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USABILITY OF FRACTOMETER FOR THE PURPOSE OF A PRACTICAL PRELIMINARY ASSESSMENT TOOL FOR WOOD DENSITY OF *Pinus brutia*

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ABSTRACT

The fractometer is a device that breaks increment cores to measure fracture strength. The advantages of the device are that it is relatively fast, easy to use in the field, and it can perform direct strength measurements on increment cores. The main purpose of the study was to evaluate the usability of the fractometer as a preliminary evaluation tool for wood density traits of standing Turkish *Pinus brutia* (red pine) trees. Fracture strength was measured on 5 mm diameter increment cores, and X-ray densitometry was used for density measurements. Due to the high correlation between the two traits (fracture and density), a model was built using linear regression. Fifty trees were sampled to build the statistical model (r^2: 0,74), and an equal sample size was used to test the model. The density value obtained from the model was 0,546 gcm^{-3}, while the density value averaged by the X-ray method for the same group was 0,543 gcm^{-3}. When considering mean values, it can be said that the model provides a good prediction. Based on personal experience and research results, some trees exhibited better growth and wood quality traits than others. Breeding from these trees could offer improvement in timber production and performance for *Pinus brutia* (red pine). As a general consequence, the fractometer and increment core sampling can be used for pine tree breeding programs for the preliminary assessment of wood density.

Keywords: Fractometer, NDT, *Pinus brutia*, red pine, tree selection, X-ray densitometry, wood density.

INTRODUCTION

The selection of best performing trees (plus trees) for target traits is essential in tree breeding programs (Zobel and Talbert 1984, Ruotsalainen 2014). Contrary to easily measurable phenotypic selection traits, some traits which has economic importance (i.e. Wood strength and density) require considerable efforts for determination. Breeding of wood quality characters requires methods for fast screening of large numbers of trees (Ruotsalainen 2014). There is a need for assessing a large number of trees and their families for economically significant traits, such as strength and density. However, traditional methods for assessing for wood strength and density are relatively expensive, they are required laboratory works and restrict the numbers of samples that can be processed. In addition, traditional strength measurement methods involve cutting of the sample trees. Since there is a strong linear relationship between wood density and strength of tree species (Steffenrem *et al.* 2007), wood density/specific gravity is used as a relatively easily measured indicator parameter of wood quality (Panshin and de Zeeuw 1980, Haygreen and Bowyer 1996, Zhang 1997). Depending on different works investigating density-strength relations for pine species r^2 is high, i.e. Kiaei (2011), found r^2 value of 0,73 between compression strength (Cs) and density, 0,71 between MOR (Modulus of rupture) and density for eldar pine (*Pinus eldarica* Medw.); Zhang (1997) reported higher values between Cs and specific gravity for horsetail pine (*Pinus massoniana* Lamb.) (r^2=0,86) and for yunnan pine (*Pinus yunnanensis* Franch.) (r^2=0,85); Guller (2007), reported strong linear relations (r^2=0,90 for Cs; r^2=0,68 for MOR) for red pine (*Pinus brutia* Ten.). Moreover, positive moderate to high genetic correlation was reported between density and wood strength for pine species (Kumar 2004, Missanjo and Matsumura 2016).

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The relationship of the mechanical properties with wood density/specific gravity at species level, to some extent, is different from species to species. In general, maximum crushing strength in compression parallel to the grain in a species from the one softwood category (softwoods with abrupt transition from earlywood to latewood) appears more closely related to specific gravity as compared to the species from the other softwood category (softwoods with gradual transition within a ring) (Zhang 1997).

Red pine (*Pinus brutia* Ten.), having a large commercial use, was given the highest priority and is defined as target species for intensive tree breeding studies (Yildirim *et al.* 2011, Kandemir 2013).

Tree improvement programs for red pine (*Pinus brutia* Ten.) have mainly focused on breeding of trees with superior growth characteristics (Isik 1998). However, wood quality is important for end user (Barnett and Jeronimidis 2003) indeed, particular attention should be given to wood technological characteristics to be considered in the tree selection process (Nocetti 2008, Yildirim *et al.* 2011). In Turkey, there are relatively few studies on heritability of wood properties compared to growth characteristics. The preliminary results of a study conducted by Yildirim *et al.* (2011) suggested that selection for some wood characteristics (ie. specific gravity determined on small clear samples with 0,42 ± 0,07 individual (hi^2) (and 0,55 ± 0,03 family mean heritability- h_{hs}^2) and growth traits in Turkish red pine could be practiced at early ages for short rotation (about 30 years) industrial plantations (Yildirim *et al.* 2011). For the same species medium to high heritability values (hi^2 between 0,45 and 0,74; h_{hs}^2 between 0,68 and 0,80) were reported for wood density (determined by x-ray densitometry) and ring density components (except for latewood density) suggesting that these characters are under moderate to strong genetic control, and thus, by selecting populations having high wood density would lead to genetic improvement can be achieved in red pine (*Pinus brutia* Ten.)(Guller *et al.* 2011).There is a need to include wood quality traits in tree selection program to ensure future wood supplies that have the appropriate mechanical properties for primarily structural applications and other end uses.

