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Investigation on optimisation of kiln drying of the bamboo species *Bambusa stenostachya, Dendrocalamus asper* and *Thyrostachys siamensis*

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Introduction

Some important reasons to dry bamboo

- key step in processing of high quality bamboo products
- improve properties of bamboo in life
- add further value to bamboo recourse by the successful export of bamboo products into high value markets

Drying methods

Disadvantages of the traditionally used air drying

- long drying time
- bamboo can be infected by mould
- depends largely on climatic conditions and
- undertaken under uncontrollable conditions

Advantages of kiln drying

+ full control of drying conditions
+ better control of the required final moisture content
+ ensuring high level bamboo dried quality and
+ more efficient than air drying for large-scale drying operations

Problems with bamboo drying in Vietnam and other bamboo countries

The demand for the export of large quantities of quality products recently increased

Disadvantages of air drying

→ **Kiln drying**

The development of bamboo kiln drying rarely supported by adequate research efforts

Aim of the research

To develop suitable kiln drying schedules

for culm parts of the commercial species

Bambusa stenostachya,

Dendrocalamus asper and

Thyrostachys siamensis

for furniture making

Experimental

Bamboo samples

Table 1: The dimensions of the samples tested in the study

Species	Length (in mm)		Average diameter (in mm)		Average wall thickness (in mm)	
	Basic	Middle	Basic	Middle	Basic	Middle
T. siamensis	1400	1400	45	38	21	11
B. *stenostachya*	1400	1400	80	68	20	12
D. asper	1400	1400	88	72	22	13

Dry-Kiln

- Temperature up to 90°C by electrical heating coils
- Climate control by hot water spraying and venting
- Air velocity at a constant speed of 3.5 m/s
- PLC controller process visualisation in real time

Kiln Drying

- For the drying of *Thyrostachys siamensis* 154 samples were stacked in 11 rows with 1 cm distance.
- For *Bambusa stenostachya* and *Dendrocalamus asper,* 64 samples were stacked in 8 rows.
- Five controls of the sample lot were used to estimate the average moisture content and moisture loss.


Stacking middle parts of .*T. siamensis* and *D. asper*

Drying schedules

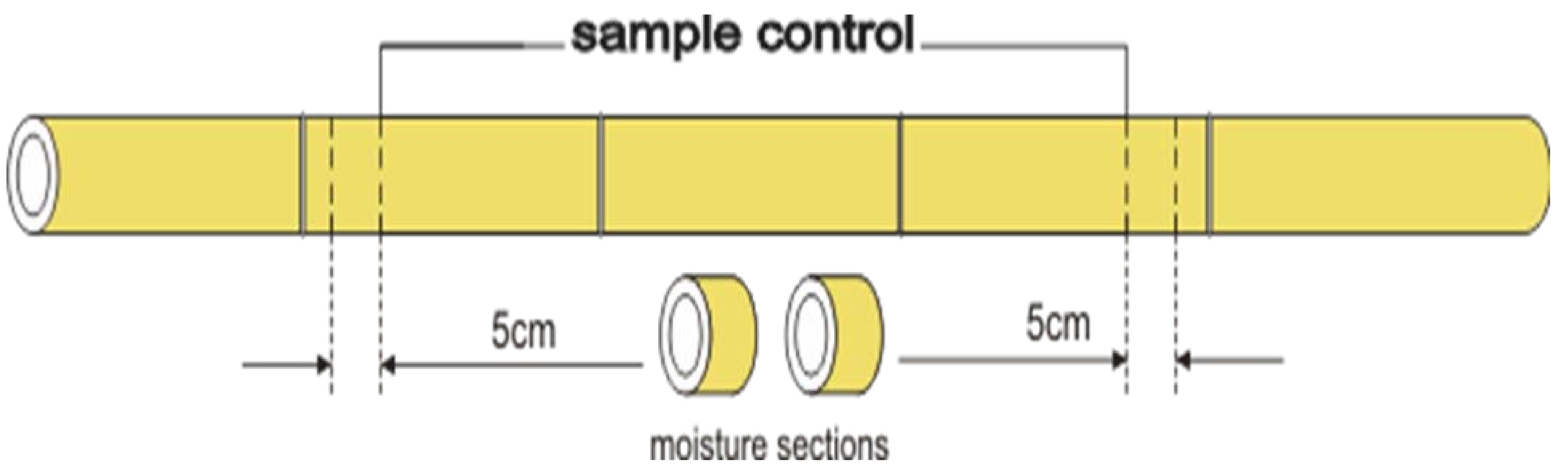
Table 2: The conditions (set-point values) of the four drying schedules

