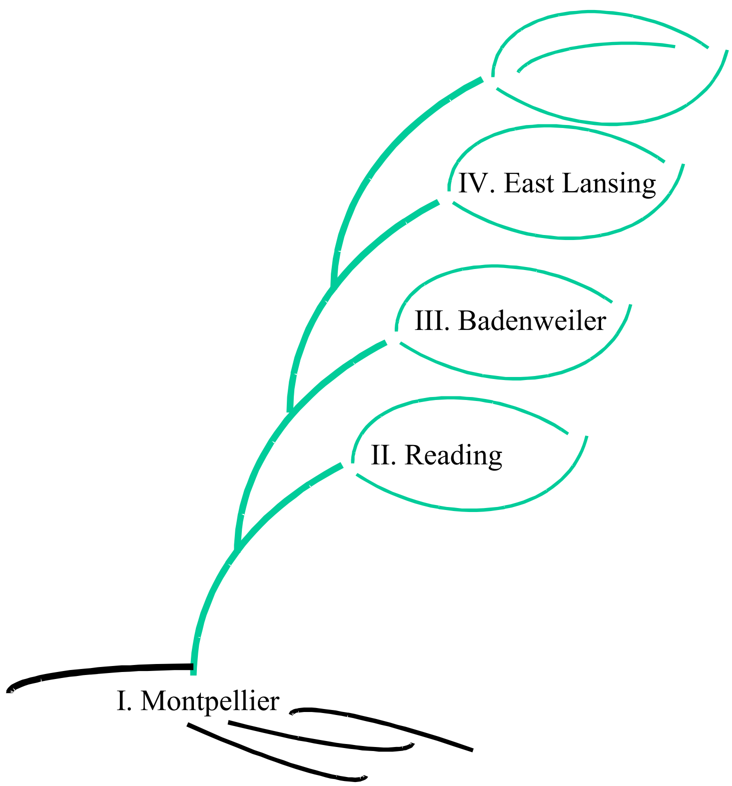
4th International Plant Biomechanics Conference

Conference Proceedings

ABSTRACTS

20-25 July 2003

Michigan State University
East Lansing, MI



4th International Plant Biomechanics Conference
Plant Biomechanics 2003

Conference Proceedings

ABSTRACTS

20-25 July 2003

Michigan State University
East Lansing, MI 48824

Editors:

F W Telewski
L Köhler
F W Ewers

www.plantbiomechanics2003.msu.edu

Published by:
W.J. Beal Botanical Garden, Michigan State University, East Lansing, MI 48824
Printed by:
Michigan State University Printing Services, 1330 South Harrison Road, East Lansing, MI 48824

ORGANIZING COMMITTEE

Dr. Guillermo Angeles, Productos Forestales Y Conservación de Bosques, Institute of Ecology, Mexico
Dr. Lawrence T. Drzal, Center for Composite Materials & Structures, Michigan State University, U.S.A.
Dr. Frank W. Ewers, Conference Co-Chairperson, Department of Plant Biology, Michigan State University, U.S.A.
Dr Barbara L. Gartner, Department of Forest Products, Oregon State University, U.S.A.
Dr. Lothar Koehler, Department of Plant Biology, Michigan State University, U.S.A.
Dr. Wendy Silk, Department of Land, Air, Water, University of California, U.S.A.
Dr Thomas Speck, Botanischer Garten, Albert-Ludwigs Universität Freiburg,Germany
Dr. Hanns-Christof Spatz, Department of Biology, Albert-Ludwigs Universität Freiburg, Germany
Dr. Frank W. Telewski, Conference Co-Chairperson, W. J. Beal Botanical Garden, Department of Plant Biology, Michigan State University, U.S.A.

SPONSORS

United States Department of Energy

Fisher Scientific International Inc.

Fisher Scientific International Inc.

MICHIGAN STATE UNIVERSITY

Department of Plant Biology
Office of the Provost
Office of the Vice President for Research and Graduate Studies
The Graduate School
Michigan Agricultural Exp. Station
College of Natural Science
College of Agriculture and Natural Resources
Campus Park and Planning/Beal Botanical Garden
Composite Materials and Structures Center
International Studies and Programs
Department of Energy Plant Research Laboratory
School of Packaging
Department of Forestry
Department of Plant Pathology
Environmental Science and Policy Program
Plant Breeding and Genetics Graduate Program

TABLE OF CONTENTS

INTRODUCTION

Welcome to Plant Biomechanics 2003. The first international conference entirely devoted to plant biomechanics was held in Montpellier, France in 1994. The conference was organized by Dr. Bernard Thibaut, National Committee for Scientific Research (CNRS) Montpellier and others to stimulate an interdisciplinary approach to addressing the major problems and questions encountered by researchers in the field of Plant Biomechanics. Plant Biomechanics as a discipline involves a synergy between scientists involved in plant biology, agriculture, modeling of complex systems, and engineers working in the field of mechanics of materials and structures. The stated intent of this first conference (Thibaut 1994) was to improve the understanding and analysis of:

- morphogenesis and function of supporting organs in plants;
- relationships between mechanical functions of cultivated plants and the quality of crops;
- growth, development, structure and mechanical strength of plant systems relative to modifications imposed by man and the environment;
- plant mechanical, structural and responsive designs as paradigms, in a biomimetic sense, for man-made applications.

Upon the conclusion of this first conference, the Organizing Committee decided future conferences should be held every three years in order to provide an international forum in which to bring this diverse group of researchers together and share state-of-the-art research developments and methods. Subsequently, the second Plant Biomechanics Conference was held at the University of Reading in 1997 (Jeronimidis and Vincent 1997) and the third conference at Badenweiler, Germany in 2000 (Spatz and Speck 2000). At the end of the 2000 conference, Drs. Frank W. Telewski and Frank W. Ewers submitted a proposal to host the fourth conference at Michigan State University. The Organizing Committee voted to award the meeting to Michigan State University and for the first time, the International Plant Biomechanics Conference was held outside of Europe.

Physical environmental restraints such as gravity, vapor pressure deficit, and drag, either induced by the flow of water or air, are among the most fundamental conditions any organism has to cope within its habitat. Biomechanics integrates many aspects of the biological and physical sciences in order to understand the development, form, and function of organisms in response to these fundamental physical restraints. This approach provides a foundation for the applied sciences by translating the understanding of the often elaborate and sophisticated structural forms found in nature into engineering solutions which are ultimately applied in advancing the use and quality of plants and plant products in our daily lives.

The field of plant biomechanics brings together scientists, engineers and technologists with a shared interest, but working in diverse fields including, but not limited to:

- Plant Biology (e.g. Beismann et al. 2000, Jaffe, Leopold, & Staples 2002, Speck 1998, Vogel 1994)
- Agriculture (e.g. Alvarez et al. 2000, Cleugh, Miller, & Bohm 1998, Crook & Ennos 1994, Donmez et al. 2001, Farquhar, Meyer, & van Beem 2000, Zebrowski 1999)
- Forestry (e.g. Coutts & Grace 1995)
- Genetic Engineering (e.g. Hepworth & Vincent 1999)
- Meteorology (e.g. Coutts & Grace 1995)
- Composite Materials (e.g. Mohanty Misra & Drzal 2001, Mohanty Drzal & Misra 2002, Reuschel & Mattheck 1999)
- Wood Technology (e.g. Cramer, Drozdek, & Wolfe 2000, Hepworth et al. 2002),
- Mathematics and Modeling (e.g. Gaffrey, Rabbe & Gebbeken 2001, Lang, & Fodor 2002, Moulia2000)
- Physics (e.g. Reuschel & Mattheck 1999)
- Material Science and Mechanics (e.g. Smith & Vincent 2002, Vincent, Saunders & Beyts 2002).

Due to the wide scope of biomechanics, research in this field is distributed over many different disciplines and the scientific exchange and feedback is not always obvious and straightforward. This is why the International Plant Biomechanics Conference has proven to be a vital forum since its initiation in 1994, bringing together scientist from a wide variety of fields and yielding productive interchange of ideas.

Since its inception in 1994, the conference has attracted greater international interest and participation. The conference provides a mechanism for both information and technology transfer across the wide array of disciplines representing both applied and fundamental fields of research. The field of plant biomechanics continues to expand, increasing the need for a greater interdisciplinary approach to address the wide range of questions within the topic. Advances have been made in all fields since the last conference. Specific topics addressed in the 4th Conference include:

- The effect of genetic modification of plants on mechanical strength, stability, and conductivity
- The properties and stability of natural and modified plant fibers in composite materials
- The role of environment in altering biomechanical properties and stability of both crops and trees
- Increasing the understanding of the physiological and molecular processes involved in perception and differentiation of plant tissues to meet biomechanical requirements.

Because the subject of plant biomechanics is so interdisciplinary, communication and sharing of information and technologies does not normally flow freely. Within North America in particular, there has not always been effective communication between researchers in fields such as plant biology, material sciences, and mechanics. Significant advances have resulted in the few cases where such partnerships have been forged. The 4th International Plant Biomechanics Conference provided a forum for researchers representing the various disciplines to continue sharing their recent findings, establish potentially new collaborations and provide new insight to address the questions currently being asked as well as to generate new questions. Ultimately, the exchange of information will advance the development of both fundamental understandings of the formation and function of plant tissues and structures as well as the technical application of this knowledge towards improving the use of the plants and plant products in our daily lives, and developing new synthetic products (i.e. cellular solids) which mimic (biomimetics) or are based on plant structures.

On behalf of the organizing committee we wish to take this opportunity to thank all those who have supported the conference.

References

Alvarez, M.D., Saunders, D.E.J., Vincent, J.F.V., & Jeronimidis, G. 2000 An engineering method to evaluate the crisp texture of fruit and vegetables. J. Text. Studies. 31 (4): 457-473

Bateman, R.M., Crane, P.R., DiMichele, W.A., Kenrick, P.R., Rowe, N.P., SpeckT., Stein, W.E. 1998 Early evolution of land plants: phylogeny, physiology, and ecology of the primary terrestrial radiation. Annual Review of Ecology and Systematics, 29:263 292

Beismann, H., Wilhelmi, H., Baillères, H., Spatz, H-CH., Bogenrieder, A., Speck T. 2000 Brittelness of twig bases in the genus *Salix*: fracture mechanics and ecological relevance, J Exp Bot 51:617-633

Cleugh, H.A., Miller, J.M., & Bohm, M. 1998 Direct mechanical effects of wind on crops. Agroforestry Systems 41(1):85-112

Cramer, S.M., Drozdek, J.M., & Wolfe, R.W. 2000 Load sharing effects in light-frame wood-truss assemblies J. Struct. Engr-ASCE 126(12):1388-1394

Crook, M.J., & Ennos, A.R. 1994 Stem and root characteristics associated with lodging resistance in 4 winter-wheat cultivars. Journal of Agricultural Science 123:167-174

Donmez, E., Sears, R.G., Shroyer, J.P., Paulsen, G.M. 2001 Genetic gain in yield attributes of winter wheat in the great plains. Crop Science. 41(5): 1412-1419

Farquhar, T., Meyer, H., van Beem, J. 2000 Effect of aeroelasticity on the aerodynamics of wheat. Mat. Sci. & Eng. Sci. & Eng. C-Biomimetic and Supramolecular Syst. 7(2):111-117.

Fontaine, M. 1998 Thigmomorphogenesis in the classroom. Amer. Biol. Teacher 60 (4): 285-287.

Gaffrey, D., Rabbe, K.H., & Gebbeken, N. 2001 Investigating the elastomechanics of Douglas fir. 1. Modelling with the Finite Element Method. All. For. Jagd. 172(5-6):101-116

Gordon JE & Jerominidis G 1980. Composites with High Work of Fracture, Phil. Trans. R. Soc. Lond. A 294:545-550

Hepworth, D.G. & Vincent, J.F.V. 1999 The growth response of the stems of genetically modified tobacco plants (*Nicotiana tabacum* >Samsun=) to flexural stimulation. Ann. Bot., 83: 39-43

Hepworth, D.G., Vincent, J.F.V., Stringer, G., Jeronimidis, G. 2002 Variations in the morphology of wood structure can explain why hardwood species of similar density have very different resistances impact and compressive loading. Philo. Trans. R. Soc. London Ser. A-Math. Phys. Engr. Sci. 360(1791):255-272

Jaffe, M.J., Leopold, A.C., & Staples, R.C. 2002 Thigmo responses in plants and fungi. Am. J. Bot. 89(3):375-382

Jeronimidis, G. & Vincent, J. F. V. (eds.) 1997 Plant Biomechanics 1997: Conference Proceedings I. Center of Biomimetics, University of Reading, Reading.

Lang, E.M., & Fodor, T. 2002 Finite element analysis of cross-halved joints for structural composites. Wood and Fiber Sci. 34(2):251-265

MohantyA.K., Misra, M., & Drzal, L.T. 2001 Surface modifications of natural fibers and performance of the resulting biocomposites: An overview. Composite Interfaces 8(5):313-343.

Mohanty, A.K., Drzal, L.T., & Misra, M. 2002 Engineered natural fiber reinforced polypropylene composites: influence of surface modifications and novel powder impregnation processing. Journal of Adheasion Science and Technology. 16(8):999-1015

Moulia, B. 2000. Leaves as shell structures: Double curvature, auto-stresses, and minimal mechanical energy constraints on leaf rolling in grasses. J. Plant Growth Reg. 19(1):19-30

Reusche,l D., & Mattheck, C. 1999 Three-dimensional fibre optimisation with computer aided internal optimisation. Aero. J. 103 (1027): 415-420

Smith, C.W., & Vincent, J.F..V 2002 Biomimetics: technology transfer from biology to engineering - Introduction. Phil. Trans. R. Soc. London Ser. A-Math. Phys. Engr. Sci.360(1791):155-157

Spatz, H.C. & Speck, T. (eds.) 2000 Plant Biomechanics 2000. Thieme, Stuttgart.

SpeckT. & Rowe, N.P. 1998. Introduction: Modelling form and function in fossil plants. Review of Palaeobotany and Palynology, 102:VII - IX

Thibaut, B. (ed.) 1994 Biomécanique des végétaux (Plant Biomechanics). Elsvier, Paris.

Vincent, J.F.V., Saunders, D.E.J., & Beyts, P. 2002. The use of critical stress intensity factor to quantify "hardness" and "crunchiness" objectively. J. Texture Studies. 33(2):149-159

Vogel, S. 1994 Life in moving fluids : the physical biology of flow. Princeton University Press, Princeton, N.J.

Zebrowski, J. 1999 Dynamic behaviour of inflorescence-bearing *Triticale* and *Triticum* stems. Planta 207(3): 410-417

GENERAL PLANT BIOMECHANICS

KEYNOTE

Answering Botanical Questions Using Biomechanics

A.R. Ennos

School of Biological Sciences, University of Manchester, 3.614 Stopford Building, Oxford Road, Manchester M13 9PT, U.K.

Abstract: Biomechanics should ideally help us answer important botanical questions. For instance simple beam theory has helped us understand the early diversification of land plants and the evolution of trees. But beam theory by itself has been unable to answer many other questions. Why, for instance have only ferns and angiosperms evolved lianescent and fast-growing herbaceous forms? Why do angiosperm trees dominate tropical rainforests? Why are lianas rare outside this habitat? It is suggested here that such questions may only be answered by taking into account not only the structural role of the long organs but also their role in water transport. I present plausible answers to the questions posed above and call for studies that might experimentally test these hypotheses. A final question that is considered is why buttresses are restricted to lowland tropical rainforests. A hypothesis is presented here, along with supporting preliminary evidence.

Biphasic behavior of mechanically stressed isolated tomato fruit cuticles. The influence of relative humidity and temperature

Antonio J. Matas [1], Gloria López-Casado [2], Jesús Cuartero [1], Antonio Heredia [2]

[1]Estación Experimental La Mayora (CSIC), Algarrobo-Costa, Málaga, Spain;
[2]Departamento de Biología Molecular y Bioquímica, Universidad de Málaga, 29071 Málaga, Spain.

Abstract: The mechanical properties of enzymatically isolated cuticles from ripe tomato fruits have been investigated. Stress-strain experiments performed on cuticular samples yielded curves with a clear biphasic shape indicating a complex and dual elastic-plastic behavior. The influence of sample hydration (45 and 75% relative humidity and aqueous solution) and temperature (range from 10°C until 45°C) were studied. Whereas low relative humidity and temperature induced an elastic-plastic behavior, wet experimental conditions and high temperatures induced a clear plastic behavior in all cuticular samples. The influence of the degree of development of the tomato fruit cuticle was also checked. Isolated cuticles form young tomato fruits presented similar mechanical characteristics, but the measured elastic moduli were significantly lower. From structural analyses of tomato fruit cutin, a molecular basis of the cuticle elasticity of tomato fruit cuticle is proposed in this communication.