There has been an increasing interest in developing and using cost-effective non-destructive/semi-destructive technologies to evaluate the strength of standing trees all around the World (Bucur 2003, Wu *et al.* 2007, Brashaw *et al.* 2009).

Although many of non-destructive methods which are used for determination of wood strength are indirect methods (Brashaw *et al.* 2009), Fractometer can perform direct strength measurements on 5 mm diameter cores (Goetz *et al.* 2002, Chiu *et al.* 2006, Matsumoto *et al.* 2010). The advantages of the device are that it produces relatively fast results obtained relatively fast, portable, and easy to use (even in the field), causes less damage on trees (Lin *et al.* 2007, Matsumoto *et al.* 2010). Required increment core sample for the device also give a chance to see and compare visually growing performance of the investigated trees. Due to its numerous advantages, the Fractometer has been employed for assessing the wood strength of standing trees for various purposes, in general by arborist to monitor trees (Mattheck *et al.* 1995, Dolwin 1996, Matheny *et al.* 1999, Lin *et al.* 2004, Chiu *et al.* 2006, Matsumoto *et al.* 2010). There are few works which compares standard strength measurements performing on clear samples and Fractometer measurements. Matsumoto *et al.* (2008) compared Fractometer measurements and static test results for bending and compression strength of two Japanese softwoods (sugi (*Cryptomeria japonica* (L.f.) D.Don) and akamatsu, japanese red pine (*Pinus densiflora* Siebold & Zucc.)) at green condition using small clear specimens according to Japan Industrial Standard. They reported no significant relationship between bending strength of core samples and static bending strength of small clear specimens. In contrast, significant positive relationship was reported for compression strength suggesting, the standard small clear sample compression strength of the woods can be estimated non-destructively by using core samples and Fractometer. Few years later, Matsumoto *et al.* (2010) reported a relatively high relationship between Fractometer-measured compressive strength and basic density for five Indonesian plantation species (kauri (*Agathis sp* Salisb.), merkus pine (*Pinus merkusii* Jungh. & de Vriese), silver wattle (*Acacia mangium* Wild.), american mahogany (*Swietenia sp.* Jacq.), and teak (*Tectona grandis* L.)). Kraler and Beikircher (2013) stated that the Fractometer device can be used for a preliminary assessment of wood strength rather than determining/predicting the strength value which is performed by standard test method.

Cown (2005) mentioned about GF Plus system in operation (Cown 2005) whereby individual traits are ranked as growth, straightness, branch frequency, disease resistance, wood density, and spiral grain. Among the different wood traits wood density which is determined easier than wood strength and which has been regarded as an important indicator of wood quality has been given the highest priority for tree improvement for many tree species worldwide (Zobel and van Buijtenen 1989, Cown 2006) and generally researchers have been focused on estimating of wood strength by using density as an independent variable. Innovations on portable non-destructive/semi-destructive devices and practical procedures for direct measurement of wood strength in the field, might shift that approach vice-versa.

The study's theoretical approach postulates that if it is possible to estimate wood strength based on the linear relationships between density (as an independent variable) and wood strength (as a dependent variable), the reverse should also hold true. The primary aim of this study was to assess the practical usability of the fractometer as an initial evaluation tool in the field for selecting red pine (*Pinus brutia* Ten.) trees based on certain wood quality traits. Specifically, the focus was on density, with the intention of showing possibility for integrating these traits and the device into pine tree breeding programs.

MATERIALS AND METHODS

Sample materials and applied method

Red pine (*Pinus brutia* Ten.) increment cores (5 and 10 mm in diameter, defect-free) from 1,30 m height of experimental trees were used as sample material. The primary data for this study were obtained as part of a project (Project number: TUBITAK 110-O-560). Increment core samples were collected from 5 experimental stands for the project, as shown in Figure 1 and Table 1. Since all experimental stands were protected areas used for seed source and genetic trials, there was no option for tree harvesting in the project. Indeed, considering previously published results regarding the relationships between Fractometer measurements and standard tests, which suggest that it can only be used for a rough estimation of standard strength test results for standing trees. Small clear sample tests were not conducted as part of the project, and this study did not include any comparisons with standard tests.

