KRAFT PULPING OF THE MAIN HARDWOODS USED AROUND THE WORLD FOR PULP AND PAPER PRODUCTION

Segura, T. E. S.[1]; Zanão, M.[2]; Santos, J. R. S.[3]; Silva Jr., F. G.[4]

Laboratory of Chemistry, Pulp and Energy - Department of Forest Sciences, University of São Paulo

Av. Pádua Dias 11, CP 09, CEP 13418-900, Piracicaba, Brazil

Phone: +55 19 2105 8665, Fax: +55 19 2105 8666

[1] Forest Engineer, Msc. PhD Student of Forest Resources – tiago.segura@usp.br

[2] Student of Forestry Engineering – marina.zanao@usp.br

[3] Forest Engineer, Msc. – julianasiviero@yahoo.com.br

[4] Professor of Department of Forest Sciences – University of São Paulo – fjr@usp.br

ABSTRACT

The objective of this work is to evaluate some of the main hardwoods used around the world for pulp production. For that, we studied seven species from different world regions: *Eucalyptus grandis* x *Eucalyptus urophylla (*6 years, Brazil), *Eucalyptus globulus* (12 years, Chile), *Eucalyptus nitens* (12 years, Chile), *Acacia mangium* (6 years, Indonesia), *Acacia crassicarpa* (6 years, Indonesia), *Populus tremuloides* (55 years, Canada) and *Betula pendula* (67 years, Finland). Chemical characteristics and basic density were determined for each material. Kraft pulping was performed applying 5 different levels of active alkali: 16, 18, 20, 22 and 24% (NaOH based). The others pulping conditions were sulphidity of 25%, 90 minutes for heating and 60 minutes on constant maximum temperature of 166ºC. The results show that *E. globulus* is the densest material and *P. tremuloides* presents the lowest density, while the highest lignin proportion was found on *A. crassicarpa*. On pulping, the wood of *P. tremuloides* was the easiest to remove lignin, while *A. crassicarpa* had the most difficult delignification. In addition, *P. tremuloides*' pulping presented the highest yields and best selectivity, and the wood of *A. mangium* had the lowest alkali consumption.

Keywords: Wood technology, wood chemistry, chemical pulping.

INTRODUCTION

Around the world different wood species are used for the pulp production. The forestry species are divided in softwood and hardwood, and present distinct genetic, chemical and anatomical characteristics. These types of wood produce different types of pulp with specific characteristics and uses. While the softwood pulp is used for resistance papers production, hardwood pulp is the raw material for tissue, printing and writing papers. The characteristics of produced pulp are directly related to some wood parameters, like basic density and chemical composition, which influences the pulping processes.

Nowadays, the world hardwood pulp market is lead by emerging countries, like Brazil and Indonesia, the biggest producers of this type of pulp. These countries have edaphic and climatic advantages if compared to its European and North American concurrent. In addition, the species used present good adaptability and fast growing, reducing the costs and consequently increasing the competitiveness on international market. Brazil, Chile and Indonesia are examples of these countries and are among the ten largest world producers of pulp. In Brazil and Chile the predominate species are from *Eucalyptus* genus, while in Indonesia the main genus for pulp production is *Acacia*.

As the European and the North American hardwood pulp production is insufficient for its internal demand, the greatest part of emerging countries production is exported for these locations. In Brazil, for an example, 59% of pulp production in 2008 was exported (Bracelpa, 2009).

Some of the main hardwood species used around the world for pulping were analyzed in this work - *Eucalyptus grandis* x *Eucalyptus urophylla* (Brazil), *Eucalyptus globulus* (Chile), *Eucalyptus nitens* (Chile), *Acacia mangium* (Indonesia), *Acacia crassicarpa* (Indonesia), *Populus tremuloides* (Canada) and *Betula pendula* (Finland).

Eucalyptus grandis x *Eucalyptus urophylla* is a hybrid that was naturally originated in Brazil for the proximity of experimental areas of *Eucalyptus grandis* and *Eucalyptus urophylla* species. This new species was tolerant to some important forestry pests, and it became economically important. Nowadays, this hybrid is the most important species for Brazilian pulp industry.

Eucalyptus globulus and *Eucalyptus nitens* occur naturally in Australia and it was introduced in Africa, Central and South America, Asia, Mediterranean European countries and USA. These species has economical importance in Portugal, Spain and Chile, where it is used for pulp production.

The species from *Acacia* genus are originated in Australia and large-scale plantations have already been established in Indonesia and Malaysia for the production of pulp. Commercial planting of *A. mangium* in other Asian countries such is increasing and this species also has potential in parts of Africa and Central and South America. *A. crassicarpa* is one of the fastest-growing acacias for planting on degraded sites in the seasonally-dry tropics. It has the potential to produce a dense hardwood that can be used in industrial pulp production, as sawn or round timber for construction or as fuelwood (Forestry Compendium).

Populus tremuloides is the most widely distributed tree in North America. It grows on a range of soils, and it is quick to pioneer disturbed sites where there is bare soil. The most wood is used for pulping and manufacturing flakeboard.

Another important hardwood for pulp production on north hemisphere is *Betula pendula*. It is an important component of forests over a large area of Russia and Finland, as well as being important for silviculture in other European countries. This species is the most important hardwood for pulp production on north of Europe.

In this context, the objective of this work is to evaluate the wood of some of the main hardwoods used around the world for pulp production.

MATERIAL AND METHODS

Wood

Five trees of each studied species were collected in different world regions. All the trees were ready to be harvested to pulp production on local industries. Wood discs of all these trees were used to manually wood chips production, with regular thickness (around 4 mm). The characteristics of each wood samples are presented on table I.

Table I: Wood samples

Species	Common name	Location	Age
E. grandis x *E. urophylla*	Urograndis hybrid	Brazil	6 years
Eucalyptus globulus	Tasmanian blue gum	Chile	12 years
Eucalyptus nitens	Shining gum	Chile	12 years
Acacia mangium	Brown salwood	Indonesia	6 years
Acacia crassicarpa	Northen wattle	Indonesia	6 years
Populus tremuloides	Aspen	Canada	55 years
Betula pendula	Birch	Finland	67 years

Wood Characterization

The wood chips were analyzed by their chemical characteristics according to TAPPI Methods T204 / T222 and their basic density according to Foelkel et al. (1972).

Pulping

The cooking were made in a rotating digester with 8 capsules with capacity of 70 g of dry wood each one. An alkaline curve, with 5 active alkali levels, was performed to kraft pulping evaluation of each species. The pulping conditions were the same for all the samples and can be checked on table II.