The hierarchy of chirality

K. Schulgasser [1], A. Witztum [2]

[1]Department of Mechanical Engineering, Ben-Gurion University of the Negev, Beer Sheva, Israel
[2]Department of Life Sciences, Ben-Gurion University of the Negev, Beer Sheva, Israel

Abstract: Twisting is a prevalent feature of long, thin vertical leaves; it has been shown that this twist contributes to the mechanical integrity of the leaf. We address the question as to how this twist comes about, and posit that it is a reflection of twist at a lower structural (geometric) level. The stiffness required for maintaining verticality in the leaves is contributed by vascular bundles and fibers. These contain cellulose in the cell walls. Such cellulose chains spiral upward within the cell wall layers that are of characteristic handedness. This results in an isolated cell behaving mechanically in a chiral manner; specifically any elongation (contraction) of a single cell will result in rotation of the cell about its axis of particular handedness. We propose a mathematical model which shows that when cells are mechanically associated in groups, the chiral behavior of the cell will be expressed at larger scales, albeit to a mitigated degree. Thus cell extension during leaf development may explain the characteristic twist in such leaves.

Poster #01: Effect of the presence of unlignified parenchyma on the biomechanical properties of stems of Urticaceae.

Guillermo Angeles, Jorge López-Portillo, Ignacio Salomón-Quintana, Fernando Ortega-Escalona

Instituto de Ecología, A.C. Km. 2,5 Carretera Antigua a Coatepec No. 351. Xalapa, Veracruz 91070. Mexico.

Abstract: The secondary xylem of the Urticaceae family forms unlignified and lignified parenchyma. In the tropical rainforest of Los Tuxtlas, Veracruz, Mexico, the family is represented by the genera *Urera* and *Myriocarpa*, which can be shrubs or lianas. In lianas, unlignified parenchyma is found mainly in the radial parenchyma, whereas in the shrubs, it is found mainly in the axial parenchyma. To find out how the presence of unlignified parenchyma affected the mechanical properties of stems, we tested for elastic flexure in fresh branches. Force was applied at constant speed, until the maximum load was attained. Plotting force *vs*. deformation, modulus of elasticity (MOE) and modulus of rupture (MOR) were obtained. A one-centimeter segment of the middle portion of the specimen was taken to observe under the SEM, under low vacuum, without coating. In this way, we could precisely identify which kind of cells failed under the applied force.

BIOMECHANICS AND EVOLUTION

KEYNOTE

Big or small, complex or simple: The evolution of "complex" mechanical architectures

Nick Rowe

Botanique et Bioinformatique de l'Architecture des Plantes, UMR 5120 CNRS, TA40/PS2, Boulevard de la Lironde, 34398 Montpellier, France

Abstract: The evolution of increasingly diverse growth forms is often but not always a story of complexification. The transition from an early world land flora to a complex vegetation of "tropical rain forest" size and diversity required many mechanical innovations in form and structure within numerous lineages of the plant kingdom. However, a significant part of the history of mechanical architectures also involved drastically changing environments, mass extinctions and extreme changes in mechanical architecture including simplification and reduction. Such events and the "re-radiations" of mechanical architectures from mechanically simplified forms have contributed markedly to the wide diversity of mechanical architectures contributing to land plant diversity today. In this talk we will investigate the evolutionary processes underlying mechanical complexification, the processes favouring simplification and what happens when simplified forms begin to radiate and develop new complex mechanical architectures.

Phylogenetic constraints and canalization of plant growth forms: a biomechanical approach

Sandrine Isnard [1], Nick Rowe [1], Thomas Speck [2]

[1]Botanique et Bioinformatique de l'Architecture des Plantes, UMR 5120 CNRS, TA40/PS2, Boulevard de la Lironde, 34398 Montpellier, France.
[2] Plant Biomechanics Group, Institute for Biology II, Botanical Garden of the Albert-Ludwigs-Universität, Schänzlestrasse 1, D-79104 Freiburg, Germany.

Abstract: Studies carried out on climbing growth forms show distinct changes of mechanical properties and anatomy during development. In the dicotyledonous liana *Clematis* (Ranunculaceae), the drop in Young's modulus during the development is due to secondary growth, which eliminates fibrous mechanical tissues in the primary body. In the climbing palm *Calamus* (Calamoideae), the Young's modulus remains relatively stable in intact stems during the development. In this species, without secondary thickening, an effective change in mechanical properties is due to a mechanical process involving breakage of the outer leaf sheath and exposure of the more compliant central stem to mechanical forces. This mechanism allows the plant to withstand mechanical stresses and differs markedly from that of dicotyledonous lianas. Both genera show canalization of the growth form. As monocots, Calamoid palms have adopted a mechanical strategy in the absence of secondary growth. In the Ranunculaceae the dominance of herbaceous species with rhizomatous stems suggests a canalized developmental constraint limiting the evolution of self-supporting growth forms.

Biomechanics and functional morphology of the interaction between pollinators and the staminal levers: key characters for the adaptive radiation in the genus Salvia

Thomas Speck [1], Regine Regine Claßen-Bockhoff [2]

[1]Plant Biomechanics Group, Botanic Garden / Insitute of Biology II, University of Freiburg, Schäzlestr. 1, 79104 Freiburg, Germany
[2]Botanical Institute & Botanic Garden, Universität of Mainz, Bentzelweg 2, 55099 Mainz, Germany

Abstract: For an integrative understanding of the importance of flower structures, staminal lever mechanics and exact pollen positioning for reproductive isolation and speciation in Salvia, the interaction between pollinators and flowers are studied. One aspect is the biomechanics of the staminal lever, its functioning and diversity. By means of a custom made device, allowing for the measurement of forces in the milli-Newton range in intact flowers, forces and energies necessary to move the staminal lever are measured in different Salvia species. The other aspect is related to the pollinators (insects and hummingbirds). With an artificial flower equipped with sensors, forces and energies are determined which are exerted by pollinating insects in order to get to the nectar. One aim is to test if the forces and energies required to get to the nectar in Salvia flowers are relevant for the foraging behavior of the pollinators, and whether certain animals are excluded mechanically from pollination.

How shrub-like forms evolved from lianas: Phylogenetics, Biomechanics and Development

R. Lahaye [1], L. Civeyrel [1], N. Rowe [2], T. Speck [3]

[1]Laboratoire d'Ecologie Terrestre, University Paul Sabatier, 118, route de Narbonne, bât., 4R3, 31062 TOULOUSE cedex; France
[2]Botanique et Bioinformatique, TA 40 / PS2, Boulevard de la Lironde, 34398 Montpellier, cedex 5; France
[3]Plant Biomechanics Group Botanic Garden / Insitute of Biology II, University of Freiburg, Schäzlestr. 1, 79104 Freiburg, Germany

Abstract: We combine molecular phylogenetic approaches with biomechanical methods to explore the evolutionary transitions from twining lianas to "shrub-like" forms. Many lianescent members of angiosperm families have probably evolved from self-supporting ancestors while the transition from lianescent forms back to self-supporting growth forms is apparently much rarer. We investigate a group of endemic Malagasy representatives of the Asclepiadaceae. Within this group, most species are lianescent but ongoing molecular phylogenies indicate several transitions to shrub-like growth forms. Biomechanical analyses indicate that such shrub-like forms are not typical of self-supporting growth forms and show relatively minor variations in anatomy and development from the related lianas. These results suggest further evidence that in at least some groups of angiosperms, the evolution of lianescence possibly carries a high degree of developmental burden that limits subsequent evolution of diverse mechanical architectures.

Poster #01 Biomechanical correlates with stem age and anatomy of the dry tropical "broomstick tree" *Pittocaulon (Senecio) praecox* (Asteraceae)

J. Rosell, M.E. Olson

Instituto de Biología, Universidad Nacional Autónoma de México, Tercer Circuito s/n, Ciudad Universitaria, Copilco, Coyoacán A. P. 70-367, C. P. 04510, México, D. F. México

Abstract: Few studies of plant biomechanics have focused on plants of tropical dry habitats though these areas support a range of architectural types that are poorly represented elsewhere. Remarkable biomechanical phenomena have thus remained largely unstudied. We present a brief overview of some of these functional types with examples from our study of *Pittocaulon (Senecio) praecox*. This unusual-looking shrub or small tree bears thick, heavy stems with a wide parenchymatous pith, a very thin xylem cylinder, and thick, largely parenchymatous bark. The annual growth of *P. praecox* produces conspicuous rings on the stem that allow the age of any portion to be determined. This property permitted documentation of ontogenetic variation in flexural stiffness (EI) and structural elastic modulus (E_{struct}) of the stem, and E and EI of wood and bark separately. Anatomical correlations with biomechanical characteristics are presented. Other unusual trees (*Jacaratia*, *Bursera*) currently under examination are briefly mentioned.

Poster #02: The bee's point of view: analyzing co-evolutionary adaptations between pollinators and the staminal lever mechanism in Salvia

Martin Reith [1], Regine Claßen-Bockhoff [2], and Thomas Speck [1]

[1]University of Freiburg i. Br., Botanic Garden, Plant Biomechanics Group, Institute of Biology II, 79108 Freiburg, Germany
[2]University of Mainz, Institute of Specific Botany and Botanic Garden, 55099 Mainz, Germany

Abstract: The staminal lever mechanism of the genus Salvia was analyzed as a template for the technological implementation of a miniaturized lever system. Moreover, this lever system is thought to play a major role in the evolution and speciation within the genus Salvia. In the present study, we examined the hypothesis that particular bee species are excluded from the Salvia flowers by the lever mechanism. The forces exerted by flower-visiting bees were measured with a custom-built artificial flower. The experimental setup included a lower lip with a highly sensitive force transducer and a retractable nectare source. It was thus possible to increase the distance between the insects' heads and the food source. The bees reacted with an increased application of force by pressing their heads against the plate with the access to the nectare source. First results indicate that the tested bee species can exert forces many-fold higher than required to trigger the lever mechanism in the natural flower.

Poster #03: Quantitative analysis and simulation of structural and functional aspects of secondary growth in Palaeozoic seed plants: comparison with living plants

Tom Masselter [1], Nick Rowe [2], Thomas Speck [1]

[1]Botanic Garden, Plant Biomechanics Group, Institute of Biology II, University of Freiburg, Germany
[2]Botany and Plant Architecture Bioinformatics, Montpellier II, France

Abstract: The aim of this work is to understand functional aspects of different constructional strategies in extinct woody plants. Some Palaeozoic plants lack significant development of secondary outer tissues such as bark that allows an increase in stem diameter. As a consequence, secondary growth of internal tissues such as phloem and especially xylem may lead to mechanical destruction of parenchymatous inner cortex without its replacement by secondary cortical tissues. Changes of the different tissues due to secondary growth during ontogeny were measured in two Palaeozoic seed ferns (*Lyginopteris* and *Calamopitys*). The results are used as a basis for simulating the secondary growth of these plants. First results indicate that the changes of plant tissues can be approximated by simulations with pressurized foams and are also observed in living plants (e.g. *Aristolochia*). These results may help to understand the intriguing question why other (than lygnophyte/seed plant) constructional strategies have become extinct.

BIOMECHANICS AND ECOLOGY

KEYNOTE:

Tree adaptation to the threat of damage from wind and snow

Barry Gardiner and Chris Quine

Forest Research, Northern Research Station, Roslin, Midlothian EH25 9SY, Scotland, UK.

Abstract: Trees are able to survive in a range of climatic conditions and this adaptation has been primarily through evolutionary selection. However, trees are also able to adapt individually to local site conditions. We will explore the mechanisms by which trees respond to the threats of wind and snow damage. We will show how large the differences can be between different provenances of the same species according to the conditions under which they are growing and we will show how certain species have developed survival strategies because of the threat from extreme events. Different tree species have different susceptibilities to damage and the risk of damage varies with location. We will discuss how understanding the biomechanics of trees can lead to a more complete understanding of the ecology of natural forests and we will discuss the implications for managed forests in which trees are grown outside their natural range.

Biomechanics and height growth strategies in a tropical rainforest sapling community. A key role of tree pre-stresses?

M. Fournier [1], B. Clair [1], J. Gaëlle [1], J. Ruelle [1], M. F. Prevost [2]

[1]UMR ECOFOG CIRAD ENGREF INRA, BP 709 97379 KOUROU, French Guiana, France.
[2]UMR AMAP CIRAD CNRS INRA IRD Univ. Montpellier II, IRD de Cayenne, Route de Montabo, 97300 CAYENNE, French Guiana, France

Abstract: Tropical forest ecology has sometimes questioned tree biomechanics for the adaptive significance of species morphological traits. Usually, safety factors (against buckling or windbreaks) are compared among species and environmental conditions. However, trees are living structures that restore verticality using maturation stresses (and reaction wood), but such reactions have been scarcely discussed in ecological studies. The present work aims at defining, in addition to safety factors, biomechanical variables (state of lean and rectitude, gravitational continuous disturbance, reaction curvatures) from measurements of stem and cross section geometries, mass distributions, stem stiffness, and maturation strains, relevant for growth strategy studies. Their variability has been observed in a sapling community (one plot in a mature forest near the St Elie Station in French Guiana, 100 trees between 2.5 and 5cm DBH): Height and diameter explains most of the variability of safety factors that increase with diameter and height. The most important result is that active reactions are usually much greater than gravitational disturbances.

Biomechanical responses to elevated CO_2 in tropical lianas

Julian Granados

University of Basel, Institute of Botany, Schoenbeinstrasse 6, 4051, Basel, Switzerland

Abstract: Severe light limitation enhances liana growth response to elevated CO_2. Thus, liana competitiveness may become vigorous and potentially leading to enhance forest dynamics. Climbing plant competitiveness depends in a number of physiological and biophysical aspects. Mechanical strength determines seedling survival in the understory. I investigate the mechanical responses of two tropical climbing plant species to a four- step CO_2-enrichment, ranging from pre-industrial (280 ppm) to future (700 ppm) CO_2 concentration. Young's modulus of Elasticity in Gonolobus and Ceratophytum increased together with elevated CO_2. When elevated CO_2 increases the relationship Elasticity vs. wood density increased to. However, this effect changed with light availability. Wood density is a function of stem anatomy and elevated CO_2 had an enhancement effect on Pith, Xylem, Parenchyma, Sclerenchima and Phloem surface areas. There was a positive increment between SLA and Elasticity and a negatively relation with stem liana density. Climbers stem CO_2-elasticity enhancement because of CO_2-SLA, wood density and anatomy changes, represent a major feature for climbing plant's competitiveness. Thus, potency the possibility of enhanced forest dynamics. A more dynamic forest will store less carbon in the long run.

The influence of light availability on the development of the neotropical liana *Croton nuntians*

Friederike Gallenmüller [1], Ulrich Müller [1], Nick Rowe [2], Thomas Speck [1]

[1]Plant Biomechanics Group, Botanic Garden / Insitute of Biology II, University of Freiburg, Schäzlestr. 1, 79104 Freiburg, Germany
[2]Botanique et Bioinformatique, TA 40 / PS2, Boulevard de la Lironde, 34398 Montpellier cedex 5; France

Abstract: The neotropical species *Croton nuntians* occurs in juvenile, self-supporting growth phases and in adult climbing growth phases. Cross-sections of climbing stems show a transition from a stiff wood type to a more flexible one with large vessels like that reported for many other tropical lianas. Plants of *C. nuntians* start to climb (i.e. loose their capacity to maintain an upright position without a support) because of an accelerated growth in length, leading to the formation of long, slender and unstable stems. In this species the transition to the formation of the flexible wood type with large vessels does not take place simultaneously with the shift to the climbing growth phase, as assumed so far. Light availability has a strong influence on growth, biomass distribution and wood anatomy in *C. nuntians*, but cannot be considered as the exclusive factor triggering the shift from the self-supporting to the climbing growth phase.

Costs of mechanical stability in competing and non-competing tobacco plants

Niels P.R. Anten

Department of Plant Ecology Utrecht University, P.O.Box 800.84 NL-3508-TB Utrecht & Chair Group Plant Production Systems, Wageningen University, Haarweg 333, 6709 RZ Wageningen, Netherlands

Abstract: We examined the fitness costs and benefits of mechanical hardening in plants. Tobacco (*Nicotiana tabacum*) plants were flexed 40 each and grown either in isolation or in a dense stand, (flexed and control plants were mixed). Flexed plants produced shorter and thicker stems with a lower elastic modulus but equal maximum break stress than control plants. It was estimated that as a result, they would be able to resist 40-70% greater lateral forces (F_{max}) and that they had 60 - 500% greater buckling safety factors. For all plants F_{max} values exceeded wind forces measured in a wind tunnel at wind speeds of up to 13 ms^{-1}. For isolated plants the increase in stability had no consequences for either growth or seed production. By contrast, in the dense stand flexed plants were progressively shaded by control plants and had considerably lower rates of seed production and survival. These results show that the fitness costs of mechanical stability depend strongly on the degree to which plants compete for light.

Relating leaf tensile properties to drought and desiccation tolerance for selected species of *Eragrostis*

R.A. Balsamo [1], C. van der Willigen [2], J. Farrant [2]

[1]Department of Biology, Villanova University, Villanova, PA 19085; USA
[2]Department of Molecular and Cell Biology, University of Cape Town, Private Bag Rondebosch 7701; South Africa

Abstract: Leaf mechanical parameters were measured for the dehydration tolerant grass *Eragrostis curvula* when fully hydrated and when dried to below its turgor loss point. Tensile strength, toughness, and the elastic modulus all decreased with distance from the base of the lamina yet all values increased under turgor loss conditions. *Eragrostis curvula* had significantly higher tensile strength values than *Eragrostis tef*, *E. capensis*, or *E. nindensis*. However, unlike the other species, leaf tensile strength for the desiccation tolerant *E. nindensis* did not increase with water loss. Further, when leaves were flash dried the tensile strength of *E. curvula* was unchanged from leaves dried naturally while there was a marked increase in *E. nindensis*. These results confirm that leaf mechanical properties are affected by water status and suggest a positive correlation between leaf tensile strength and tolerance to dehydration. Further, the distinctive mechanical behavior of *E. nindensis* during desiccation may suggest a fundamental difference in strategy from dehydration tolerance for surviving tissue water loss.

