INTERNATIONAL TROPICAL TIMBER ORGANIZATION

PROJECT COMPLETION REPORT

ITTO PROJECT PD 20/95 REV. 2(1)

CHEMICAL MODIFICATION OF BAMBOO CULMS AND THEIR RESITANCE TO WEATHERING

INSTITUTE OF BOTANY
CHINESE ACADEMY OF SCIENCES
XIANG SHAN, BEIJING 100093
THE PEOPLE'S REPUBLIC OF CHINA

AUGUST 22, 1999

PROJECT COMPLETION REPORT

PROJECT IDENTIFICATION

(a) Title:
CHEMICAL MODIFICATION OF BAMBOO CULMS AND THEIR RESITANCE TO WEATHERING

(b) Serial Number:
ITTO PROJECT PD 20/95 REV. 2(1)

(c) Executing Agency:
INSTITUTE OF BOTANY,
CHINESE ACADEMY OF SCIENCES

(d) Host Government(s):
THE PEOPLE'S REPUBLIC OF CHINA

(e) Starting Date:
March, 1996

(f) Actual Duration (Months):
48 months

(g) Expected Project Cost (US$):

Actual Project Costs:	162,345
ITTO Contribution:	83,345

PART I---EXECUTIVE SUMMARY

1. Background Information About the Project

(a) The key problem it intended to solve (Pre-project situation)

Bamboos have been used as a main material for house construction, furniture, handicraft articles and for pulp and paper-making in many tropical and subtropical countries and considered as a highly promising NTFP (non-timber forest product) because of its unique properties and the fast growing habitats. However, bamboo undergoes twisting, splitting and surface degradation during exterior exposure due to the solar irradiation and stresses imposed by cyclic wetting and fungal attack. In order to improve the dimensional stability and the resistance of bamboo culms to the degradation caused by weathering or organisms, it is of significance to make an overall investigation on the chemical modification of such an important material. Although different kinds of chemical treatments have been applied to wood products and earlier reports have shown that the treatment have greatly enhanced the biological resistance and physical properties of wood. From the survey of bamboo literature, it was found that most of earlier researches concerning bamboo utilization dealt with the structure, physical and mechanical properties of bamboo culms themselves, while the effects of chemical treatments on bamboo culms received only little attention. Therefore, it is highly essential to improve a range of bamboo culm properties by chemical modification as to expand their utilization in the industry and enhance the quality of products which will result in great beneficiaries to both bamboo producing and consuming countries. The project was proposed to assess effects of different chemical treatments on bamboo culms including the mechanical properties, dimensional stability,

morphological and color changes of chemically modified bamboos under accelerated conditions and ascertain the suitable concentrations of chemical reagents for different species of bamboos.

(b) The Specific Objectives and Outputs:

1) Development objectives

To explore an effective means of relieving pressure on the major tropical timber species by improving a range of bamboo culm properties.

2) Specific Objectives

---To improve the dimentional stability and the resistance of bamboo culms to degradation by means of chemical modifications;

---To determine the feasibility of chemical modifications in large scale production in the industry;

---To investigate the weathering effects on chemical modified bamboos;

---To introduce the knowledge and extend the technique of chemical modification on bamboos to the relevant units in the producing countries.

3) Output

--- To submit a research report on the production of chemical modified bamboos;

--- To edit, publish and mail an treatise of "Chemical modification of bamboo culms and their resistance to weathering". The treatise will mainly contain:

i) A review of chemical modification of woods with implications for bamboo utilization;

ii) Selecting chemical agents for bamboo culms in this project;

iii) Effects of different chemical treatments on dimensional

stability and mechanical properties of different taxa of bamboo culms;

iv) Effects of weathering on modified bamboos under accelerated conditions;

v) The useful prescription for bamboo treatment and its potential applications in the bamboo industry.

(c) The strategy adopted in carrying out the project

The research works of this project include the following three parts: field investigations, laboratory experiments and weathering tests.