Table II: Pulping conditions

Species	**Basic density, g·cm^{-3}**
Active alkali, % (NaOH based)	16, 18, 20, 22, 24
Sulphidity, %	25
Heating time, min.	90
Time at maximum temperature, min.	60
Maximum temperature, ^{o}C	166
H Factor	780

After the pulping the yields were calculated and the pulps kappa number was determinate according to TAPPI T236. The analysis of residual alkali at black liquor was performed according to SCAN-N 2:88 modified (AB titration). The other calculated parameters were wood specific consumption (following equation), selectivity (ratio between screened yield and kappa number) and consumed alkali (difference between applied and residual alkali).

$$WSC = \left(\frac{1}{BD \cdot SY} \right)$$

WSC: Wood Specific Consumption, $m^3 \cdot t^{-1}$;

BD: Basic Density, $g \cdot cm^{-3}$;

SY: Screened yield, in decimal.

RESULTS

The basic density is an important characteristic for the evaluation of wood quality for pulping process and it is correlated to genetic and environmental parameters. It has influence on wood impregnation, pulping yields and wood specific consumption. The results of basic density are showed on table III.

Table III: Wood basic density

Species	**Basic density, g·cm^{-3}**
E. grandis x *E. urophylla*	0.468
Eucalyptus globulus	0.630
Eucalyptus nitens	0.525
Acacia mangium	0.522
Acacia crassicarpa	0.569
Populus tremuloides	0.378
Betula pendula	0.502

In this work, *E. globulus* is the densest wood, followed by *A. crassicarpa*, *E. nitens*, *A. mangium*, *B. pendula*. *E. grandis* x *E. urophylla* and *P. tremuloides*, which presents the lowest basic density.

Another characteristic that have influence on wood quality for pulping is the chemical composition. The main objective of pulping processes is to remove the lignin, separating the fibers. Consequently the lignin content influences directly the chemical pulping. The extractives have negative influence on pulping, consuming alkali and increasing the incidence of pitch, which can reduce the pulp quality. The holocellulose content resumes the carbohydrate portion of the wood and influences the pulping yields. The table IV presents the chemical characterization of the studied woods.

Table IV: Wood chemical characterization

Species	Total Extractives	Total Lignin	Holocellulose
		%	
E. grandis x *E. urophylla*	3.1	28.1	68.9
Eucalyptus globulus	5.6	25.9	68.5
Eucalyptus nitens	4.5	27.1	68.4
Acacia mangium	5.2	28.0	66.8
Acacia crassicarpa	4.1	29.4	66.5
Populus tremuloides	6.9	22.1	71.0
Betula pendula	4.8	17.4	77.8

P. tremuloides is the wood with the highest content of extractives, while *E. grandis* x *E. urophylla* is the material with the lowest quantity of these components. *B. pendula* and *P. tremuloides* are the species with the lowest portion of lignin and the highest quantity of holocellulose, while *A. crassicarpa* presents the highest lignin portion and the lowest quantity of holocellulose.

Table V presents the maximum and minimum values for screened yield and kappa number of each species.

Table V: Maximum and minimum values for screened yield and kappa number

Species	Screened yield (%)		Kappa number	
	Maximum	Minimum	Maximum	Minimum
E. grandis x *E. urophylla*	57.6	53.3	22.3	13.1
Eucalyptus globulus	60.7	54.8	29.4	12.2
Eucalyptus nitens	59.3	53.6	33.3	12.4
Acacia mangium	60.5	54.1	52.6	18.1
Acacia crassicarpa	60.3	54.3	65.2	23.0
Populus tremuloides	60.7	54.3	16.7	8.8
Betula pendula	56.5	50.7	35.1	11.7

On pulping, the wood of *P. tremuloides* presents the easiest delignification, achieving a kappa number of 8.8. Despite a high delignification degree the yields of *P. tremuloides*' pulping are high – the minimum screened yield is 54.3%. On the other hand, *A. crassicarpa* is the wood with the most difficult delignification, achieving a minimum kappa number of 23.0 and *B. pendula* presents the lowest screened yields.

The results of delignification show the influence of wood lignin content on pulping processes. The easiest delignification was found to *P. tremuloides* (wood with lowest lignin content), while the wood with higher quantity of lignin (*A. crassicarpa*) has the most difficult delignification.

The figure I present the screened yields on different kappa number levels.

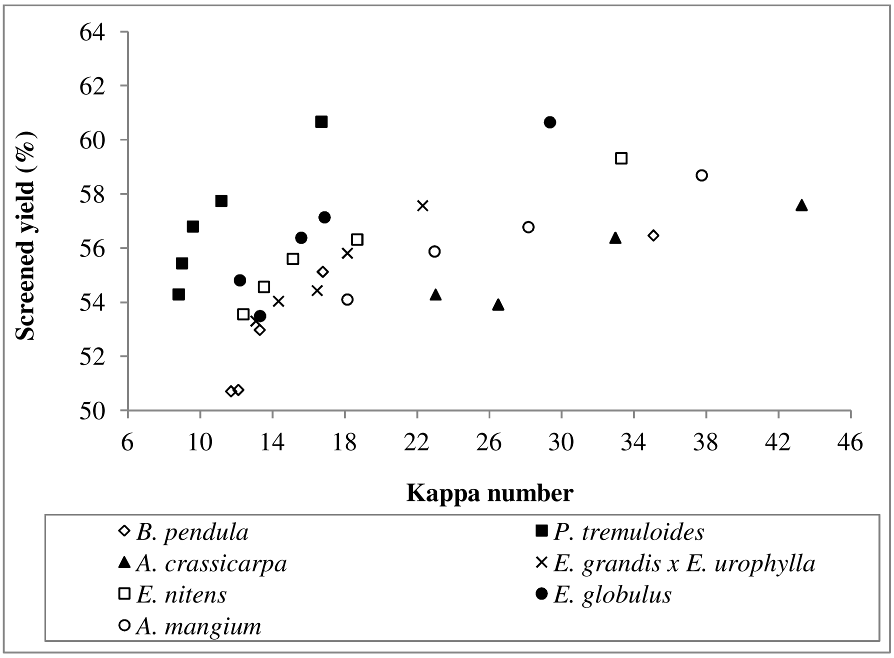

Figure I: Screened yield

For a same delignification level, the pulping of *P. tremuloides* presents the highest yields, achieving low kappa number. Despite the low lignin portion, *B. pendula* has the worst results on yield when a kappa number below 15 is analyzed. For a higher kappa number, *A. crassicarpa* presents the lower yields.

The figure II presents the process selectivity for each wood on different kappa levels. This parameter considers the screened yield and the kappa number.