Step	Moisture content (%)	No.1		No.2		No.3		No.4	
		T(^{o}C)	RH (%)	T(^{o}C)	RH (%)	T(^{o}C)	RH (%)	T(^{o}C)	RH (%)
1	Over 90	45	80	50	80	55	80	65	80
2	90 - 70	45	70	50	70	55	75	65	60
3	70 - 50	50	60	60	60	60	65	70	45
4	50 - 40	50	50	60	50	65	50	70	35
5	40 - 30	50	40	60	30	65	35	70	30
6	30 - 20	55	40	65	30	70	25	75	25
7	20 -10	55	30	65	20	70	20	75	15
Conditioning with 50^{o}C T and 70% RH									

Determination moisture content (MC)

- **The initial MC of the control sample** was estimated from the moisture sections cut from each end of the control sample

- **The average initial MC** was determined from moisture sections of five controls and five further samples



Method of cutting sample control and moisture sections for initial MC

MC of the moisture sections was measured by oven dry method and calculated as

$$MC\,(\%) = \frac{W_{or} - W_o}{W_o} \times 100$$

W_{or} as original weight and

W_o as oven dry weight of section

The oven - dry weight of control sample (W_{oc}) was computed by using the following formula:

$$W_{oc} = \left(\frac{W_{or}}{100} + AMC \right) \times 100$$

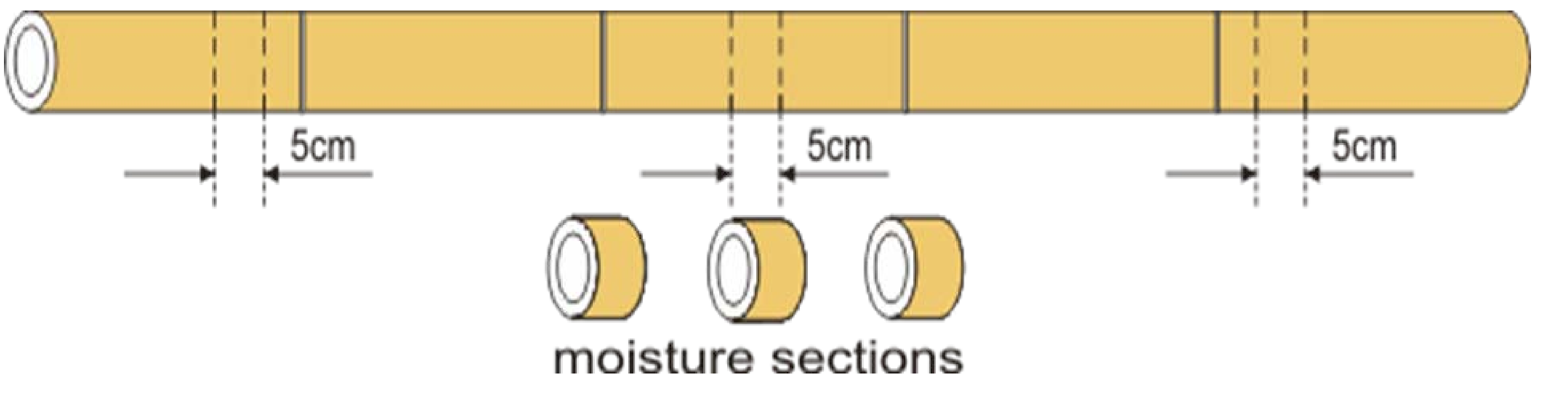
W_{or} as original weight of control sample

AMC as average moisture content of two sections

Table 3: The average initial moisture content of the four experiments with samples n= 20

Schedule	Species	*T. siamensis*		*B. stenostachya*		*D. asper*	
	Moisture content	Basic	Middle	Basic	Middle	Basic	Middle
No. 1	**Mean (in %)**	**-**	**-**	**103**	**92**	**102**	**89**
	SD (in %)	-	-	6.8	5.0	7.5	5.6
No. 2	**Mean (in %)**	**120**	**110**	**102**	**99**	**105**	**93**
	SD (in %)	8.8	7.2	6.1	5.9	6.9	4.8
No. 3	**Mean (in %)**	**119**	**106**	**105**	**96**	**108**	**92**
	SD (in %)	8.1	7.2	6.4	4.8	7.1	5.9
No. 4	Mean (in %)	120	108	-	-	-	-
	SD (in %)	8.2	7.1	-	-	-	-