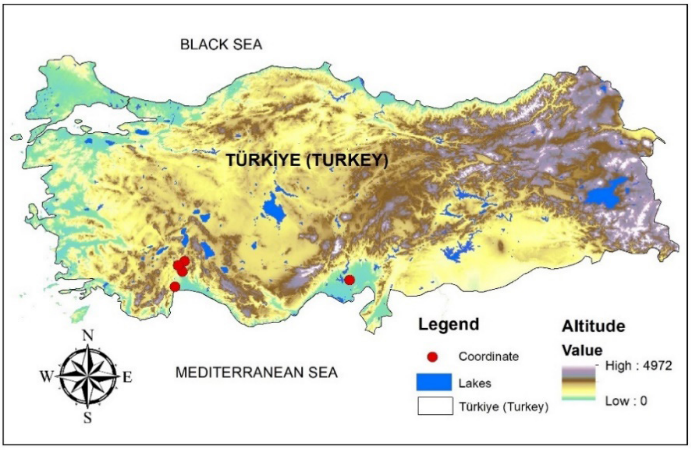

Figure 1: Location of experimental stands (depending on their coordinates in Table 1).

Table 1: Information for experimental stands.

City- Nearest settlement	Name of trial area (Abbreviation)	Altitude	Average tree age of stands	Coordinates
Antalya/Kepez	Kepez (AK) **	90	34	36° 55′ 18″ N 30° 37′ 00″ E
Burdur/Bucak	Melli (BM) *	350	100	37° 16′ 28″ N 30° 49′ 08″ E
Isparta/Sutculer	Karadag (SK) *	650	105	37° 30′ 49″ N 30° 51′ 56″ E
Burdur/Bucak	Pamucak (BP) *	800	112	37° 24′ 53″ N 30° 41′ 21″ E
Isparta/Golhisar	Golhisar (G) *	1100	115	37° 04′ 16″ N 29° 32′ 16″ E

**: Genetic trial consists of half-siblings from 10 families of 6 populations from different altitude, *: Natural seed stands.

In the initial stages of the project, the plan was to acquire a high-speed motorized coring device to collect a larger number of cores. However, as the project commenced, the manufacturer of the intended device ceased production of the unique equipment. Consequently, an alternative approach was adopted for high-speed incremental coring. Classical 5 mm and 10 mm increment borers were purchased, and their steel cores were fitted with two fundamental steel adapters (designed by Bilgin Icel specifically for this application). These adapters were then affixed to two distinct rotary devices, both of which were acquired from the local market.

One of the devices operated using a portable electric generator, while the other utilized a rechargeable drill (Figure 2a and Figure 2b). The adapted devices performed effectively when used on younger, smaller diameter trees. However, they encountered frequent obstructions in larger trees, particularly during the process of obtaining 10 mm cores (for x-ray densitometry) in seed stands.

Consequently, the proportion of increment cores collected from younger trees was greater than that from older ones in the total of one hundred sampling trees. 1,30 meters of trees were marked, and then 5 mm and 10 mm increment cores were taken as close to each other as possible.

Figure 2: (a) Modified devices for 10 and (b) 5 mm increment core samplings.

Data sets

The overall dataset (obtained 100 trees, 2 different cores in diameter, and x-ray and Fractometer measurements per tree) was randomly divided into two equal parts, designated as modelling (M) and testing (T) datasets. All experimental stands were represented by a minimum of three trees in both datasets. However, due to the unequal representation of experimental stands in the datasets, the impact of this unequal distribution on the correlation between fracture strength and density was additionally assessed by segregating data from younger stand and older stands (Figure 4, below; A: data from AK genetic trial , and B: data from BM, SK, BP, and G stands).

Determination of wood density

X-ray densitometry dataset, which was validated at INRA laboratories through the collection of cores from the same trees were utilized in the project, and was employed for model estimations. A mass attenuation coefficient of 3,03 cm²/g for red pine (*Pinus brutia* Ten.) (Guller 2010) was applied to the formula provided below (Equation 1). Fracture strength (FS) was measured using the IML Fractometer (Figure 3) in laboratory conditions. Measuring bending and compression strengths with the Fractometer is straightforward.

The recommended approach involves initiating measurements at the bending station using intact increment cores. Subsequently, the next step involves utilizing broken segments (cut to the measurement interval of 6-10 mm) for the compression unit. However, conducting measurements on the compression unit with such a small sample size can pose challenges in the field, contingent upon topography and forest structure. Conversely, the bending unit employs entire increment cores.

After each core is fractured, data is measured and automatically recorded for each broken part. Therefore, utilizing the bending unit alongside a simple model allows for swift preliminary assessments of tree density and strength. This approach proves advantageous and more feasible for tree breeders during the process of tree selection in various scenarios. This constituted the primary rationale for selecting fracture strength as an independent variable for modeling in this study.