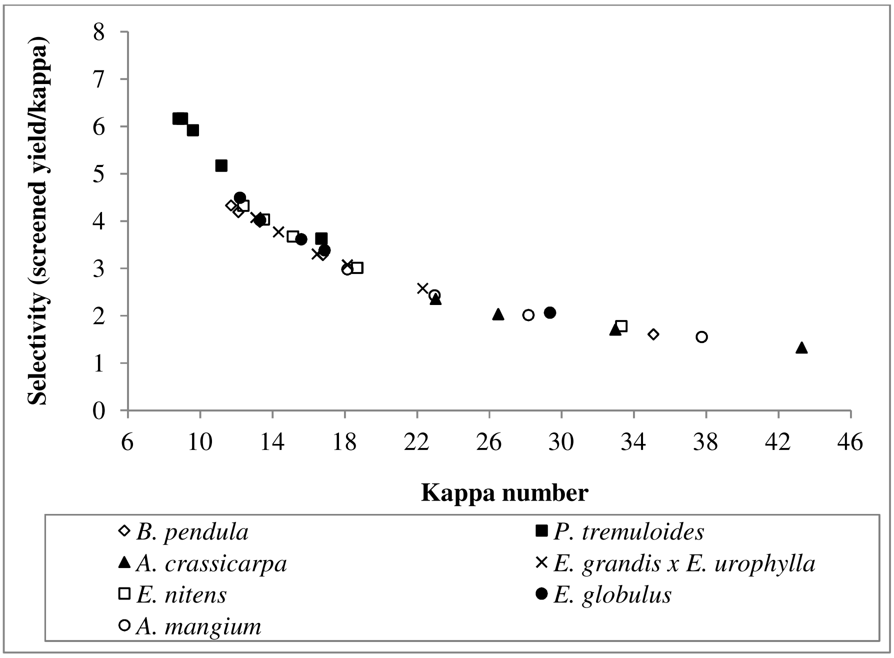

Figure II: Selectivity x kappa number

For all samples the process selectivity increases with the decrease of the kappa. Consequently, the best selectivity is found for *P. tremuloides* pulping, while *A. crassicarpa* process has the worst value of this parameter.

The figure III presents the process selectivity on different alklai consumption levels.

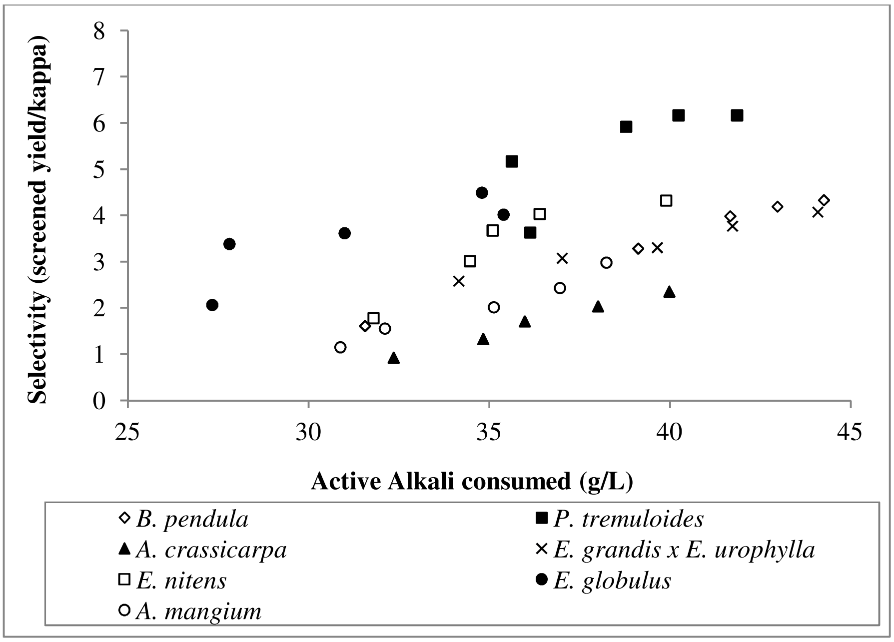

Figure III: Selectivity x active alkali consumed

On process that consumes more than 40 $g \cdot L^{-1}$ of active alkali (NaOH based), the pulping of *P. tremuloides* has the best selectivity. Below this value, *E. globulus*' pulping has the best results, while *A. crassicarpa*'s process has the worst results of selectivity in all consumption ranges. The species *P. tremuloides*, *B. pendula* and *E. grandis* x *E. urophylla* present the higher alkali consumptions, while *E. globulus*' pulping has low consumption.

The consumed active alkali on different levels of kappa number is showed in figure IV.

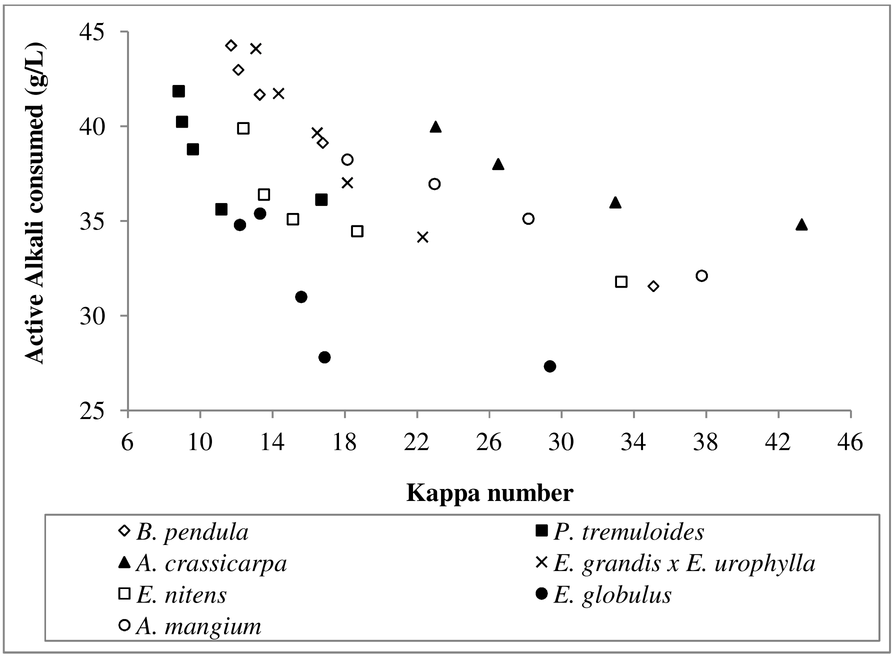

Figure IV: Active alkali consumed

Usually, the hardwood pulping aims the pulp production with a kappa below 20. In this kappa range the wood of *E. grandis* x *E. urophylla* presents the highest alkali consumption, while in a range of higher kappa *A. crassicarpa* is the wood that consumes more alkali. In all delignification levels, the wood of *E. globulus* presents the lowest alkali consumption.

On figure V the wood specific consumption can be observed.