Field investigation to get a basic data about bamboo is important for the project as China is very rich in bamboo resources, in which there are more than 500 bamboo species belonging to 37 genera, mainly distributed in south of China. The bamboo stand area is about 3.7 million hectares, possessing more than one quarter of total bamboo stand area in the world. The field investigations was conducted by the researchers and technicians in the group to the main bamboo producing regions of China, including Fujian Province, Guangdong Province, Guangxi Province, Zhejiang Province, Jiangsu Province. Based upon the results of field investigation, five bamboo species, namely *Phyllostachys pubescens, Bambusa lapidea, Sinocalamus latiflorus, Sinocalamus oldhemi* and *Pseudosasa amabilis*, was chosen as materials for further laboratory experiments and tests. All five bamboo species are high in height and large in culm diameter, among which *Phyllostachys pubescens* is the most important species for its ditribution and economic importance.

To select chemical reagents for modification of bamboo culm is the crucial point of chemical experiments. After a number of comparative experiments, five kind of chemical reagents had been synthesized, namely Phenolformaldehyde resin (low molecular condensation compound of

phenol and formaldehyde), Monomer acrylic acylamine derivatives, Allyl phthalate, blocked Isocyanate and Acrylicetin. While selecting chemical reagents, the technological process of modification had been improved. Some pre-treatments, such as vacuum, high pressure and prolongation in the maceration treatment, microwave treatment and drying within the oven in the solidification were applied in order to improve the effectiveness of modification which was reflected by the physical tests and scanning electron microscopy observations.

The weathering tests for bamboo culms of five species under natural and accelerated condition treated with ultraviolet irradiation had been carried out together with two wood species, *Populus tomentosa* (hardwood) and *Cunninghamia lanceolata* (softwood), chosen as control. Structural changes were observed by light microscopy and scanning electron microscopy. Changes in color and brightness were determined by colorimeter.

During the experiments, it was found that there are great differences in the results of modification between bamboo culms and woods. Such differences resulted from the structural differences between bamboo culm and wood, indicating that the structure characteristics are closely correlated with the physical, mechanical properties of bamboo culm, methods of chemical modification and resistance to weathering. Thus, the biological studies on bamboo culm development were carried out. This part of work is beyond the description of the project proposal, but they provided the fundamental data for better understanding of modification and utilization of bamboo culms.

To exchange experience, and to give full play to bamboo utilization, the co-operation with other institutes and organizations in China and abroad were developed, including the Institute of Wood Industry, Chinese Academy of Forestry, the Research Center of Bamboo Culm Engineer,

Nanjing Forestry University, Longyan (Fujian Province) Forest Bureau, the Institute of Botany in Guangxi, Anji Bamboo Garden (Zhejiang Province), Hamberg University in Germany, Wood Science Institute of Kyoto University and Forestry and Forest Products Institute (FFPRI) in Japan, etc.

(d) Project's planned duration and planned overall costs

The project was planned for 48 months, to start from March, 1996 and to end by December, 1999.

The project's planned overall cost was US$ 162,345 in which ITTO contribution was US$ 83,345 and China Government contribution was US$ 79,000.

(e) Specific sector at country or regional level to which the project relates

According to the forth national forest resources inventory, China has a total bamboo stand area of 3.6602 million hectares, occupying more than one quarter of total bamboo stand area in the world. They are mainly distributed in south of China, especially in Fujian Province (609.2 thousand ha), Jiangxi Province (534 thousand ha), Hunan Province (522 thousand ha), and Zhejiang Province (486.2 thousand ha), where the bamboo stand area occupied 58.9% of total area in China. Bamboo industry developed quickly in China recent years. At present about a thousand of factories all over the country engaged in the production of various bamboo boards, bamboo pulping, weave articles, chopsticks and so on. In short, the bamboo industry plays an increasingly important role in the development of economy in bamboo producing regions.

2.Project Achievements

(a) Outputs achieved

The following technical reports were produced resulting from the research activities conducted:

1). A technical report on Chemical modification of bamboo culms and their resistance to weathering, which contains five parts:

--- Report of Advance in Chemical Modification of Wood and Wood/Plastic Composites (WPC)

The report introduced the principle and reaction of chemical modification of wood and reviewed the manufacturing methods of chemical modified wood, wood/plastic composites (WPC) and their properties and applications.