Furthermore, Tang *et al.* (2016) reported a positive and significant correlation between bending and compressive strength, as measured with the fractometer, for certain subtropical urban trees.

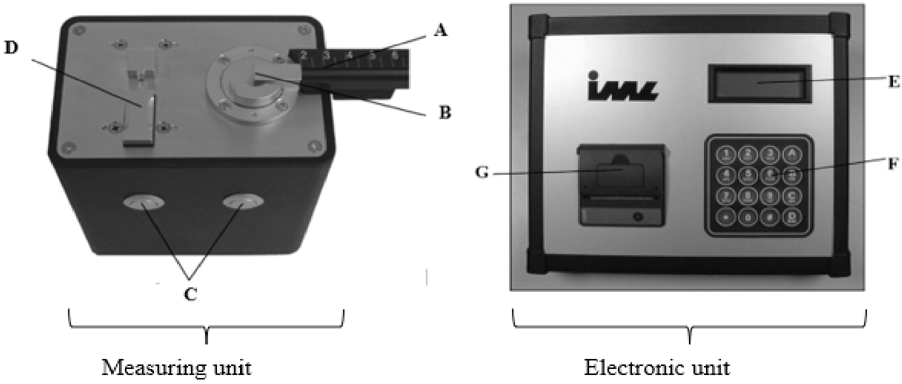

Figure 3: Fractometer (IML Fractometer II, print version) (a) Support for drilling core with ruler; (b) Measuring station for bending strength; (c) Start keys, aligned to the stations; (d) Measuring station for compressive strength; (e) LC display; (f) Keypad; (g) Printer.

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Acclimatization for 8 % equilibrium moisture was applied in all samples to eliminate the moisture content effect between x-ray densitometry and Fractometer samples. Moisture- control samples (which were the same size and the same species, but different than study samples), were used for determining target moisture level. Internal condition of the chamber was determined by preliminary experiment to prevent cracks and, required time to reach the target moisture (8 % here) a couple weeks in acclimatization chamber, and the ending time determined by checking moisture of the control samples. To prevent shape changing, each sample was taped into a core holder.

The resultant scatter plot which exhibited definable trend was linear and, supported of the usage of the simple linear functional form. Linear regression model was constructed for estimating of wood density by using relationship between fracture strength and wood density. Fifty samples were used for constructing the statistical model (linear regression). The equal sample size was used to test the model.

Paired sample t-test (Davis 2013, McDonald 2014) used to compare model and x-ray densitometry results. Kolmogorov-Smirnov and Shapiro-Wilk tests were used to check normality of distribution (Additional Table1 for statistics). ANOVA test was applied to reveal the statistical difference among groups for the four determined parameters of which were Fracture strength (FS), density (D), annual ring width (ARW) and fracture angle (FA). The level of confidence level was chosen as 95 % for all statistical analysis. Equation 1 (Bucur 2003).

$$\rho = \frac{\mu}{\mu'} \quad (1)$$

: The attenuation of an x-ray beam passing through the wood specimen

: Mass attenuation coefficient

ρ: Density of sample

RESULTS AND DISCUSSION

Descriptive statistics for the two investigated groups (1: Data set A for genetic trial and 2: Data set B for seed stands) are shown in Table 2. There was not a significant difference in terms of simple linear regression model between two parameters for separated data sets (A, B) and combined ones (A+B) (Figure 4). Therefore, the combined data were used for all evaluations.

Dependent (density) and independent variables (fracture strength) mean values of model data set were

0,547 gcm^{-3} ± 0,035 and 48,3 ± 9,89 MPa respectively. There was a considerably high r^2 value (r^2=0,74; adjusted r^2=0,732) between fracture strength and density (Figure 4, Table 3). Pearson correlation coefficient between the two parameters (for model training data set) was 0,859 (Table 3). The visual parallelism of measured and estimated densities of the model testing data set (Figure 5), and high correlation coefficient (0,96) between them, clearly indicates the power of model estimates.

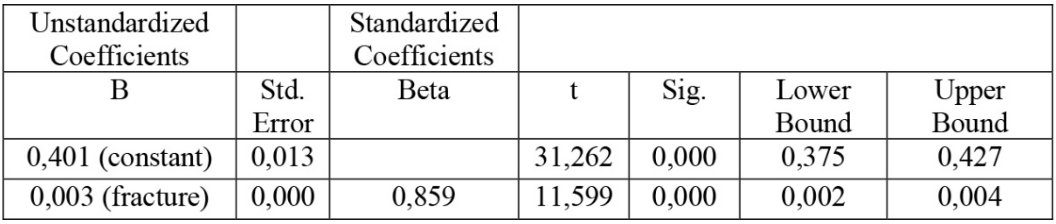
The mean density values of measurements and estimates were found as 0,546 gcm^{-3} and 0,543 gcm^{-3} respectively with 0,003 gcm^{-3} standard deviation, which meant the simple model is very successful for predicting mean density of population. On the other hand, because of the fact that the samples of model data set and testing data set were even randomly selected from the total amount of samples, both data set included half-siblings (from AK trial area). Therefore, this might be the reason of high parallelism between statistical estimates and x-ray measurements or at least contribute it.