The effect of residence time in the rumen on plant biomechanical properties

Debbie Archer [1], Gordon Sanson [2], Adrian Egan [3]

[1]School of Biological Sciences, Monash University, Clayton, Australia, 3800
[2]School of Biological Sciences, Monash University, Clayton, Australia, 3800
[3]Institute of Land and Food Resources, Melbourne University, Victoria, Australia, 3010

Abstract: Studies investigating chewing in ruminants often state that microbial fermentation weakens or softens cell wall structure, facilitating particle breakdown during rumination. However changes in the biomechanical properties have not actually been measured. In this study lucerne stem particles were immersed in the rumen of fistulated sheep and shearing tests were performed on particles at various intervals over a 48-hour period. The effect of turgidity, tissue structure, fluid entry and associated microbial access and particle size were tested.

While strength and work of fracture decreased during residence time in the rumen, the rate and extent varied over immersion time in the rumen. The results suggest that changes occurring may be mostly due to the ability of the stem to maintain its geometric shape during hydration in the rumen fluid rather than to microbial weakening of the cell walls. These results also suggest that previously researchers have overestimated the extent of change. This has implications for the extent and timing of rumination chewing and the degree of specialization of the dentition.

Velocity of fracture as a factor in food processing by ruminant herbivores.

Gordon Sanson

School of Biological Sciences, Monash University, Victoria , 3800, Australia.

Abstract: The functional spatial relationships between the shearing crests of buffalo molars during occlusion reveal a complex set of interactions. It is suggested that the patterns of crests and basins that form the occlusal surface capture turgid regurgitated food from the cheek pouch during rumination and guide pulses of food along channels, concentrating that food into regions where opposing shearing crests meet at a maximized velocity. It appears that velocity is maximized at the expense of mechanical advantage, potentially promoting brittle fracture, likely in itself to limit the fracture process zone to a small region. This seems paradoxical in animals seeking to maximize cell damage to promote bacterial fermentation sites. However, other occlusal mechanisms may exist to counteract this effect. It is suggested that promoting brittle fracture reduce strain limitations, possibly a case of overcoming displacement-limited defenses in grasses, sensu Lucas et al. (2000).

Size dependence of boundary layer properties in the white cushion moss: Model development and field evaluation

Steven K. Rice and Nicole Schneider

Department of Biological Sciences, Union College, Schenectady, NY 12308, U.S.A.

Abstract: We developed a boundary-layer conductance model for the white cushion moss (*Leucobryum glaucum*) by evaluating the size dependence of cushion shape, surface roughness and boundary-layer properties. Canopy shape and surface roughness were measured on 34 3.8-33 cm diameter cushions using a contact probe. Cushion surface area was employed in functional studies and obtained by quantifying the relationship between surface roughness and leaf area index. Boundary-layer properties were evaluated on 14 cushions over 0.8-4 m/s wind speeds in a laminar-flow wind tunnel. Cushion diameter and roughness length dimensions were used to model the relationship between flow and conductance with dimensional analyses (i.e., R_e and S_h-S_c numbers). The ecological significance of the model was tested by measuring evapotranspiration rates and chlorophyll fluorescence (DF/Fm') to estimate physiological performance during a 5 d drying cycle under field conditions. Differences in moss cushion structure predictably influenced plant water and carbon budgets under natural conditions.

Poster #04: Mechanical modeling of tree and forest stand stability to wind: a population approach.

Philippe Ancelin [1], Benoît Courbaud [2] and Thierry Fourcaud [1]

[1]Plant Modeling Program CIRAD/AMIS, Laboratoire de Rhéologie du Bois de, Bordeaux, UMR 5103 CNRS/INRA/Univ. Bordeaux I, Domaine de l'hermitage, 69 route d'Arcachon, 33612 CESTAS GAZINET; France
[2]CEMAGREF - Grenoble Regional Center, Mountain Ecosystems and Landscapes Research Unit, 2 rue de la Papeterie, BP 76, 38402 Saint-Martin-d'Hères cedex; France

Abstract: Wind damage is a major disturbance interacting with forest development processes. Either probabilistic or mechanistic models have been proposed to assess this risk. Mechanistic models are potentially interesting tools for testing the influence of silvicultural strategies on damage. Usually, the risk of damage in a stand is summarized by the behavior of the mean tree. Wind damage in forest stands is nevertheless far from a whole or nothing process. This work proposes a population model of wind damage based on the mechanical behavior of all trees in a stand. Using the Transfer Matrix Method of beams, this model allows wind and gravitation loads, as well as mechanical state of stems to be well described. Applying the model on a heterogeneous Norway spruce stand, we try to explore how damage at stand level can be predicted from the distribution of individual characteristics, and how damage is related to wind speed.

Poster #05: The relationship between biomechanical and chemical anti-herbivore defense: Do chemical defenses decline as developing leaves become tougher?

J. Read, G.D. Sanson, E. Gras, C. Brunt, and F. Clissold

School of Biological Sciences,
Monash University, Victoria 3800, Australia.

Abstract: Expanding leaves cannot be tough because of the constraints of cell expansion, and therefore are particularly vulnerable to being eaten. We predicted that chemical defense would decline as the leaf increased its mechanical defense (toughness) during development. Consistent with this hypothesis, higher concentrations of total phenolics were recorded in expanding leaves than mature leaves in species whose leaves became tough at maturity, but no difference was recorded between expanding and mature leaves in soft-leafed species. In addition, cyanogenic glycosides were recorded in the expanding leaves of one species with tough mature leaves, but not in the mature leaves of the same species. Despite the higher concentrations of putative chemical defenses in young leaves of most species they were eaten more by a generalist herbivore, *Epiphyas postvittana*, than mature leaves, consistent with the higher nitrogen concentration in leaves that required less force and energy to chew.

Poster #06: Sprouting on undamaged tree stems after Hurricane Georges

Skip J. van Bloem [1], Peter G. Murphy [1], Ariel E. Lugo [2]

[1]Department of Plant Biology, Michigan State University, East Lansing, MI 40024 USA
[2]International Institute of Tropical Forestry, USDA Forest Service, Rio Piedras, PR.

Abstract: Wounding or breakage of trees following a disturbance commonly results in sprouting, but sprouting on undamaged trees after a disturbance is less common. Following Hurricane Georges in 1998, we measured sprout development on over 1400 stems in Guanica dry forest in Puerto Rico. We counted the number of sprouts, measured their location on stems, and followed survival for two years. Stems that showed no signs of wounding produced 5.7 to 10.1 sprouts per stem after the hurricane, with 3-6 times higher than pre-hurricane sprouting rates. As expected, sprouting was also high on wounded stems. More than three-quarters of the hurricane induced stem sprouts originated within 40 cm of the ground. After 2 years, only about 13% of these sprouts had died. We hypothesize that the hurricane caused prolonged vertical displacement of the stems. Displacement would increase the production of ethylene where bending was greatest near root collars. Ethylene production has been shown to inhibit auxin transport in stems, which could spur sprout development. Dry forests in the Caribbean are shorter, more slender, and have more multi-stemmed trees than do dry forests in other locations. The sprouting responses seen after Hurricane Georges may help explain Caribbean dry forest structure.

Poster #07: Pollinators of *Salvia pratensis* L. are not excluded by physical force - evidence from biomechanical measurements and field investigations

Sascha Thimm [1], Enikö Tweraser [1], Thomas Speck [2], Regine Claßen-Bockhoff [1]

[1]Institut für Spezielle Botanik und Botanischer Garten, Universität Mainz, Germany,
[2] Botanischer Garten, Universität Freiburg, Germany

Abstract: In *S. pratensis* the hypothesis was tested that nectar-searching insects are excluded from the process of pollen transfer by the levers restricting access to nectar. Force measurements were carried out by a specific device. It is illustrated that the forces needed to move the lever range from 2 mN to 12 mN in different flowers of *S. pratensis*.. Field studies showed that different *Salvia* species can share a large range of pollinators. But each *Salvia* has its own domain to deposit pollen on the insect's body.
Contrary to our expectation, these findings do not favor a narrow selection of specific pollinators in *S. pratensis* via the forces required for triggering. It seems more likely that the levers are designate for ease of triggering. This allows a large range of pollinators and at the same time, species-specific pollen transfer through the exact placement of pollen on the animal's body.

MECHANORECEPTION AND MECHANICAL GROWTH PROCESSES

KEYNOTE TALK:
Receiving and responding to mechanical signals

Barbara G. Pickard

Gladys Levis Allen Laboratory of Plant Sensory Physiology, Biology Department, Washington University in St. Louis, St. Louis, MO 63130-4899 USA

Abstract: Early indications that Ca2+ entry into the cell might be a common feature of many kinds of signal reception and the importance of responses to mechanical signals led to discovery of mechanosensitive plasmalemmal Ca2+ channels that could also serve as receptors for other signals and thus help integrate plant response to all of them. Recent studies suggest a structure by which force is transmitted to these channels: a mechanically rigid reticulum. At least in globose protoplasts, it can be a polygonal array rich with arabinogalactan-protein footed in the plasmalemma as well as wall-associated kinase connecting cell interior with wall at vertices. Application of a highly specific arabinogalactan-protein-binding agent to intact cells causes massive cytoplasmic Ca2+ elevation, which is inhibited by a blocker of the channel. Ways in which channels feed back information about mechanical forces experienced by the cells to alter their mechanical properties are currently under study.

Influence of wind loading and the role of ethylene in compression wood formation.

F. Salin [1], A. Stokes [1], A. Moya-Leon [2], G. Le Provost [2], R. Herrera [2]

[1]Laboratoire de Rheologie du Bois de Bordeaux, (Mixed Unit: INRA/CNRS/University, Bordeaux I), Domaine de l'Hermitage, 69 route d'Arcachon, 33612 Cestas cedex, France
[2]INRA Equipe de Génétique Amélioration des Arbres Forestiers, 69 route d'Arcachon 33612 Cestas cedex

Abstract: In this study the relationship between wind loading and the role of ethylene in the formation of compression wood was examined. One year old seedlings of Maritime pine (*Pinus pinaster* Ait.) were treated with 1-Methylcyclopropene (1-MCP) for 24 hours. 1-MCP is a compound that blocks ethylene binding and prevents or seriously interferes with ethylene induced fruit ripening. Treated trees and controls were grown in a wind tunnel and subjected to wind speeds of 5-6 ms^{-1} for 15 minutes every two hours during a period of tree months. An anatomical study was carried out to determine the rate of compression wood formation in all plants, along with a molecular study using cDNA AFLP techniques. A biochemical analysis was also performed to measure ACC synthase and ACC oxydase activity, key enzymes in the ethylene biosynthesis pathway.

Kinematics of root-soil interactions in nutrition of growing tissue

Wendy K. Silk, Ruth A. Bartlett, and Laura J. Hess

Department of Land, Air, and Water Resources
University of California, Davis, CA 95616-8627
U.S.A.

Abstract: As roots penetrate soil, growing cells encounter a changing array of soil particles. Root cells from adjacent soil will extract nutritional elements. For growing root particles, the pathlines Z(t) show particle position as distance Z from the soil surface over time t. These pathlines in a stationary reference frame can be used to discover the history of contacts between tissue elements and soil particles. The Z(t) can be computed from marking experiments used to obtain the particle pathlines X(t)in the conventional moving reference frame, where X is the distance from the moving root tip. We have conducted kinematic analyses in conjunction with nutritional uptake studies for calcium and phosphorus in stratified soils. Preliminary results indicate that growing cells obtain calcium only from soil adjacent to the growth zone, while phosphorus is obtained both locally and from soil near tissue basal to the growth zone.

Root growth dynamics are affected by external nutrient availability

Achim Walter[1], Regina Feil[2] and Uli Schurr[3]

[1]Biosphere 2 Center, Columbia University, P.O. Box 689, Oracle, AZ 85623, USA
[2]Max-Planck-Institut für Molekulare Pflanzenphysiologie, Am Mühlenberg 1, 14476 Golm, Germany
[3]Forschungszentrum Jülich, ICG III (Phytosphäre), 52425 Jülich, Germany

Abstract: The effect of external nutrient availability on growth dynamics of the primary root of *Zea mays* was investigated by means of digital image sequence processing. Plants were cultivated hydroponically either in pure water or in complete nutrient solution or were transferred from one situation to the other.
The organ elongation rate was lower in nutrient solution than in pure water, although biomass gain was comparable. The REGR-distribution along the growth zone often showed two peaks. In nutrient solution, the basal peak was more prominent than the apical one and vice versa in pure water. Circumnutatory movements of the root growth zone were observed with higher frequencies in nutrient solution than in pure water. The frequencies corresponded to frequencies of ion uptake. A wide range of metabolite compound distributions within the growth zone were measured, deposition rate distributions and transfer over the interface between growth zone and differentiated tissue were calculated.

Cytomechanical analysis of pollen tube penetration growth

Anja Geitmann and Elodie Parre

Institut de Recherche en Biologie Végétale, Université de Montréal, 4101, rue Sherbrooke est, Montréal, Québec H1X 2B2, Canada

Abstract: Tip-growing cells have the capacity to rapidly elongate and to penetrate a semi-solid or solid substrate. At the same time these cells resist lateral deformation forces exerted by the penetrated substrate. This latter aspect is pivotal in pollen tubes, since they serve as a tunnel-like passageway for the male gametes through the female flower tissue. Its cell wall, the internal turgor pressure and the cytoskeletal elements determine the cytomechanical properties of this plant cell.
By analyzing the growth behavior of pollen tubes through semi-solid media in vitro under varying conditions we attempt to identify the role of these different cellular components for the exertion of forces during penetration growth. Using micro-indentation techniques we analyze the cell's resistance to lateral forces as well as the pollen tube's hysteresis as a function of distance from the growing apex. We relate these data to the architecture of the cell determined by ultrastructural and fluorescence light microscopic studies. The experimental results are compared to computer models created with the help of finite element analysis.

Root contractility in bulblets of *Lilium longiflorum*

M.J. Jaffe and A.C. Leopold

The Boyce Thompson Institute for Plant Research, Cornell University, Ithaca, NY 14853 U.S.A.

Abstract: Daughter bulblets (*Lilium longiflorum*) growing on scales of the mother bulb are pulled away from it as a dispersion mechanism that also serves to protect the bulblets from a hostile surface environment. The scales have abscission regions at which they break when sufficient pulling force is applied. The forces developed by contraction, as well as the forces needed to overcome the soil resistance are measured and compared. The roles of auxin and ethylene in developing contractile roots and pulling force are discussed.

Poster #08: Anatomical and biochemical responses of two *Populus* hybrids to flexure stress

M.L. Pruyn [1], and F.W. Telewski [2]

[1]Department of Wood Science and Engineering, Oregon State University, Corvallis, OR, U.S.A.
[2]W. J. Beal Botanical Garden, Department of Plant Biology, Michigan State University, East Lansing, MI 48824, U.S.A.

Abstract: We compared effects of stem flexure (F_s) on xylem anatomy and lignin chemistry in two different young hybrid poplars, 47-174 and 11-11 (*Populus trichocarpa* torr. & A. Gray × *P. deltoides* Bart. *ex* Marsh). In response to F_s, the xylem's proportion of vessel lumen area (both hybrids) and total lignin content (47-174) was 20% lower versus controls ($P < 0.05$). Hybrid 47-174 mean vessel lumen area was 22% higher than 11-11 (F_s), but number of vessels per mm^2 was 20% lower (both treatments). Thus, hybrids contrasted in their strategies for reducing lumen area in response to flexure. Unlike 47-174, the lignin composition in flexed 11-11 stems was altered, with 20% less 4-vinyl guaiacol units (analogous to ferulic acid) than controls ($P < 0.05$). Because ferulic acid is a ubiquitous phenolic and not a main lignin component in dicot angiosperm xylem, 11-11's response to flexure was

Poster #09 Plagiogravitropic orientation of silver queen maize seedling roots is based on decay of a gravifacilitative echanism.

Clifford E. LaMotte and Barbara G. Pickard

Gladys Levis Allen Laboratory of Plant Sensory Physiology, Biology Department, Washington University, St. Louis, Missouri 63130-4899 USA

Abstract: This web-page abstract aims to give a broad overview of implications of our experiments on maize root gravitropism - the abstract printed on the poster presents the technical basis. The main implication is that gravitropism of roots requires two gravity receptors that must act in sequence. The first is nondirectional in output but facilitates the second, which directs gravitropic curvature according to the vectorial input. The advantage of this dual system is that the first can decay and in so doing brake the induction of the second to produce relatively stable oblique root orientations. The extent of the gravifacilitative response, and hence stable orientation, is controlled by light and by water potential.