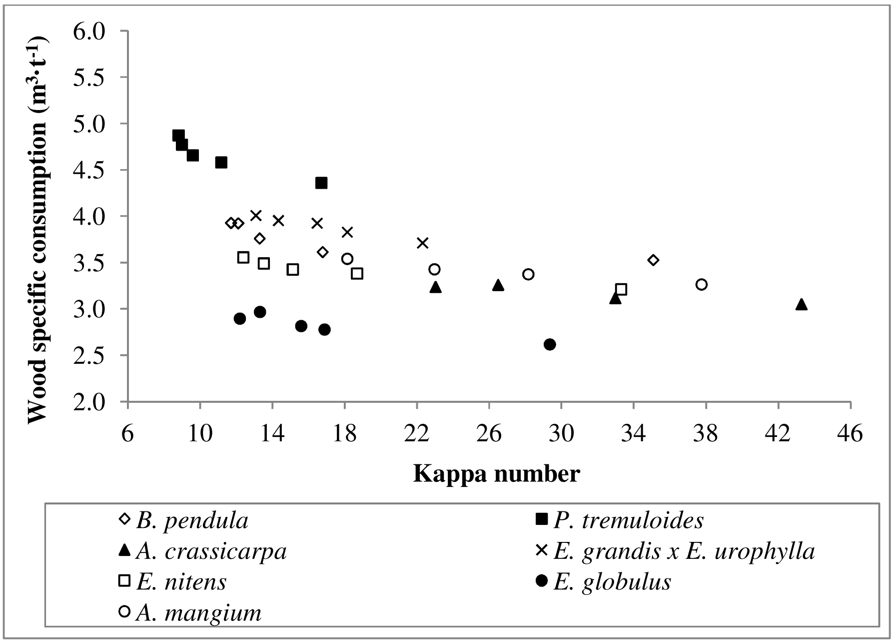

Figure V: Wood specific consumption

For a kappa number lower than 20, the best results of wood specific consumption are found for *E. globulus*, followed by *E. nitens*, *B. pendula*, *A. mangium*, *E. grandis* x *E. urophylla* and *P. tremuloides*. Despite the good yields, the wood of *P. tremuloides* presents a low density, which demands higher wood volume for the pulp production. *A. crassicarpa* didn't achieve this kappa level. These results confirm that the basic density has an important role on pulping costs and the densest materials present the lowest wood specific consumption, reducing the wood and process costs.

The figure VI shows the total solids on black liquor.

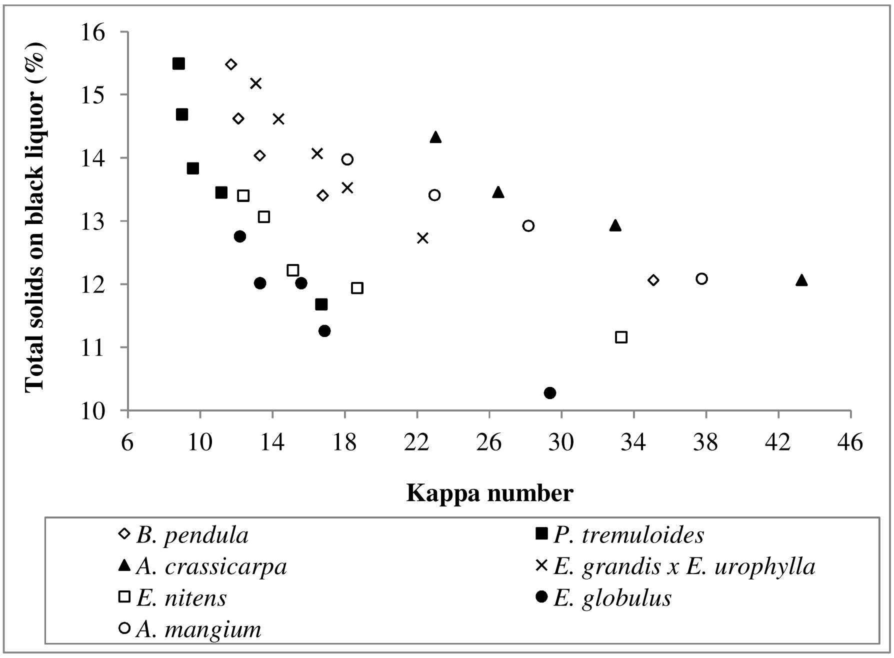

Figure VI: Total solids on black liquor

The black liquor of *E. grandis* x *E. urophylla* pulping presents the highest content of solids in a range of kappa below 20, followed by *B. pendula*, *E. nitens*, *P. tremuloides* and *E. globulus*. Over this level, the black liquor of *A. crassicarpa* has the highest solids content. For all the species, the black liquor solids content increases with the increase of delignification and the consequent decrease of yield.

CONCLUSIONS

This work shows an overview of the wood quality of the main hardwoods used around the world for pulp production. Seven species of different places had their technological characteristics analyzed and were submitted to kraft pulping. The results show that *E. globulus* planted in Chile is the densest wood, while *P. tremuloides* has the lowest basic density. *B. pendula* has the best chemical characteristics for pulping, with low lignin content and high holocellulose proportion.

On pulping, *E. globulus* and *P. tremuloides* presented the higher yields and *P. tremuloides* the best delignification, while *B. pendula* had low yields and *A. crassicarpa* is the wood with the most difficult delignification. For a same kappa number, *P. tremuloides* had the best yields and selectivity and the higher wood consumption, while *E. globulus* presented the lowest alkali and wood consumption.

These results confirm that the raw materials from north hemisphere had good technological characteristics for pulp production. The main advantage of emergent countries is their climate and the well adapted species, which allows the growth cycle of forests be shorter.

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Laboratory of Chemistry, Pulp and Energy - LQCE/ESALQ
University of Sao Paulo – USP
Piracicaba, SP, Brazil

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Tiago Edson Simkunas Segura – tiago.segura@usp.br

Marina Zanão – marina.zanao@usp.br

Juliana R. S. dos Santos – julianasiviero@yahoo.com.br

Francides Gomes da Silva Júnior – fjr@usp.br

Presentation

1. Introduction
2. The species
3. Material and Methods
4. Results
5. Conclusions

Introduction

- ✓ Softwood x Hardwood
- ✓ Hardwood pulp market: emerging countries
- ✓ Adaptability and fast growing
- ✓ Eucalyptus and Acacia

Eucalyptus grandis x Eucalyptus urophylla

- ✓ naturally originated in Brazil
- ✓ Tolerant for some pests
- ✓ most important in Brazil

Eucalyptus globulus

- ✓ Australian
- ✓ Introduced on Africa, Central and South America, Asia, Europe and USA
- ✓ Portugal, Spain and Chile

Eucalyptus nitens

- ✓ Australian
- ✓ Introduced on Africa, Central and South America, Asia, Europe and USA
- ✓ Portugal, Spain and Chile