Table 2: Descriptive statistics for the two investigated groups (1: Genetic trial and 2: Seed stands) (for modelling data set).

Group		N	Min	Max	Mean	Std Error	Std Deviation
1	FS (MPa)	38	22,00	71,50	48,20	1,72	10,62
	D (gcm^{-3})	38	0,490	0,619	0,545	0,01	0,04
	ARW (mm)	38	0,92	3,34	2,03	0,09	0,58
2	FS (MPa)	12	33,75	60,67	48,65	2,17	7,53
	D (gcm^{-3})	12	0,504	0,601	0,552	0,01	0,03
	ARW (mm)	12	1,10	3,04	1,86	0,19	0,67

Fracture strength (FS), density (D), annual ring width (ARW)

Table 3: Model parameters.



Unstandardized Coefficients		Standardized Coefficients				
B	Std. Error	Beta	t	Sig.	Lower Bound	Upper Bound
0,401 (constant)	0,013		31,262	0,000	0,375	0,427
0,003 (fracture)	0,000	0,859	11,599	0,000	0,002	0,004

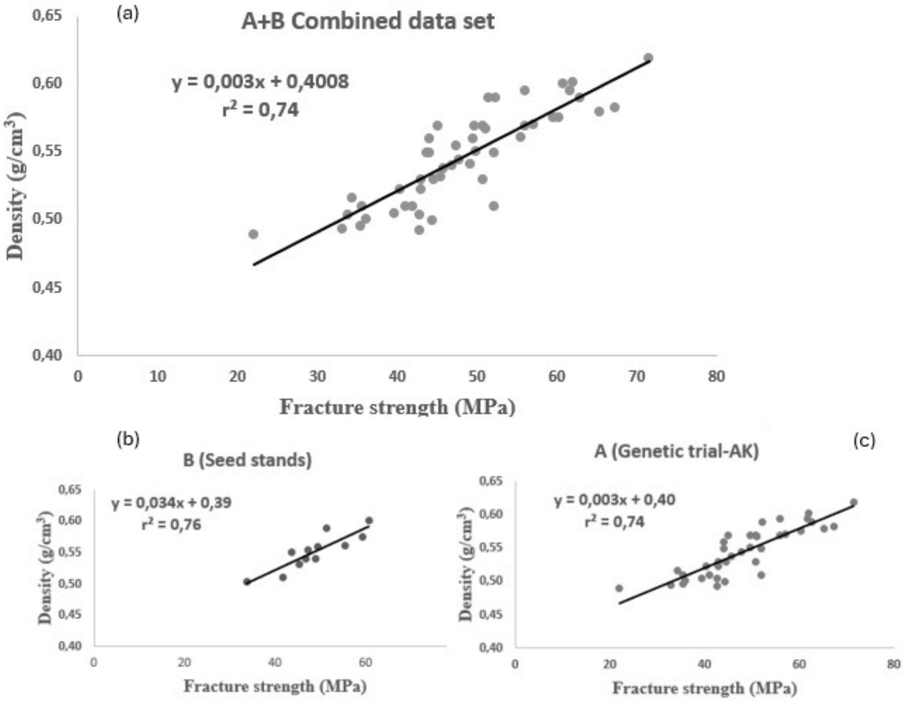


Figure 4: Fracture strength-density relations for combined (a), and separated (b), (c) data from modelling data set (M data set). A: data from AK (Genetic trial, younger age); B: data from natural seed stands BM, SK, BP, and G (older ages).