This dual receptor model has been tested only for roots, which typically orient either straight or obliquely downward and which have only a vertical setpoint, but in principle it can explain the sometimes much more complicated gravitropic orientations of shoot parts. Toward this end, participation of additional plant behaviors (such as nastic responses) must be taken into account.

At the poster session, I am particularly interested in meeting people who may have ideas about the evolution of the dual system and about unusual gravitropic behaviors that might (or might not) be explained by our model.

PROPERTIES OF CELL WALLS

KEYNOTE:

Analysis of secondary cell walls using *Arabidopsis*

Simon Turner and Neil Taylor
University of Manchester, School of Biological Science, 3.614 Stopford Building, Oxford Road, Manchester M13 9PT, UK

Abstract: The Arabidopsis inflorescence stem has been used to study plant secondary cell wall formation. Under normal growth conditions these stems exhibit no secondary growth and the secondary cell walls of small number of cells dominate the mechanical properties of the stem. A number of cell wall mutants have been isolated that exhibit a defective secondary cell wall and are characterized by a collapsed irregular appearance of the tracheary elements of the xylem. These mutants have been used to study how alterations in cellulose and lignin composition affect the physical properties of the wall and to try and determine the function of these polymers in determining secondary cell wall structure. More recently, mutants have been identified that affect a number of parameters such as cellulose microfibril orientation and cellulose microfibril structure. These mutants are being used to examine the role of cellulose microfibrils in determining cell wall structure and mechanical properties.

Fourier transform infrared spectroscopy of mechanically deformed tissues and cell walls

Marta Kačuráková, Andrew C. Smith, Geraldine A. Toole, Keith W. Waldron, Nikolaus Wellner, Reginald H Wilson

Institute of Food Research, Norwich Research Park
Colney, Norwich, NR4 7UA, UK

Abstract: Fourier Transform Infrared (FT-IR) microspectroscopy was used to investigate the effects of an applied strain on the structure of the algal Chara cell wall, both in its native state and following the removal of various biopolymers by a sequential extraction. FT-IR microspectroscopy with polarised radiation (infrared dichroism) was used to examine the orientation of different biopolymers in cell wall samples subjected to longitudinal strain. Polarized one- and two-dimensional infrared spectra were obtained from the epidermis of onion (*Allium cepa*, L) under hydrated and mechanically stressed conditions. By Fourier-transform infrared (FT-IR) microspectroscopy the orientation of macromolecules in single cell walls was determined. In parallel deformation of microscopic images of cells within the tissue were collected and analysed. Two-dimensional infrared spectroscopy (2D FT- IR) was used to determine the nature of the interaction between the main polysaccharide networks during deformation.

Young's Modulus of tomato cell wall

C. Wang, L. Wang, C.R. Thomas

School of Engineering, Department of Chemical Engineering, University of Birmingham Edgbaston, Birmingham B15 2TT, United Kingdom

Abstract: Micromanipulation has the potential to provide mechanical property information at the individual cell level, with deformation up to cell bursting. It has been used to study the mechanical strength of various types of cells. However, the intrinsic material properties of cell walls cannot be obtained directly from micromanipulation experiments. In the present study, a linear elastic material model was used to estimate the Young's Modulus of tomato cell walls, by comparing a mathematical model of cell compression with micromanipulation experimental results. On the time scale of the compression (a few seconds), it appeared that water loss due to cell permeability was not significant, and neglecting this factor, very good fits between the model and the experiments were obtained. It was concluded that the linear elastic model is very suitable for estimating tomato cell wall elastic moduli. Although the Poisson ratio could not be determined, it seemed that Young's modulus did not depend greatly on its value. When the Poisson's ratio was assumed to be 0.40, the Young's modulus of walls of 2 week old tomato cells from suspension cultures was about 1.1 ± 0.1 GPa, which is comparable to values reported in the literature. However, this depends critically on a proper estimate of cell wall thickness.

Microtensile properties of single, mechanically isolated compression wood tracheids: biomechanical strategies

I. Burgert[1,2], K. Frühmann[1], J. Keckes[2], P. Fratzl[2], S.E. Stanzl-Tschegg[1]

[1]Institute of Meteorology and Physics, University of Agricultural Sciences, Vienna, Austria
[2]Erich Schmid Institute for Materials Science, Austrian Academy of Sciences and Institute of Metal Physics, University of Leoben, Austria

Abstract: The mechanisms behind compressive stress generation of gymnosperms are not yet fully understood. In compression wood, the absence of an S3 layer, a high microfibril angle in the S2 layer and a high lignin content are common. In addition, spiral gaps occur within the cell wall, which are not well understood in their mechanical relevance, but can be looked at with regard to evolutionary trends in compression wood development. Compression wood tracheids of four gymnosperm species (*Ginkgo biloba* L., *Taxus baccata* L. *Juniperus virginiana* L. *Picea abies* [L.] Karst.) were investigated. The tracheids were isolated mechanically by peeling them out by thin tweezers. In contrast to chemical maceration, the cell wall components remained in their original condition. Tensile properties of tracheids were measured in a microtensile apparatus in wet conditions and were compared with tissue properties. Comparing the species, strategies for a more flexible compression wood by a relatively small reduction of strength properties could be examined. Biomechanical aspects are discussed.

Structural and fractographic study on chemically and enzymatically treated wood

Tanja Zimmermann

Swiss Federal Laboratories for Materials Testing and Research, Ueberlandstrasse 129, CH-8600 Duebendorf, Switzerland

Abstract: One possibility for getting more informations about the arrangement of cell wall components in the nanoscale is the use of microscopical, analytical or spectroscopical methods with a resolution below 10nm. These methods are rare and require a high preparation effort that could result in structural changes.
Another possibility is to modify wood by solving gradually the main cell wall components hemicelluloses, lignin, or cellulose out of the cell wall and to characterise structural changes. In the presented study, the cell walls of different wood species were treated chemically and enzymatically. The resulting structures were studied on fracture surfaces and on ultrathin sections by high resolution Scanning Electron Microscopy (FE-SEM) as well as Transmission Electron Microscopy. The results were compared with findings of a previous SEM study on photochemically degraded cell walls of weathered wood. From these results it is possible to derive additional information about

Characterization of microfibril angle variation utilizing soft rot cavities

Susan E. Anagnost and Robert B. Hanna
SUNY College of Environmental Science and Forestry, 1 Forestry Drive, Syracuse, NY 13210, U.S.A.

Abstract: In the wood cell wall, the orientation of the cellulose microfibrils within the S2 layer is a significant factor in determining wood strength. The microfibrils with the smallest angle to the longitudinal axis provide the greatest strength. The formation of cylindrical cavities by soft rot fungi along the microfibrils was shown to be an accurate method for determining the microfibril angle in the S2 layer, correlating well to both the x-ray and iodine methods. In this study, the soft-rot method was applied to measuring the variation within individual fibers of southern pine, and variation between fibers occupying the same annual ring of southern pine. Trends in variation through earlywood and latewood zones were observed. Also, in southern pine, microfibril measurements of both radial and tangential sections of the same growth ring were obtained. Within growth ring variations of microfibril angles were measured in the radial, tangential and intermediate planes of the softwoods loblolly pine, and black spruce, and the hardwoods black cherry, sugar maple and canelo.

Some ideas about the structural aspect of the gelatinous layer from tension wood.

B. Clair [1], J. Sugiyama[1], J. Gril[2] & B. Thibaut[2]

[1] Laboratory of Cell Structure and Function, Wood Research Institute, Kyoto University, Uji, Kyoto 611-0011, Japan
[2] Equipe Bois, Laboratoire Mécanique et Génie Civil, CNRS-Université Montpellier 2, CC 048 Place Eugène Bataillon, 34095 Montpellier Cedex 5, France

Abstract: Angiosperms keep the trunks and branches in "predetermined" angles by generating high-tension stresses on the upper face of the axes. This mechanical state is accompanied by important changes in the structure of the wood cells. Particularly, in some tension wood, a change appears as a new layer called the gelatinous layer (G layer). Longitudinal MOE and shrinkages were measured on macroscopic samples taken from identified growth stress zones. The proportion of fibres containing a G layer was measured by optical microscopy techniques. The influence of the amount of fibres containing G-layer on the macroscopic wood properties was examined. Complementary SEM and AFM experiments were done at the cell wall level in order to observe the drying behaviour of each cell wall layer. Finally, the ultrastructural features were characterized by FTIR spectroscopy. These physical, mechanical and structural observations provided us new possible insights into the structure of the G layer.

***Arabidopsis* whole-transcriptome profiling defines the features of coordinated regulations that occur during the wood formation**

Jae-Heung Ko and Kyung-Hwan Han

Department of Forestry, Michigan State University, East Lansing, MI 48824 U.S.A.

Abstract: Wood is formed by the successive addition of secondary xylem, which differentiates from the vascular cambium. We developed a novel experimental system to study the molecular regulation of secondary growth in *Arabidopsis thaliana* and demonstrated that, 1.) the most well characterized herbaceous plant, *Arabidopsis thaliana*, can be effectively used as a model for wood formation in tree, 2.) the weight carried by the stem is a primary signal for the induction of cambium differentiation, and 3.) the plant hormone, auxin, is a downstream carrier of the signal for this process. Using whole-transcriptome (23K) GeneChip analysis, we examined gene expression profiles in wood-forming stems. Over 70% of the 23,000 genes were expressed in stem tissues. Wood formation-associated genes were under strict developmental stage-specific transcriptional regulation. For example, more than 50 lignin biosynthesis genes were up-regulated in the mature stage. The overall gene expression profile of weight treatment was similar to that of the intermediate stage of wood-forming stem, further supporting that increasing body weight in a growing tree triggers the transition from primary growth to secondary growth.

Poster #10: The role of the cell wall properties in pollen tube growth

E. Parre, A. Geitmann

Institut de Recherche en Biologie Végétale, Université de Montréal, 4101, rue Sherbrooke est, Montréal, Québec H1X 2B2, Canada

Abstract: Pollen tubes are tip-growing cells that have the impressive mechanical ability to elongate tens of micrometers per minute and to penetrate tissues such as the transmitting tract of a receptive flower. These cells exert penetration and lateral resistance forces to be able to grow through the flower style in vivo or the artificial semi-solid medium in vitro. The mechanical properties of plant cells are strongly influenced by the surrounding cell wall. The polysaccharide composition of the cell wall in the pollen tube is known to change with increasing distance from the growing apex. It has therefore been proposed for a long time that the mechanical behavior of this cell vary along its longitudinal axis. We show for the first time experimental evidence that this is indeed the case. Experiments with a micro-indentation device demonstrate that the pollen tube's capacity to resist lateral deformation as well as its hysteresis is a function of the location on the longitudinal axis of the cell.

Poster #11: Confocal microscopy gives a unique view of sclereid structure

Guillermo Angeles [1], Shirley Owens [2], Frank W. Ewers [3]

[1] Instituto de Ecología, A.C., 91070 Xalapa, Veracruz, Mexico.
[2] Michigan State University, Center for Advanced Microscopy, East Lansing, Michigan 48824-1325 USA
[3] Michigan State University, Department of Plant Biology, East Lansing, Michigan 48824-1312 USA

Abstract: Confocal Laser Scanning Microscopy (CLSM) was used to observe sclereids from stems of *Avicennia germinans* and from fruits of two species of pear (*Pyrus calleryana* 'Bradford'and *Pyrus communis* 'Red Bartlett'). The images obtained from thick (25 to 100 µm) freehand sections were, in some ways, far superior to those obtained by other more invasive and/or time consuming microscopic techniques, upon which previous reports of sclereid morphology were based. In particular, the cell wall surfaces, including the "internal" surfaces of the branched pit canals and cell lumens, are much accentuated with the techniques we describe, resulting in a "fluorescent shell" image. By controlling the time of staining with 1% aqueous Safranin O before observation with CLSM, or by changing the fluorescent filters and/or optical sections used in extended focus images, it was possible to get either a conventional view of the cell wall structure or a unique, three-dimensional view of the elaborate cell interconnections.

Poster #12: Low temperature modifies cell wall mechanical properties and leaf growth

Danuta Solecka[1], Jacek Zebrowski[2], Alina Kacperska[1]

[1] Department of Plant Resistance, Institute of Experimental Plant Biology, Warsaw University, Miecznikowa 1, 02-096 Warsaw, POLAND
[2] Plant Breeding and Acclimatization Institute, Radzików, 95-870 Blonie, POLAND

Abstract: In experiments concerning the role of cell walls in plant acclimation to low temperatures we studied: 1) modifications in mechanical properties of cell walls and expansion growth of winter oilseed rape (*Brassica napus* L. var. *oleifera* L.) leaves; 2) possible involvement of expansins and wall-bound phenylpropanoids in the control of cell growth. Cold (2°C) treatment increased the rigidity and decreased extensibility and stress relaxation of cell walls. The cold-induced changes were associated with retardation of leaf growth. Brief and sublethal freezing (-5°C) increased markedly cell walls extensibility and relaxation and transiently reversed the cold-dependent inhibition of leaf growth. The expansin activity was much higher in the warm-grown or frost-treated plants than in the cold-acclimated ones. The inhibition of phenylpropanoid synthesis (caused by inhibition of phenylalanine ammonia-lyase activity) reversed partially the cold-induced increase of cell wall rigidity and inhibition of leaf growth.

Poster #13: The complex mechanical behavior of wheat bran results from the specific properties of its constitutive layers

Carole Antoine, Frédéric Mabille, Joël Abecassis, Xavier Rouau.

Address

Abstract: Manual dissection of wheat seed coat allowed to separate three different layers from wheat bran, according to radial and longitudinal grain orientations, which were identified by confocal laser scanning microscopy as outer pericarp; an intermediate strip (comprising inner pericarp, testa and nucellar tissue); and aleurone layer, respectively. Submitted to traction tests, whole bran, intermediate and aleurone layers behaved elasto-plastic whereas pericarp exhibited elastic behavior. By longitudinal orientation, pericarp governed 50% bran elasticity whereas, in radial orientation, the other tissues mostly influenced bran elastic properties. Regardless test orientation, linear force to rupture of bran corresponded to the sum of intermediate and aleurone layers strength. According to radial orientation, the intermediate strip governed bran extensibility but according to longitudinal orientation, all tissues contributed until bran disruption. Mechanical tissue properties were connected to major cell wall components and tissue microstructure. Lastly, a structural model of wheat bran layers helped to elucidate the detachment of pericarp from intermediate layer within radial bran strips.

Poster #14: Wood decay fungi - analytical tools for tree ring analysis?

Giuliana Deflorio[1], Sebastian Hein[2], Francis Willis, Mathew Robert Schwarze[1]

[1]Institute for Forest Botany, Albert-Ludwigs-Universität Freiburg, Germany
[2]Institute for Forest Growth, Albert-Ludwigs-Universität Freiburg, Germany

Abstract: The application of wood decay fungi for tree ring analysis in diffuse porous wood was compared with a range of traditional preparation techniques. Wood blocks of sycamore (*Acer pseudoplatanus* L.), silver birch (*Betula pendula* Roth.) and aspen (*Populus tremula* L.) were incubated for 4, 8 and 12 weeks with two brown-rot fungi, *Fomitopsis pinicola* and *Laetiporus sulphureus*. Exposure of tree rings in decayed wood was compared with several sanding and staining techniques and/or combinations of the latter. The detection of tree rings in the treated wood varied depending on the wood spp., method applied and duration of degradation. In comparison to decayed wood samples, results obtained with traditional methods applied to birch and poplar wood samples were more convincing. By contrast, exposure of ring borders in degraded sycamore wood samples was apparently superior to traditional methods. Further studies are required to improve the potential use of wood decay fungi as analytical tools in tree ring analysis.

BIOMECHANICS AND GENETIC MODIFICATION

KEYNOTE

How Does Altered Lignin Composition Reflect on Xylem's Multifunctional Role? - Studies on the Mechanical and Conductive Properties in Xylem of Genetically Modified Poplar

L. Köhler[1], K.A. Kern [2], F.W. Ewers [2], F.W. Telewski [1]

[1]W. J. Beal Botanical Garden, Department of Plant Biology, Michigan State University, East Lansing, U.S.A.
[2]Department of Plant Biology, Michigan State University, East Lansing, U.S.A.

Abstract: The availability of a rapidly increasing number of cell wall mutants and genetically modified plants opens an exciting new perspective for plant biomechanics. Well-defined alterations in specific cell wall components, created by genetic engineering, can be applied to investigate the biomechanical contribution of individual cell wall component.

In a structure as complex as the cell wall, it is virtually impossible to elucidate the role of individual components which contribute to the overall mechanical behaviour by just scrutinising the structure in situ. Comparative information can be obtained by analysing different ontogenetical stages or related plant species[1], by in vitro experiments with specific cell wall components[2], by investigating bacterial cellulose composites[3] or by evaluating the alterations in cell wall composition introduced via genetic engineering. The latter approach offers the most promising perspectives for addressing a wide range of biomechanical questions in a specifically altered system.

This talk will outline the current status of applying genetically modified plants in biomechanical studies and present work on xylem biomechanics and water conductance in poplar with genetically altered lignin composition (syringyl to guiacyl ratio). The plant's response to wind and the alterations in structure and function of the xylem will be detailed.

