysis samples were put in new signed nylon bags which were left opened and stored for other two weeks in labour to reach the labour's environment conditions. Thus samples were ready for fuel properties analysis.

Because of the short span of time to allow all samples to reach steady moisture condition, moisture content (MC), which could be an interesting fuel variable, was not analyzed in comparison tests, but it was measured only in relation to GCV measures to compute NCV necessary to calculate FVI.

2.4.1 Calorific Value

Three determination of gross calorific value were carried out for each sample in this thesis work in accordance with normative UNI EN 14918:2010 whose principle was presented in the previous chapter.

Three pressed sampled with a weight ranging 0,4 – 0,5 g were prepared with a manual sample press from the sawdust obtained from the milling process for each collected sample.

Weight was recorded to the nearest 0,1 mg and the value was written in the operative window of the bomb's software which calculates automatically the GCV being the bomb calorimeter directly connected to the labour's computer.

Therefore the pressed samples were placed in the apposite quartz crucible and connected to the ignition wire through a cotton fuse which length was measured and energetic dispersion taken into account for the calculation. One millilitre water was dropped into the bomb before being closed and saturated with oxygen at a pressure of 0,3 MPa. Every component of the bomb calorimeter was accurately cleaned before each trial.

Bomb calorimeter model IKA C200 was used, which is able to give back the correct value of GCV (Gross calorific value). Repeatability limit of 120 J/g between repetition of the same sample was observed.

General analysis samples were left to reach equilibrium with labour temperature and humidity (22°C; 20%) just for not enough time: two weeks for BA and almost one month for W. So that GCV on *as analyzed* basis (GCV_{ad}) was measured. For each measure moisture content (MC) of the same general analysis sample was also determined, so that GCV on dry basis (GCV_d) could be calculated with the following equation:

$$GCV_d = \frac{GCV_{ad}}{\frac{100-MC}{100}}$$

From GCV_d it is possible to calculate the net calorific value on dry basis (NCV_d) with the following:

$$NCV_d = GCV_d - 2{,}44 * 9 * \%H$$

where: 2,44 MJ/kg_{H2O} is the water's latent heat of vaporisation, 9 is the weight of half molecule of water originated from the oxidation of one hydrogen atom and *%H* is the percentage of hydrogen. Generally the value of this percentage is not far from 6% (Hellrigl, 2006) for every wood species, so that it's possible to write again the previous equation as:

$$NCV_d = GCV_d - 1{,}32$$

Values of GCV_d and NCV_d have been computed for bark (*BA*), branches (*BR*) and wood (*W*) of the two sample sites: Igouza (*IG*) and Tre Confini (*TC*). Table 2.2 highlights that mean values are respectively higher in IG samples and for both variables they have increasing values through BA, W and BR.

Table 2.2 : Mean Gross Calorific Value GCV_d and Net Calorific Value NCV_d in two sample sites of Tre Confini (TC) and Igouza (IG), evaluated for each origin of wood (W), bark (BA) and branches (BR)

	GCV_d		NCV_d	
	IG	TC	IG	TC
	MJ/kg	MJ/kg	MJ/kg	MJ/kg
BR	21,96	21,79	20,64	20,47
BA	21,48	21,34	20,16	20,02
W	21,59	21,48	20,27	20,16

2.4.2 Ash Content

Three determinations of ash content were carried out for each sample in this thesis work in accordance with normative UNI EN 14775:2009 whose principle was presented in the introduction.

Empty dishes, made of porcelain, were heated in the furnace to (550±10)°C for at least 60 min, then removed for 3 min over a resistant plate and cooled to ambient temperature in a dessicator with dissecant.

When dishes were cool, were weighted with samples' sawdust to the nearest 0,1 mg and mass was recorded. Twelve dishes could be handled at the same time, that means 4 samples because 3 repetition for each sample were managed.

The general analysis sample were mixed carefully before weighing. Minimum 1g of sample was placed on the bottom of the dish and spread in an even layer over the bottom surface.

Dish plus the sample were weighted to the nearest 0,1 mg and the mass recorded. Dishes filled with test samples were oven-dried for all the night (minimum 8 hours) at 105 °C and then weights were recorded. Thereafter samples were burned according to the following routine:

- Raise the heating plate temperature evenly to 300°C over a period of 30 min to 50 min (i.e. a heating rate of 4,5°C/min to 7,5°C/min). Maintain at this temperature level for 60 min to allow the volatiles to leave the sample before ignition;
- In the furnace, continue to raise the temperature evenly to (550 ± 10) °C over a period of 30 min (i.e. a heating rate of 10 °C/min). Maintain at this temperature level for at least 120 min.

At the end of this time dishes with their contents were removed from the furnace and cooled in the same way illustrated at the beginning of the procedure (when dishes were empty). So, samples were weighted and mass recorded.

The ash content on dry basis A_d of the sample expressed as a percentage by mass on a dry basis were calculated using the following formula:

$$A_d = \frac{(m_3 - m_1)}{(m_2 - m_1)} * 100 * \frac{100}{100 - M_{ad}}$$

where:

m_1 is the mass, in g, of the empty dish;

m_2 is the mass, in g, of the dish plus the test sample;

m_3 is the mass, in g, of the dish plus ash;

M_{ad} is the % moisture content of the test sample used for determination.

The result was reported as the mean of duplicate determinations to the nearest 0,1 %.

Table 2.4 shows that ash content follows the same pattern in both sites with higher values in TC wood; values increase throughout W, BA and BR:

Table 2.3 : Mean ash content (AC) in the two sample sites of Tre Confini (TC) and Igouza (IG), evaluated for each origin of wood (W), bark (BA) and branches (BR)

	IG	TC
	%	%
BR	2,40	2,57
BA	1,42	1,66
W	0,33	0,37

2.4.3 Wood Density

Particle density measurement for pellets were used to determine density value of wood cores sampled in the two analyzed sites of Tre Confini (TC) and Igovza (IG).

Each core was removed from the bark and divided in four parts. Each part was submerged and density was measured for each single part.

Mean density value was calculated for each core afterwards, not as the average of the four densities but reloading the calculation as if it was done directly for the whole core. Actually this methodology is not the proper one when measuring wood density because it doesn't take into account the variability of density that the analyzed tree could have on radial gradient or along its height.

Nevertheless a study that is on work in the same labour will detect if there is a statistical difference in assuming the density value of a single core as representative of the whole plant.

To achieve a proper measurement, beaker glass was filled with water to a level that ensured full submersion of samples. Detergent Triton-X was added with a concentration of 1,5 g/l.

In this case 500 ml of distilled water with 0,525g of Triton-X were stirred with a magnetic stirring device until full homogeneity. Later, the beaker was positioned onto the bridge of the balance, and the empty submergence apparatus with an additional iron wire to fix samples, was positioned onto the designated bracket of the supporting frame. Weighting measures in air and in liquid were recorded to the nearest 0,1 mg referring to the same tare for each sample. The reading of the weight in liquid took place immediately after submersion in order to prevent them from uptake any liquid or from decay. The reading was conducted within the first 3 to 5 s when the displayed value on the balance was relatively constant.

Calculation was computed with the following equation:

$$\rho_M = \frac{m_a}{m_a - m_l} * \rho_l$$

where:

ρ_M is the density of wood cores at the given moisture content *M*, in g/cm³

m_a is the mass of the sample in air (including sample moisture), respectively, in grams

m_l is the mass of the sample in liquid (including sample moisture), in grams

ρ_l is the density of the applied liquid, in g/cm³. Its value is already recorded in literature as 0,9958 g/cm³ (UNI EN 15150).

Table 2.4 : Mean density (Den) in two sample sites of Tre Confini (TC) and Igouza (IG), evaluated for wood (W) origin

	IG	TC
	g/cm^3	g/cm^3
W	0,72	0,71

2.4.4 Moisture Content

Three determination of moisture content were carried out for each general analysis sample in this thesis work in accordance with the UNI EN 14774-2:2009 which principle was presented in the introduction.

For each test sample an empty clean drying container of aluminium was weighed to the nearest 0,01 g. Samples were transferred from the bag to the drying container in a way that sawdust spread uniformly on the bottom of the containers, which were weighed another time. Then containers were left drying in the oven all night long, thus at least 8 hours at 105 °C of temperature and dry weight was recorded afterwards.

For each determination the moisture content, M_{ad}, in the analysis sample, as analysed, expressed as a percentage by mass, shall be calculated using the following formula:

$$M_{ad} = \frac{(m_2 - m_3)}{(m_2 - m_1)} * 100$$

where:

m_1 is the mass in g of the empty dish;

m_2 is the mass in g of the dish plus sample before drying;

m_3 is the mass in g of the dish plus sample after drying.

Results of duplicate determination were accepted when didn't differ more than 0,2%.

In table 2.5 is possible to observe another common pattern in result's values: they are respectively higher in TC samples following an increasing order through W, BR and BA.

Table 2.5 : Mean moisture content (MC) in two sample sites of Tre Confini (TC) and Igouza (IG), evaluated for each origin of wood (W), bark (BA) and branches (BR)

	IG	TC
	%	%
BR	10,12	10,99
BA	12,62	13,98
W	6,96	7,88

Different mean values of MC for origins are in accordance with time they were analyzed. In fact group of bark general analysis sample was the first instead group of wood was the last. This is due to the fact that there wasn't enough time to wait for complete equilibrium of the samples with labour's conditions.

So moisture values are used only to compute the calculation of NCV and FVI, but no comparison analysis has been carried out just for MC's values.

2.5 DATA ANALYSIS

2.5.1 Dataset

All data were collected and used for a descriptive and inferential statistics. Principal dataset can be consulted in the ANNEX II and ANNEX III, in which both values of growth and fuel properties are reported. These data were used to carry out some statistical analysis, but a previous filtering process to delete data which didn't fit on a normal distribution was carried out, therefore not all data presented were used in all analysis. All statistical analysis were realized with software STATGRAPHICS® Centurion XVI.

2.5.2 Statistical Analysis

Significance level of α = 0.05 was set for all tests. Data transformations were not considered necessary as the variables exhibited normal distributions, otherwise in some sample some outliers were detected and deleted in order to ensure normal distribution of samples before being tested. Normal distribution was considered when skewness and kurtosis of samples had values between -2 and +2 and Shapiro-Wilk test reached values for $p>0,05$. Outliers individuation was carried out with Grubb's test. Significance level in statistics is assessed to decide for which value of probability the null hypothesis can be accepted or rejected. Statistical null hypothesis defines that differences between sampled values and model values are null or that differences between two or more samples are null.

Significant difference between mean values of growth properties (*UnBD*, *UpBD*, *BaTh* and *h*) and fuel properties (*GCV*, *AC*, *FVI* and *Den*) in the two sites (TC and IG) was analyzed with t-test (test of Tukey, $p < 0,05$) whenever F-test was overcome, that means variance of two sample is considered the same ($p > 0,05$).

In case this condition was not satisfied, non parametric test of Mann Withman or Wilcoxon was applied (comparison of medians).

The same analysis were carried out for each origin (three tree's part: BA, BR and W) too.

Also significant difference among GCV and AC of different origins within and among site was analyzed with test of variance or ANOVA test. It was considered valid whenever standard deviations of samples didn't differ significantly in accordance with Levene's test ($p>0,05$), differently non parametric Kruskal-Wallis test (test of medians) was used.

Finally correlation within and between appropriate fuel and growth properties was tested for each origin depending on data available and their meaning respect different origins.

3 RESULTS

3.1 GROWTH PROPERTIES

Growth variables of upper bark diameter (*UpBD*), under bark diameter (*UnBD*), bark thickness (*BaTh*) and height (*h*) were compared between two sites. Significant differences of these values could reflect that environmental variables influence tree growth capacity and pattern respect to other factors, as could be genetic factors.
Results obtained for these four variables are reported in the following tables and graphs.

3.1.1 Two-Sample Comparison

For every two-sample comparison are reported following tables and figure:

- *Summary Statistics table*, with basic statistical information about two samples. Important to note are values of standardized skewness and standardized kurtosis: they don't have to beyond values of -2 and +2
- *Box-and-Whisker plot*, where distribution of two sample values can be visually compared
- *Comparison of Standard Deviation table*, where values of variances and their ratio is computed through F-test. Significance of F-test is important to allow parametric t-test be applied.