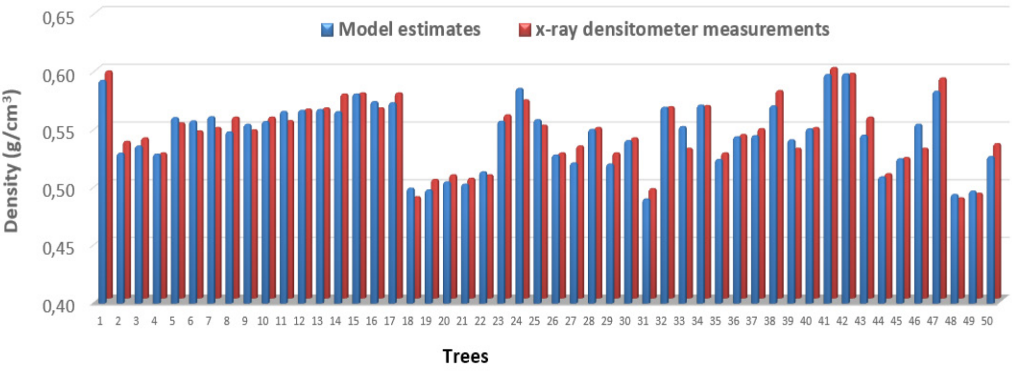


Figure 5: Visual comparison graph between model estimates and x-ray densitometry measurements for the trees in the testing group (T data set).

Depending on ANOVA statistics for the two groups (Trees from seed stands and trees from genetic trial), with p values of 0,031<0,05, there were only a statistically significant difference for ARW (Table 4 and Table 5). However, values clearly indicate that the trees which have the highest fracture strength also have the highest density in ranking (Table 6 and Table 7).

Table 4: ANOVA results for genetic trial (AK).

		Sum of Squares	df	Mean Square	F	Sig.(p)
D	Between Groups	0,005	5	0,001	0,669	0,65
	Within Groups	0,045	32	0,001		
	Total	0,049	37			
FS	Between Groups	565,516	5	113,103	1,004	0,431
	Within Groups	3604,002	32	112,625		
	Total	4169,518	37			
ARW	Between Groups	3,82	5	0,764	2,837	0,031
	Within Groups	8,618	32	0,269		
	Total	12,437	37			
FA	Between Groups	44,744	5	8,949	2,015	0,103
	Within Groups	142,142	32	4,442		
	Total	186,886	37			

Table 5: ANOVA results for seed stands.

		Sum of Squares	df	Mean Square	F	Sig. (p)
D	Between Groups	0,003	3	0,001	1,165	0,381
	Within Groups	0,006	8	0,001		
	Total	0,009	11			
FS	Between Groups	56,394	3	18,798	0,265	0,849
	Within Groups	567,117	8	70,89		
	Total	623,511	11			
ARW	Between Groups	3,178	3	1,059	4,992	0,031
	Within Groups	1,698	8	0,212		
	Total	4,876	11			
FA	Between Groups	13,262	3	4,421	1,227	0,361
	Within Groups	28,815	8	3,602		
	Total	42,077	11			

Table 6: Ranking of parameters for the trees from genetic trial (AK).

	D (gcm^{-3})	FS (MPa)	ARW (mm)	FA (a^{0})
1	AK-D (0,561 ± 0,046)	AK-D (53,6 ± 13,81)	AK-D (2,46 ± 0,48)	AK-M (17,67 ± 2,26)
2	AK-K (0,559 ± 0,019)	AK-K (52,55 ± 6,30)	AK-S (2,26 ± 0,45)	AK-D (16,5 ± 2)
3	AK-S (0,541 ± 0,022)	AK-B (49,2 ± 13,18)	AK-K (2,16 ± 0,57)	AK-S (15,58 ± 2,20)
4	AK-B (0,541 ± 0,049)	AK-S (44,9 ± 7,58)	AK-M (2,04 ± 0,71)	AK-H (15,55 ± 1,93)
5	AK-H (0,535 ± 0,036)	AK-M (44,6 ± 4,35)	AK-B (1,95 ± 0,48)	AK-B (15,04 ± 2,26)
6	AK-M (0,534 ± 0,028)	AK-H (44 ± 11,53)	AK-H (1,48 ± 0,43)	AK-K (14,27 ± 2,55)

Letters after hyphen refer 6 populations mentioned in ** for Table 1, S and D: Populations from low altitude; M and B: Populations from mid- altitude; K and H: Populations from high altitude

Table 7: Ranking of parameters for the trees from seed stands (IG, BM, BP, and SK).

	D (gcm^{-3})	FS (MPa)	ARW (mm)	FA (a^0)
1.	IG (0,569 ± 0,028)	IG (50,52 ± 8,97)	BP (2,70 ± 0,54)	BM (16,14 ± 3)
2.	BP (0,563 ± 0,025)	BM (49,93 ± 5,04)	SK (1,80 ± 0,46)	BP (15,10 ± 1,65)
3.	BM (0,543 ± 0,02)	BP (49,15 ± 2,28)	BM (1,65 ± 0,55)	IG (14,11 ± 1,41)
4.	SK (0,530 ± 0,04)	SK (44,99 ± 13,13)	IG (1,30 ± 0,22)	SK (13,32 ± 0,82)

Matsumoto *et al.* (2010) reported high coefficient of correlation between fractometer-measured compressive strength and basic density for five Indonesian plantation species, and based on their results for strength values of clear samples, they mentioned that fractometer could be applied for the selection of trees with high strength properties. Results from this study agreed with that idea.