[1] Hoffmann B, Chabbert B, Montes B, Speck, T (2002) Mechanical, Chemical and X-ray Analysis of Wood in the two Tropical Lianas *Bauhinia guianensis* and *Condylocarpon guianense*: Variations During Ontogeny. Planta, accepted

[2] Hayashi T, Baba K, Ogawa K (1994) Macromolecular Complexes of Xyloglucan and Cellulose Obtained by Annealing. Plant and Cell Physiol 35, 219-223

[3] Chanliaud and Gidley (1999) In Vitro Synthesis and Properties of Pectin/*Acetobacter xylinus* Cellulose Composites. Plant J 20, 25-35

The Arabidopsis TCH Genes: Tools for Investigating Plant Response to Environmental Stimuli

Janet Braam, Dennis Lee, Elizabeth McCormack, Jaime Becnel, Nikkí Delk and Diana Polisensky

Biochemistry and Cell Biology, Rice University, Houston, TX 77005-1892; USA

Abstract: Expression of the Arabidopsis TCH genes is rapidly and dramatically upregulated in response to a variety of environmental stimuli, including touch or wind. We are interested in understanding how plants sense touch and transduce cellular signals to regulate gene expression. In addition, we are investigating the functions of the TCH gene products to elucidate their roles, if any, in touch responses such as thigmomorphogenesis. TCH1 encodes calmodulin (CaM), TCH2 and TCH3 encode CaM-like proteins and TCH4 encodes a xyloglucan endotransglucosylase/hydrolase (XTH) that has enzymatic activities predicting a role in wall modification. Reverse genetic approaches are being used to shed light on the functions of the numerous CaM-like and XTH genes of Arabidopsis. In addition, to reveal functions required for stimuli sensing and the regulation of TCH expression, we are isolating mutants that fail to regulate the TCH genes appropriately.

Poster #15: Quantitative Trait Loci for some Biomechanical Traits in Barley (*Hordeum vulgare* L.)

Jacek Zebrowski[1], Gerhard H. Buck-Sorlin[2]

[1]Plant Breeding and Acclimatization Institute, Dept. Biotechnology and Cytogenetics, Radzików, 05-870 Blonie; Poland
[2]Institute of Plant Genetics and Crop Plant Research IPK, Dept. Cytogenetics – Transcriptome Analysis Corrensstr. 3, 06466 Gatersleben; Germany

Abstract: The DH-F2 winter barley population W766, which is segregating for several obvious vegetative morphological traits (tillering, culm length), was investigated in the field (Radzików, Blonie, Poland) in order to get information about the genetic background and heritability of several biomechanical traits of barley. Plants were replicated in two environments (two years: 2001 and 2002), and genotype means were subjected to a QTL-analysis using a molecular and morphological marker map prepared previously for this population.
Almost all traits evaluated yielded one or more QTLs. However, most of the QTLs (for seven traits) were pleiotropic effects of the morphological marker sca (short crooked awn) on chromosome 3H, which is responsible for short stiff internodes. The most promising results were obtained for the elasticity indices of several plant parts, with a reproducible pattern of two significant QTLs on chromosomes 7H and 1H, and for the shape factor, with one QTL.

APPLIED BIOMECHANICS: WHOLE PLANT AND PLANT PRODUCTS

KEYNOTE:
Using tree biomechanics to improve practices in forestry and forest industries.

Bernard Thibaut

Laboratory of Mechanics and Civil Engineering, University Montpellier 2, CC048, Place Eugène Bataillon, 34095 Montpellier cedex 5, France

Abstract: The great storm Lothar crashed down the equivalent of 3 years of forest harvesting in France in December 1999. Many scientists were involved since to analyse the phenomena and look for short term and long term solutions to limit the impact of such more and more frequent storms.

Observations and models looking at tree stability put in evidence the main role of wind pressure on crown surface, the lever arm between crown centre and root system and the ability of the root / soil system to resist flexure moment transmitted by the trunk. There are many evidences of the impact of management practices on tree uprooting risk, which appears to be largely the more important source of damage.

Apart from tree uprooting, a high proportion of trees (mainly young trees) we inclined by the storm, sometimes with a very strong slope. It is known that such trees will react in the coming years to restore verticality, thus leaving inside the trunk large sectors of reaction wood and sometimes sectors of compression failure. The occurrence of reaction wood will also be high in broken head trees where large branches should replace in the future the broken main axis.

Reaction stresses and reaction wood will have serious effects on timber processing and use, with strong differences between gymnosperms (where compression wood is the main defect) and angiosperms (where high growth stresses is the main problem).

From this knowledge and analysis, possible strategies at the forest management and the forest industry levels are discussed.

Interactive effects of temperature and water status on mechanical properties of radish and carrots tubers

Werner B. Herppich [1], Federico Gomez Galindo[2]

[1]Institute of Agricultural Engineering, Department of Horticultural Engineering, Max-Eyth-Allee 100, D-14469, Potsdam, Germany
[2]Department of Food Engineering, Lund University, P.O. Box 124, SE - 221 00, Lund, Sweden

Abstract: Tissue firmness and stiffness are functions of tissue and cell wall structure, water status and temperature, and their interactions. This investigation elaborates the physiological basics of temperature and water status effects on firmness of fresh intact carrots and radish tubers. The results provide the database for a better understanding of this mechanical property. Water potential of carrot roots and radish tubers was measured with a pressure bomb, cutting force with a microtome knife adapted to a universal testing machine, and osmotic potential psychrometrically in expressed tissue sap.
Water potential and turgor were positively correlated with cutting force. Beyond wilting, the variation of cutting force with declining water potential was less pronounced. Firmness changed with the longitudinal position on the tuber. Forces and turgor were higher at lower tissue temperature, reaching highest values at 5°C. It is yet not clear whether temperature affects water status and/or cell walls.

Interactive effects of water status and produce texture - an evaluation of non-destructive methods

Sandra Landahl [1], Werner B. Herppich [2], and Josse De Baerdemaeker [1]

[1] Laboratory for Agricultural Machinery and Processing, Katholieke Universiteit Leuven, Kasteelpark Arenberg 30, B-3001 Leuven, Belgium,
[2] Department of Horticultural Engineering, Institute for Agricultural Engineering Bornim, Potsdam, Germany

Abstract: Texture is a very important determinant of fruit or vegetable freshness and quality. It changes during maturation and ripening and during senescence or decay in storage and retail. Product texture can be described by tissue elastic properties and tissue firmness. While the latter can only be determined destructively, elasticity can be measured non-destructively by quasi-static compression tests (Mohsenin, 1970) or by dynamic acoustic impulse-response measurements (Yamamoto et al., 1980). This method is fast and yields a produce-averaged stiffness. Tissue elasticity is interdependently determined by water status and cell wall mechanical properties. Short-term texture changes under unfavorable storage conditions mainly result from a decline of cell water potential or water volume while elastic cell-wall properties remain unchanged. An experiment was set up to test whether i) both above mentioned methods measure water-deficit dependent texture changes; ii) variation of elasticity is correlated to variation of water status.

Effects of cold-acclimation on the mechanical properties of carrots

Werner B. Herppich [1], Federico Gomez Galindo [2], Marianne Sommarin [3], Maggie Smallwood [4], David Vaughan [4] and Ingegerd Sjöholm [2]

[1]Institute of Agricultural Engineering, Division of Horticultural Engineering, Max-Eyth-Allee 100, 14469, Potsdam, Germany
[2]Department of Food Engineering, Lund University, P.O. Box 124, SE - 221 00, Lund, Sweden
[3]Department of Plant Biochemistry, Lund University, P.O. Box 124, SE - 221 00, Lund, Sweden
[4]Department of Biology, Centre for Nover Agricultural Products, University of York, P.O. Box 373, York, UK

Abstract: Although the cold-acclimation capability of the biennial carrots, which provides the freezing resistance necessary for second year re-growth, has been recently described, knowledge of the physiological mechanisms behind this acclimation needs to be improved. The variation of mechanical properties of intact carrot tubers and root tissue during cold-acclimation was investigated by water relations analysis, force-deformation measurements, cutting experiments, and at the enzyme and cell wall composition level. Carrots can adjust osmotically and elastically in response to low temperature conditions. This means that their cell sap concentration of osmotically active substances is increased while, concomitantly, their tissue becomes less elastic to be prepared to potentially withstand the stress of ice formation. This is accompanied by accumulation of anti-freezing proteins within the cell walls, which increases the resistance to ice crystal formation. However, changes in tissue elasticity and firmness showed different dynamics.

Two-dimensional tension tests in plant biomechanics – cherry fruit skin as a case study

Hendrik Bargel [1], Thomas Speck [2], Hanns-Christof Spatz [2], Christoph Neinhuis [1]

[1]Institut für Botanik, TU Dresden, 01062 Dresden, Germany
[2]Plant Biomechanics Group, Universität Freiburg, 79104 Freiburg, Germany

Abstract: Splitting of fruits can cause large losses in the crop industry, resulting in high production deficits. Fruit skins consist of a cuticle and dermal cell layers. Many studies on splitting resistance or mechanical properties of fruit skins were performed, but mostly one-dimensional tension was applied. However, splitting is a function of two-dimensional tension. We have set up a hydraulic custom-built two-dimensional testing device in order to analyze cracking in spherical plant material, and chose sweet cherry (*Prunus avium* L.) fruit skins as a model system. The stress-deflection curves are J-shaped, with a long flat initial phase, and a distinct linear increasing end part. From these curves, stiffness and strength are calculated with a new mathematical approach. The first results reveal Young's moduli within the range of other fruit skins, or isolated cuticles. Thus, the newly developed method seems to be a reasonable approach to apply two-dimensional tension tests in crop production.

Stochastic Finite Element modeling of fruit's vibrations for quality measurement purposes.

Pál T. Jancsók [1], Eddie Schrevens [2] and Josse De Baerdemaeker [1]

[1]Laboratory for Agro- Machinery and Processing, Katholieke Universiteit Leuven, Kasteelpark Arenberg 30, B-3001 Leuven, Belgium.
[2]Research Unit for Quality Management, Katholieke Universiteit Leuven, Willem de Croylaan 42 B-3001 Leuven Belgium

Abstract: Firmness is an important internal quality parameter of fruits. It is related to the resonant frequency of the fruit and can be measured non-destructively using the acoustic impulse response method. In this method a small hammer excites the fruit and the response is recorded and analyzed. In this work stochastic finite element models are used to study the influence of the factors like irregular shape, material inhomogeneity, density variations etc.
Random fruit shapes are generated by a geometry modeling system and the models were used in an experimental strategy with the different levels of material inhomogeneity and densities. In this way the stochastic behavior of batches of fruits was modeled assuming that the different properties are multivariate normally distributed. The resonant frequencies of the virtual fruits are calculated by a validated finite element procedure based on the FEMLAB code and the propagation of the uncertainties is analyzed.

Poster #16: Isothermal Modeling of Bean Texture

Maureen E. Beck, Kirk D. Dolan

Department of Food Science and Human Nutrition
Michigan State University
East Lansing, MI 48824, USA

Abstract: The purpose of this research was to determine whether or not the thermal softening of ten bean classes is suitably modeled by a first order reaction. Beans were cooked for various amounts of time at three different temperatures, and then tested for firmness. The firmness was then linearized in order to determine rate constants and activation energies. A nonisothermal experiment was conducted to check the model created based on the isothermal experiments. Four of the ten bean classes were satisfactorily modeled, while the other classes require more research. The model was able to predict the firmness of the beans in the nonisothermal experiment.

APPLIED BIOMECHANICS: FIBERS AND COMPOSITES

KEYNOTE

Plant fibers for composites: Divide and re-assemble

George Jeronimidis

Centre for Biomimetics, School of Construction Management and Engineering, The University of Reading, Whiteknights, Reading RG6 2AY UK

Abstract: Pressures for more sustainable technologies provide major opportunities for plant fibers in composite materials. Current methods of utilization of plant fibers often require partial destruction of very good biological composites, recovery of cellulosic fibers and incorporation into technical composites. Wood is the only exception where the biological and the technical composite is the same. In the process of fiber separation significant mechanical attributes, designed and optimized along plant biomechanical principles are degraded or lost. Very often plant-fiber composites of wood or bast origin have poorer properties that those of the tissues they were part of. Besides the question of improving fiber extraction methods to minimize degradation, the plant biomechanics community should also address the issue of understanding the design process occurring in the plants themselves, and their benefits. This will provide information for better plant selection, breeding and agronomy to enable a more efficient exploitation of what biology offers.

Value-added nonfood applications of soybean through green composites and green nanocomposites: The hope and reality for US agriculture

A.K. Mohanty, P. Tummala, J. P. Latere, W. Liu, H. Miyagawa, L. T. Drzal, M. Misra

Composite Materials and Structures Center, Michigan State University, East Lansing, MI 48824 U.S.A.

Abstract: This research is targeted at enhancing value and use of agricultural products. Soybean is a major crop in the U.S. and accounts for about 40% of total world production (over 75 million metric tons per year). In this paper soy protein as well as soy oil are converted in to bioplastics. Soy protein based bioplastics reinforced with agricultural based natural fibers, result in high value-added green composite materials showing potential for use in automotive interior parts and rigid packaging materials. Novel green polyols with controlled and desired properties are made from soy oil, which show strong potential for applications in foams, coatings and green polyurethane based materials. Through nano-reinforcement of organo-clay with functionalized soy oil new green nanocomposites are made showing promising perspectives for application in automotive, naval and aeronautics.

Acknowledgement: Our research on soybean-based materials are being funded through project GREEEN, USDA and CMSC- REF.

Poly(lactide); A natural "green" alternative for plastic packaging materials

Rafael Auras*, Bruce Harte, Susan Selke
School of Packaging, Michigan State University, East Lansing, MI. 48824-1223, USA

Abstract: The attractiveness of high molecular mass poly(lactide), PLA, as a packaging material has increased due to its nature as a biodegradability (compostable), thermoplastic, is produced from renewable resources, and shows mechanical and barrier behavior comparable to synthetic polymers like polystyrene (PS) and polyethylene terephthalate (PET). PLA is now potentially available for use as a food packaging polymeric material, one of the main concerns is to better understand the mechanical, physical, and barrier properties of PLA. The aim of this research was to study two PLA resins. Results from tensile testing and differential scanning calorimetry, and moisture-sorption characteristics at 5, 23, and 40ºC for water activities (aw) from 0.1 to 0.9 were obtained. Also, permeation coefficients for CO_2, O_2, and water vapor were acquired. The results showed that PLA films have good tensile strength with higher values than PS but lower than PET, and that both PLA films have lower Tm and Tg than PS and PET. In terms of barrier properties, PLA has lower CO_2 and O_2 permeability coefficients than PS, comparable to those of PET.

Environmentally friendly biocomposite beams and plates from natural fibers and unsaturated Polyester resin

Mario J. Quagliata [1], Rigoberto Burgueño [1†], Geeta Mehta [2], Amar K. Mohanty [2], Lawrence T. Drzal [2] and Manjusri Misra [2]

[1] Department of Civil and Environmental Engineering, Michigan State University, East Lansing, MI 48824-1226 USA [†] Corresponding Author
[2] Department of Chemical Engineering and Materials Science, Michigan State University East Lansing, Michigan 48824 USA

Abstract: Increased environmental awareness and interest in long-term sustainability of material resources has motivated advancements in natural fiber and resin composite materials. However, despite the developments on biocomposites technology, lower stiffness and strength properties has limited applications to non-load-bearing components. Stiffness of a structural component depends on both the material and structural stiffness. Thus, the material stiffness shortcomings of biocomposites can be overcome through efficient structural configurations, such as cellular and sandwich structures which respectively maximize material and structural performance. This paper presents a study aimed at developing cellular design concepts for the use of biocomposites in load-bearing structural components. Experimental and analytical results on the performance of small-scale honeycomb beams and plates manufactured with natural fibers and unsaturated polyester resin will be presented. A discussion on the potential of biocomposites for full-size structural components for civil structures will be provided.
ACKNOWLEDGMENTS: The study is funded by a REF (Research Excellence Funds) 2002 award through Michigan State University's Composite Materials and Structures Center.

Poster #17: Economic feasibility for producing native grasses in Michigan as a fiber source for use in biocomposites.

Andrew Peot, A. K. Mohanty, L. T. Drzal, T. M. Smith, M. Misra

Composite Materials and Structures Center, Michigan State University, East Lansing, MI 48824, USA

Abstract: The introduction of native grass based biocomposites as a feasible alternative to current fiber glass and petroleum based composites will be directly dependent on the economic feasibility of growing and harvesting native grasses at the farm level. The focus of this research is to determine the economic feasibility of producing native grasses on marginal and underutilized land in Michigan and the surrounding Upper Great Lakes region. The native warm season grasses included in this study are; big bluestem (*Andropogon gerardii*), Indian grass (*Sorgastrum*), little bluestem (*Andropogon scoparius*), prairie cord grass (*Spartina pectinata*), and switchgrass (*Panicum virgatum*). The primary aspects pertaining to the economic feasibility of producing native warm season Michigan grasses included in this study are the costs of production, transportation, storage and processing of raw fiber into pellets and/or other flow able forms.