Acacia mangium / Acacia crassicarpa

- ✓ Australian
- ✓ Established in Asia

7

Populus tremuloides

- ✓ Most widely distributed tree in North America
- ✓ Pulping and flakeboard

Betula pendula

- ✓ Russia and Finland
- ✓ Most important for pulping in north Europe

Material and Methods

Species	Common name	Location	Age
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Acacia crassicarpa	Northen wattle	Indonesia	6 years
Populus tremuloides	Aspen	Canada	55 years
Betula pendula	Birch	Finland	67 years

Material and Methods

- ✓ Chemical charcacterization
- ✓ Basic density
- ✓ Pulping:

Species	Basic density, g·cm^{-3}
Active alkali, % (NaOH based)	16, 18, 20, 22, 24
Sulphidity, %	25
Heating time, min.	90
Time at maximum temperature, min.	60
Maximum temperature, °C	166
H Factor	780

Material and Methods

- ✓Kappa number
- ✓Residual alkali
- ✓Wood Specific Consumption
- ✓ Selectivity
- ✓Consumed alkali

Results

Species	Basic density, g·cm^{-3}
E. grandis x *E. urophylla*	0.468
Eucalyptus globulus	0.630
Eucalyptus nitens	0.525
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Populus tremuloides	0.378
Betula pendula	0.502

Results

Species	Total Extractives	Total Lignin	Holocellulose
	%		
E. grandis x *E. urophylla*	3.1	28.1	68.9
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Results

Species	Screened yield (%)		Kappa number	
	Maximum	Minimum	Maximum	Minimum
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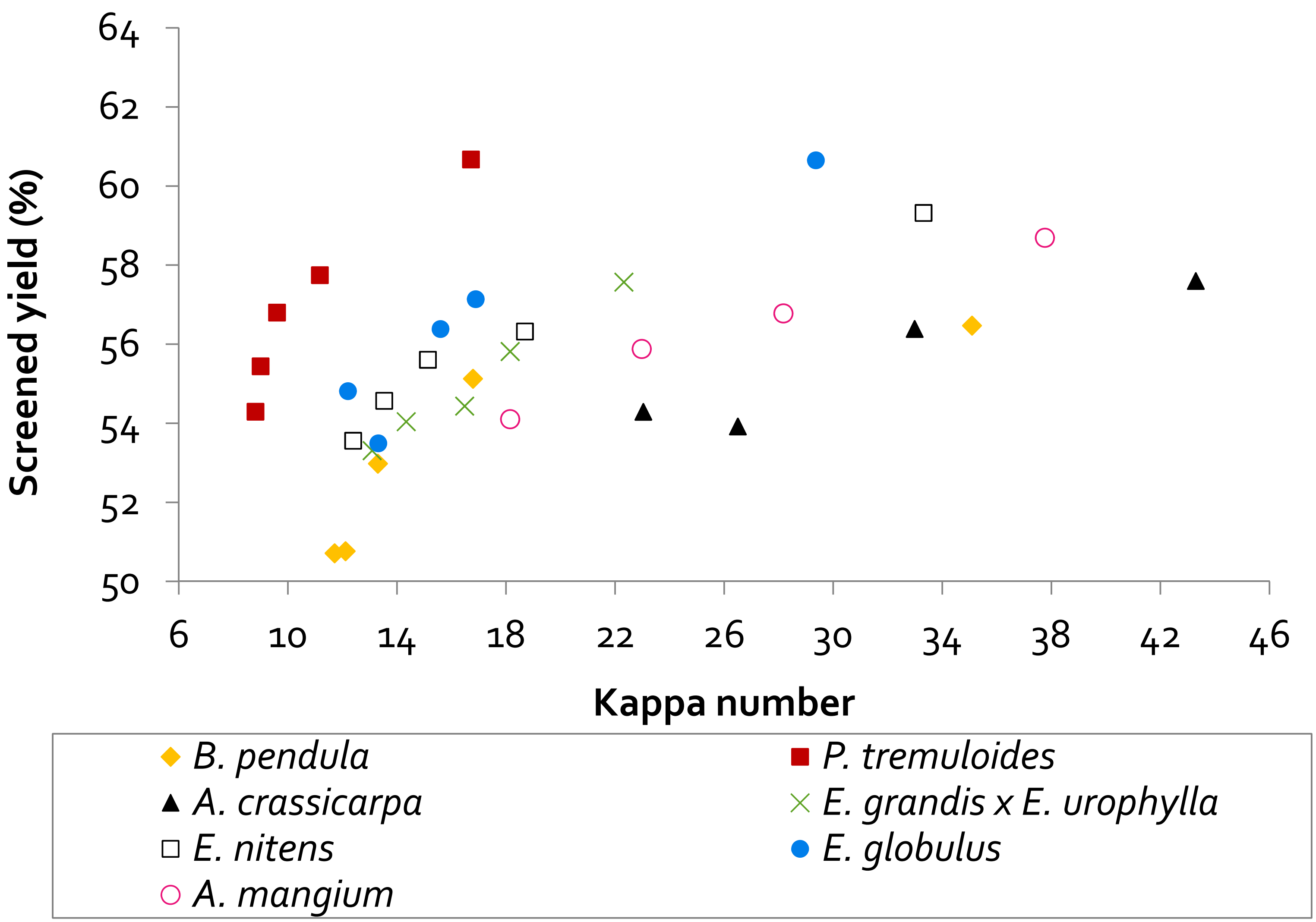
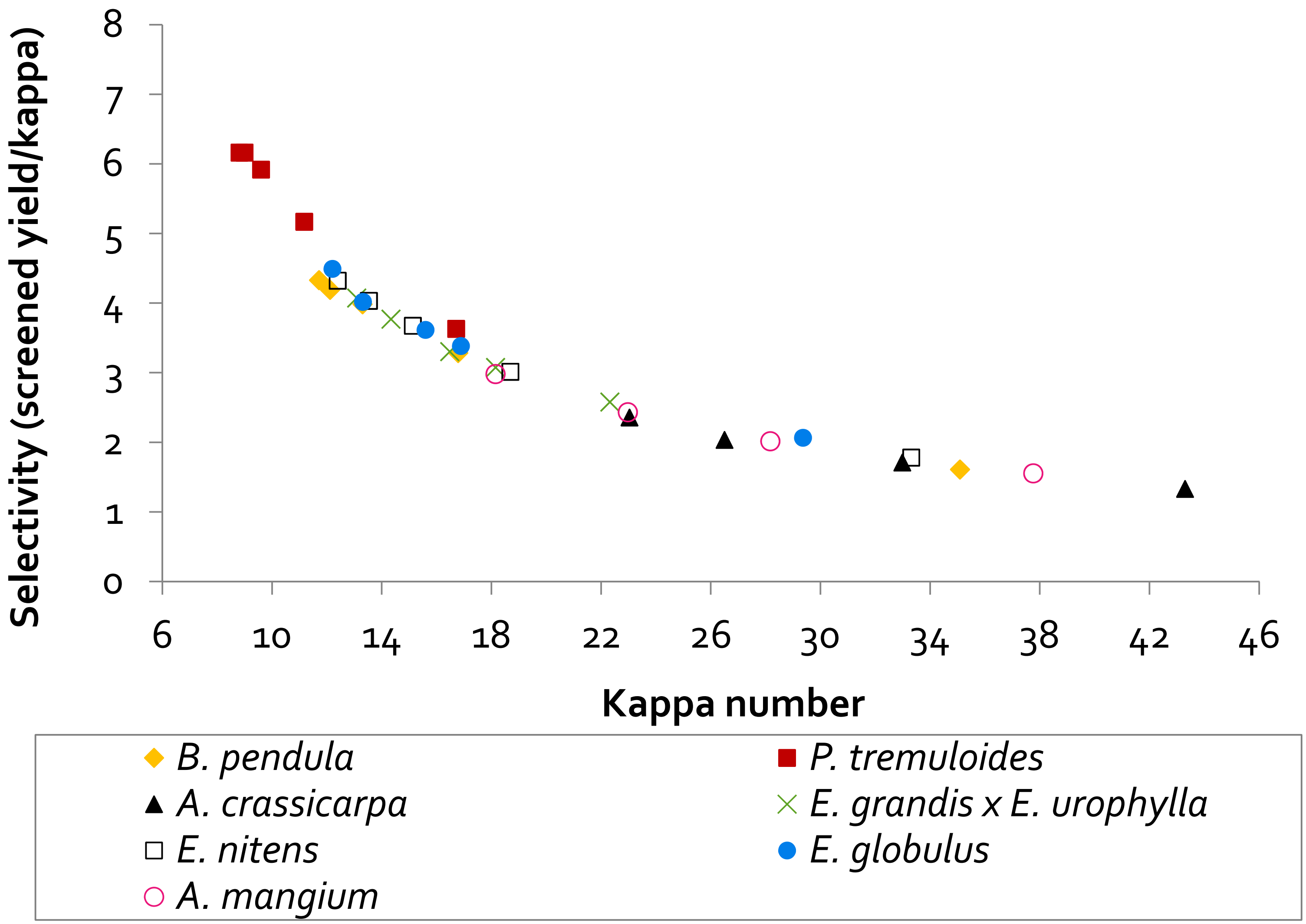
Results