Depending on literature knowledge, genetic correlations are useful to make inferences and prediction about indirect responses of one trait from the selection of other one (Neyhart *et al.* 2019). If two traits are genetically correlated, a response to selection would also be expected in a second trait (Neyhart *et al.* 2019).

Therefore, the result of study and other previous findings on high positive linear density-strength relations for pine species (Zhang 1997, Guller 2007, Kiaei 2011), furthermore positive moderate to high genetic correlation previously reported between density and wood strength for pine species (Kumar 2004, Missanjo and Matsumura 2016), all reveal that even a selection based solely on wood fracture strength, which is easily measurable with fractometer in the field, would result in improvement for density trait of red pine (*Pinus brutia* Ten.).

“The breaking resistance of wood is best represented by the fracture moment and the energy that is expended to break the wood sample. This energy is a function of the fracture moment and the fracture angle. The fracture angle measures the elasticity of the wood sample” (Ganesan and Abdul-Hamid 2010: referring to the book titled as Body language of trees, a handbook for failure analysis by C. Mattheck).

All these mean that if it is possible to determine breaking resistance, fracture angle and density of wood in the field, then it would be possible to make estimation for other wood quality traits at site depending on the relations among all traits. While looking at the ranking tables (Table 6 and Table 7), although there is not an exact matching in ranking among all parameters higher fracture strength means higher density, but does not means higher FA.

Elasticity of wood is a very complex topic and is affected not only by density but also different wood anatomical properties (i.e. microfibril angle) (Haygreen and Bowyer 1996). There is an indication of weak correlation between wood density and MOE for red pine (*Pinus brutia* Ten.) (Guller 2007).

Although the following indication of Steffenrem *et al.* (2007) for Norway spruce as “The strong correlations found between MOE and MOR, both on individual tree level and family-mean level, suggest that they can be treated as the same trait in practical tree breeding” found in the literature, we did not see any clear relationship between FS and FA (Table 6 and Table 7).

Some defects occurred by natural or artificial reasons, for example drying of wood may cause micro cracks, may have negative effect on elasticity (Haygreen and Bowyer 1996). The drying process of increment cores in the study might have such negative effects, particularly on larger increment cores. Therefore, the relationship should be investigated on fresh samples (increment cores which keep their moisture content). There is a previously published work of the author on the same site (Guller *et al.* 2011).

The population which is abbreviated as AK-D here, reported in the paper as the best performing population for ARW and shared the top performance with the mid-altitude population M1 at Kepez site (abbreviated as AK-M here) in terms of wood density. The ranking shows that some populations (i.e. AK-D: one of low altitude populations) can show superior growth, wood density and strength and it is possible to select those kind of populations in the field by using Fractometer (Table 6).

Evaluation of individual tree density in the field is also an important topic for practice. The results of paired sample t-test with p=0,034<0,05 (Table 8), indicated that although mean values of the two density groups (model and x-ray densitometry) were very close, the model did not provide exact matching in individual base at 95 % confidence level.

Table 8: Paired samples t test statistics (for model testing data set).

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	density-model	0,546	50	0,0288	0,004
	density-x-ray	0,543	50	0,0290	0,004

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	density-model & density-x-ray	50	0,961	0,000

Paired Samples Test (Paired Differences)

		Mean	Std. Deviation	Std. Error	Lower	Upper	t	df	Sig.
Pair 1	density-model density-x-ray	0,00244	0,0081	0,0012	0,00014	0,0047	2,128	49	0,038

The highest difference between model estimated density (0,555 gcm^{-3}) and x-ray densitometry measurement (0,530 gcm^{-3}) for the same sample in testing data set was found as 0,025 gcm^{-3} while the lowest difference was found as 0,001 gcm^{-3} (Figure 6). Therefore, estimation of individual tree x-ray density by using the simple linear model is not exactly match.

Although statistical test (paired sample t-test) identified differences at individual base, considering the range of numerical results there is not practically important difference in terms of having pre-estimates for tree selection in practice. Results are showing the clear correlation between density and fracture strength even relatively small number of data and additionally project experiences indicated that there is a high possibility for development of a new model, of which individual estimates would be more powerful, by considering possible intervening factors and foreseeable causes of few high individual deviations in the data set.

For example, increment core samples were acclimatized to have equal moisture content for both x-ray densitometry and fractometer samples. During the moisture losing period larger cores were affected from different forces more than shorter ones. Occurrence of some invisible cracks might have caused higher decrease on fracture strength of such size of samples.