Bark Thickness – *BaTh*

Table 3.1 : Summary Statistics for BaTh (cm) in the two sample sites of Tre Confini (TC) and Igouza (IG)

	Unit	IG	TC
Count	N°	16	16
Average	cm	1,9875	2,425
Standard deviation	cm	0,419325	0,598331
Coeff. of variation	%	21,0981	24,6734
Minimum	cm	1,4	1,5
Maximum	cm	3,0	3,5
Range	cm	1,6	2,0
Stnd. skewness	-	**1,34817**	**0,266608**
Stnd. kurtosis	-	**0,805676**	**-0,637439**

Table 3.2 : Comparison of Standard Deviation for BaTh [Ratio of Variances = 0,49]

	Unit	IG	TC
Standard deviation	cm	0,419325	0,598331
Variance	cm	0,175833	0,358
Df	N°	15	15

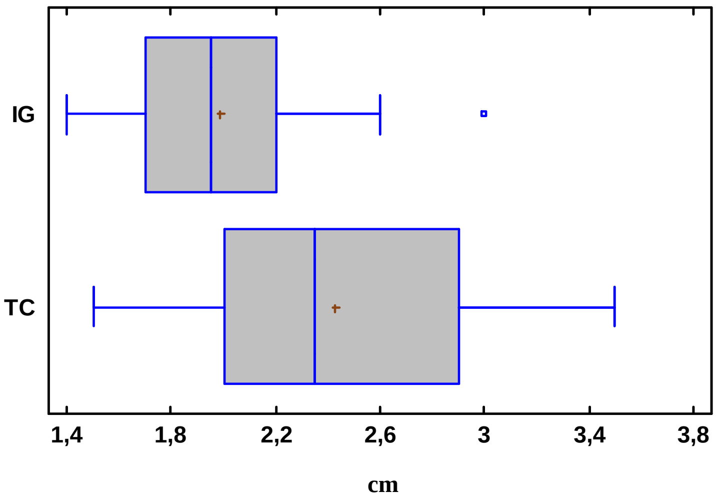

Figure 3.1 : Box-and-Whisker plot for BaTh (cm)

F-test to Compare Standard Deviations brings out following results: F = 0,49 P-value = 0,18. Because of P>0,05 the null hypothesis for α = 0,05 is not rejected. That means standard deviations of two sample are not considered statistically different, thus it is possible to compare their means with test of Tukey (t-test).

T-test's outcomes are: t = -2,39 P-value = 0,023. Because of P<0,05 the null hypothesis for α = 0,05 is rejected. As a consequence mean value of bark thickness in Tre Confini wood is significantly higher that that in Igouza wood.

Height – *h*

Table 3.3 : Summary Statistics for h (m) in the two sample sites of Tre Confini (TC) and Igouza (IG)

	Unit	IG	TC
Count	N°	16	16
Average	m	15,7125	16,375
Standard deviation	m	2,22317	1,72105
Coeff. of variation	%	14,1491	10,5102
Minimum	m	13,0	13,5
Maximum	m	20,0	19,3
Range	m	7,0	5,8
Stnd. skewness	-	0,910374	-0,018488
Stnd. kurtosis	-	-0,65224	-0,836569

Table 3.4 : Comparison of Standard Deviation for h (m) [Ratio of Variances = 1,66]

	Unit	IG	TC
Standard deviation	m	2,22317	1,72105
Variance	m	4,9425	2,962
Df	N°	15	15

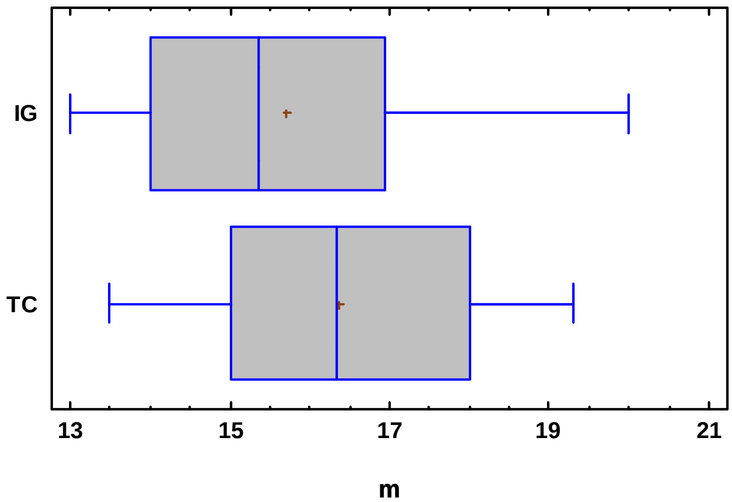

Figure 3.2 : Box-and-Whisker plot for h (m)

F-test to compare Standard Deviations brings out following results: F = 1,66 P-value = 0,33. Because of P>0,05 the null hypothesis for α = 0,05 is not rejected.

From t-test come out following results: t = -0,94 P-value = 0,35. Therefore the null hypothesis for α = 0,05, is not rejected. As a consequence it means that tree heights in two sites are not significantly different.

Under Bark Diameter – *UnBD*

Table 3.5 : Summary Statistics for UnBD (cm) measured at 1,30m in the two sample sites of Tre Confini (TC) and Igouza (IG)

	Unit	IG	TC
Count	N°	16	16
Average	cm	27,6687	28,525
Standard deviation	cm	5,00889	4,8034
Coeff. of variation	%	18,1031	16,8393
Minimum	cm	19,6	20,5
Maximum	cm	35,2	35,7
Range	cm	15,6	15,2
Stnd. skewness	-	-0,0281901	0,00422672
Stnd. kurtosis	-	-0,870264	-0,992274

Table 3.6 : Comparison of Standard Deviation for UnBD (cm) [Ratio of Variances = 1,08]

	Unit	IG	TC
Standard deviation	cm	5,00889	4,8034
Variance	cm	25,089	23,0727
Df	N°	15	15

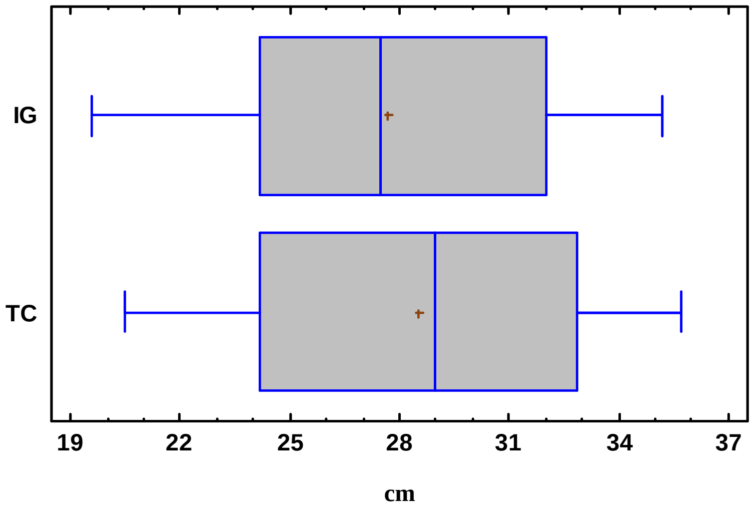

Figure 3.3 : Box-and-Whisker plot for UnBD (cm)

F-test to compare Standard Deviations gives following results: F = 1,08 P-value = 0,87. Because of P > 0,05 the null hypothesis for $\alpha = 0,05$ is not rejected.

From t-test come out following results: t = -0,49 P-value = 0,62. Therefore the null hypothesis for α = 0,05, is not rejected. As a consequence it means that tree under bark diameters in two sites are not significantly different.

Upper Bark Diameter – *UpBD*

Table 3.7 : Summary Statistics for UpBD (cm) measured at 1,30 m in the two sample sites of Tre Confini (TC) and Igouza (IG)

	Unit	IG	TC
Count	N°	16	16
Average	cm	32,7125	32,4375
Standard deviation	cm	6,21266	5,14832
Coeff. of variation	%	18,9917	15,8715
Minimum	cm	23,5	24,5
Maximum	cm	41,8	40,0
Range	cm	18,3	15,5
Stnd. skewness	-	-0,0460007	0,0883036
Stnd. kurtosis	-	-1,02285	-1,15718

Table 3.8 : Comparison of Standard Deviation for UpBD (1,30m) [Ratio of Variances = 1,45]

	Unit	IG	TC
Standard deviation	cm	6,21266	5,14832
Variance	cm	38,5972	26,5052
Df	N°	15	15

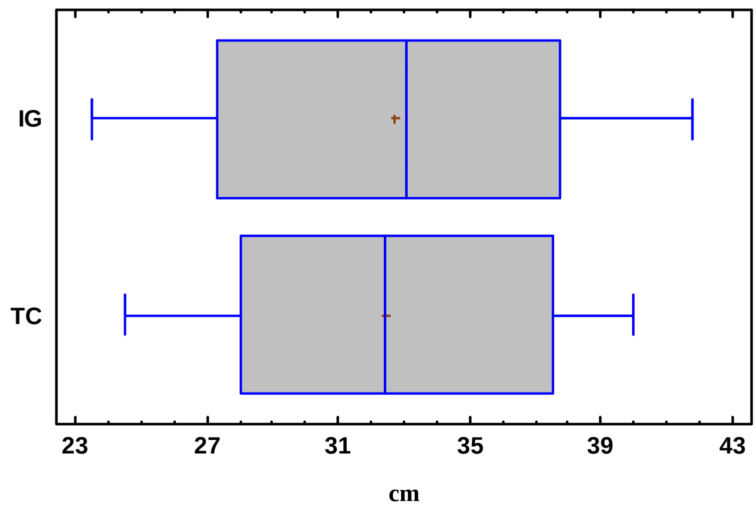

Figure 3.4 : Box-and-Whisker plot for UpBD (cm)

F-test to compare Standard Deviations highlights following results: F = 1,45 P-value = 0,475. Because of P > 0,05 the null hypothesis for $\alpha = 0{,}05$ is not rejected.

From t-test come out following results: t = 0,136 P-value = 0,892. Therefore the null hypothesis for α = 0,05 is not rejected. As a consequence it means that tree upper bark diameter in two sites are not significantly different.

In the summary table below (Table 3.9) the only significant difference of BaTh between two sites is highlighted with an * (P < 0,05).

Table 3.9 : Summary table of mean growth variables' results. P-value reported refer to a two-sample comparison between the same variable measured on two different sample sites (IG and TC)

Variable	Unit	*IG*		*TC*		*P-value*		Sig.
		Mean	SD	Mean	SD	t-test	W-test	
UpBD	*cm*	32,43	± 5,14	32,71	± 6,21	0,89		
UnBD	*cm*	28,52	± 4,8	27,66	± 5	0,62		
BaTh	*cm*	2,42	± 0,59	1,98	± 0,41	0,023		*
h	*m*	16,37	± 1,72	15,71	± 2,22	0,35		

3.2 FUEL PROPERTIES

Fuel variables of gross calorific value (GCV) and ash content (AC), were compared between two sites with two-sample comparison. Then the same analysis was carried out for each origin W, BA and BR.

Finally an *ANOVA* test was applied to compare fuel values of each origin within and between site. Instead values of density (Den) and fuel wood index (FVI), which are available only for wood origin (W), were tested only with two-sample comparison.

Significant differences of these values could reflect that environmental variables influence tree growth capacity and pattern respect to other factors, as could be genetic factors. Knowledge of such kind of relations may be useful to assess proper management plans in terms of forecasting heating capacity of wood respect time and location.

3.2.1 Two-Sample Comparison (general)

Gross Calorific Value on dry basis – GCV_d

Table 3.10 shows 47 number of increments for each sample instead of the complete number of 48. This is due to the fact that GCV_d of two increments (TC12W and IG14W) were not considered in the computation. TC12W was recognized as outlier with Grubb's test, while IG14W wasn't recognized as outlier from the Grubb's test, but its deletion allowed to accept the null hypothesis with F-test.