--- Report of Bamboo Culms Structure and Its Chemical Modification

The report reviewed the structural characteristics of bamboo culms, the structural variation among different bamboo species and among different portions within one culm. Furthermore, the modification methods of bamboo culm were introduced and the factors that affected the results of chemical modification of bamboo culms were also discussed.

--- Experimental Report on Chemical Modification of Bamboo culms

The report summarized the experimental results of chemical modification of bamboo culms, including chemical reagents synthesized, selected, technological process developed and the measurement for increasing in weight of modified samples.

--- Experimental Report on Chemical Modification of Bamboo culms and Measurements of Their Physical Properties

The report summarized the experimental results of the Tests on

Physical Properties of Chemical Modified Bamboo culms, including basic density, directional shrinkage, shearing strength, compression strength parallel to the grain, strength of static bending and modulus of elasticity

--- Report on Weathering Tests of Bamboo Culms Under Natural and Accelerated Condition

The report summarized the experimental results of weathering test on non-modified and modified bamboo materials under natural and accelerated condition.

2) A technical report on Biological Studies on Bamboo Culms Development, especially on its lignification, which contains five parts:

--- An introduction and review on the recent advance in bamboo research and lignification of cell wall.

--- Histochemical studies on lignification of bamboo culms during its growth.

--- Microspectrofluorometric Analysis of Autofluo-rescence in the cell walls of bamboo culms

--- Ultrastructural studies on lignification of fiber and vessel walls in bamboo culms.

--- Histo- and cytochemical localization of peroxidase in bamboo culms and its relationship with lignification.

3) Study Tour Report

From 13th October, 1998 to 29th October, 1998, One researcher, Dr. He Xinqiang, visited Department of Bio-Material Science, the University of Tokyo; Wood Research Institute, Kyoto University; Forestry and Forest Products Research Institute (FFPRI) in Tsukuba, Japan.

4) Reports of Attending International Conferences

--- Dr. He Xinqiang attended the International Workshop of Bamboo Towards 21st Century hold on Hangzhou, Zhejiang Province, in September, 1997.

--- On April 23-24, Prof. Lin Jinxing, Prof. Hu Yushi and Dr. Liu Chengang were invited to attend the workshop of Chinese Bamboo and Rattan Experts held by INBAR in the Scientific Meeting Hall of Chinede Academy of Forestry. During the workshop Prof. Hu presented a talk on chemical modification of bamboo culms and its perspectives.

5) Four academic papers had been published:

--- Bamboo Structure and its modification. Chinese Botanical Bulletin, 1997, 14(4): 30-37

--- Microspectrofluorometric Analysis of Autofluo-rescence in the cell walls of bamboo culms. Acta Botanica Sinica, 1999, 41(7): 711-714

--- Comparative anatomical studies on four bamboo species from Guangxi Province. Journal of Bamboo Research, 1998, 17(1): 18-23

--- Modifications of Bamboo. Tropical Forest Update (ITTO Newsletter), 1997, 7(4): 30-37

(b) Specific objectives achieved

Two pamphlets entitled "Chemical Modification of Bamboo Culms and Their Resistance to Weathering" and " Biological Studies on Bamboo Culms Development, with special references on its lignification" were completed in Chinese based on the observation and results of this project. The pamphlets will be useful to the public and individuals who wish to make further studies and utilization of bamboo culms. The pamphlets were distributed to INBAR headquarter in Beijing, the related

government sectors and organizations in China such as National Library of China, Library of Chinese Academy of Sciences, etc. Thus, they are accessible as reference books to wood scientists, botany scientists, bamboo farmers, bamboo product manufacturers, and university students.

(c) Contribution to the Achievement of the Development Objectives

With the output achieved after the implement of the project, it is shown that it is possible to improve the physical properties of bamboo culms by means of chemical modification. The results showed potentiality to relieve pressure on the major tropical timber species by developing utilization of bamboo culms with fast growing and high yielding features.

(d) The Situation Before and After Project Completion

There are few reports about the chemical modification of bamboo culms before the implement of the project, though different kinds of chemical treatments have been applied to wood and the results have shown that the treatments have greatly enhanced the biological resistance and physical properties of wood. It was necessary to improve the physical properties of bamboo culms by the chemical treatments similar to those applied to wood as the investigation may be beneficial to bamboo farmers, bamboo product manufacturers and bamboo product consumers.