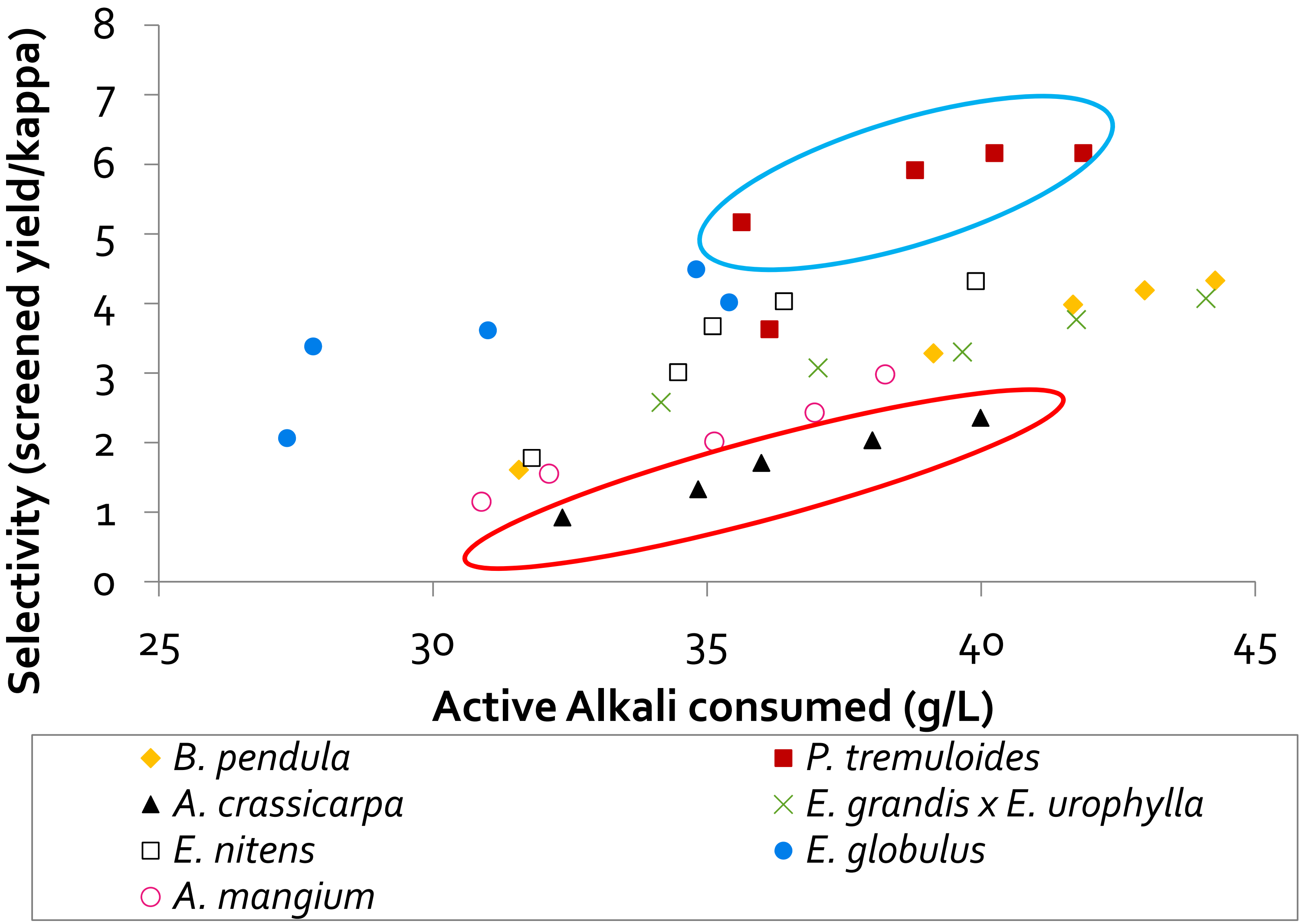


Screened yield (%)
64
62
60
58
56
54
52
50
6
10
14
18
22
26
30
34
38
42
46
Kappa number
B. pendula
P. tremuloides
A. crassicarpa
E. grandis x E. urophylla
E. nitens
E. globulus
A. mangium