Table 3.10 : Summary Statistics for *GCV$_d$* (MJ/kg) in general two-sample comparison in the two sample sites of Tre Confini (TC) and Igouza (IG)

	Unit	IG	TC
Count	N°	47	47
Average	MJ/kg	21,6441	21,4748
Standard deviation	MJ/kg	0,638184	0,48079
Coeff. of variation	%	2,94853	2,23885
Minimum	MJ/kg	20,1117	20,2627
Maximum	MJ/kg	23,0885	22,6954
Range	MJ/kg	2,97682	2,43272
Stnd. skewness	-	0,265724	0,465084
Stnd. kurtosis	-	0,0626029	0,384698

Table 3.11 : Comparison of Standard Deviation for *GCV$_d$* in general two-sample comparison [Ratio of Variances = 1, 76]

	Unit	IG	TC
Standard deviation	MJ/kg	0,638184	0,48079
Variance	MJ/kg	0,407278	0,231159
Df	N°	46	46

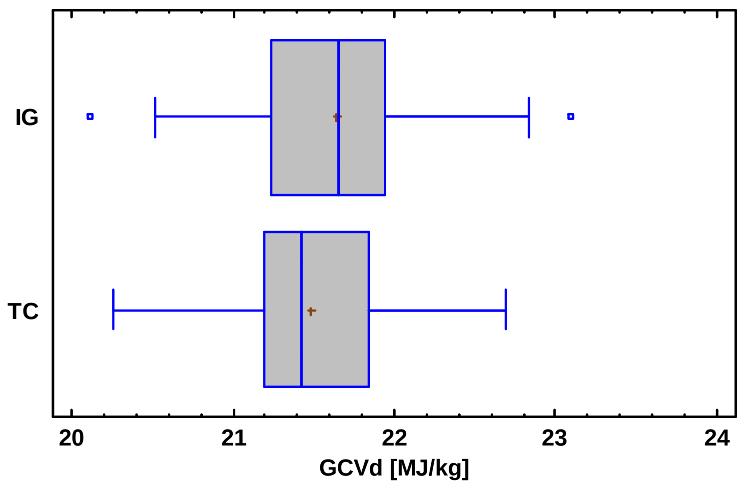

Figure 3.5 : Box-and-Whisker plot for *GCV$_d$* in general two-sample comparison

F-test to compare Standard Deviations highlights following results: F = 1,76 P-value = 0,057. Because of P > 0,05 the null hypothesis for $\alpha = 0{,}05$ is not rejected.

From t-test following results are obtained: t = 0,45 P-value = 0,14. Therefore the null hypothesis for α = 0,05 is not rejected. As a consequence it means that gross calorific value on dry basis in two sites is not significantly different.

Ash Content – *AC*

Table 3.12 : Summary Statistics for AC (%) in general two-sample comparison in the two sample sites of Tre Confini (TC) and Igouza (IG)

	Unit	IG	TC
Count	N°	48	48
Average	%	1,38143	1,53331
Standard deviation	%	0,915212	1,00913
Coeff. of variation	%	66,2511	65,8137%
Minimum	%	0,245073	0,230514
Maximum	%	3,50559	4,11378
Range	%	3,26052	3,88327
Stnd. skewness	-	0,854471	0,988816
Stnd. kurtosis	-	-1,34789	-0,857808

Table 3.13 : Comparison of Stadard Deviation for AC (%) in general two-sample comparison [Ratio of Variances = 0,82]

	Unit	IG	TC
Standard deviation	%	0,915212	1,00913
Variance	%	0,837613	1,01834
Df	N°	47	47

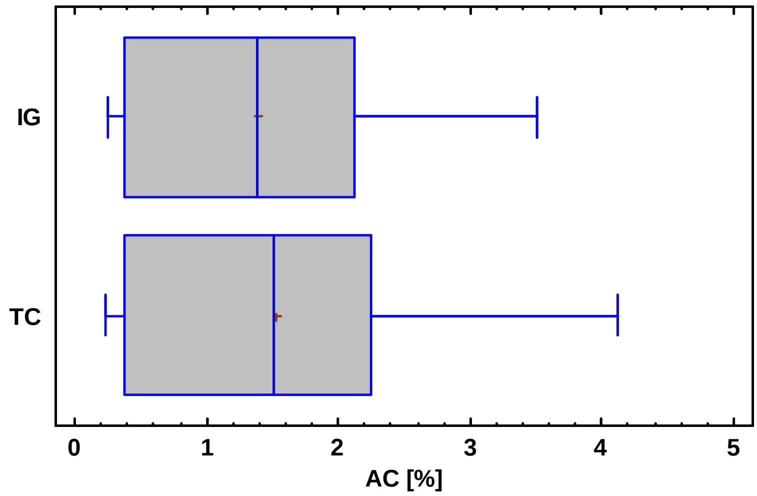

Figure 3.6 : Box-and-Whisker plot for AC in general two-sample comparison

F-test to compare Standard Deviations highlights following results: F = 0,822 P-value = 0,505. Because of P > 0,05 we do not reject the null hypothesis for α = 0,05.

From t-test following results are obtained: t = - 0,772 P-value = 0,441. Therefore the null hypothesis for α = 0,05, is not rejected. As a consequence it means that ash content in two sites is not significantly different.

In the summary table below (Table 3.14) no significant values are highlighted.

Table 3.14 : Summary table of mean fuel properties' results. P-value reported refer to a two-sample comparison between the same variable measured on two different sample sites (IG and TC)

Variable	Unit	*IG*		*TC*		*P-value*		Sig.
		Mean	SD	Mean	SD	t-test	W-test	
GCV_d	MJ/kg	21,64	± 0,63	21,47	± 0,48	0,14		
AC	%	1,38	± 0,91	1,53	± 1,00	0,44		

3.2.2 Two-Sample Comparison (by origin)

Wood (W)

Gross Calorific Value on dry basis – *GCV_d*

Table 3.15 : Summary Statistics for GCV_d (MJ/kg) in wood two-sample comparison in the two sample sites of Tre Confini (TC) and Igouza (IG)

	Unit	IG	TC
Count	N°	16	15
Average	MJ/kg	21,5904	21,2873
Standard deviation	MJ/kg	0,921951	0,536239
Coeff. of variation	%	4,27018	2,51906
Minimum	MJ/kg	20,1117	20,2627
Maximum	MJ/kg	23,3142	22,3023
Range	MJ/kg	3,20254	2,03962
Stnd. skewness	-	0,212407	0,160426
Stnd. kurtosis	-	-0,787176	-0,103453

Table 3.16 : Comparison of Standard Deviation for GCV_d (MJ/kg) in wood two-sample comparison [Ratio of Variances = 2,95]

	Unit	IG	TC
Standard deviation	MJ/kg	0,921951	0,536239
Variance	MJ/kg	0,849993	0,287552
Df	N°	15	14

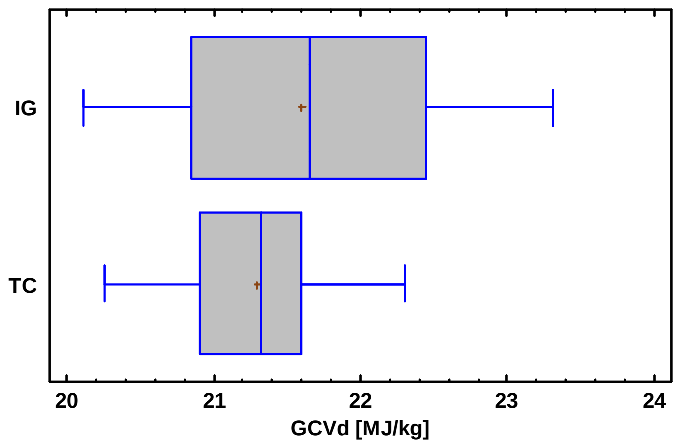

Figure 3.7 : Box-and-Whisker plot for GCV_d in wood two-sample comparison

F-test to compare Standard Deviations highlights following results: F = 2,955 P-value = 0,049. Because of P < 0,05 we reject the null hypothesis for $\alpha = 0{,}05$.

With this condition it's not possible to carry on with t-test to compare means. It's possible to compare medians with non-parametric Mann-Whitney (Wilcoxon) test. From this test we obtain W = 98,0 P-value = 0,395. This result allow to do not reject the null hypothesis for alpha = 0,05, and consider GCV_d of wood the same in two sites.

Ash Content – *AC*

Table 3.17 : Summary Statistics for AC (%) in wood two-sample comparison in the two sample sites of Tre Confini (TC) and Igouza (IG)

	Unit	IG	TC
Count	N°	16	14
Average	%	0,330606	0,336302
Standard deviation	%	0,0649638	0,0452339
Coeff. of variation	%	19,6499	13,4504
Minimum	%	0,245073	0,230514
Maximum	%	0,494493	0,409026
Range	%	0,24942	0,178512
Stnd. skewness	-	1,47784	-0,979623
Stnd. kurtosis	-	0,995404	0,864256

Table 3.18 : Comparison of Standard Deviation for AC (%) in wood two-sample comparison [Ratio of Variances = 2,06]

	Unit	IG	TC
Standard deviation	%	0,0649638	0,045233
Variance	%	0,0042203	0,002046
Df	N°	15	13

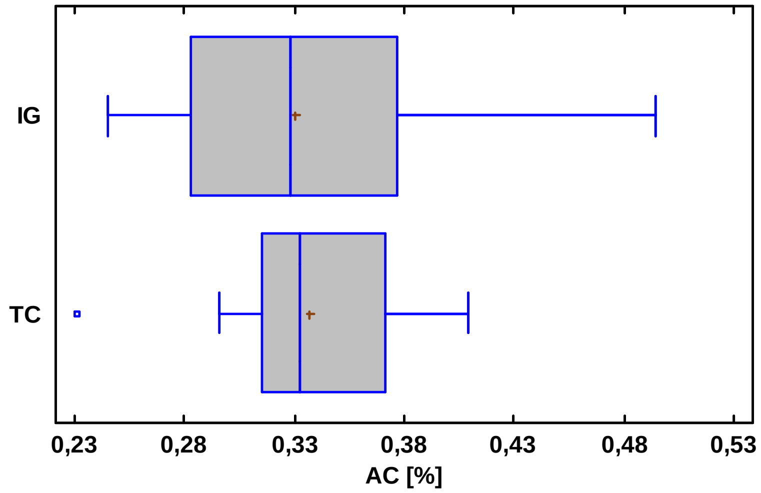

Figure 3.8 : Box-and-Whisker plot for AC in wood two-sample comparison

F-test to compare Standard Deviations highlights following results: F = 2,062 P-value = 0,197. Because of P > 0,05 we do not reject the null hypothesis for α = 0,05.

From t-test following results are obtained: t = - 0,274 P-value = 0,785. Therefore the null hypothesis for α = 0,05, is not rejected. As a consequence it means that wood ash content in two sites is not significantly different.

Density – *Den*

Table 3.19 : Summary Statistics for Den (g/cm3) in wood two-sample comparison in the two sample sites of Tre Confini (TC) and Igouza (IG)

	Unit	IG	TC
Count	N°	16	15
Average	g/cm^3	0,715518	0,713364
Standard deviation	g/cm^3	0,0343745	0,0735813
Coeff. of variation	%	4,80415	10,3147
Minimum	g/cm^3	0,654551	0,619594
Maximum	g/cm^3	0,766313	0,835921
Range	g/cm^3	0,111762	0,216328
Stnd. skewness	-	-0,677811	1,05528
Stnd. kurtosis	-	-0,800061	-0,714351

Table 3.20 : Comparison of Stadard Deviation for Den (g/cm³) in wood two-sample comparison [Ratio of Variances = 0,21]

	Unit	IG	TC
Standard deviation	g/cm^3	0,0343745	0,073581
Variance	g/cm^3	0,0011816	0,005414
Df	N°	15	14

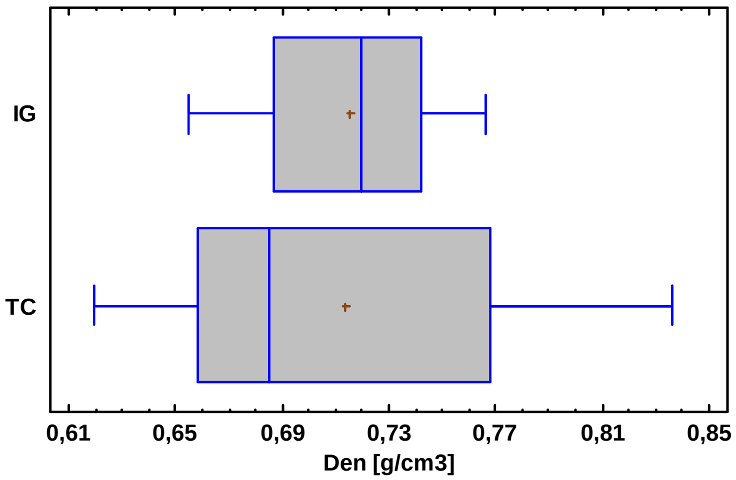

Figure 3.9 : Box-and-Whisker plot for Den in wood two-sample comparison

F-test to compare Standard Deviations highlights following results: F = 0,218 P-value = 0,0058. Because of P < 0,05 the null hypothesis for $\alpha = 0{,}05$ is rejected .