With the implement of this project, we investigated not only the effects of different chemical reagent treatments on bamboo culm, but also made a further study on the biology of bamboo culm development, especially on the lignification during its growth. It was noticed that there are differences in results of modification between bamboo culm and wood. Such differences were caused by the structural difference between

bamboo culm and wood. Furthermore, the biological studies on the bamboo culm development were carried out. This part of work is beyond the description in the project proposal, but they provided the basic knowledge for better understanding of modification and utilization of bamboo culms. By presenting the results in a meeting for experts on bamboo and rattan held by INBAR, several bamboo experts and processing workers were interested in our results as the results of this project showed promising future for bamboo utilization.

3.Target Beneficiaries Involvement

The beneficiaries of this project include the non-government organizations, local forest authorities and international organizations.

(a) **Non-government organizations:**

1) Chinese Academy of Sciences allocated a grant to purchase a reaction chambers, computer and electronic analytical balance, costing US$ 52.000.
2) Anji Bamboo Botanical Garden at Zhejiang Province, Bamboo Botanical Garden of Nanjing Forestry University provided us with bamboo materials during our field trip in 1996 and 1997.

(b) Local forest Authorities:

1) Longyan (Fujian Province) Forest Bureau, Anji (Zhejiang Province) Forest Bureau provided us with help in our field investigation.
2) The Institute of Botany in Guangxi belonging to Science and Technology Committee of Guangxi Province also provided us with assistance in the field investigation.

(c) International Organizations:

1) INBAR provided us a number of publications and literatures about the bamboo resources, bamboo industry and utilization.
2) Federal Institute of Forest and Wood Research, Germany provided us with literature and technical advice.
3) Forestry and Forest Products Research Institute (FFPRI) in Japan provided us with several publications about chemical modification on wood.
4) Wood Research Institute of Kyoto in Japan provided us with a number of publications about chemical modification on Bamboo research.

In return for the assistance and involvement of this project implement, the organizations were given the relevant research results and findings of this project. They can use the results for various purposes.

4.Lessons Learned

(a) Development Lessons

It was designed in the project that the aims by chemical modification was to improve the utilization properties and to extend the utilization of bamboo resources. In order to achieve the goal, selecting chemical reagents and technological process were crucial for the implement of this project. In the project design, we tried to synthesize three kind of chemical reagents, however, the scale of increasing weight of modified bamboo specimens turn to be not as good as expected, two other chemical reagents were synthesized, and the technological process of modification has been developed. The results showed that the weight had a little increased, less than 30%, much lower than that of wood, partly due to the

radial components in bamboo culms unlike rays in wood. In order to give more information for better understanding of modification and utilization of bamboo culms, biological studies on bamboo culm development were carried out.

Sub-contracts were made for cooperation with Institute of Chemistry, Chinese Academy of Sciences, Research Center of Bamboo Engineering at Nanjing Forestry University. Additional arrangements should have been made with a view to improving cooperation such as cooperation with Research Institute of Forest Industry, Chinese Academy of Forestry and some bamboo factories which had long experience in wood modification. It is difficult at present to put the laboratory result into the market due to the complex modified process and high production cost. Possible studies on simplifying the modified process and lowering the production cost should be encouraged.

(b) Operation lessons

Compared with the project work plan, the project should be considered well performed and efficient since the responsibilities of every project members were defined and confirmed ever since the beginning of the project execution. For the purpose of better implementation of this project, a well-trained Ph.D student and a technician were recruited with the financial support of this project in 1996, so they can concentrate all their efforts on the project and executed as planned. In 1998 and 1999, the graduate students successfully got their degrees from the implementing agency.

All the project records including sample collection, laboratory experiments and results analyses were well prepared. In addition, progress reports and technical reports were duly prepared by the project leader together with his group researchers and graduate students. The

reports were sent to ITTO head quarter every six months at the end of March and September throughout the project duration. The original copies of these reports were kept in the Research Planning Office, Institute of Botany, Chinese Academy of Sciences.

The project monitoring and evaluation carried out half yearly by the ITTO Project manager was very effective and regular. In addition, any minor changes on the proposed research activities were reported to ITTO project manager before the implementation.