Poster #18: Comparative life cycle assessment of biobased composites and conventional composites.

Salil Arora, A.K. Mohanty [1], L.T Drzal [1], M. Misra [1], S. Joshi [2], B.E. Dale [3]

[1] Composite Material and Structures Center, Michigan State University, East Lansing, MI 48824, USA.
[2] Department of Agricultural Economics, Michigan State University
[3] Department of Chemical Engineering, Michigan State University

Abstract: Life Cycle Assessment (LCA) has emerged as an innovative tool for evaluating the sustainability of the industrial products/processes and consequently suggesting alternatives for improvement. LCA is a compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle (ISO 14040, 1997). Since, conventional composites are derived from nonrenewable material sources and their manufacturing processes are energy and pollution intensive, the need for improved processes and environmentally friendly alternative products is evident. The objective of the current research project is to carry out life cycle inventory analysis for conventional composites and bio-based composite matrices, assess the impacts, and finally interpret the inventory and impacts to enable judgements about the relative environmental performance of these composites. The inventory includes energy and materials usage and emissions to environment (e.g.: air emissions, wastewater discharge and solid waste disposal). The matrices being compared are Polypropylene-Glass fiber and Polyhydroxybutyrate-Kenaf fiber.

Acknowledgments: To NSF-PREMISE-2002 for providing financial support.

Poster #19: The Effects of Accelerated Freeze-Thaw Cycles on the Properties of Wood-Plastic Composites

Jeanette M. Maurice, Laurent M. Mutuana

Department of Forestry, Michigan State University, East Lansing, MI 48824, USA

Abstract: Although wood-plastic composites are being used for various outdoor applications in regions where freeze-thaw action is prevalent, little information is available on the freeze-thaw durability of these composites. High-density polyethylene (HDPE) was mixed with sawdust (either maple or pine) in a 50:50 ratio by weight with 12% of the plastic component being a processing lubricant. The mixtures were processed in a conical twin-screw extruder to produce a composite 1" (wide) by 3/8" (thick). The composites were exposed to 15 cycles of accelerated freeze-thaw actions according to the ASTM standard D6662. There was less than a 3% increase in width and thickness following the 15 cycles of freeze-thaw. However, the modulus of elasticity (MOE) was significantly reduced (approximately 40%) for both wood species, as was modulus of rupture (MOR). For pine samples 95% of the original MOR was retained versus just 82% for maple following the 15 freeze-thaw actions.

Poster #20: Performance properties of green cell foam.

Samina Arif[1], Gary Burgess[1], Ramani Narayan[2], and Bruce Harte[1].

[1]MSU School of Packaging, Michigan State University, East Lansing, MI 48824 USA
[2]Department of Chemical Engineering, Michigan State University, East Lansing, MI 48824 USA

Abstract: Green Cell Foam is a commercially available, biodegradable foam material produced from a proprietary cornstarch. It has recently become available in a variety of laminations and constructions. Green Cell Foam may have substantial use as a cushioning material and in applications where thermal insulation is essential. To compete with synthetic plastic foams it must have similar performance properties. Cushioning ability and percent dynamic set are fundamental properties required of foam cushioning materials. High thermal resistance (R value) is necessary for materials to be used in insulating containers. Since it is biodegradable, Green Cell Foam will absorb some moisture, which will likely affect the above properties. Moisture sorption isotherms at three temperatures will be developed to determine its moisture sensitivity. Experiments are currently underway to determine its cushioning and insulation properties. Biodegradable packaging materials will find niche markets, as long as their properties are comparable. Results will be presented which address Green Cell Foam's cushioning and insulating properties.

Poster #21: Effects of alkali treatment on structure, morphology and thermal properties of grass fiber

Wanjun Liu, Amar K. Mohanty, Manju Misra, Lawrence T. Drzal

Composites Materials & Structures Center, Michigan State University, East Lansing, MI 48824, USA

Abstract: Natural fibers such as kenaf, flax, jute, hemp, and grass, reinforced composites have been attractive in recent years because natural fibers have advantages of low cost, low density, and acceptable specific strength properties. As a part of our ongoing project on development of grass fiber reinforced bio-composites for automotive application, the physical, morphological and thermal properties of raw and alkali treated grass fibers were studied by using X-ray photoelectron spectroscopy (XPS), Fourier transform infrared spectroscopy (FTIR), environmental scanning electron microscopy (ESEM), and thermogravimetric analysis (TGA). It was found that most hemi-cellulose and a part of lignin in grass fibers were removed during alkali solution treatment. This removal reaction first occurred on outside surface and then on inside surface of the grass fibers. After treated with alkali solution, the materials in inter-fibrillar region were etched, which led to shrinkage, thinning and improved thermal stability of grass fibers.
ACKNOWLEDGMENTS: To GREEEN (Generating Research and Extension to meet Economic and Environmental Needs) 2002 Award No. GR02-066 for providing financial support.

FLUID DYNAMICS

KEYNOTE
Moving heat within leaves

Steve Vogel

Department of Biology, Duke University, Durham, NC U.S.A.

Abstract: A leaf in sunlight and nearly still air can reach temperatures well in excess of that of its surroundings. Where external convective transfer provides a major avenue of heat loss, the area around a midrib may be substantially warmer than that near the margins, and as much as 20 E C above ambient. That sharp contrast with the temperature distribution on the surface of materials of high conductivity implies that metallic models of leaves are inappropriate. But it also suggests a role for devices that augment lateral conductivity and thereby reduce peak, average, and fluctuations of leaf temperature. Several such devices can be envisioned. Thus cyclosis in adjacent palisade cells might create a cascade of counterflow heat exchangers, adding convection to conduction. Or water might vaporize near the midrib, pass laterally through spongy mesophyll, condense near the margins, and be wicked back medially, thus creating a heat pipe that capitalizes on phase change as well as bulk movement. At present, evidence for such augmentation mechanisms remains equivocal.

Effects of buoyancy and flexural stiffness on hydrodynamic force and relative velocity of a morphologically variable alga using real thalli and physical models.

H.L. Stewart

Dept. of Integrative Biology, University of California, Berkeley, California USA 94720

Abstract: An upright position in the water column can potentially increase mass transfer and light interception but also exposes algae to greater hydrodynamic forces. The tropical marine alga *Turbinaria ornata* uses flexural stiffness (EI) or buoyancy to maintain an upright posture across different flow habitats. Thalli of *T. ornata* from wave-exposed environments lack air bladders and are negatively buoyant, but have higher EI than buoyant thalli from calm environments. Simultaneous measurements of water velocity, hydrodynamic force and algal motion were recorded for pairs of thalli positioned side by side on the reef at a site of moderate wave action. Buoyant, flexible algae that moved with the water experienced lower relative velocities and forces than stiff algae. To explore parameter space not available using real algae, the consequences of shape, buoyancy and EI on force and relative velocity were quantified for a variety of physical models in waves and unidirectional flow.

Structure and radial gas permeability of reaction zones in beech

Primoz Oven, Ales Straze, Maks Merela

University of Ljubljana, Biotechnical faculty, Department of wood science and technology, Rozna dolina VIII/34, 1001 Ljubljana, P.O. Box 95, SI-Slovenia

Abstract: Anatomy and radial gas permeability of boundary layers at 2 hollowed and 4 beech trees (*Fagus sylvatica* L.) with decayed core have been investigated. Tissues were stained with Acridin red - Chrysoidin / Astra blue (ACA) for bright field and fluorescence microscopy and investigated under a microscope. Volume flow through the samples of reaction zones was measured by modified Petty`s apparatus and coefficients of radial gas permeability were calculated. Boundary layers anatomically corresponded to the reaction zones in all investigated trees and not to the barrier zones as proposed and described by the CODIT model. Vessels were intensely occluded with deposits of gums and suberized tylosis. Lumina of ray and axial parenchyma, fiber tracheids and all pit apertures were filled with insoluble deposits. The mean coefficient of radial gas permeability of the reaction zones (1.07×10^{-12} $m^3 m^{-1} Pa^{-1} s^{-1}$) was significantly lower than in the sapwood (3.39×10^{-12} $m^3 m^{-1} Pa^{-1} s^{-1}$). The specific anatomy of reaction zones decreases the permeability of the woody tissue, thereby indirectly preserving the high moisture content of the sapwood.

Drag relationships for conifer species from coastal British Columbia.

S.J. Mitchell[1], M. Rudnicki, M. Novak and K. Byrne

University of British Columbia, 3041-2424 Main Mall, Vancouver BC, Canada, V6T 1Z4

Abstract: Having lower drag per unit of crown mass would provide a substantial adaptive advantage in locations with high winds. Juvenile crowns of three morphologically different conifers, lodgepole pine, western hemlock and western redcedar were exposed to wind speeds from 4 to 20 $m \cdot s^{-1}$ in a wind tunnel. Drag forces were measured directly. Crown frontal areas at each speed were obtained using image capture and classification software. At 20 $m \cdot s^{-1}$, streamlining reduced the frontal area by 36% for lodgepole pine, 39% for western hemlock and 54% for redcedar. Using the classical formulation of drag with initial frontal area held constant, drag coefficients decreased from 0.55 to 0.11 with increasing wind speed. Red cedar had the lowest drag coefficient. A simple linear regression was obtained for drag as function of the product of crown mass and wind speed. The slope of this equation was lowest for red cedar. Removing 20% of crown mass did not affect the regression coefficients.

The wind drag equation and trees: A practical consideration of the velocity exponent

Scott Cullen

P.O. Box 31152, Greenwich, CT 06831-0852 USA

Abstract: Arborists and urban foresters are increasingly concerned with tree risk management. Risk of failure is highly dependent on wind load or drag. The aerodynamic drag equation is well established and in conventional form relates drag to velocity squared. The literature suggests, however, that drag on trees varies more linearly with velocity. Some sources therefor suggest that the velocity exponent should be 1. For the practitioner, concerned with public safety and legal liability, this is more than an academic curiosity. Uncertainty about the appropriate exponent questions the reliability of the conventional form. This paper considers the velocity exponent from a practical perspective and concludes that the conventional form - velocity squared - is appropriate. When drag varies linearly with velocity it is properly reflected by varying the drag coefficient or surface area with velocity. More importantly, the derivation of the drag coefficient may demand that velocity be squared in the drag equation.

Poster #22: Ecobiomechanical implications of different types of reconfiguration in the bullkelp *D. antarctica* (Phaeophyceae)

Deane L. Harder [1,2], Thomas Speck [1], and Catriona L. Hurd [2]

[1]University of Freiburg i. Br., Botanic Garden, Plant Biomechanics Group, Institute of Biology II, 79108 Freiburg, Germany
[2]University of Otago, Botany Department, Dunedin, New Zealand

Abstract: The large brown seaweed *D. antarctica* only thrives at rocky coasts with moderate to high wave exposure. The tensional forces on whole thalli of *D. antarctica* were measured for the first time in situ and in a flume. The maximum forces scale with the overall length of the tested thalli rather than projected or planform area. However, the relative decrease in tensional forces is dependent on the particular ecobiomechanical adaptation of the blade. Large undulating blades of wave-sheltered individuals exhibited a decreased ability to reconfigure and thus to reduce drag at higher velocities compared to thin-bladed wave-exposed kelps. The different modes of reconfiguration show the importance of a functional adaptation of the blade morphology in order to minimize the risk of dislodgment through large waves while maximizing the photosynthetically active area.

Poster #23: A comparison of factors affecting leaf-level drag in trees and shrubs

M.C. Dietze

University Program in Ecology, Duke University, Box 90338, Durham, NC 27708

Abstract: Foliage drag effects both susceptibility to wind damage and stand-level gas exchange, however little research has been done on leaf-level drag. Drag measurements were made on 37 species of tree and shrub in the Carolina Piedmont, over a broad taxonomic and ecological range, for a range of wind speeds from 0 to 30 m/s. Drag forces (F), normalized by leaf area, were compared to wind velocity (V) using a power-law relationship (F=A*V^B). The threshold speed for leaf damage (V_{max}) was also assessed. V_{max} is positively associated with leaf density, petiole thickness, and evergreen leaves. Drag exponent (B) was negatively correlated with V_{max}, petiole thickness, and drag constant (A). Drag constant was positively associated with evergreen leaves, and leaf density, negatively correlated with total leaf length, and differs significantly by genus. These results suggest that mechanical properties are more important than morphology in determining leaf drag characteristics in trees and shrubs.

Poster #24: Measuring dynamic mechanical properties of oscillating plant stems using video and image analysis

O. Doaré [1], B. Moulia [2], C. Py [1] ,E. de Langre [1]

[1]Département de Mécanique/LadHyX, Ecole Polytechnique, 91128 Palaiseau, France
[2]UEPF-INRA, 86600 LUSIGNAN, France

Abstract: Plant shoots submitted to wind experience dynamic oscillations and collisions. A novel experimental method to measure stem dynamical properties and elastic collision properties is presented with an illustration on alfalfa stems. Free bending oscillatory motion of single stems and the motion of two stems before and after collision were recorded using a numerical video camera. The motion of a single point on the stems was then obtained using simple image analysis. The mass distribution along the stem was then measured. The dynamical properties of the stem where obtained by fitting the recorded motion using a single oscillator equation (representing the fundamental mode) and of the elastic collisions parameters were then derived assuming a linear elastic collision model. This method is illustrated on alfalfa stems.

Poster #25: Modeling plant motion within a plant canopy submitted to wind using a continuous wave propagation model: a case study in alfalfa

O. Doaré [1], C. Py [1], E. de Langre [1] and B. Moulia [2]

[1]Département de Mécanique/LadHyX, Ecole Polytechnique, 91128 Palaiseau, France
[2]UEPF-INRA, 86600 Lusignan, France

Abstract: Plant motion due to wind influences plant growth (thigmomorphogenesis). However despite intensive work on the turbulence over plant canopies, the study of plant motion induced by wind have been limited to individual trees or cereal plants (Farquhar et al. 2000). Very few models of canopy motions are available (Farqhar and Eggleton, 2000). Moreover, being based on individual stem models, their numerical analysis becomes very long when dealing with plant crops.
A novel model of motion within the canopies is presented using a wave propagation equation within a homogenized continuous medium, and a forcing function representing turbulent eddies walk over the canopy. This model is derived from a discrete model of a set of plant shoots represented as 1D oscillators, including elastic contacts between shoots. Such contact induces non-linearity in the wave equation. Results obtained modeling plant motions in an alfalfa crop are presented.

PUBLIC LECTURE

Stems and Trunks: Twisting in the wind without getting bent out of shape

Steven Vogel
Department of Biology, Duke University, Durham, NC U.S.A.

Abstract: Low torsional stiffness is usually something to be avoided or offset in human-built structures, and insufficient torsional stiffness has made trouble for both airplanes and buildings. Nature, though, goes in for less rigid structures than we do. In her world solid and fluid mechanics don't stay obligingly distinct, and flow forces may reshape structures so they suffer lower levels of those very forces. In particular, twisting around may reduce wind-facing surface area and thus reduce a structure's drag. The ratio of flexural to torsional stiffness provides an index to such effects, one of especial applicability to gravity-resisting structures – such as petioles, flower stems, and tree trunks

BIOMECHANICS OF WOOD

KEYNOTE

Mesostructure engineering properties in loblolly pine

Steven Cramer [1], David Kretschmann [2], Roderic Lakes [1], and Troy Schmidt [1]

[1]University of Wisconsin-Madison, 1415 Engineering Drive, Madison, WI 53706, U.S.A.
[2]USDA FS Forest Products Laboratory, 1 Gifford Pinchot Drive, Madison, WI 53705, U.S.A.

Abstract: Historically, engineering properties of wood have been established at the macroscale and assuming wood material to be a homogeneous continuum. The resulting variability from the use of such a simplifying assumption has been handled by characterization, and inevitable and begrudging acceptance of the resulting wide statistical variation in properties. With managed commercial forests geared toward rapid growth and shorter rotation harvests, wood products now contain significantly fewer growth rings with increasing conflict in the assumption of a homogeneous continuum. Herein we report a study that has measured the property differences and variability of earlywood and latewood (mesostructure) samples from a Loblolly Pine commercial plantation. Properties measured included specific gravity, longitudinal modulus of elasticity, shear modulus, loss tangent, microfibril angle and longitudinal shrinkage. Novel testing procedures were developed to measure properties from 1-mm by 1-mm by 30-mm mesostructure specimens. The test results show dramatic differences in the properties of adjacent earlywood and latewood – differences that are believed to impact product performance. As important as the differences, the variability of these properties has been established. But characterization of differences and variability are not enough. Ultimately, the variability of these properties must be linked to the biological growth processes that produce the differences.

Need for further structural mechanics study on wood quality

Ping Xu

Forest Research, Sala Street, Private Bag 3020, Rotorua, New Zealand

Abstract: This paper stresses the need for structural mechanics on wood stiffness and strength through a review of current research on trees, structural boards and wood cell walls. In macro-scale, there was a poor relationship between wood density and tensile strength. However, knot structural factors, such as branch growth angle and structural discontinuity of wood grain significantly affected the mechanical properties at the weakest point, though knot area ratio alone did not predict mechanical properties at the weakest point in structural boards. In micro-scale, average microfibril angle rather than mass factor was responsible for the mechanical properties in radiata pine stems; various structural factors were recognized to contribute to mechanical properties of individual wood cell walls. A further structural mechanics investigation on wood-based biomaterials is thus proposed to fill the gaps in the understanding of wood structural mechanics.