With this condition it's not possible to carry on with t-test to compare means. It's possible to compare medians with non-parametric Mann-Whitney (Wilcoxon) test. From this test we obtain W = 103,0 P-value = 0,51. Therefore the null hypothesis for α = 0,05, is not rejected. As a consequence it means that wood ash content in two sites is not significantly different.

Fuel Wood Index – *FVI*

Table 3.21 : Summary Statistics for FVI in wood two-sample comparison in the two sample sites of Tre Confini (TC) and Igouza (IG)

	Unit	IG	TC
Count	-	16	15
Average	-	6,6061	4,9764
Standard deviation	-	1,66951	1,19039
Coeff. of variation	%	25,2723	23,9207
Minimum	-	3,9634	2,9461
Maximum	-	10,0272	7,08174
Range	-	6,06377	4,13564
Stnd. skewness	-	0,433609	0,56662
Stnd. kurtosis	-	-0,376624	-0,0922553

Table 3.22 : Comparison of Standard Deviation for FVI in wood two-sample comparison [Ratio of Variances = 1,96]

	Unit	IG	TC
Standard deviation	-	1,66951	1,19039
Variance	-	2,78728	1,41702
Df	N°	15	14

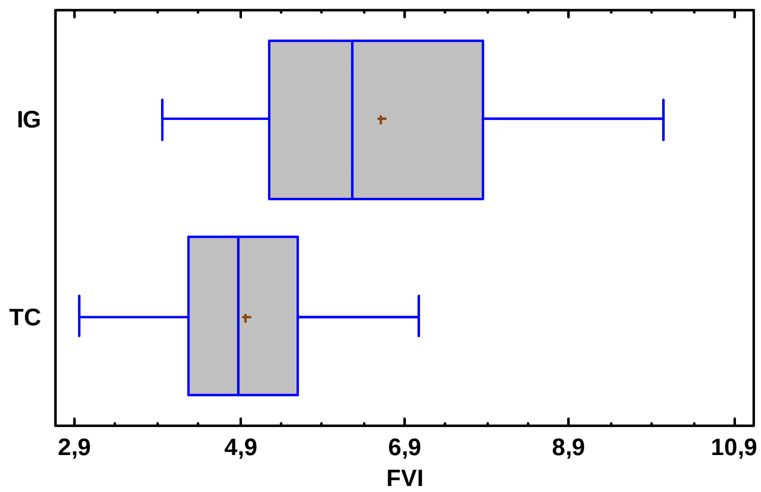

Figure 3.10 : Box-and-Whisker plot for FVI in wood two-sample comparison

F-test to compare Standard Deviations highlights following results: F = 1,96 P-value = 0,21. Because of P > 0,05 the null hypothesis for $\alpha = 0{,}05$ is not rejected.

From t-test following results are obtained: t = 3,11 P-value = 0,004, so the null hypothesis for α = 0,05 is rejected. As a consequence it means that wood FVI value in IG site is significantly higher that that in TC.

In the summary table below the only significant difference of wood's FVI between two sites is highlighted with an * (P < 0,05).

Table 3.23 : Summary table of mean wood fuel properties' results. P-value reported refer to a two-sample comparison between the same variable measured on two different sample sites (IG and TC)

W - Variable	Unit	*IG*		*TC*		*P-value*		Sig.
		Mean	SD	Mean	SD	t-test	W-test	
GCV_d	MJ/kg	21,59	± 0,92	21,28	± 0,53		0,39	
AC	%	0,33	± 0,064	0,33	± 0,045	0,78		
Den	g/cm^3	0,71	± 0,034	0,71	± 0,073		0,51	
FVI	-	6,6	± 1,66	4,97	± 1,19	0,0041		*

Bark (BA)

Gross Calorific Value on dry basis – *GCV_d*

Table 3.24 : Summary Statistics for GCV_d (MJ/kg) in bark two-sample comparison in the two sample sites of Tre Confini (TC) and Igouza (IG)

	Unit	IG	TC
Count	N°	16	16
Average	MJ/kg	21,4818	21,3386
Standard deviation	MJ/kg	0,298532	0,311248
Coeff. of variation	%	1,3897	1,45862
Minimum	MJ/kg	20,9889	20,8425
Maximum	MJ/kg	22,0234	21,8472
Range	MJ/kg	1,03452	1,00479
Stnd. skewness	-	0,726401	-0,100902
Stnd. kurtosis	-	-0,529045	-0,747867

Table 3.25 : Comparison of Stadard Deviation for GCV_d in bark two-sample comparison [Ratio of Variances = 0,91]

	Unit	IG	TC
Standard deviation	MJ/kg	0,298532	0,311248
Variance	MJ/kg	0,0891211	0,096875
Df	N°	15	15

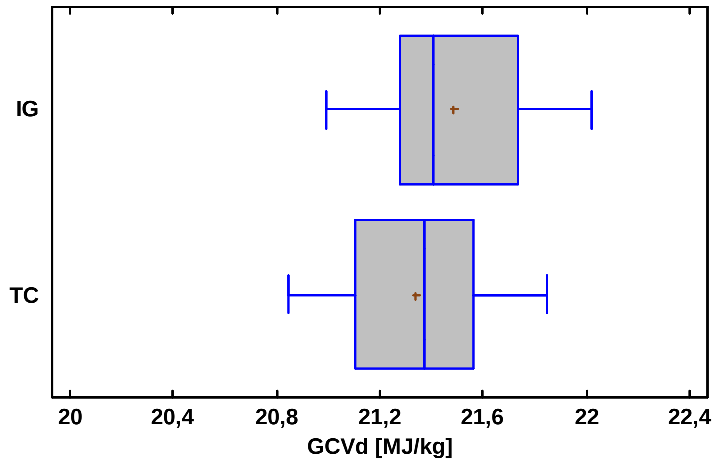

Figure 3.11 : Box-and-Whisker plot for GCV_d in bark two-sample comparison

F-test to compare Standard Deviations highlights following results: F = 0,91 P-value = 0,87. Because of P > 0,05 the null hypothesis for $\alpha = 0{,}05$ is not rejected.

From t-test following results are obtained: t = 1,328 P-value = 0,194, the null hypothesis for α = 0,05 is not rejected: this means that bark gross calorific value on dry basis in two sites is not significantly different.

Ash Content – *AC*

Table 3.26 : Summary Statistics for AC (%) in bark two-sample comparison in the two sample sites of Tre Confini (TC) and Igouza (IG)

	Unit	IG	TC
Count	N°	16	16
Average	%	1,4178	1,65782
Standard deviation	%	0,258271	0,383421
Coeff. of variation	%	18,2163	23,128
Minimum	%	0,949737	1,12036
Maximum	%	1,8884	2,40134
Range	%	0,93866	1,28098
Stnd. skewness	-	-0,0872998	1,06558
Stnd. kurtosis	-	-0,165463	-0,566331

Table 3.27 : Comparison of Stadard Deviation for *AC* (%) in bark two-sample comparison [Ratio of Variances = 0,45]

	Unit	IG	TC
Standard deviation	%	0,258271	0,383421
Variance	%	0,0667038	0,147012
Df	N°	15	15

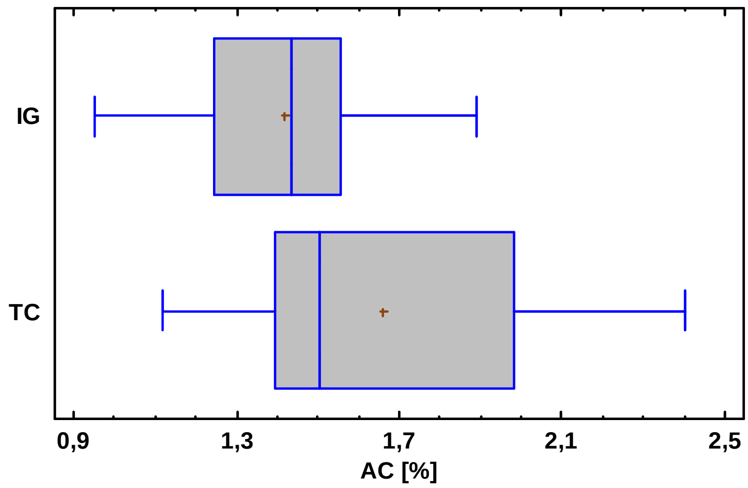

Figure 3.12 : Box-and-Whisker plot for *AC* in bark two-sample comparison

F-test to compare Standard Deviations highlights following results: F = 0,45 P-value =0,13. Because of P > 0,05 the null hypothesis for $\alpha = 0{,}05$ is not rejected.

From t-test following results are obtained: t = - 2,07 P-value = 0,04, so we do not reject the null hypothesis for α = 0,05, this means that bark ash content in two sites is not significantly different.

In the summary table below (Table 3.28) the only significant difference of bark's ash content between two sites is highlighted with an * (P < 0,05).

Table 3.28 : Summary table of mean bark fuel properties' results. P-value reported refer to a two-sample comparison between the same variable measured on two different sample sites (IG and TC)

BA - Variable	Unit	*IG*		*TC*		*P-value*		Sig.
		Mean	SD	Mean	SD	t-test	W-test	
GCV_d	MJ/kg	21,48	± 0,29	21,33	± 0,31	0,19		
AC	%	1,41	± 0,25	1,65	± 0,38	0,046		*

Branches (BR)

Gross Calorific Value on dry basis – GCV_d

Table 3.29 : Summary Statistics for GCV_d (MJ/kg) in branch two-sample comparison in the two sample sites of Tre Confini (TC) and Igouza (IG)

	Unit	IG	TC
Count	N°	16	16
Average	MJ/kg	21,9645	21,787
Standard deviation	MJ/kg	0,595924	0,429764
Coeff. of variation	%	2,71312%	1,97257%
Minimum	MJ/kg	20,8989	21,2436
Maximum	MJ/kg	23,0885	22,6954
Range	MJ/kg	2,18961	1,4518
Stnd. skewness	-	0,811796	0,887443
Stnd. kurtosis	-	-0,365551	-0,349511

Table 3.30 : Comparison of Stadard Deviation for GCV_d (MJ/kg) in branch two-sample comparison [Ratio of Variances = 1,9227]

	Unit	IG	TC
Standard deviation	MJ/kg	0,595924	0,429764
Variance	MJ/kg	0,355125	0,184697
Df	N°	15	15

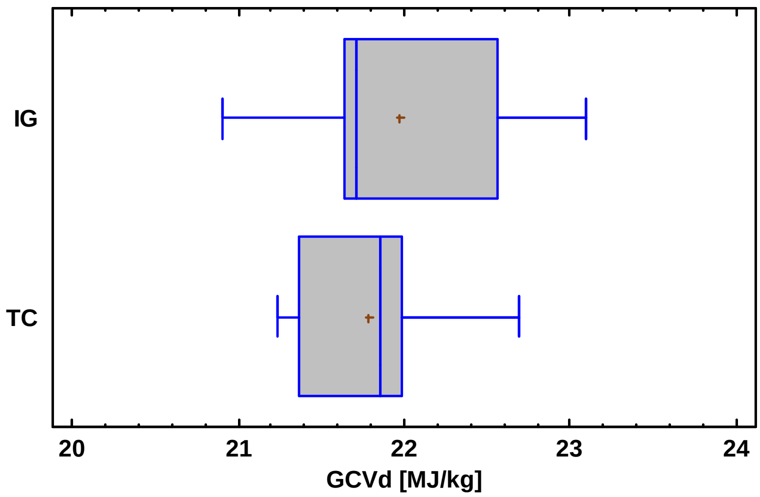

Figure 3.13 : Box-and-Whisker plot for GCV_d in branch two-sample comparison

F-test to compare Standard Deviations highlights following results: F = 1,92 P-value = 0,217. Because of P > 0,05 the null hypothesis for α = 0,05 is not rejected.