The quality of project planning was good and well adopted. In order to reach the development objectives, some additional activities were also planned, such as biological studies on bamboo culm development. However, the study tour to Japan as a part of project was postponed due to the belated contact with the host organizations.

During the implementation of this project, the rules and responsibilities of the institutions involved in the project implementation were clearly defined. Institute of Botany, Chinese Academy of Sciences was the implementing agency involved in carrying out the research activities, data collection, document and report preparations as stated in the project. The project leader was the department director, which brought this institution in practice as a part of the project execution body with laboratory facilities available throughout the duration of project implementation.

As a result of well implementation, variation between planned and actual implementation was reduced to a lesser extent. Regular meetings and discussions between the project leader and research group members were organized to meet the schedule and modify any deviation from the planned activities and any expenses.

There were no external factors that negatively influenced the project.

5.Recommendations:

The project was designed to improve the physical properties of bamboo culms by chemical modification as to extend the utilization of bamboo resources and relieving the pressure on the major tropical timber. In order to achieve the goal, selecting chemical reagents and technological process were crucial for the implement of this project. In the project, we synthesized five kind of chemical reagents, and developed the technological process of modification of bamboo culms. Although the increasing of weight in bamboo modification may reach 30%, much lower than that of wood, it indeed could improve the physical properties of bamboo culms. In order to give more information for better understanding of modification and utilization of bamboo culms, we also carried out the biological studies on bamboo culm development, especially on lignification of bamboo culms during its growth, which provided important information for further studies and utilization of bamboo resources.

Part II. MAIN TEXT

6.Project Results

After the completion of this ITTO research project, we have obtained some positive results: two pamphlets entitle "Chemical Modification of Bamboo Culms and Their Resistance to Weathering" and " Biological Studies on Bamboo Culms Development, ---especially on its lignification" were completed; four academic papers had been published in academic magazines. The detail contents are as follows:

(a) The pamphlet entitled "Chemical modification of bamboo culms and their resistance to weathering" contains five parts:

1) Report of Advance in Chemical Modification of Wood and Wood/Plastic Composites (WPC)

The report introduced the principle and reaction of chemical modification of wood and reviewed the manufacturing method of chemical modified wood, wood/plastic composites (WPC) and their properties and applications.

2) Report of Bamboo Culms Structure and its Chemical Modification

The report reviewed the structural characteristics of bamboo culms, the structural variation among different bamboo species and among different portion in one culm. Furthermore, the modification methods of bamboo culm were introduced and the factors that affected the results of chemical modification of bamboo culms were also discussed.

3) Experimental Report on Chemical Modification of Bamboo culms

The report summarized the experimental results of chemical modification of bamboo culms, including chemical reagents synthesized, selected, technological process developed and the measurement of the increase in weight of modified samples. To select chemical reagents for modification of bamboo culm is the key to the chemical experiments. After several comparative experiments, five kind of chemical reagents had been synthesized, namely Phenolformaldehyde resin (low molecular condensation compound of phenol and formaldehyde), Monomer acrylic acylamine derivatives, Allyl phthalate, blocked Isocyanate and

Acrylicetin. Meanwhile, the technological process of modification had been improved. Some pre-treatments, such as vacuum, high pressure and prolongation in the maceration treatment, microwave treatment and drying within the oven in the solidification were applied in order to improve the effectiveness of modification which was reflected by the physical tests and Scanning electron microscopy observations. The results showed that the increasing weight ranging from 10% to 30%, lower than that of wood partly because the presence of knots, occurrence of tyloses in the vessels after cutting and lack of radial components in the bamboo culms.

4) Experimental Report on the Chemical Modification of Bamboo Culms and Measurements of Their Physical Properties

The report summarized the experimental results of the Tests on Physical Properties of Chemical Modified Bamboo culms, including basic density, directional shrinkage, shearing strength, compression strength parallel to the grain, strength of static bending and modulus of elasticity. The results indicated that the dimensional stability, weight and density increased, however, the scale of increase were different in response to various chemical treatments. The modified samples had better physical properties. They showed fine specific strength and specific rigidity.