Wood specific gravity as a variable entity

Deborah Woodcock

University of Hawaii, PO Box 1303, Marlboro MA 01752, U.S.A.

Abstract: Wood specific gravity (wood density) of forest trees should be a conservative entity owing to the metabolic costs of wood production and considerations relating to support and maintenance of structural integrity. The degree of variation exhibited, especially in tropical forests, is thus somewhat surprising. Successional position is one factor known to influence species-to-species variation as well as within-tree variation. Understanding specific gravity variability requires knowledge of the biology of individual species plus a precise representation of the biomechanical constraints in play given a certain architecture and stature as a mature tree, range of environmental stresses and hazards present (wind and ice loading, wind throw, etc.), and dynamic responses including both resistance and deformation.

Relationship between anatomical morphology, density and local shrinkage of wood. An experimental device for the simultaneous inspection of these parameters.

E. Badel and P. Perre

LERMAB (Laboratory of Wood Science), UMR 1093 INRA/ENGREF/Université Henry Poincaré, ENGREF – 14 rue Girardet, F-54042 Nancy Cedex, France

Abstract: Based on a digital X-ray imaging system coupled with a humid air generator, a new device allows to measure the shrinkage behavior of thin samples. The air generator controls both, temperature and relative humidity in the chamber. It provides stable conditions that enable experiments over several months. The X-ray beam passes through the chamber to the 2D detector. 10 samples are placed on a rotary sample holder. The determination of the strain field due to the moisture content variations uses a specific algorithm, which compares X-ray images collected at different moisture conditions. X-ray inspection simultaneously gives complementary data about the nature of the shrinkage mechanism (local density and spatial organization of the tissues).

These experimental results are compared to a computed prediction in order to validate a modeling approach of shrinkage (see 3rd Plant Biomechanics Conference). A wide range of anatomical patterns is selected for this purpose

The influence of mechanical stress on heartwood formation in trees

A. Stokes [1], F. Salin [1], J-P Charpentier [2], C. Jay-Allemand [2], C. Gachet [3]

[1]Laboratoire de Rhéologie du Bois de Bordeaux, (Mixed Unit: CNRS/INRA/Université Bordeaux I), 69, Route d'Arcachon, 33612 Cestas cedex, France
[2]Unité Amélioration, Génétique et Physiologie Forestières, Équipe Physiologie du Développement, INRA Orleans, BP 20619 Ardon, 45166 Olivet, France
[3]LEPT-ENSAM, University of Bordeaux I, 351, Cours de la Libération, 33405 Talence cedex, France.

Abstract: In order to test the hypothesis that mechanical stress induces heartwood formation in leaning or wind-stressed trees, samples were cut from Maritime pine (*Pinus pinaster* Ait) and subjected to mechanical loading. 20x1x1 cm batons were removed in the radial direction from freshly felled logs of 30-year-old trees. The samples were then held in 3-point bending for 5, 16 or 48 hours, with a load of 10N applied at the transition zone, located between the heart- and sapwood. The transition zone was then removed for chemical analysis. Initial results show that certain polyphenols, which are implicated in heartwood formation, were formed in samples subjected to mechanical loading, but were not found in control samples. Once these polyphenols have been identified, the next step will be to determine if genes in the transition zone are expressed when a mechanical stress is applied to this region.

Wood Response to Periodic Compressive Straining

Petri P. Kärenlampi, Pekka Tynjälä and Pasi Ström

University of Joensuu, Faculty of Forestry, P.O.Box 111, FIN-80101 Joensuu

Abstract: The response of steamed wood to repeated compressive straining has been investigated. Applied stress levels, stress amplitude, loading frequency, process temperature and straining direction have been used as independent variables. Both irrecoverable strain and reduction of small-strain stiffness are largely determined by the amount of accumulated compressive strain, being apparently independent of strain amplitude, stress amplitude, loading frequency and energy dissipation.
Structural changes in cell walls have been characterized using Differential Scanning Calorimetry. Unlike irrecoverable strain and stiffness decrement, the non-freezing water content changes in a manner, which depends on the details of the process. A threshold stress level appears to be required for cell wall reorganization. After exceeding such a threshold, the increment in non-freezing water content appears to depend on strain amplitude. Further work applied in terms of additional compression cycles advances the cell wall reorganization, and such a process accelerates as the temperature is increased. The increment of non-freezing water content due to mechanical loading appears to be reversible.

Anatomical analysis of the vessel network in some ring-porous hardwoods

Peter Kitin [1], Tomoyuki Fujii [1], Hisashi Abe [1], Ryo Funada [2]

[1]FFPRI (Forestry and Forest Products Research Institute), Tsukuba, Japan
[2]Graduate School of Agriculture, Hokkaido University, Sapporo, Japan

Abstract: We studied the three-dimensional arrangement of vessels and the vessel-to-vessel connections through bordered pits in the secondary xylem of species from the genera *Fraxinus*, *Kalopanax* and *Zelkova* on resin casts by SEM and in series of thick transverse sections by epifluorescence microscopy and confocal laser scanning microscopy (CLSM).
The courses of vessels were not parallel to stem axis but deviated in tangential and, to a smaller extent, in radial direction. Individual vessels, which were solitary on some sections, along stem axis appeared in different vessel multiples and were consequently in contacts with a number of different vessels, and therefore, were integrated in a continuous axial and radial vessel network. Densely-arranged bordered pits were present in the regions of contacts between adjacent vessels. Intervessel pits, which could serve as bridges for radial water transport, occurred at the annual ring boundaries between earlywood and latewood vessels.

Poster #26: Biomechanical adaptation of the wood structure of European chestnut to growth stresses

Patrick Fonti [1], Nicola Macchioni [2], Bernard Thibaut [3] and Juergen Sell [4]

[1]WSL Sottostazione Sud delle Alpi, CH-6504 Bellinzona, Switzerland
[2]IVALSA - CNR, I-50136 Firenze, Italy
[3]LMGC - UM II, F-34095 Montpellier, France
[4]EMPA, CH-8600 Dübendorf, Switzerland

Abstract: Ring shake is a tangential crack that forms along annual rings due to the release of internal growth stresses of a stem after felling of the tree and during wood drying. Because of the weak radial structure of sweet chestnut wood (*Castanea sativa* Mill.), this wood is one of the species most affected by ring shake. Quantitative anatomical analysis of earlywood vessels and parenchymatic rays of 60 chestnut trees with and without ring shake have revealed that, contrary to the expectation, ring shaken trees display smaller earlywood vessels and higher volume portions of rays. Such structure elements should actually strengthen the wood against ring shake. This seeming contradiction can be explained by the hypothesis that chestnut trees with high growth stresses might be able to adapt their vessel and ray features to compensate the stresses. However, after tree felling and during wood drying, the internal stresses are increasing strongly and thus exceed even the improved radial cohesive strength of the adapted wood structure.

Poster #27: Physical and Mechanical Properties of Wood from Tropical Angiosperms Related to their Pre-Stressed State in Standing Tree.

Anne Thibaut [1] Jacques Beauchêne [2], Marie-Françoise Prévost [3], Bernard Thibaut [4]

[1] CIRAD-Forêt, Montpellier, France;
[2] CIRAD-Forêt, Kourou, French Guyana;
[3] IRD, Cayenne, French Guyana;
[4] Laboratory of Mechanics and Civil Engineering, University Montpellier 2 CC048, Place Eugène Bataillon, 34095 Montpellier cedex 5, France

Abstract: Our research project aims at understanding the influence of reaction wood on the properties of the material, from both a biomechanical and technological viewpoint. 11 trees from different angiosperm families were selected in French Guyana according to shape criteria; residual strains have been measured at 8 peripheral positions of tree surface and matched material was cut for conventional measurement of longitudinal Young's modulus and strength, shrinkage in radial, tangential and longitudinal directions and colour according to CieLab system. In most cases, the occurrence of tension wood, suggested by unusual levels of in situ residual strain, was marked by corresponding variations of properties. However, the effect was not always of the same nature, and in some cases was absent. Thus we gathered a number of specimens showing contrasting combination of properties. In addition to this sampling of tropical woods, we performed equivalent work on a few temperate hardwood or softwood species.

Poster #28: Mapping tension wood in discs of a tropical rain forest species *Symphonia globulifera*

B. Clair, J. Gaëlle, M. Fournier, J. Beauchêne

UMR ECOFOG CIRAD ENGREF INRA, BP 709 97379 KOUROU, French Guiana, France.

Abstract: Mapping tension wood in large samples (whole discs, great number of cross sections, stems and trees) is always a limiting problem in biomechanical studies. Here, we compared three methods: mechanical measurements of longitudinal residual maturation strains (single hole method, growth stress indicator GSI, Clair et al. 2002) that gives a quantitative accurate but peripheral information, macroscopic tension wood mapping by zinc chloro-iodide on discs (Greskowiak et al, 1996) that gives only a binary result (tension wood or not), physical measurements of drying shrinkages that give quantitative data everywhere in the cross section. An original method on sawn discs, based on image analysis in the transverse plane and micrometric measurements in the longitudinal direction, has been developed for shrinkage measurement. Good correlations exist between the different methods. The tangential shrinkage could be a very efficient and easy to measure continuous variable, to characterize tension wood at large scales.

Poster #29: Effect of the presence of unlignified parenchyma on the biomechanical properties of stems of Urticaceae.

Guillermo Angeles, Jorge López-Portillo, Ignacio Salomón-Quintana, Fernando Ortega-Escalona

Instituto de Ecología, A.C. Km. 2,5 Carretera Antigua a Coatepec No. 351. Xalapa, Veracruz 91070. Mexico.

Abstract: The secondary xylem of the Urticaceae family forms unlignified and lignified parenchyma. In the tropical rainforest of Los Tuxtlas, Veracruz, Mexico, the family is represented by the genera *Urera* and *Myriocarpa*, which can be shrubs or lianas. In lianas, unlignified parenchyma is found mainly in the radial parenchyma, whereas in the shrubs, it is found mainly in the axial parenchyma. To find out how the presence of unlignified parenchyma affected the mechanical properties of stems, we tested for elastic flexure in fresh branches. Force was applied at constant speed, until the maximum load was attained. Plotting force *vs*. deformation, modulus of elasticity (MOE) and modulus of rupture (MOR) were obtained. A one-centimeter segment of the middle portion of the specimen was taken to observe under the SEM, under low vacuum, without coating. In this way, we could precisely identify which kind of cells failed under the applied force.

Poster #30: Tension wood in French Guiana species: Comparison between some anatomical and physical criteria

J. Ruelle [1], J. Beauchêne [1], B. Clair [1] and M-F, Prévost [2]

[1]Unité Mixte de Recherche « Ecologie des Forêts de Guyane » CIRAD ENGREF INRA, BP 701, 97381 Kourou, Guyane Française, France
[2]UMR « Botanique et Bioinformatique de l'architecture des plantes AMAP » IRD Centre de Cayenne, BP 165, 97323 Cayenne, Guyane Française, France

Abstract: Wood cubes have been sampled from the upper and lower sides of 24 naturally bent trees in tropical forest. Measurements of residual maturation distortions ensure that the samples are made of mechanically different wood. The trees have been identified and belong to 24 species from 21 families. Thin sections were cut from the 48 samples, which were stained and then numerated.
Quantitative criteria describing the transverse section of the fibers and vessels were then defined. The student test enables to compare the differences between the criteria in tension wood and in the corresponding opposite wood.
The more important results are a decrease in the number of vessel and in the lumen diameter of the fibers of normal wood compared to tension wood. Moreover, a higher density and higher longitudinal and tangential shrinkage are observed in tension wood.

Poster #31: Vertical and radial profiles in tracheid characteristics in Douglas-fir with implications for water transport

Paul J. Schulte

Department of Biological Sciences, University of Nevada, Las Vegas, NV 89154-4004 USA

Abstract: The anatomical characteristics of tracheids are important in determining the hydraulic resistance of stems. Mathematical models suggest that a sufficient gradient in tracheid diameter might result in plants whose total flow resistance is independent of plant size. This study measured vertical and radial profiles in tracheid characteristics (diameter, length, numbers and sizes of pits) for Douglas-fir trees. Average tracheid diameter spanned nearly an order of magnitude from needles high in the crown to roots. Tracheid size was fairly constant below the crown and among the outer growth rings, but tapered considerably within the upper crown and near the pith. Pit size was fairly constant with respect to tracheid size, but the number of pits increased with cell diameter and length. However, the resistance of the cell lumen is likely related to its diameter to the fourth power, and so flow may become increasingly limited by pits as tracheid diameter increases.

TREES AND BIOMECHANICS

KEYNOTE

The effect of growth space characteristics on the internal stem structure of trees – some consequences for tree mechanics

Franka Brüchert

Institute of Forest Utilisation and Work Science, Albert-Ludwigs-University Freiburg, Werderring 6, 79085 Freiburg, Germany

Abstract: Bending and swaying characteristics of trees are the sum of the size and the shape of crown and stem, the internal structure of the stem and the mechanical properties of the present tissues, mainly the wood. The internal structure of the stem enfolds the spatial distribution of the wood, bark and pith as well as spiral grain.
Silvicultural management aims to use the tree's ability for adaptive tree growth to maximise volumetric increment and the wood "quality". The size of the growth space also determines the degree of mechanical impact on the tree. The mechanical perturbation influences the subsequent wood formation in terms of the development of specific wood types, of spiral grain and undesirable wood defects.
This paper will present the results of investigations on spruce grown under different growth situations. The focus is given to the formation of compression wood and its three-dimensional distribution in the stem. Its distribution and its morphological and anatomical appearance are investigated with respect to the nature and the strength of mechanical impact and the periodicity. The investigations aim to analyse the influence of growth space characteristics and critical events on the wood formation of the tree and the patterns of spiral grain and wood characteristics.

Buttresses and gravitropic reorientation: are buttresses an alternative or complementary strategy to reaction wood formation?

M. Fournier [1], B. Clair [1], J. Ruelle [1], C. Coutand [2], M-F, Prévost [3]

[1]UMR ECOFOG CIRAD ENGREF INRA, BP 709 97379 KOUROU, French Guiana, France.
[2] UMR PIAF INRA Univ. Clermont Ferrand, 234 Av. du Brézet, 63039 Clermont-Ferrand cedex 02 France
[3]UMR AMAP, RD Centre de Cayenne, 97300 CAYENNE, French Guiana, France

Abstract: Buttresses are mainly involved in tree anchorage (Ennos 1993), but are also multifunctional organs formed during tree developmental crises (Kaufman 1988). Their role in tree tropism and stem reorientation has never been discussed, although some authors have studied the presence of tension wood (Fisher 1982, Steege et al. 1997), or the level of peripheral growth stresses (Chouquet et al. 1995), in buttresses. In this poster, we present mechanical models of the reorientation due to tensile stress formed on growing buttress ridges. Simulations use an experimental set of data from 11 buttressed tropical trees of small diameter (French Guiana) where both geometry and maturation strains have been measured. The buttress strategy is compared to circular concentric or eccentric growth with reaction wood formation. The simulation shows that the asymmetric growth of one high, and not necessarily large, buttress on the upper side (in respect to lean) is an efficient way to restore verticality. Actually, this morphology is commonly observed.

Links Between Forest Management, Tree Morphology and Growth Stresses in Beech

Caroline Loop and Bernard Thibaut

Laboratory of Mechanics and Civil Engineering, University Montpellier 2, France
CC048, Place Eugène Bataillon, 34095 Montpellier cedex 5, France

Abstract: Growth stresses develop during the life of a tree in order to maintain tree verticality or allowing for trunk reorientation. Therefore, through growth stress induced log-end checking, tree growth stress history can be assessed. The link between tree shape, growth stress and checks has been studied on 500 Beech trees from 10 stands representative of the forest management of 5 European countries. Another aspect of this research was to investigate characteristics of tree shape that could provide with an early indicator of checks. Parameters of growth stresses and crack levels were correlated with tree shape characteristics. The best parameters influencing stresses, and consequently cracks, were tree height, slenderness and crown width. Unlike generally accepted ideas, diameter was negatively linked to growth stress, straight trunks were more stressed than bending or curved ones, and mountain trees were not particularly stressed. These results lead us to propose a type of forest management that would produce low stress-level Beeches.

Plastic deformation in the xylem of living trees

Richard Jagels

Department of Forest Ecosystem Science, University of Maine, Orono, ME 04469 U.S.A.

Abstract: Living trees are designed with a mechanical strength that generally exceeds static self-loading. This safety margin helps to sustain short-term additional static (e.g. ice, snow) or dynamic (wind) loads. Under unusual conditions the mechanical strength safety margin can be exceeded, in which case buckling occurs. However, it is theoretically possible that safety margins can be exceeded, with plastic deformation (PD) occurring, but no outward sign that mechanical limits have been exceeded. Recently, a device for inducing PD in wood has been developed for the wood bending industry. Characterization of the microscopic features of experimentally induced PD in various species of wood provides a reference base for examining living trees for PD. We have used key microscopic features to detect PD in the low-density xylem of dawn redwood, and have differentiated this from buckling failure in paper birch. These findings are discussed in terms of the biomechanical strategies of different tree species.