From t-test following results are obtained: t = - 0,96 P-value = 0,34, the null hypothesis for α = 0,05 is not rejected, this means that branches' gross calorific value in two sites is not significantly different.

Ash Content – *AC*

Table 3.31 : Summary Statistics for AC (%)in branch two-sample comparison in the two sample sites of Tre Confini (TC) and Igouza (IG)

	Unit	IG	TC
Count	N°	16	16
Average	%	2,39588	2,57223
Standard deviation	%	0,52595	0,649388
Coeff. of variation	%	21,9523%	25,2461%
Minimum	%	1,34199	1,54457
Maximum	%	3,50559	4,11378
Range	%	2,1636	2,56921
Stnd. skewness	-	-0,202328	1,32066
Stnd. kurtosis	-	0,762505	0,650981

Table 3.32 : Comparison of Stadard Deviation for AC (%) in branch two-sample comparison [Ratio of Variances = 0,65]

	Unit	IG	TC
Standard deviation	%	0,52595	0,649388
Variance	%	0,276624	0,421704
Df	N°	15	15

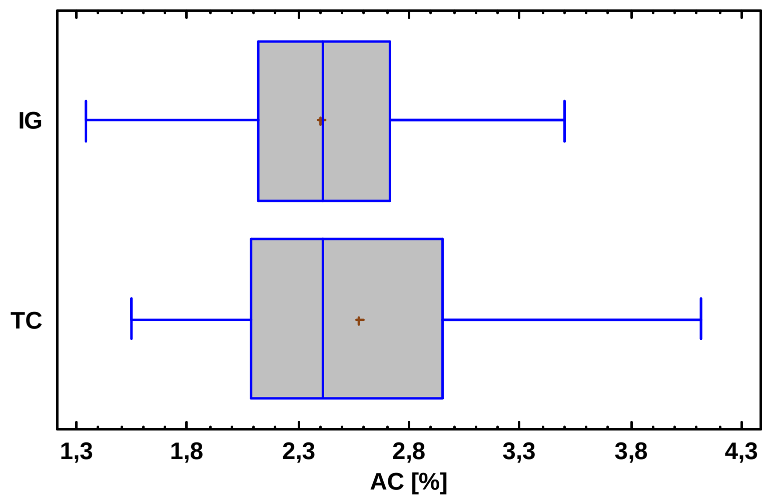

Figure 3.14 : Box-and-Whisker plot for *AC* in branch two-sample comparison

F-test to compare Standard Deviations highlights following results: F = 2,06 P-value = 0,42. Because of P > 0,05 the null hypothesis for $\alpha = 0{,}05$ is not rejected.

From t-test following results are obtained: t = - 0,84 P-value = 0,40, the null hypothesis for α = 0,05 is not rejected, this means that branches' ash content in two sites is not significantly different.

In the summary table below branches' values are reported and no significant values have been found.

Table 3.33 : Summary table of mean branch fuel properties' results. P-value reported refer to a two-sample comparison between the same variable measured on two different sample sites (IG and TC)

BR - Variable	Unit	*IG*		*TC*		*P-value*		Sig.
		Mean	SD	Mean	SD	t-test	W-test	
GCV_d	MJ/kg	21,96	± 0,59	21,78	± 0,42	0,34		
AC	%	2,39	± 0,52	2,57	± 0,64	0,4		

3.2.3 Multiple-Sample Comparison

For every Multiple-sample comparison that has a Levene's test result with p>0,05, following tables and figure are reported:

- *ANOVA table*, which decomposes the variance of the data into two components: a between-group component and a within-group component. The F-ratio reported, is a ratio of the between-group estimate to the within-group estimate. If the P-value of the F-test is less than 0,05 there is a statistically significant difference between the means of the variables at the 95,0% confidence level
- *Multiple Range test table,* to determine which means are significantly different from which others;
- *Graph of means,* where mean values and intervals of 95%

For every Multiple-sample comparison that has a Levene's test result with p<0,05, following tables and figure are reported:

- Kruskal Wallis test table, where data from all the columns is first combined and ranked from smallest to largest. The average rank is then computed for the data in each column. If the P-value is less than 0,05, there is a statistically significant difference amongst the medians at the 95,0% confidence level;
- Box-and-Whisker plot, where medians are represented with median notch of 95% intervals.

Tre Confini (TC)

<u>Gross Calorific Value on dry basis – *GCV_d*</u>

Table 3.34 : Variance Check

	Test	*P-Value*
Levene's	1,90993	0,160168

Table 3.35 : ANOVA test for GCVd [MJ/kg] by Origin

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	2,38401	2	1,192	6,36	0,0038
Within groups	8,24931	44	0,187484		
Total (Corr.)	10,6333	46			

Table 3.36 : Multiple Range Tests for GCVd [MJ/kg] by Origin (95%, Tukey HSD)

Origin	*Count*	*Mean*	*Homogeneous Groups*
W	15	21,2873	X
BA	16	21,3386	X
BR	16	21,787	X

Contrast	*Sig.*	*Difference*	*+/- Limits*
BA - BR	*	-0,448433	0,371358
BA - W		0,0513051	0,377496
BR - W	*	0,499738	0,377496

* denotes a statistically significant difference.

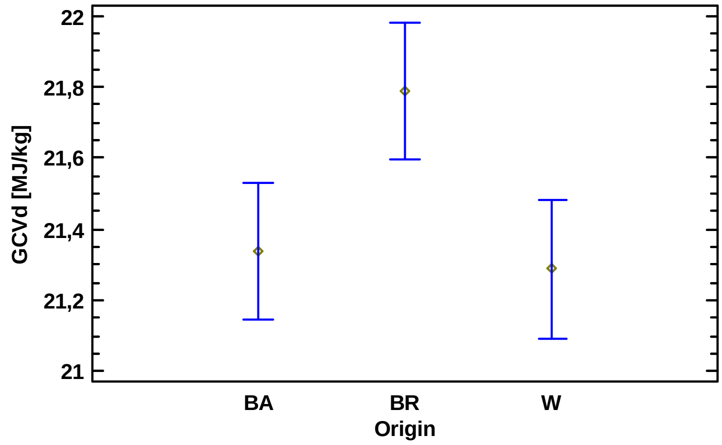

Figure 3.15 : Means and 95% Bonferroni interval

Levene's test indicates that differences among standard deviation of single sample are not significant (table 3.34), this allows to carry on with ANOVA test which shows a significant difference analysing between and within groups comparison: P-value of 0,0038 (Table 3.35). In Table 3.36 and Figure 3.15 emerges that mean BR's GCV_d is significantly higher than BA and W one.

Ash Content – *AC*

Table 3.37 : Variance Check

	Test	*P-Value*
Levene's	12,8339	0,000042596

Table 3.38 : Kruskal-Wallis Test for AC [%] by Origin

Origin	*Sample Size*	*Average Rank*
BA	16	24,125
BR	16	36,875
W	14	7,5

Test statistic = 35,8141 P-Value = 1,67138E-8

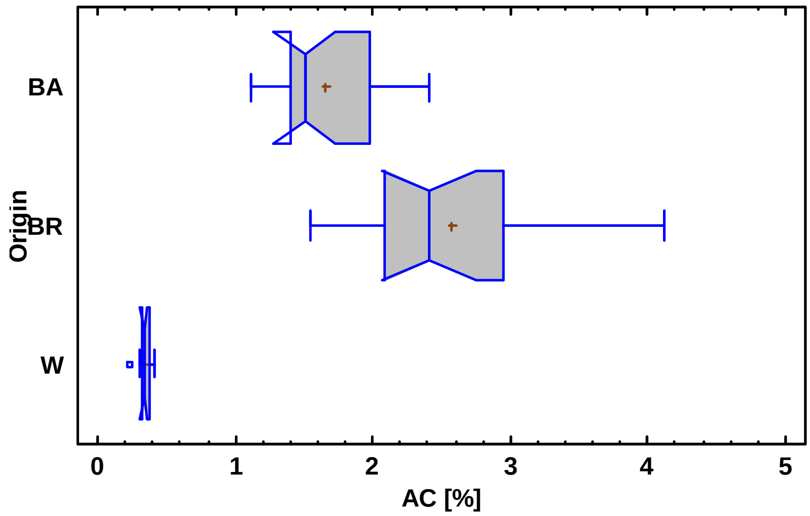

Figure 3.16 : Box-and-Whisker plot for AC (%)

Levene's test indicates that differences among standard deviation of single sample are significant (Table 3.37), this implies that only medians comparison can be tested.

Using Kruskal Wallis test it emerges that AC is significantly different among samples (Table 3.38) and it is confirmed from Figure 3.16. Their mean values are W 0,33%; BA 1,65%; BR 2,57%.

Igouza (IG)

Gross Calorific Value on dry basis – *GCV_d*

Table 3.39 : Variance Check

	Test	*P-Value*
Levene's	10,0256	0,000250633

Table 3.40 : Kruskal-Wallis Test for GCVd [MJ/kg] by Origin

Origin	*Sample Size*	*Average Rank*
BA	16	19,75
BR	16	30,875
W	16	22,875

Test statistic = 5,375   P-Value = 0,0680509

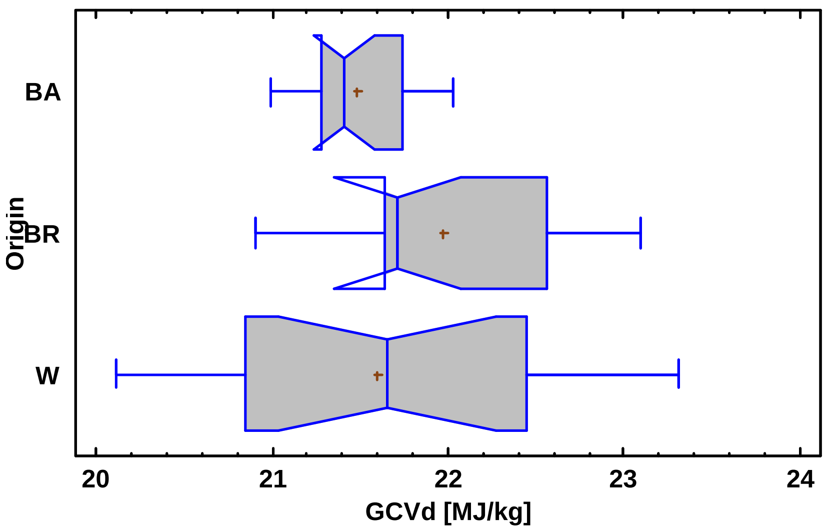

Figure 3.17 : Box-and-Whisker plot for GCV_d [MJ/kg]

Levene's test indicates that differences among standard deviation of single sample are significant (Table 3.39), this implies that only medians comparison can be tested.

Using Kruskal Wallis test it emerges that GCV_d is not significantly different among samples (Table 3.40) and it is confirmed from Figure 3.17. Their mean values are W=21,59 MJ/kg ; BA=21,48 MJ/kg ; BR=21,96 MJ/kg.