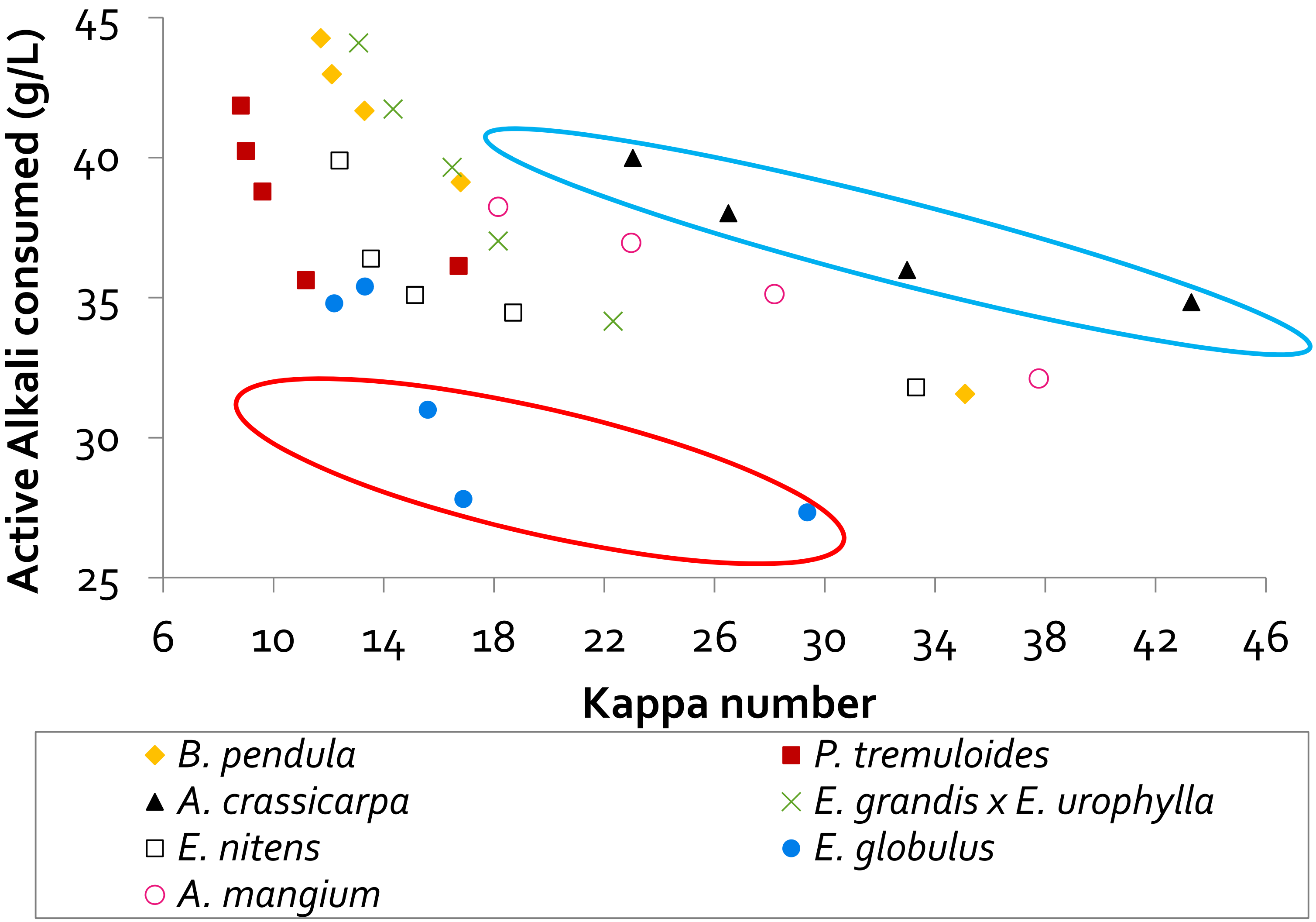
Results


Selectivity (screened yield/kappa)
8
7
6
5
4
3
2
1
0
6
10
14
18
22
26
30
34
38
42
46
Kappa number
B. pendula
P. tremuloides
A. crassicarpa
E. grandis x E. urophylla
E. nitens
E. globulus
A. mangium