- **The moisture gradient and the final average MC** was evaluated by sections taken from both ends and from the middle of the samples (n=13)



Method of cutting moisture content sections for final MC

Drying rate, drying defects

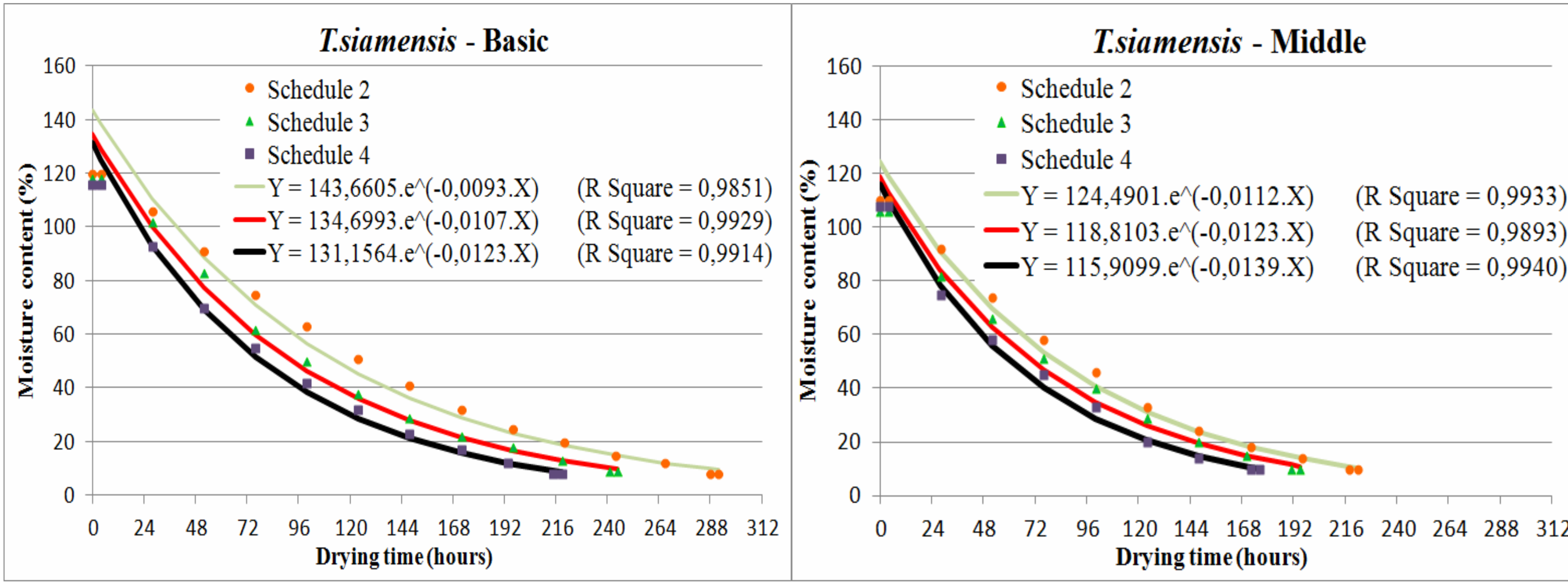
The drying rate was determined by the relationship between moisture loss over drying time

Drying defects

- All culms of the drying experiment were visually inspected for defects like collapse, cracking, and splitting that had occurred during drying.
- Drying defects were expressed as percentage of all samples in each kiln run.