Ash Content – *AC*

Table 3.41 : Variance Check

	Test	*P-Value*
Levene's	8,33261	0,000834399

Table 3.42 : Kruskal-Wallis Test for AC [%] by Origin

Origin	*Sample Size*	*Average Rank*
BA	16	25,5
BR	16	39,5
W	16	8,5

Test statistic = 39,3469 P-Value = 2,85707E-9

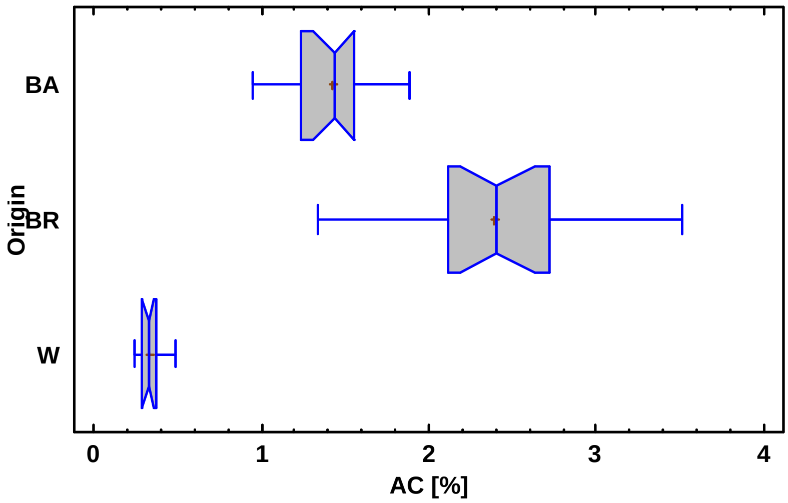

Figure 3.18 : Box-and-Whisker plot for AC [%]

Levene's test indicates that differences among standard deviation of single sample are significant (Table 3.41), this implies that only medians comparison can be tested.

Using Kruskal Wallis test it emerges that *AC* is significantly different among samples (Table 3.42) and it is confirmed from Figure 3.18. Their mean values are W=0,33 MJ/kg ; BA=1,41 MJ/kg ; BR=2,39 MJ/kg.

Table 3.43 : Summary table of Origin multiple comparison for GCV$_d$ and AC

Soil	*Variable*	*Unit*	*Sig. Difference*	*Test*
TC	*GCV$_d$*	MJ/kg	BR > BA ; BR > W	ANOVA
	AC	%	BR > BA > W	Kruskal - W.
IG	*GCV$_d$*	MJ/kg	BR > BA	Kruskal - W.
	AC	%	BR > BA > W	Kruskal - W.

General Comparison (both data from IG and TC)

Gross Calorific Value on dry basis – *GCV_d*

Table 3.44 : Variance Check for GCV_d [MJ/kg] by Sample

	Test	*P-Value*
Levene's	7,18698	0,000010853

Table 3.45 : Kruskal-Wallis Test for GCV_d [MJ/kg] by Sample

Sample	*Sample Size*	*Average Rank*
IG_BA	16	43,5625
IG_BR	16	65,75
IG_W	16	47,6875
TC_BA	16	35,5625
TC_BR	16	59,875
TC_W	15	34,7333

Test statistic = 16,7487   P-Value = 0,00500197

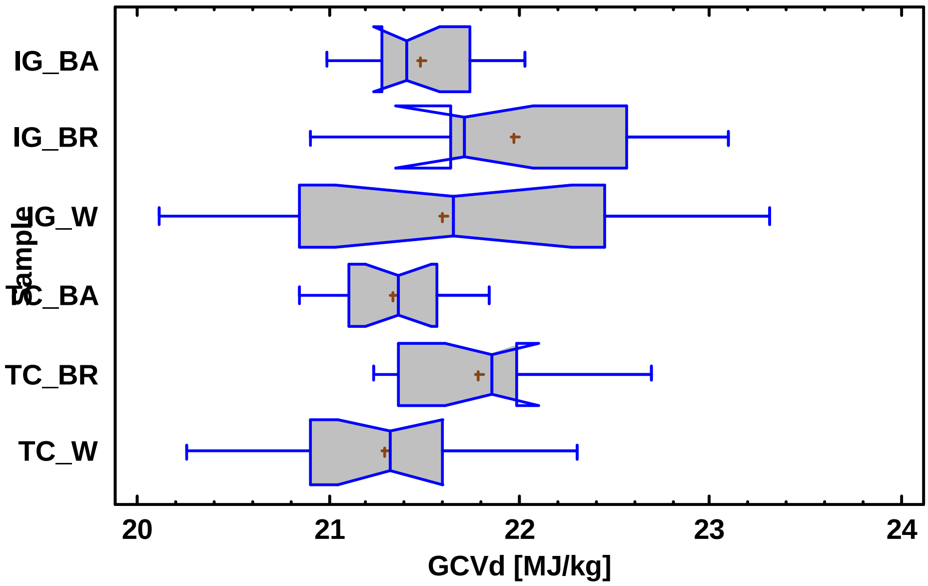

Figure 3.19 : Box-and-Whisker plot for *GCVd* [MJ/kg] by sample

Levene's test indicates that differences among standard deviation of single sample are significant (Table 3.44), this implies that only medians comparison can be tested.

Using Kruskal Wallis test it emerges that GCV_d is not significantly different among samples (Table 3.45) otherwise from Figure 3.19, comparing variables coming from different origin it's possible to observe that IG_BR is significantly higher than TC_W and TC_BA . Their mean values are reported in the following table:

Table 3.46 : Mean values GCV_d [MJ/kg] for all samples

Sample	*Count*	*Average*	*Standard deviation*
IG_BA	16	21,4818	0,298532
IG_BR	16	21,9645	0,595924
IG_W	16	21,5904	0,921951
TC_BA	16	21,3386	0,311248
TC_BR	16	21,787	0,429764
TC_W	15	21,2873	0,536239
Total	95	21,5779	0,593296

Ash Content – *AC*

Table 3.47 : Variance Check for AC [%] by Sample

	Test	*P-Value*
Levene's	9,3598	3,53628E-7

Table 3.48 : Kruskal-Wallis Test for AC [%] by Sample

Sample	*Sample Size*	*Average Rank*
IG_BA	16	45,3125
IG_BR	16	74,5
IG_W	16	14,5625
TC_BA	16	52,75
TC_BR	16	77,4375
TC_W	14	16,5714

Test statistic = 76,9609   P-Value = 0

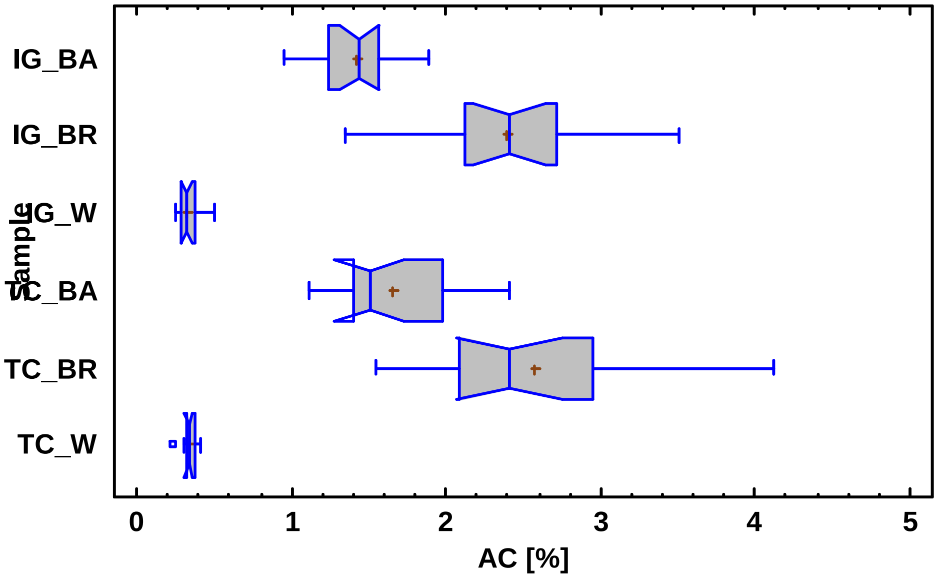

Figure 3.20 : Box-and-Whisker plot for AC (%)

Levene's test indicates that differences among standard deviation of single sample are significant (Table 3.47), this implies that only medians comparison can be tested.

Using Kruskal Wallis test it emerges that *AC* is significantly different among samples (Table 3.48). In the Figure 3.20 it's interesting to see how, without regard to which site, significant difference among samples depend from origin: BR > BA > W. Their mean values are reported in the following table:

Table 3.49 : Mean values AC [%] for all samples

Sample	*Count*	*Average*	*Standard deviation*
IG_BA	16	1,4178	0,258271
IG_BR	16	2,39588	0,52595
IG_W	16	0,330606	0,0649638
TC_BA	16	1,65782	0,383421
TC_BR	16	2,57223	0,649388
TC_W	14	0,336302	0,0452339
Total	94	1,47551	0,96328

Table 3.50 : Summary table of Origin multiple comparison for GCV_d [MJ/kg] and AC [%]

Variable	*Unit*	*Sig. Difference*	*Test*
GCV_d	MJ/kg	IG_BR > TC_W ; IG_BR > TC_BA	Kruskal - W.
AC	%	IG_BR,TC_BR > IG_BA,TC_BA > IG_W,TC_W	Kruskal - W.

3.2.4 Correlations

Results of correlation are reported in a table (Table 3.51-3.52-3.53-3.54-3.55) that shows Pearson product moment correlations between each pair of variables.

These correlation coefficients range between -1 and +1 and measure the strength of the linear relationship between the variables. Also shown in parentheses is the number of pairs of data values used to compute each coefficient. The third number in each location of the table is a P-value which tests the statistical significance of the estimated correlations. P-values below 0,05 indicate statistically significant non-zero correlations at the 95,0% confidence level.

TC_W (Tre Confini – Wood)

Table 3.51 : Correlations among growth and fuel variables for TC's wood samples

	GCVd [MJ/kg]	AC [%]	Den [g/cm3]	FVI	Age	UnBD (cm).	BaTh (cm)	h (m)
GCVd [MJ/kg]		-0,3507	0,3428	0,5537	0,3628	0,1869	-0,2482	0,0541
		(13)	(13)	(13)	(13)	(13)	(13)	(13)
		0,2401	0,2516	0,0496	0,2231	0,5410	0,4136	0,8605
AC [%]	-0,3507		-0,5095	-0,7939	0,4249	0,3173	0,0236	-0,0902
	(13)		(13)	(13)	(13)	(13)	(13)	(13)
	0,2401		0,0753	0,0012	0,1478	0,2907	0,9391	0,7694
Den [g/cm3]	0,3428	-0,5095		0,8920	0,2415	0,1999	-0,1192	0,3623
	(13)	(13)		(13)	(13)	(13)	(13)	(13)
	0,2516	0,0753		0,0000	0,4266	0,5126	0,6981	0,2237
FVI	0,5537	-0,7939	0,8920		0,0427	0,0194	-0,1207	0,2715
	(13)	(13)	(13)		(13)	(13)	(13)	(13)
	0,0496	0,0012	0,0000		0,8898	0,9499	0,6944	0,3696
Age	0,3628	0,4249	0,2415	0,0427		0,6785	-0,0643	0,2633
	(13)	(13)	(13)	(13)		(13)	(13)	(13)
	0,2231	0,1478	0,4266	0,8898		0,0108	0,8346	0,3848
UnBD (cm).	0,1869	0,3173	0,1999	0,0194	0,6785		-0,0576	0,4460
	(13)	(13)	(13)	(13)	(13)		(13)	(13)
	0,5410	0,2907	0,5126	0,9499	0,0108		0,8517	0,1267
BaTh (cm)	-0,2482	0,0236	-0,1192	-0,1207	-0,0643	-0,0576		0,3528
	(13)	(13)	(13)	(13)	(13)	(13)		(13)
	0,4136	0,9391	0,6981	0,6944	0,8346	0,8517		0,2370
h (m)	0,0541	-0,0902	0,3623	0,2715	0,2633	0,4460	0,3528	
	(13)	(13)	(13)	(13)	(13)	(13)	(13)	
	0,8605	0,7694	0,2237	0,3696	0,3848	0,1267	0,2370	

The following pairs of variables have P-values below 0,05:

- AC [%] and FVI
- Age and ubd (cm)
- Den [g/cm^3] and FVI
- GCVd [MJ/kg] and FVI

As it is expected GCV_d, AC and Den variables are related to FVI as they are part of its computation.