5) Report on Weathering Tests of Bamboo Culms Under Natural and Accelerated Condition

The report summarized the experimental results of weathering test on non-modified and modified bamboo materials under natural and accelerated condition. Under the accelerated condition treated with ultraviolet irradiation, the ultrastructure

and color changes of five bamboo culm samples have been studied. SEM observation of cross section showed that the deterioration process in the fiber cell wall was initiated in the thin layers of second wall which contain high lignin, followed by the cell corners and the middle lamellae. While the process of deterioration of parenchyma began from the cell corners follow by the middle lamellae. Consequently, all of the cell walls eventually eroded. From the Weisner color reaction, it is shown that after 40 days of ultraviolet irradiation of cross section of *Ph. pubescens* the deterioration of lignin reached a depth of 590-810 μm in the parenchyma and 146-219 μm in fiber from the surface. Using the colorimeter, it was determined that the bamboo surface underwent dramatic changes in color and brightness during the first two weeks, and remained relatively constant after two weeks. Resulting from the chemical modification, the weathering tests of modified bamboo specimens under natural condition were studied. It was indicated that modified samples showed better resistance to degradation of natural weathering condition and ultraviolet irradiation.

(b) The pamphlet entitle "Biological Studies on Bamboo Culms Development, especially on its lignification" contains five parts:

1) An introduction and review on the recent advance in bamboo research and lignification of cell wall in bamboo culm and wood.
2) Histochemical studies on lignification of bamboo culms during its growth.

The results showed that the protoxylem vessels initiated lignification in the early stage of vascular bundle

differentiation, whereas metaxylem vessels and fiber walls started lignification from the middle lamella and cell corners after completion of vascular bundle differentiation. The walls of most parenchyma cells lignified after the stem reached its full height, while a few parenchyma cells remained non-lignified even the culm is 7 years old. The secondary wall of fibers and parenchyma cells thickened further during the stem growth and formed polylamellate structure. The fiber walls were rich in guaiacyl lignin in the early stage of lignification, in contrast to some lignin rich in syringyl units deposited in the later stage. The vessel walls mainly contained guaiacyl lignin, unilke in the walls of parenchyma cells where both guaiacyl and syringyl lignin were present.

3) Microspectrofluorometric Analysis of Autofluo-rescence in the cell walls of bamboo culms

All tissues of bamboo culm showed blue autofluorescence under ultraviolet irradiation. With the treatment of ammonia, the tissues increased their fluorescence intensity, among which those rich in ferulic acid changed their color into green, the peak of fluorescence emission spectra shifted from 470 nm to 510 nm. Nevertheless, the fluorescence intensity of all tissues decreased dramatically after the treatment of NaOH. With H_2O_2/HAC treatment, the lignified tissues remained strong blue autofluorescence, while the fluorescence from unlignified tissues disappeared. The results indicated that protoxylem vessels had already showed lignification before phloem and metaxylem formed in the tissues; ferulic acid was widely distributed in the young tissues of bamboo shoot, the content of

which decreased with the progress of the lignification. It was further confirmed that H_2O_2/HAC treatment was an effective method to discriminate phenolic acids bounded to hemicelluloses from phenolics existed in the lignin molecule.

4) Ultrastructural studies on lignification of fiber and vessel walls in bamboo culms.

The number of the organelles, such as Golgi bodies together withsmall vesicles, rough endoplasmic reticulum and lomasomes, increased during the rapid thickening and lignification stages of the secondary walls, indicating that the organelles played the key role in synthesizing and storing lignin precursors and transporting them to the walls. Cortical microtubules were abundantly and orderly localized at the plasmalemma even in the late stages of fiber development. Although their role in formation and deposition of cellulose microfibrils had been proposed, they may also performed a funcetion in the lignification. Lignin deposition occurred at numerous discrete sites within various cell wall regions, and the carbohydrate matrix would affect the style of lignin deposition. In the middle lamella region, lignin deposition occurred by addition of protolignin monomers to spherical particles of lignin, and lignification was completed by expansion of these spherical particles. In the secondary wall of vessels, lignification occurred by deposition of protolignin monomers to the ends of expanding lignin lamella between cellulose microfibril leading to greatly elongated patches of lignin due to the greater rate of deposition along the microfibril axis compared to that across it. While in the Sl

layer of fiber wall, lignin deposition occurred by addition of protolignin monomers to several discrete sites and formed some lignin lumps.