Results

Drying rate and moisture loss



Relationship between drying time and moisture loss of *T. siamensis*

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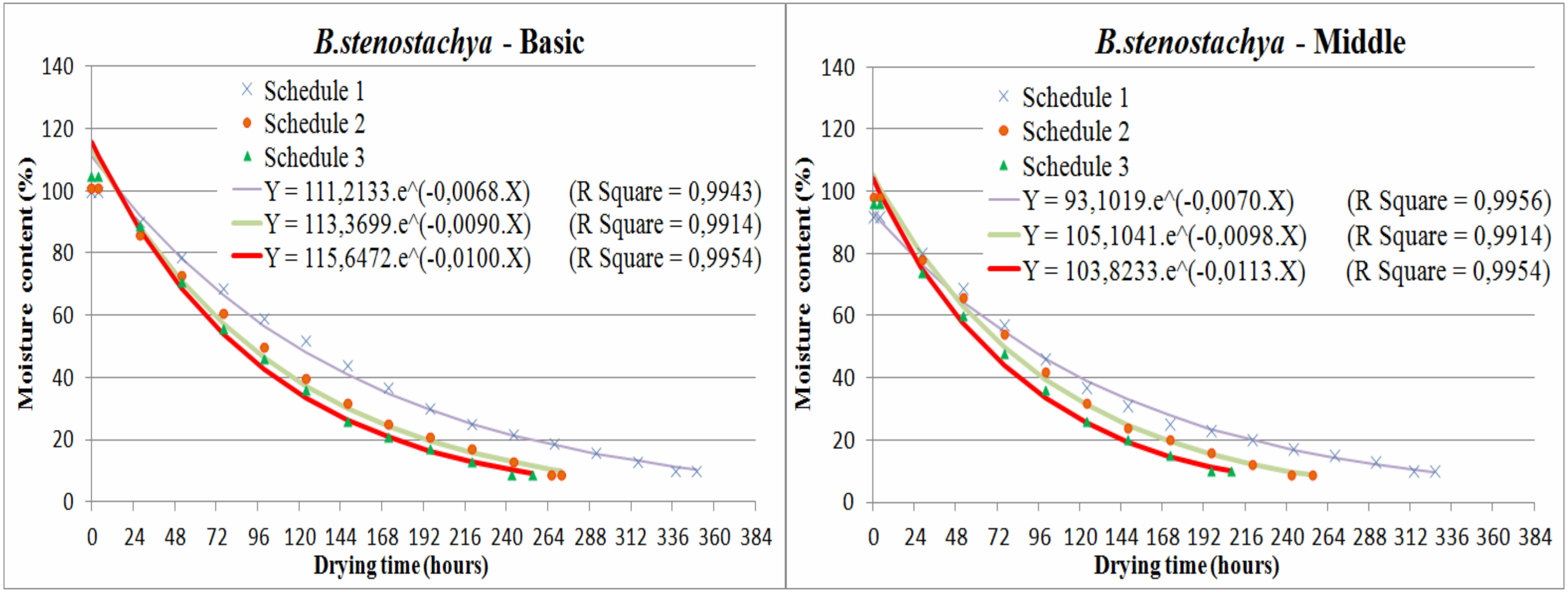
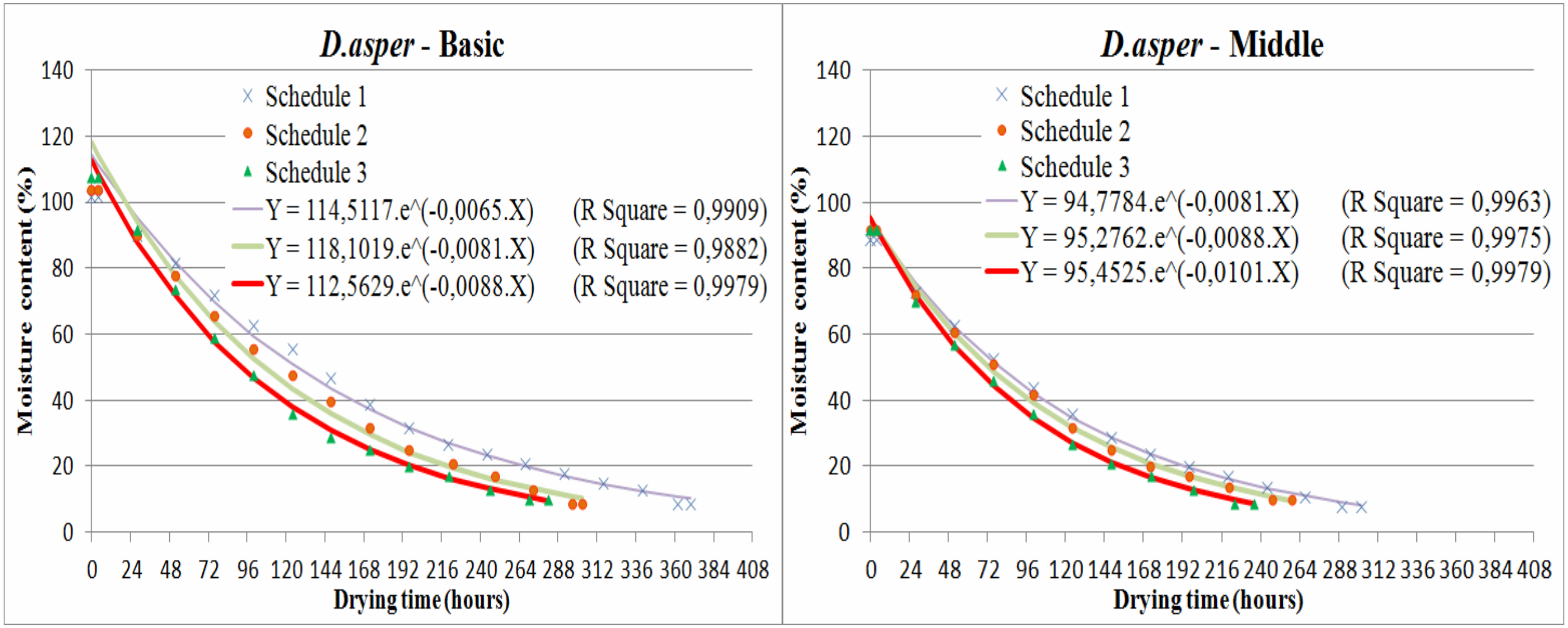
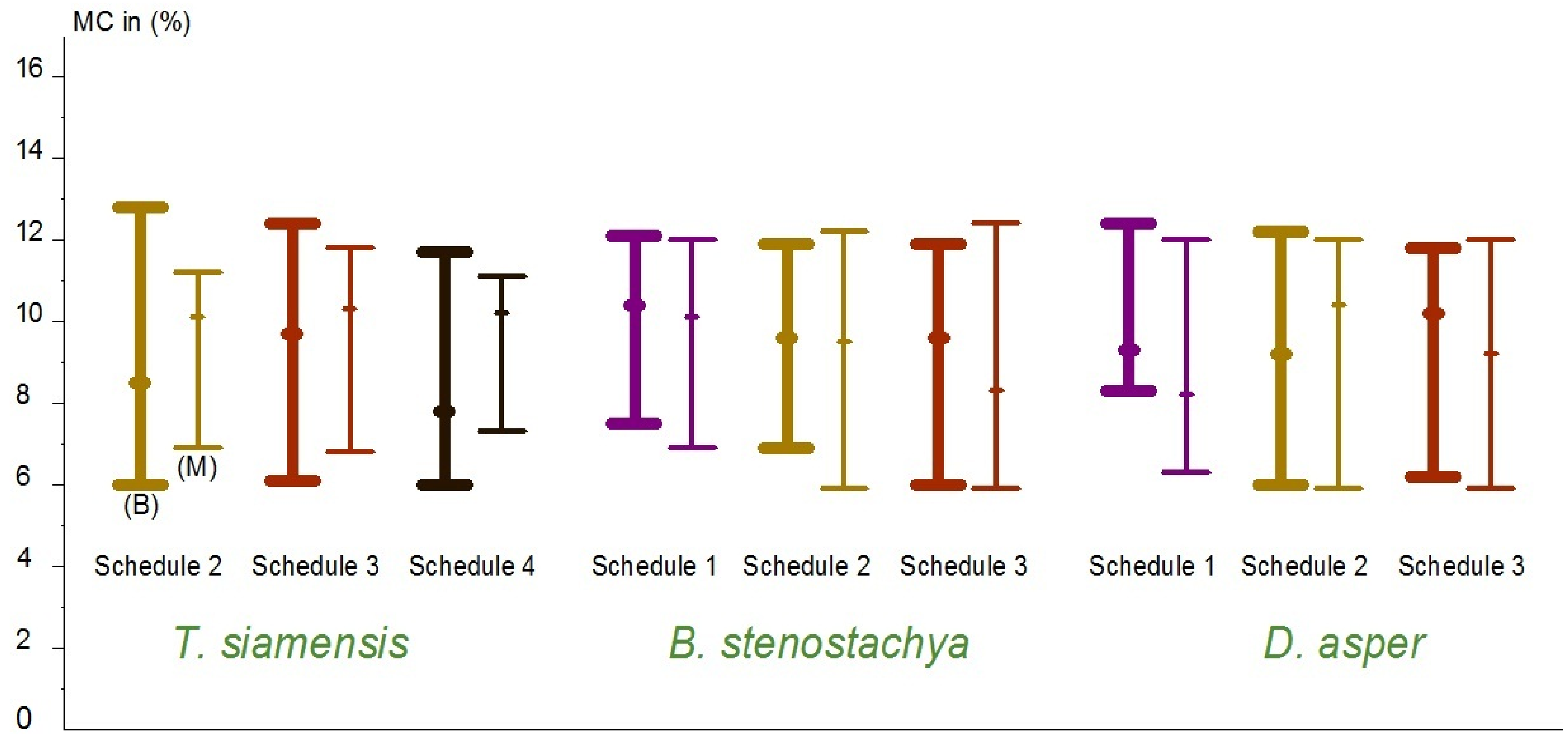