Age is directly related with diameter but not with height. This aspect could reflect the mature high even-aged forest stage of TC wood.

IG_W (Igouza – Wood)

Table 3.52 : Correlations among growth and fuel variables for IG's wood samples

	GCVd [MJ/kg]	AC [%]	Den [g/cm3]	FVI	Age	UnBD (cm).	BaTh (cm)	h (m)
GCVd [MJ/kg]		-0,6664	0,3088	0,7850	0,2575	0,1455	-0,5330	-0,0096
		(16)	(16)	(16)	(16)	(16)	(16)	(16)
		0,0048	0,2445	0,0003	0,3357	0,5907	0,0335	0,9717
AC [%]	-0,6664		-0,3500	-0,9003	-0,2187	0,2909	0,3044	0,3943
	(16)		(16)	(16)	(16)	(16)	(16)	(16)
	0,0048		0,1839	0,0000	0,4158	0,2743	0,2517	0,1307
Den [g/cm3]	0,3088	-0,3500		0,5633	0,6717	0,5792	-0,5178	0,3568
	(16)	(16)		(16)	(16)	(16)	(16)	(16)
	0,2445	0,1839		0,0231	0,0044	0,0187	0,0399	0,1749
FVI	0,7850	-0,9003	0,5633		0,4755	0,0470	-0,4321	-0,0916
	(16)	(16)	(16)		(16)	(16)	(16)	(16)
	0,0003	0,0000	0,0231		0,0627	0,8627	0,0946	0,7359
Age	0,2575	-0,2187	0,6717	0,4755		0,5187	-0,1581	0,6899
	(16)	(16)	(16)	(16)		(16)	(16)	(16)
	0,3357	0,4158	0,0044	0,0627		0,0395	0,5586	0,0031
UnBD (cm).	0,1455	0,2909	0,5792	0,0470	0,5187		-0,2881	0,7353
	(16)	(16)	(16)	(16)	(16)		(16)	(16)
	0,5907	0,2743	0,0187	0,8627	0,0395		0,2792	0,0012
BaTh (cm)	-0,5330	0,3044	-0,5178	-0,4321	-0,1581	-0,2881		-0,0492
	(16)	(16)	(16)	(16)	(16)	(16)		(16)
	0,0335	0,2517	0,0399	0,0946	0,5586	0,2792		0,8565
h (m)	-0,0096	0,3943	0,3568	-0,0916	0,6899	0,7353	-0,0492	
	(16)	(16)	(16)	(16)	(16)	(16)	(16)	
	0,9717	0,1307	0,1749	0,7359	0,0031	0,0012	0,8565	

The following pairs of variables have P-values below 0,05:

- GCVd [MJ/kg] and AC [%]
- GCVd [MJ/kg] and FVI
- GCVd [MJ/kg] and BaTh (cm)
- AC [%] and FVI
- Den [g/cm^3] and FVI
- Den [g/cm^3] and Age
- Den [g/cm^3] and ubd (cm).
- Den [g/cm^3] and BaTh (cm)
- Age and ubd (cm).
- Age and h (m)
- ubd (cm) and h (m)

Interesting correlation that have to be taken into account are GCV_d that decreases with AC and BaTh. The former is already widely explained in the literature (Sotelo Montes et al.,2011; Kumar, 2010) whereas the latter could indicate that increasing allocation of resources for bark production reduces allocation of resources for wood production and in particular for

secondary cell wall's components, which have higher calorific value (Kumar et al., 1992). This is in accordance also with the negative density and bark thickness correlation.
Age, diameter and height are positively correlated each other. Also density is positively correlated with age and diameter, thus confirming that the bigger is the tree, the higher is amount of compression wood (so density), also due to the higher weight of the tree.

TC_BA (Tre Confini – Bark)

Table 3.53 : Correlations among growth and fuel variables for TC's bark samples

	GCVd [MJ/kg]	AC [%]	Age	BaTh (cm)
GCVd [MJ/kg]		-0,3336	0,4966	0,3017
		(16)	(16)	(16)
		0,2067	0,0504	0,2561
AC [%]	-0,3336		-0,3888	-0,1369
	(16)		(16)	(16)
	0,2067		0,1367	0,6132
Age	0,4966	-0,3888		-0,0901
	(16)	(16)		(16)
	0,0504	0,1367		0,7399
BaTh (cm)	0,3017	-0,1369	-0,0901	
	(16)	(16)	(16)	
	0,2561	0,6132	0,7399	

No pairs of variables had significant correlation for bark variables in Tre Confini site.

IG_BA (Igouza – Bark)

Table 3.54 : Correlations among growth and fuel variables for TC's bark samples

	GCVd [MJ/kg]	AC [%]	Age	BaTh (cm)
GCVd [MJ/kg]		-0,5287	0,2174	-0,1491
		(16)	(16)	(16)
		0,0353	0,4186	0,5816
AC [%]	-0,5287		-0,0478	-0,0225
	(16)		(16)	(16)
	0,0353		0,8605	0,9341
Age	0,2174	-0,0478		-0,1581
	(16)	(16)		(16)
	0,4186	0,8605		0,5586
BaTh (cm)	-0,1491	-0,0225	-0,1581	
	(16)	(16)	(16)	
	0,5816	0,9341	0,5586	

The following pairs of variables have P-values below 0,05:

- GCV_d [MJ/kg] and AC [%]

BR (Branches)

Table 3.55 : Correlations among growth and fuel variables for branch samples

	GCVd [MJ/kg]	AC [%]
GCVd [MJ/kg]		-0,3543
		(32)
		0,0467
AC [%]	-0,3543	
	(32)	
	0,0467	

The following pairs of variables have P-values below 0,05:

- *GCV_d* [MJ/kg] and AC [%]

3.3 SUMMARY

Before concluding with all useful information that emerge from this study, some tables which sum up important values and their significance level are placed below.

Two-Sample Comparison

Table 3.56 : Mean values of fuel- and growth-variables that was significantly different between two sites

Variable	Unit	*IG*		*TC*		*P-value*		Sig.
		Mean	SD	Mean	SD	t-test	W-test	
FVI	-	6,6	± 1,66	4,97	± 1,19	0,0041		*
BA_AC	*%*	1,41	± 0,25	1,65	± 0,38	0,046		*
BaTh	*cm*	2,42	± 0,59	1,98	± 0,41	0,023		*

Multiple-Sample Comparison

Table 3.57 : Significant differences within and between sites in fuel properties for different origins

Soil	*Variable*	*Unit*	*Sig. Difference*	*Test*
TC	*GCV_d*	*MJ/kg*	BR > BA ; BR > W	ANOVA
	AC	*%*	BR > BA > W	Kruskal - W.
IG	*GCV_d*	*MJ/kg*	BR > BA	Kruskal - W.
	AC	*%*	BR > BA > W	Kruskal - W.
	GCV_d	*MJ/kg*	IG_BR > TC_W ; IG_BR > TC_BA	Kruskal - W.
	AC	*%*	IG_BR,TC_BR > IG_BA,TC_BA > IG_W,TC_W	Kruskal - W.

4. DISCUSSIONS

Soil type had a general effect on BaTh, wood FVI and bark AC. FVI was higher in pine's wood of drier leptosols (IG), while bark was thicker but with lower ash content than that of pines grown on more fertile and humid cambisols (TC).

The higher general amount of ash contained in TC's trees (Table 2.4) suggest that it is more affected by local soil conditions.

Sarmiento et al. (1985) have also stated that the concentration of these minerals in plant tissues is generally higher in more fertile soils. Moreover this result is enforced from the fact that difference in ash content is significantly higher for bark samples of TC (Table 3.56). In fact minerals, such as ash's components, are principal constituents of secondary wall cell, which are highly developed in bark's tissues (Longo and Marziani, 2005). Focusing on sites, in both cases ash's concentration has decreasing value throughout branches, bark and wood (Table 3.57). Higher value of ash content in branches respect wood is in accordance with the fact that ash content is higher in tissues of juvenile trees respect mature trees' (Kumar et al., 2010).

It was not found in literature any study about correlation between site condition and bark thickness (Table 3.56). Anyway plants respond to environmental conditions modifying their physiology and morphology. In this case it could be stated that on less fertile and drier soil black pine reacts reducing transpiration and risk of general physical attacks with an increase of bark production.

Instead, regarding FVI, in all variables related to it: NCV_d, Den, AC and MC, there are not significant differences for each of them between two sites, but direct proportional variables (NCV_d and Den) are higher in IG, whereas indirect proportional variables (AC and MC) are higher in TC. Hence, FVI is significantly higher in IG wood.

Then it has to be pointed out that GCV_d for branches is always higher than that of other origins both in within and among site samples. Maybe alteration processes linked to this sample alter the real value of black pines branches' GCV_d. The calorific value of biomass is dependent on its chemical composition i.e., cellulose, hemicellulose, lignin, extractives and ash forming minerals (Shafizadeh, 1981).

Lignin and extractives have lower degree of oxidation and considerably higher heat of combustion in comparison with celluloses and hemicelluloses (Kumar et al., 1992).

As already explained branches' samples do not come directly from the tree, but were collected from the ground where fungi's degradation processes were already begun. This could explain either higher ash content in branches than in other origins, as fungi absorb metals (ash constituents); either higher GCV_d in branches than in other origin for both sites, as it's likely to suppose that fungi degradation is easier on molecules with less carbon-carbon bonds, which have lower heating value.

In particular carbon-oxygen and carbon-hydrogen bonds contain lower energy than carbon-carbon bonds. Higher proportion of oxygen and hydrogen in biomass reduces the energy value of fuel (Nordin, 1994). Only exception is found in IG where BR's GCV_d is not significantly higher than W's one (Figure 3.17; Figure 3.19). Whereas, multiple comparison among samples brings out that GCV_d of IG_BR is also significantly higher than that in TC_W and TC_BA (Table 3.50 ; Table 3.57).

Correlations show that GCV_d is negatively related with AC in cases of IG_W (Table 3.52), IG_BA (Table 3.54) and BR (Table 3.55) with a $p<0,05$ and also in case of TC_W (Table 3.51) and TC_BA (Table 3.53), but not significantly. Negative relation between these two variables is something expected as increasing concentration of ashes turn the heating value down (Kumar et al., 2010; Sotelo Montes et al., 2011; Bhatt et al., 2010). It would seem that correlation differ in magnitude between the drier and more humid soil. This pattern was already observed correlating growth and wood variables for some Sahelian species (Sotelo Montes et al., 2011).

Other significant correlations in TC_W and IG_W regards GCV_d, AC and Den with FVI. As already explained for Table 3.51, significance and versus of these correlations are an obvious consequence of the fact that first three variables concur to build up FVI's computation.

Also positive correlation between age and UnBD observed in trees of both sites (Table 3.51 and Table 3.52) is the natural consequence of tree growth. Diversely significant positive correlation between h and age, and between h and UnBD observed only in IG's trees reflect poorer soil conditions of this site. In fact, mature trees of an even-storey forest, grown on fertile soil do not show differences in height since they have fairly reached the upper storey. Instead, on drier soils, even if the upper storey is reached, there are differences between trees which have just become mature tree and other that are almost older: growth rate become lower and lower. Nevertheless this difference could be fund itself just on forest structure's difference: IG's population is older and with double values of standard deviation (Table 2.1), so competition is stronger.

Density of IG wood was positively correlated with age and UnBD. Study of growth-density correlation made by Sotelo Montes et al. (2011) brings out two opposite trends for two different species respect humid and dry soils. The relationship between tree growth and wood density may be an adaptation to reduce bending stress produced by wind (Weber and Sotelo

Montes, 2005). In general, large trees require greater strength at the base of the stem in order to reduce bending stress (Mosbrugger, 1990), and strength can be increased by producing denser wood (Niklas, 1997; Sotelo Montes et al., 2007). This correlation could be another consequence of the drier soil conditions: since growth rate become slower and slower specially in the mature stage, the correlation is stronger in this site whereas it is not significantly strong in TC.

Finally negative correlation between BaTh with GCV_d and Den in IG wood could indicate that increasing allocation of resources for bark production reduces allocation of resources for wood production and in particular for secondary cell wall's components, which have higher calorific value (Kumar et al., 1992).