Results

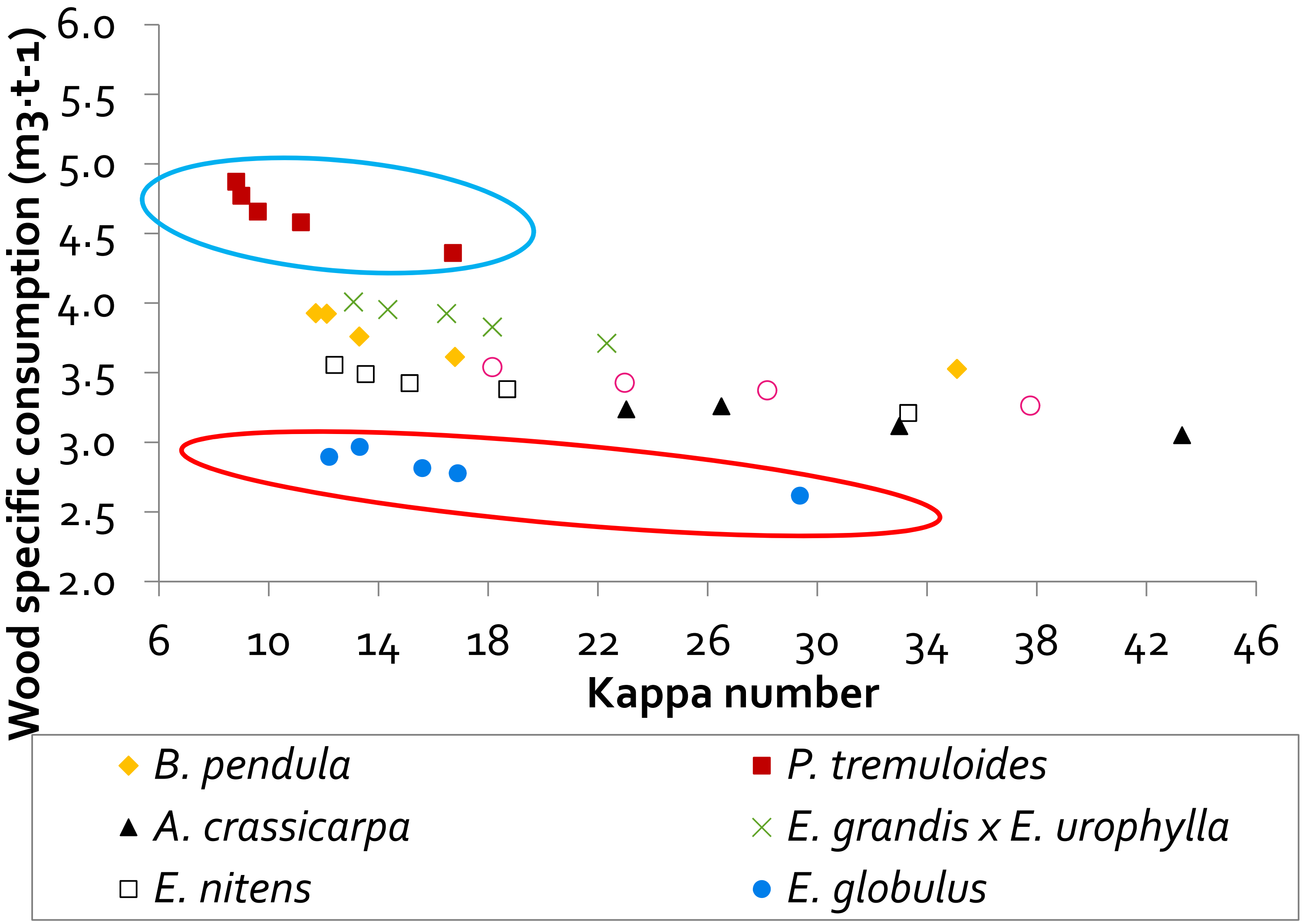

Selectivity (screened yield/kappa)
Active Alkali consumed (g/L)
0
1
2
3
4
5
6
7
8
25
30
35
40
45
B. pendula
A. crassicarpa
E. nitens
A. mangium
P. tremuloides
E. grandis x E. urophylla
E. globulus

Results



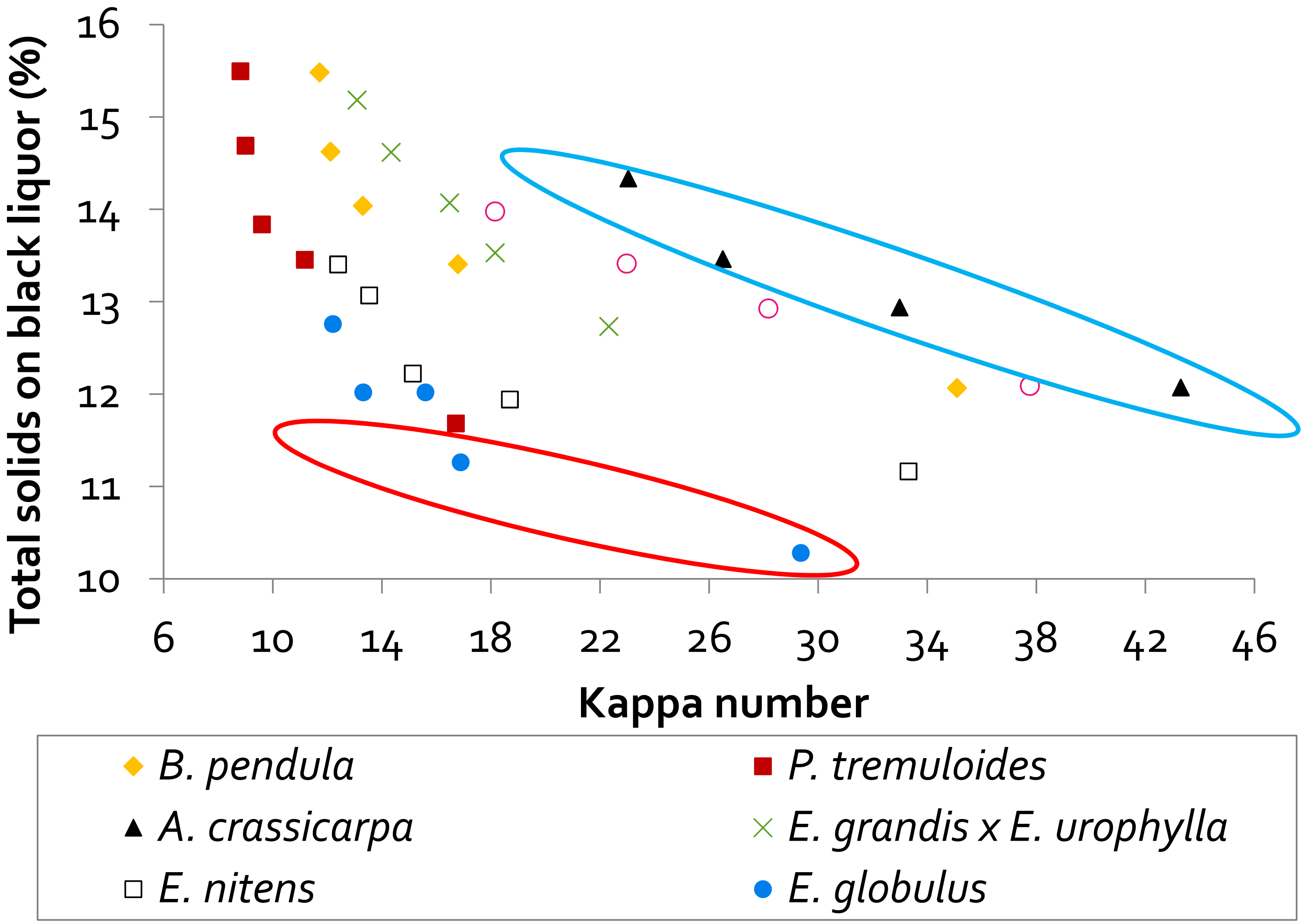
Active Alkali consumed (g/L)
45
40
35
30
25
6
10
14
18
22
26
30
34
38
42
46
Kappa number
B. pendula
P. tremuloides
A. crassicarpa
E. grandis x E. urophylla
E. nitens
E. globulus
A. mangium

Results



Wood specific consumption (m3·t-1)
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
6
10
14
18
22
26
30
34
38
42
46
Kappa number
B. pendula
P. tremuloides
A. crassicarpa
E. grandis x E. urophylla
E. nitens
E. globulus

Results



Total solids on black liquor (%)
16
15
14
13
12
11
10
6
10
14
18
22
26
30
34
38
42
46
Kappa number
B. pendula
P. tremuloides
A. crassicarpa
E. grandis x E. urophylla
E. nitens
E. globulus

Conclusions

- ✓ *E*. *globulus* planted in Chile is the densest wood, while *P*. *tremuloides* has the lowest basic density

- ✓ *B*. *pendula* has the best chemical characteristics for pulping, with low lignin content and high holocellulose proportion

- ✓ *E*. *globulus* and *P*. *tremuloides* presented the higher yields and *P*. *tremuloides* the best delignification, while *B*. *pendula* had low yields and *A*. *crassicarpa* is the wood with the most difficult delignification

Conclusions

✓For a same kappa number, *P. tremuloides* had the best yields and selectivity and the higher wood consumption, while *E. globulus* presented the lowest alkali and wood consumption

✓These results confirm that the raw materials from north hemisphere had good technological characteristics for pulp production

✓The main advantage of emergent countries is their climate and the well adapted species, which allows the growth cycle of forests be shorter.

Thank you!

tiago.segura@usp.br