Relationship between drying time and moisture loss of *B. stenostachya*



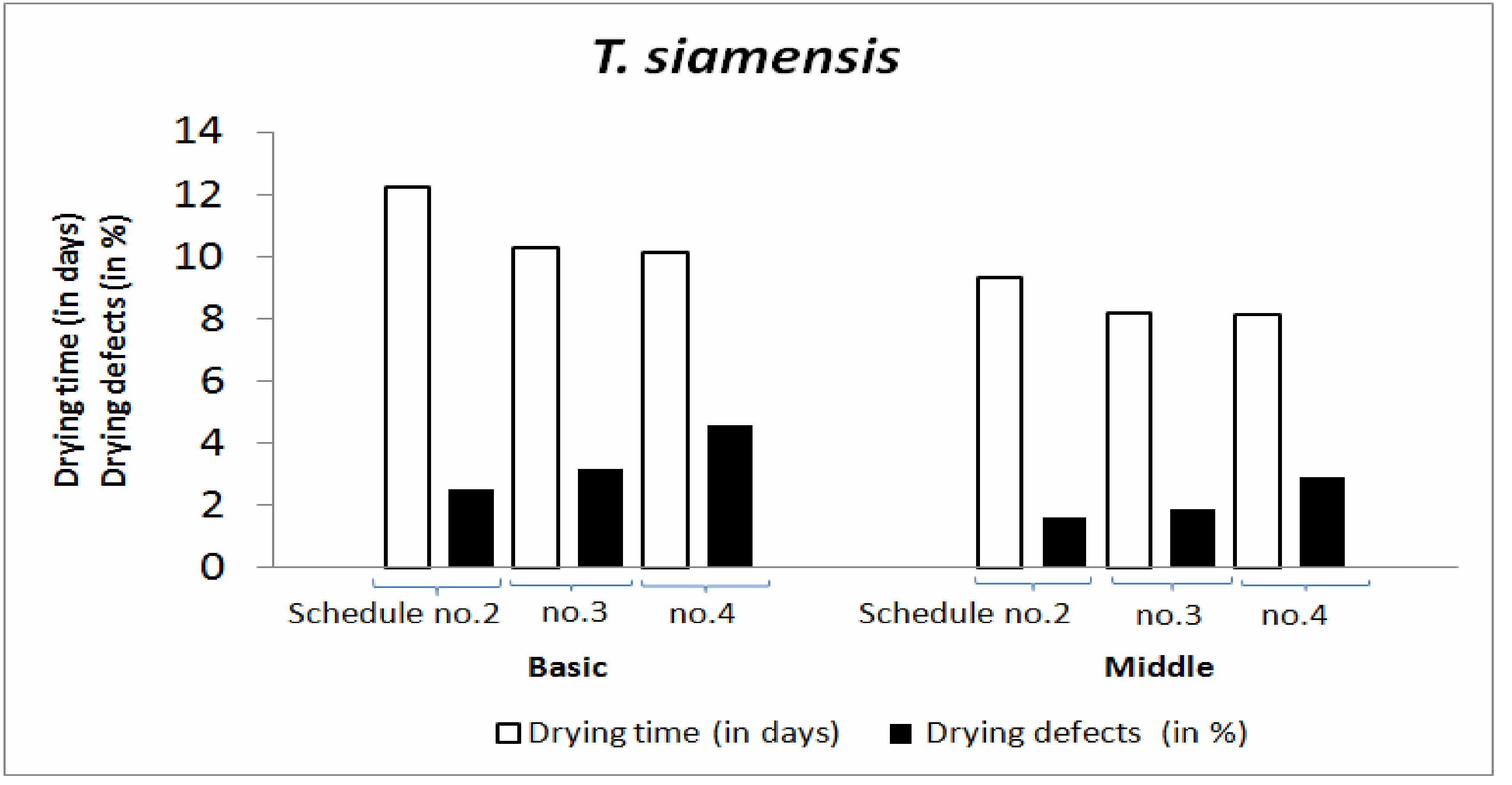
Relationship between drying time and moisture loss of *D. asper*