5. CONCLUSION

Growth and fuel properties of black pine in the Trieste area show some differences between population grown on drier soil (leptosols) and on more humid (cambisols).

In general no particular differences were found, despite the fact that older mature trees on leptosols have not higher dimensions (lower increments) than mature trees on cambisol, but have a significantly higher fuel value index (FVI).

In this study evaluation of density (necessary to compute FVI) has been carried out with a fast and less invasive method which lay on the analysis of wood's cores instead of wood's discs. Whereas long time was required for labour's analysis.

Some environmental variables that could affect this survey were not analyzed as they were considered not much influent on thesis's objectives. These are: a difference in temperature of maximum 2°C between two sites during hot and cold season (IG is fresher than TC), and a higher exposure to local inconstant wind (Bora) of IG site respect TC.

Since great utilization of black pine has been done in this area in order to recover dry Karst's soils, from this thesis study is possible to have more detailed informations about fuel properties of black pines grown on the two principal soil formations of the Trieste province. Spreading these information collected on two small sample area over all similar soil conditions of province's black pine stands, may offer a useful tool for energetic analysis and new black pine plant projects.

Practically, improved knowledge about relations between trees' growth regime and fuel wood properties may be useful to assess proper management plans in terms of felling cycles or to forecast amount of achievable energy on a certain area in a certain span of time, as a consequence of amount of wood mass and its composition.

In the end it is desirable that other studies about black pine's wood properties in relation to soil condition could be managed either in the Trieste province as well as in other places, in order to validate significant relations and clarify other potential ones found in this survey.

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7. ATTACHMENTS

ANNEX I : Field data collected for each tree.

ID_TREE	DIAMETER _CLASS	UNDER_BARK _DIAMETER (bhd 1,30)	UPPER_BARK _DIAMETER (bhd 1,30)	BARK_THI CKNESS	HEIGHT	AGE	ELEVATION
IG01	30	26,3	30,7	2,2	14	54	394
IG02	30	24,8	29,7	2	14	51	402
IG03	25	23,5	25,6	1,5	13	52	384
IG05	25	20,3	24,1	2	13	51	381
IG06	35	32,5	37	2,2	16	73	389
IG07	35	29,8	35	2,6	13,5	71	386
IG08	35	28,3	34,2	3	17,2	66	395
IG09	35	28,8	35,1	2,8	16,5	82	398
IG10	25	19,6	23,5	2	14,5	73	385
IG11	40	31,5	38,5	3,5	16,5	88	384
IG12	25	22	25,2	1,5	16,7	88	391
IG13	30	24,9	29	2	14,7	87	394
IG14	30	26,7	32	2,5	14	76	389
IG15	40	35,2	41,8	3,3	20	82	376
IG16	40	33,5	41,5	3	19	83	386
IG17	40	35	40,5	2,7	18,8	99	388
TC01	40	34,7	39	2,2	16	65	162
TC02	35	29,3	33,3	2	15,5	54	179
TC03	30	28,7	31,5	1,5	15	63	168
TC04	35	31,3	37	3	14,5	56	183
TC05	25	20,5	24,5	2	14	54	179
TC06	25	22,8	26	1,6	16,5	57	154
TC07	25	24	27	1,5	18	45	205
TC08	35	30,2	33,9	1,8	19,3	51	190
TC09	30	24,3	29	2,6	15	41	186
TC10	25	23,3	27	1,9	13,5	48	187
TC11	40	34,4	38	1,8	16,2	61	200
TC12	35	30,3	34,8	2,2	18,5	58	195
TC13	30	26,3	29	1,4	17,5	59	170
TC14	40	35,7	40	2,2	18	67	151
TC15	40	34,4	39	2,2	18	68	143
TC16	30	26,2	30	1,9	16,5	56	161

ANNEX II : Growth variables analyzed for each tree.

ID_Sample	Diameter Class	ubd (cm)	UBD (cm)	BaTh (cm)	h (m)	Age
TC01	40	34,7	39	2,2	16	65
TC02	35	29,3	33,3	2	15,5	54
TC03	30	28,7	31,5	1,5	15	63
TC04	35	31,3	37	2	14,5	56
TC05	25	20,5	24,5	2,2	14	54
TC06	25	22,8	26	2,6	16,5	57
TC07	25	24	27	3	18	45
TC08	35	30,2	33,9	2,8	19,3	51
TC09	30	24,3	29	2	15	41
TC10	25	23,3	27	3,5	13,5	48
TC11	40	34,4	38	1,5	16,2	61
TC12	35	30,3	34,8	2	18,5	58
TC13	30	26,3	29	2,5	17,5	59
TC14	40	35,7	40	3,3	18	67
TC15	40	34,4	39	3	18	68
TC16	30	26,2	30	2,7	16,5	56
IG01	30	26,3	30,7	2,2	14	54
IG02	30	24,8	29,7	2	14	51
IG03	25	23,5	25,6	1,5	13	52
IG05	25	20,3	24,1	3	13	51
IG06	35	32,5	37	2	16	73
IG07	35	29,8	35	1,6	13,5	71
IG08	35	28,3	34,2	1,5	17,2	66
IG09	35	28,8	35,1	1,8	16,5	82
IG10	25	19,6	23,5	2,6	14,5	73
IG11	40	31,5	38,5	1,9	16,5	88
IG12	25	22	25,2	1,8	16,7	88
IG13	30	24,9	29	2,2	14,7	87
IG14	30	26,7	32	1,4	14	76
IG15	40	35,2	41,8	2,2	20	82
IG16	40	33,5	41,5	2,2	19	83
IG17	40	35	40,5	1,9	18,8	99

ANNEX III : Fuel variables analyzed in Labour ABC (in Padua) for each tree.

ID_Sample	MC [%]	GCV_{ad}	GCV_d [MJ/kg]	NCV_d [MJ/kg]	AC [%]	Den [g/cm^3]	FVI
TC01	8,00	19,07	20,73	19,41	0,56	0,68	2,95
TC02	7,90	20,54	22,30	20,98	0,65	0,84	3,41
TC03	7,90	19,52	21,20	19,88	0,39	0,66	4,28
TC04	8,12	19,73	21,47	20,15	0,38	0,65	4,29
TC05	8,07	19,22	20,91	19,59	0,37	0,62	4,06
TC06	8,35	19,80	21,60	20,28	0,30	0,77	6,30
TC07	7,99	18,64	20,26	18,94	0,34	0,70	4,90
TC08	8,14	19,58	21,32	20,00	0,33	0,70	5,27
TC09	7,88	19,35	21,00	19,68	0,33	0,67	5,09
TC10	7,98	19,27	20,94	19,62	0,33	0,69	5,13
TC11	8,00	19,83	21,55	20,23	0,30	0,83	7,08
TC12	7,30	22,63	24,42	23,10	0,23	1,00	13,70
TC13	7,60	20,25	21,91	20,59	0,32	0,82	7,08
TC14	7,77	19,67	21,33	20,01	0,37	0,63	4,43
TC15	7,58	19,24	20,82	19,50	0,41	0,77	4,81
TC16	7,47	20,33	21,97	20,65	0,34	0,68	5,59
IG01	6,72	20,27	21,73	20,41	0,33	0,67	6,16
IG02	7,36	19,32	20,86	19,54	0,39	0,65	4,42
IG03	7,39	18,63	20,11	18,79	0,38	0,72	4,84
IG05	7,17	19,04	20,51	19,19	0,36	0,67	4,99
IG06	6,93	20,29	21,80	20,48	0,30	0,76	7,49
IG07	7,56	20,84	22,55	21,23	0,29	0,75	7,23
IG08	7,24	20,92	22,55	21,23	0,32	0,70	6,36
IG09	6,92	20,88	22,44	21,12	0,30	0,75	7,72
IG10	7,10	19,42	20,90	19,58	0,33	0,67	5,55
IG11	6,50	20,99	22,44	21,12	0,28	0,72	8,45
IG12	7,05	20,52	22,08	20,76	0,27	0,72	7,96
IG13	7,13	20,04	21,58	20,26	0,25	0,73	8,36
IG14	6,60	21,77	23,31	21,99	0,25	0,74	10,03
IG15	7,11	19,72	21,23	19,91	0,49	0,70	3,96
IG16	6,19	19,55	20,84	19,52	0,38	0,74	6,12
IG17	6,44	19,20	20,52	19,20	0,38	0,77	6,06
TC01	16,54	17,75	21,27	19,95	1,12		
TC02	13,84	18,26	21,20	19,88	2,13		
TC03	12,84	18,48	21,20	19,88	1,53		
TC04	14,13	18,38	21,40	20,08	2,40		
TC05	15,57	17,74	21,01	19,69	2,24		
TC06	13,99	17,98	20,90	19,58	1,47		
TC07	13,47	18,76	21,68	20,36	1,38		
TC08	13,97	18,01	20,93	19,61	1,45		
TC09	14,23	17,88	20,84	19,52	2,10		
TC10	13,97	18,36	21,34	20,02	1,76		
TC11	14,41	18,47	21,58	20,26	1,21		
TC12	13,76	18,58	21,54	20,22	1,39		
TC13	12,74	18,73	21,46	20,14	1,87		
TC14	12,83	19,05	21,85	20,53	1,61		
TC15	13,71	18,80	21,79	20,47	1,39		
TC16	13,63	18,50	21,42	20,10	1,46		
IG01	12,88	19,00	21,81	20,49	0,95		

IG02	12,41	18,81	21,47	20,15	1,38
IG03	12,84	18,50	21,23	19,91	1,48
IG05	13,11	18,57	21,37	20,05	1,54
IG06	12,97	18,61	21,38	20,06	1,25
IG07	13,94	18,20	21,15	19,83	1,47
IG08	13,11	19,07	21,95	20,63	1,58
IG09	12,59	18,65	21,33	20,01	1,48
IG10	11,76	18,52	20,99	19,67	1,89
IG11	12,31	18,62	21,24	19,92	1,74
IG12	12,78	18,90	21,67	20,35	1,00
IG13	12,56	19,11	21,85	20,53	1,40
IG14	11,85	18,89	21,43	20,11	1,76
IG15	12,11	18,73	21,32	20,00	1,34
IG16	12,50	18,80	21,49	20,17	1,20
IG17	12,20	19,34	22,02	20,70	1,24
TC01	11,69	19,77	22,39	21,07	2,42
TC02	13,75	18,32	21,24	19,92	2,26
TC03	9,21	20,60	22,70	21,38	1,54
TC04	11,84	18,79	21,31	19,99	3,50
TC05	11,06	19,56	21,99	20,67	2,84
TC06	10,53	19,68	21,99	20,67	3,07
TC07	11,65	19,68	22,28	20,96	1,93
TC08	11,59	19,00	21,49	20,17	4,11
TC09	10,76	19,59	21,96	20,64	2,68
TC10	10,22	19,36	21,56	20,24	2,08
TC11	11,41	18,94	21,38	20,06	2,40
TC12	11,42	19,35	21,84	20,52	3,06
TC13	9,26	19,87	21,90	20,58	2,78
TC14	12,24	18,73	21,35	20,03	2,08
TC15	9,77	19,26	21,35	20,03	1,99
TC16	9,43	19,80	21,86	20,54	2,39
IG01	10,27	19,37	21,59	20,27	2,12
IG02	8,72	21,07	23,09	21,77	1,51
IG03	9,08	19,72	21,69	20,37	2,53
IG05	9,09	19,00	20,90	19,58	2,04
IG06	9,56	20,46	22,63	21,31	2,27
IG07	8,60	20,57	22,51	21,19	1,34
IG08	8,68	20,85	22,84	21,52	2,38
IG09	8,86	19,86	21,79	20,47	2,72
IG10	14,81	18,44	21,65	20,33	2,13
IG11	12,11	19,22	21,87	20,55	2,52
IG12	17,92	17,83	21,73	20,41	3,01
IG13	8,45	19,68	21,49	20,17	2,71
IG14	8,94	19,74	21,68	20,36	3,51
IG15	8,87	20,67	22,68	21,36	2,44
IG16	8,93	19,69	21,62	20,30	2,38
IG17	8,95	19,73	21,67	20,35	2,74