For further research, evaluation of relation between density-fracture strength on fresh samples and building new models by using the data would give better opportunities for individual estimates. On the other hand, even core sampling theoretically applied at the same trees and at the same height (the closest place to each other), in fact two different cores sampled depending on their requirements for the two compared way. In some cases, to obtain a defect free sample sampling repeated.

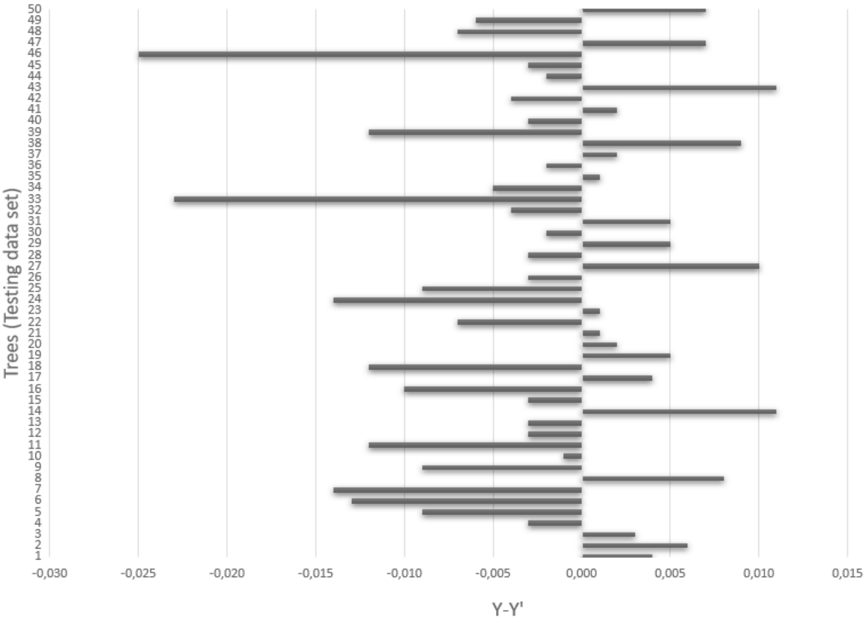


Figure 6: Differences between x-ray densitometry measurements (Y) and model estimates (Y') for the trees of testing group.

Another possible reason for few deviated FS values, which are not accepted as outliers in the study because of the size of model data set, could be the modified increment coring devices. Probett *et al.* (2013) indicated that better surface smoothness was obtained on radiate pine (*Pinus radiata* D. Don) increment cores by working with high-speed increment coring device than classical increment borers, and they made possible cause and effect relationship between lower FS values of samples which were taking with classical borers and their rough surface.

That opinion means the coring device influences fractometer measurements. In this work classical increment borer steel cores were adapted to two different devices which had different torque. Although complete and satisfying visual surface quality obtained for samples, different torque of the two devices might have resulted in different internal stress causing lower fracture strength for some samples.

During increment coring steps of the project, we only focused on taking unbroken and smoot surface cores and recording planned information about sampled trees. Unfortunately, we did not plan recording of which core extracted by which device. Although we know that generally 10 mm cores were extracted by high torque and 5 mm increment cores were extracted by lower one, we do not have exact recorded information on field sheets.

Therefore, we can only mention about two different coring device and possibility of using high torque device for taking some of samples in 5 mm diameter. This is the most probable reason of few highly deviated FS data that might affect power of the model and distorting parallelism of model estimates and x-ray densitometry results at some points (Figure 5).

It is crucial to notice the presence of similar and very close numeric results, along with the highest density difference which is only 0,025 g/cm³, supporting the potential of Fractometer and modeling as a practical approach for density estimation. Although future mix models using Fractometer data may have a high probability of achieving more close individual estimations, unfortunately, these models are unlikely to accurately estimate early and late wood band densities, especially within the narrow annual rings of pine species.

CONCLUSIONS

The mean density values of x-ray measurements and model estimates found to be quite close in terms of numerical values. Furthermore, there is a high correlation between fracture strength and wood density. All these results indicated that with a selection of higher fracture strength, an improvement in density can be achieved for *Pinus brutia*. However, to apply this method successfully, it is necessary to emphasize the importance of the surface smoothness of the increment cores.

Defects, drying defects even fine surface cracks, may affect breaking resistance value. Therefore, it is recommended to consider all these situations in future studies. Particularly investigating all relations by working on fresh increment cores recommended.

As a general conclusion, statistical modelling and Fractometer data can be used for pine tree breeding programs as a practical preliminary assessment way of wood density in the field for the purpose of population selection.

Authorship contributions

B.I.: Conceptualization, data curation, formal analysis, investigation, methodology, project administration, supervision, validation of model, resources, visualization, writing-original draft.

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