Final moisture content

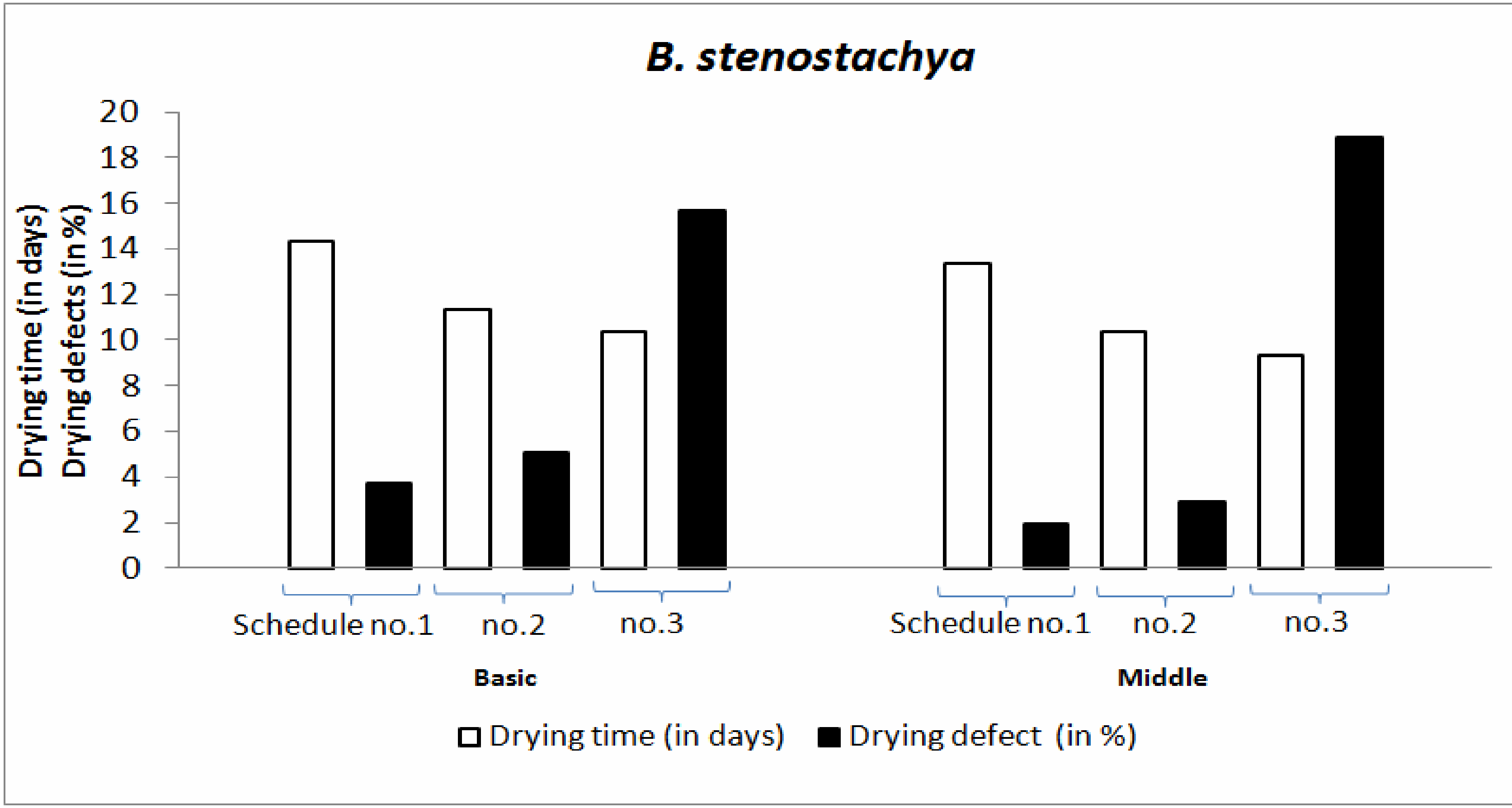


The average final moisture content with n = 39 of the four experiments

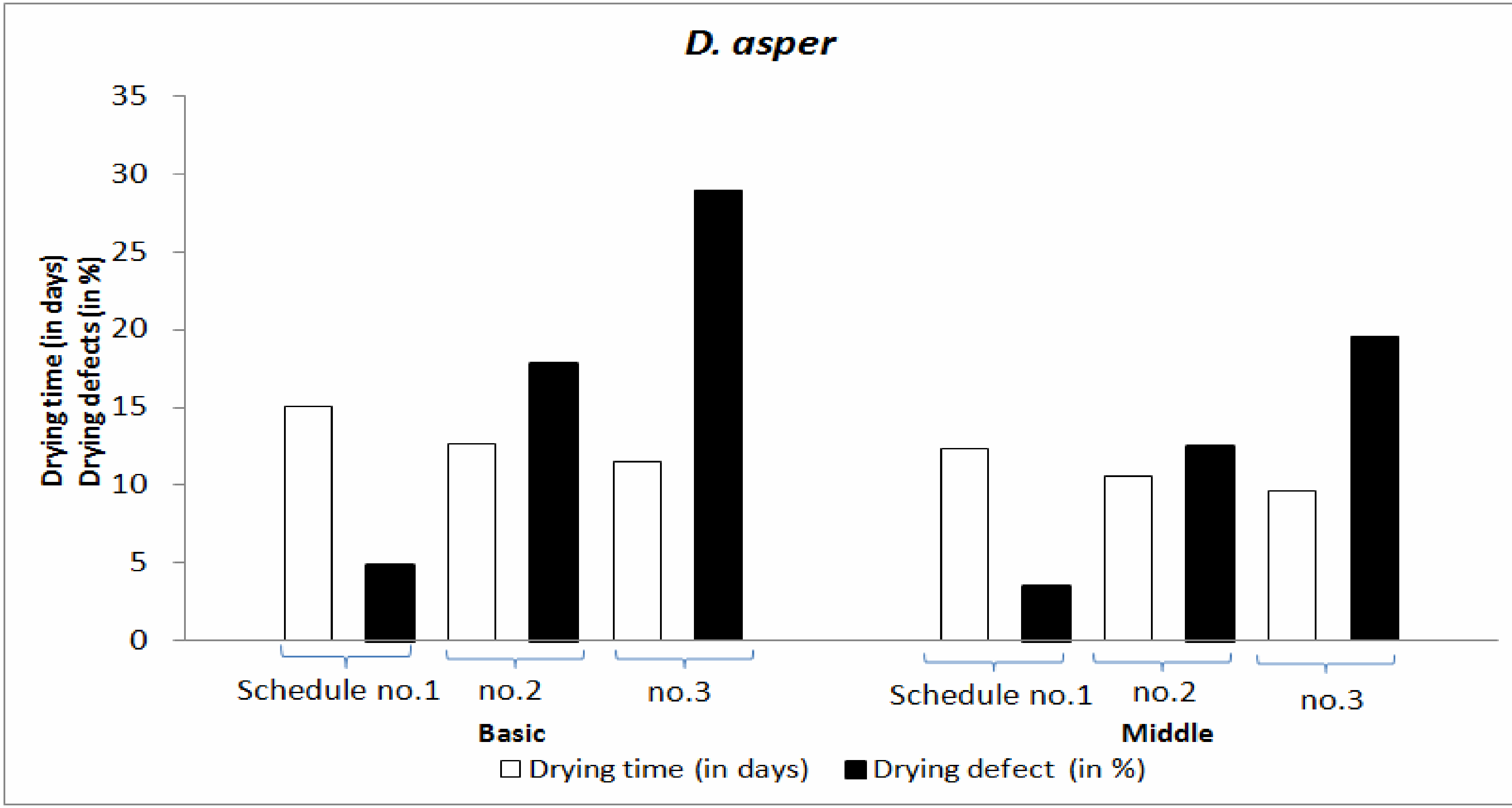
Drying time & drying defects



Drying time and percentage of defects for ***T. siamensis***



Drying time and percentage of defects for ***B. stenostachya***



Drying time and percentage of defects for ***D. asper***

End checks of *T. siamensi* and *D. asper*

Conclusion

- The initial experiments have shown that kiln drying of bamboo parts can be conducted successfully using proper schedules of temperature and relative humidity.

- Drying the solid species *Thyrostachys siamensis* requires a severe drying schedule at the initial stage with high temperature 65°C and 80% RH and temperature 75°C with low relative humidity of 15% at the final step.

- The cavity species *D. asper* is a difficult species to dry and susceptible to drying defects. Therefore it needs a mild schedule with initial temperature of 45^{o}C and initial RH of 80% and a final temperature of 55^{o}C and RH of 30 %.
- *B. stenostachya* dried moderately fast using the relative milder schedule in a initial phase with T of 50 ^{o}C and RH of 80 % and a end step with 65^{o}C and RH of 20%.

Recommendations

- The dry-kiln industry in South Vietnam will apply these effective and feasible schedules for drying longer culms.
- Also the drying schedules will be further developed for bamboo treated with preservatives based on boron compounds, CCB....
- Since drying is an essential step for processing bamboo into final products, the investigations should also include other commercial species

Acknowledgments

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Thank you for your attention!