5) Histo- and cytochemical localization of peroxidase in bamboo culms and its relationship with lignification.

The peroxidase activity changed with the progress of lignification in a bamboo shoot. It was further localized at the corner of cell wall before lignification, and then appeared in the secondary wall with the thickening and lignification of secondary wall. The peroxidase signals appeared strong in the cell walls of the annular vessels of protoxylem where lignification was almost completed, and in the cell walls of the metaxylem vessels and the fibers where active lignification occurred. The results indicated that the peroxidase had participated in the lignin biosynthesis. However, the peroxidase activity was also localized in the phloem and parenchyma cells which still remained non-lignified state. It was therefore suggested that there were several peroxidase isoenzymes with different functions in the different tissues of bamboo culms.

Situation existing at project completion compared to the pre-project situation:

Before the implement of the project, little work has been done about the chemical modification of bamboo culm, while various kinds of chemical treatments have been applied to wood and the results have shown that that the treatments have greatly enhanced the biological resistance and physical properties of wood. It was necessary to further investigate if it is possible to improve the physical properties of bamboo culm by the

chemical treatments same as that used to wood since it can provide beneficial data to bamboo farmer, bamboo product manufacturer and bamboo product consumer.

With the implement of this project, we not only investigated the effects of different chemical reagent treatments on bamboo culm, but also made a further study on the biology of bamboo culm development, especially on its lignification. It was noticed that there is a great difference between results of modification on bamboo culm and modification on wood, as a result of the structural differences between bamboo culm and wood. Furthermore, the biological studies on the bamboo culm development were carried out. This part of work is beyond the description in the project proposal, but it provided the basic knowledge for better understanding of modification and utilization of bamboo culms. By presenting the results in a meeting for experts on bamboo and rattan held by INBAR, several botanists and bamboo experts were interested and considered that our results are necessary and useful for utilization of bamboo resources.

(c) The Long term objectives:

With the output achieved after the implement of the project, the results showed that it is possible to improve the physical properties of bamboo culms by means of chemical modification. Further investigation will show potentiality to relieve pressure on the major tropical timber species by developing utilization of bamboo culms that are of fast growing and high yielding.

7 SYNTHESIS OF THE ANALYSIS

(a) Specific Objectives

Achievement Realized

- Partially Realized
- Unrealized

(b) Outputs

Realized

- Partially Realized
- Unrealized

(c) Schedule

In Advance / on time

- Delayed but not seriously
- Seriously delayed

(d) Actual Expenditures

- Below planned
- More than 10% above planned

More than 20% above planned

PART III

CONCLUSIONS AND RECOMMENDATIONS

The main conclusions drawn from the project implementation and project results are as being spelt out in the Part II. ---"Project Result" of this report mentioned above. The specific recommendations, derived from the lessons learned, that could improve the effectiveness and efficient of

future projects are as follows:

(a) Development lessons

--- Further studies on simplifying the modified process and lowering the production cost should be encouraged.

--- International cooperation with research organizations abroad, such as in Japan, Germany and other countries, need to be enhanced.

---The project should invite more bamboo product manufacturers to attend in order to promote the chemical modification technology application in practice.

(b) Operation lessons

---As far as a project proposal is accepted in its merits, discussions on the planning and strategies of implementation must be conducted with ITTO managers or consultants.

---To develop a wide-ranging cooperation with scientists abroad.

---To seek more involvement, commitments and cooperation from the bamboo industry.

(c) Recommendations for future projects:

---Identification:

The future project should be focused on extending the chemical modification techniques in bamboo industry.

---Design:

The projects should be designed to simplify the modified process and lower the production cost.

---Implementation:

The project will be executed by a research institute or non government organization which has a long experience in wood science and chemical modification, cooperated with relevant processing factories.

---Organization:

The project should be collaborated with relevant local government authority and related agencies.

---Management:

The project should be managed in accordance with a well-written work plan and timetable. The project leader should be an expert on chemical modification with good credits.

RESPONSIBLE FOR THE REPORT

Name: Dr. Jinxing Lin

Position held: Research Professor and Director of Department

Date: August 28, 1999