Influence of pruning methods on health and reliability in silver maple trees

G.A. Dahle [1], H.A. Holt [1], W.R. Chaney [1], and T.M. Whalen [2]

[1]Department of Forestry & Natural Resources, Purdue University, 15 Marsteller Street, West Lafayette IN 47907
[2]School of Civil Engineering, Purdue University, 550 Stadium Mall Drive, West Lafayette IN 47907

Abstract: Branch strength was investigated in *Acer saccharinum* (silver maple) converted from round over to v-prunes. The strength of the re-grown branch was measured by pulling the branch downwards until it broke. The unit area force and localized stress were calculated for each broken branch, and decay was measured at each break as well as for all of the main leaders and trunk. Ongoing analysis will determine if a relationship exists between the size of the re-growth (diameter and length of the branch), leader/branch diameter ratio, local stresses, the amount of decay present and the strength at the point of attachment.

Prediction of the large deflection of a pear tree limb under pear loading

Suzanne M. Peyer [1], John C. Hermanson [2], Jay A. Johnson [3],

[1]Department of Zoology, Washington State University, PO Box 641806, Pullman WA, 99164-1806; USA
[2]Forest Products Laboratory, One Gifford Pinchot Drive, Madison WI, 53726-2398; USA
[3] College of Forest Resources, University of Washington, 303 Bloedel Hall, Box 352100, Seattle WA, 98195-2100; USA

Abstract: Causal observations, over time, of a developing pear hanging from a slender limb that continued to cause excessive deformation, initiated an effort to mathematically model the shape of the bent limb. The limb shape was extracted from digital images. A set of first order differential equations for the local limb slope and curvature were used to model the limb shape. The modelling results will be compared to classical beam theory and finite element approximations.

Tree root strength: A multi-scale approach

A.J. Collins [1], M.P. Greaves [2], C.R. Thorne [3], and A. Simon [4]

[1]National Soil Resources Institute, Cranfield University at Silsoe, UK
[2]Formerly of IACR-Long Ashton Research Station, Bristol, UK
[3]School of Geography, University of Nottingham, UK
[4]USDA-ARS National Sedimentation Laboratory, Mississippi, U.S.A.

Abstract: Using a multi-scale experimental approach tree root strength and architecture at a variety of scales, from individual roots through to whole root systems, was investigated in the laboratory and field.

It was found that existing root reinforcement models omit fundamental limits on the mobilization of tensile strength in the form of *critical bonds* between root tissues, the soil-root association and the embracing soil matrix. The effectiveness of these bonds was found to vary both spatially and temporally, according to a complex interaction of factors such as age, dominant particle size (soil texture), moisture content of the soil, micro- and macro-scale root architecture as well as a variety of environmental controls.

Hydraulic, biomechanical, anatomical interactions of xylem from five species of Acer (Aceraceae)

Carrie L. Woodrum [1], Frank W. Ewers [1], Frank W. Telewski [2]

[1]Department of Plant Biology, Michigan State University, East Lansing, Michigan, 48824 U.S.A.
[2]W. J. Beal Botanical Garden, Department of Plant Biology, Michigan State University, East Lansing, Michigan, 48824 U.S.A.

Abstract: Possible tradeoffs between hydraulic conductivity and mechanical properties and any correlation with wood anatomy were assessed in stems of five species. *Acer negundo* is a ruderal tree, *A. saccharinum*, and *A. rubrum* are fast growing, shade intolerant soft maples, whereas *A. nigrum* and *A. saccharum* are slow growing, shade tolerant hard maples. It was hypothesized that ruderal and soft maples would have lower modulus of elasticity (MOE) and modulus of rupture (MOR), but higher maximum specific conductivity ($K_{s\ max}$) than hard maples. Mechanical data supported the hypothesis but were no differences in $K_{s\ max}$. Thus, no tradeoff was found between $K_{s\ max}$ and MOE or MOR across the genus. Fiber lumen diameter was inversely correlated to MOE and MOR. Results suggest that transport/mechanical tradeoffs do not occur in Acer and differences in mechanical properties may be due to fiber lumen differences that do not influence the efficient transport of water.

New method for measuring diameter in different parts of tree trunks by geometric relations.

K. Katrimi

Department of Natural Resources
Tehran University
Tehran, Iran

Abstract: Tree diameter is one of the most important geometrical characteristics for estimating the total volume of wood of a tree stand. In most cases the geometrical form of trunks isn't cylindrical but rather nailed or conic. Yet, current methods for determining stand volume assume a cylindrical trunk form and volume is calculated by measuring diameter breast high with a coefficient. In order to correctly acces the real stand volume it is necessary to determine the diameter in different parts of the trunk. This talk presents an efficient approach for a more accurate yet efficient tree stand accessment and discusses a new instrument for measuring stand tree diameter in different cross profiles along the tree trunk by using simple geometrical methods and trigonometric calculations. This new method also includes the measurement of tree height.

Poster #32: Kinematic analysis and modelling of the reorientation process in artificially tilted poplars.

Catherine Coutand [1], Jaouen Gaëlle [2], and Bruno Moulia [3]

[1]Umr PIAF, INRA, 234 avenue du Brézet, 63039 Clermont-Ferrand cedex02, France
[2]Umr PIAF, INRA, 234 avenue du Brézet, 63039 Clermont-Ferrand cedex02, France
[3]Unité d'Ecophysiologie des Plantes Fourragères, INRA, route de Saintes, 86600 Lusignan, France

Abstract: This work focuses on the reorientation process in artificially tilted poplars and gives a quantitative description of the kinematics of the righting-up process. The righting-up begins at the tip of the trunk of then propagates towards the trunk base. The kinematic analysis of curvature fields along each trunk revealed the propagation of a peak of curvature from the tip towards the base. As this peak progresses towards the base, the curvature decreases towards zero within the distal part. This gives evidence for a curvature compensation phenomenon. Interestingly this compensation process occurs before the trunk reaches the vertical. This means that the compensation phenomenon is anticipated and that inclination is not the (or not the only) variable perceived in gravitropism. We tested several hypotheses on gravity perception to build a mathematical model of the changes in curvature field occurring during the reorientation process.

Poster #33: Tree Sway: The Role of Aerial Architecture

Damien Sellier, Damien Soulier, Patrick Lac and Thierry Fourcaud

Laboratoire de Rhéologie du Bois de Bordeaux, 69 Route d'Acachon, 33612 Cestas cedex FRANCE

Abstract: Free swaying experiments have been carried out on three even-aged juvenile Maritime pines (*Pinus pinaster* Ait.) in order to assess the influence of architectural parameters on tree mechanical behavior. The chosen trees had significant differences in their aerial morphology. Trees were progressively pruned to determine the role of typical architectural elements on sway frequency and the structural damping coefficient. Continuous wavelet transform was applied to tree motion time series, allowing transient events to be detected in the structural response. Needles were shown to have an important impact on tree dynamic characteristics due to their biomass and the air friction damping. Bending and torsion coupling were also involved in natural swaying frequency. These experiments did not allow the part of the energy dissipated due to branch motion to be quantified. A better understanding of these complex movements could be achieved using numerical analysis.

Poster #34: Gravitropic response of artificially tilted young stems of a tropical tree *Symphonia globulifera*

Jaouen Gaëlle [1], Catherine Coutand [2], M. Fournier [1], Pascal Imbert [1]

[1]UMR ECOFOG CIRAD ENGREF INRA, BP 709 97379 KOUROU, French Guiana, France.
[2]UMR PIAF INRA Univ. Clermont Ferrand, 234 Av. du Brézet, 63039 Clermont-Ferrand cedex 02, France

Abstract: Reorientation by reaction wood formation is necessary to maintain tree form, especially in very slender tropical saplings. The reorientation phenomenology can be related to i) reaction wood quality mainly maturation strains intensity in reaction wood compared to normal or opposite wood, ii) geometry, size and radial growth rate of the cross section, iii) other phenomenological features of the gravitropic reaction (propagation of the response along the stem, autotropic straightening…). In tropical forests, light is a limiting resource mainly responsible of very slow growth of seedlings and saplings. Therefore, poor light conditions are expected to be associated to less significant righting movements. The gravitropic reaction of artificially tilted trees (two years old) of *Symphonia globulifera* has been studied under different light conditions by digitizing forms and measuring the above mentioned parameters. A mechanical model (cross section level) provides interpretation of the effects of the different parameters of form variations, especially the respective roles of wood quality and growth (biomass or volume).

Poster #35: Mechanical properties of the underneath compression side of branches of beech (*Fagus sylvatica* L.)

I. Burgert [1], C. Rohr[1], K. Frühmann [1,2], S.E. Stanzl-Tschegg [1]

[1]Institute of Meteorology and Physics, University of Agricultural Sciences, Vienna, Austria
[2]Laboratory for Fundamentals of Wood Machining, at the Institute of Meteorology and Physics

Abstract: The connection between the stem and branch is an interesting system in which to study adaptive growth in trees. Deciduous trees are supposed to generate tension wood in response to gravity, but are exposed to high compressive stresses at the lower side of branches. Our objective was to investigate how these high compressive stresses are compensated. From two beech trees (*Fagus sylvatica* L.) three branches were taken. Before cutting, branch height and angle between the trunk and branch were measured. Specimens for compression tests were removed from the lower side as well as from the lateral sides of the branches at different distances to the stem (approximately 80 specimens for each disk/altogether 1400 specimens). Compressive strength, modulus of elasticity in compression and density of each specimen were determined and a mapping of properties in relation to the position in the branch was carried out.

FRACTURE MECHANICS

KEYNOTE

Structure and fracture mechanical response of wood

Stefanie Tschegg

BOKU - University of Natural Resources and Applied Life Sciences, Vienna
Institute of Meteorology and Physics, CD-laboratory
Tuerkenschanzstrasse 18, A-1180 Wien, Austria

Abstract: The structure of wood is complex and hierarchical. Wood may be considered macroscopically or on a cellular level (laminated structure consisting of earlywood and latewood layers), or on an even smaller scale, like the cell wall level. It is expected that features on different levels of magnification influence the response of wood fracturing in different ways. New experimental investigations will be reported at the conference, which make use of an environmental scanning microscope (ESEM) on one hand and on the wedge splitting technique on the other hand, which allows for the determination of the specific fracture energy in an efficient way. Consequences of different microstructural features on the fracture mechanical properties will be shown and discussed, and variations of wood species, orientation and humidity will be considered. In addition, questions related to the applicability of LEFM and NLFM (non-linear fracture mechanics), and size effect will be discussed.

Puncture injury susceptibility of tomato fruit: A micromechanical approach

Ana Allende [1], Michèle Desmet [1], Els Vanstreels [1], Veerle Van linden [2], Bert E. Verlinden [1] and Bart M. Nicolaï [1]

[1]Flanders Centre / Laboratory of Postharvest Technology, Leuven, Belgium
W. de Croylaan 42, B-3001 Leuven, Belgium
[2]Laboratory for Agricultural Machinery and Processing, Leuven, Belgium
Kasteelpark Arenberg 30, B-3001 Leuven, Belgium

Abstract: Puncture injury of a tomato during handling represents an important problem for the tomato market. However, tomato puncture injury susceptibility varies among cultivars. It has been reported that the mechanical properties of tomatoes are related to the puncture injury susceptibility. Therefore, determination of mechanical properties as well as the microstructure of tomato tissue is very important. The objective of this study was to determine the relationship between mechanical properties of tomato (e.g., strength of the cuticle, fruit firmness) and the microstructure and pectin content of tomato tissue of two tomato cultivars in relation to their puncture injury susceptibility. Cuticles were enzymatically isolated before determining their strength using a universal-testing machine. Additionally, resin sections of the parenchyma tissue were evaluated with a light microscopy to determine the geometrical properties of the parenchyma tissue. Finally, the pectin content was analyzed. Hence, the relative influence of each analyzed parameter on the puncture injury susceptibility of different tomato cultivars could be determined.

New methods for the study of cereals fractionation

Frederic Mabille, Joel Abecassis

INRA-UTCA 2 place viala, 34060 Montpellier France

Abstract: The traditional grinding process for cereals have various weaknesses with regard to modern industrialized food processing. In particular, the current fractionation does not allow the selective extraction of specific fractions contained in grains. Research is thus directed in new technological solution either upstream or downstream from the traditional process. But these treatments can be truly effective only with an excellent control of the products. This is the reason we developed new mechanical methods of characterization of whole wheat and wheat endosperm.

This talk presents methods to characterize the mechanical properties of the endosperm according to compression and shearing stresses, and also hardness and resilience. The fracture energies measured in these tests are compared with the breaking energy measured on a micro mill. The goal is to propose a predictive method to describe the endosperm fractionation.

XYLEM PRESSURE AND WATER TRANSPORT

KEYNOTE

A biomechanical approach to xylem structure and function

John S. Sperry and Uwe G. Hacke

Department of Biology, University of Utah, 257S 1400E, Salt Lake City, UT 84112, U.S.A.

Abstract: Fluid flow through xylem is a physical process that generates significant pressure, stress, and strain in the cell wall framework. Xylem structure must be equal to these mechanical challenges, yet not at the expense of excessive flow resistance. Nowhere is the conflict between flow resistance and mechanical strength more apparent than in the structure of the inter-conduit pits -- permeable, and hence weak, valves connecting the xylem conduits. These pit valves are necessary to allow fluid flow while also preventing air leakage against pressures as high as 4 MPa or more. The strength of the conduit wall against such pressure depends on its thickness, the conduit width, pit structure, and pit distribution. Across the diversity of angiosperm and conifer woods, wall strength scaled with maximum operating stress with little or no safety margin. Wall failure does not occur because it is preceded by air leakage and cavitation, which eliminates the stress-inducing pressure. The necessary wall strength is achieved by a combination of wall thickness and pit structure that tends to maximize the hydraulic conductivity of the conduit per unit conduit wall area. This validates the long suspected, but never tested, assumption that conduit structure reflects an optimal compromise between transport efficiency and mechanical/hydraulic safety.

Interfacial effects and gas bubble dynamics in conduits of vascular plants - a functional component of embolism repair?

Anita Roth-Nebelsick and Wilfried Konrad

Institute for Geosciences, Tübingen University, 72076 Tübingen, Germany

Abstract: Wood represents a fibrous tissue with unique transport properties. It is able to move water over long distances without expending any pumping energy. Plant water transport is commonly explained as generated by a longitudinal water potential gradient with the water columns inside the wood conduits being partly under tension. This leads to the risk of cavitation. Recent results (Zwieniecki & Holbrook 2000) indicate that special interfacial effects created by cell wall microstructures may be involved in embolism repair. The following topics will be addressed in this contribution: 1) Is the suggested mechanism physically possible? 2) How do pit structure and cell wall material influence the interfacial effects? 3) What time scales are to be expected for embolism repair? 4) Do interfacial effects decrease the mechanical load acting on the pit membranes? 5) Can other structures (vestured pits, wall sculptures) cause interfacial effects?

Safety Factors Against Xylem Failure by Implosion, Air-Seeding, and Margo Breakage in Tall Douglas-fir Trees

Jean-Christophe Domec and Barbara Gartner

Dept. of Wood Science and Engineering, Oregon State University, Corvallis, OR 97331 U.S.A

Abstract: The cohesion-tension model of water transport states that water is held together by strong internal forces and that it is pulled through a tree in tension. This tension could cause transport failure in at least three ways: breakage of the tracheid walls (implosion), interruption of the water column by an air bubble (air-seeding), or interruption when a safety feature fails - in this case, when the margo of an aspirated pit membrane breaks, permitting a gas bubble to spread to a neighboring tracheid. Using Douglas-fir trees of two age classes and ranging from 4 to 40m in height, we ask if there is a constant safety factor with height for any of these three failure modes. We calculate the safety factor using physiological measurements of vulnerability to embolism and anatomical measurements of tracheid lumen diameter, cell wall thickness, and size of pores and thickness of strands in the margos of pit membranes. This research aims to elucidate the functional significance of variation in earlywood structure with position in a tree.

The Effect of Mechanical Perturbation on Hydraulic Conductivity, Mechanical Strength, and Productivity of Seven Hybrid Poplars

Kristine A. Kern [1], Frank W. Ewers [1], Lothar Köhler [2], Frank W. Telewski [2]

[1]Department of Plant Biology, Michigan State University, East Lansing, Michigan 48824, U.S.A.
[2]W. J. Beal Botanical Garden, Department of Plant Biology, Michigan State University East Lansing, Michigan 48824, U.S.A.

Abstract: The effect of mechanical perturbation on several properties of hydraulic conductivity, mechanical strength, and productivity was quantified for seven hybrids of a cross between *Populus trichocarpa* (black cottonwood) and *P. deltoides* (eastern cottonwood). To mimic the wind-induced back and forth motion of plants under greenhouse conditions, mechanical perturbation (20 flexures per day) was applied to stems of sapling poplar clones for 70-90 days. Mechanical perturbation of stems was expected to decrease hydraulic conductivity (k_h) and productivity, and increase flexural rigidity (EI). Mechanical perturbation significantly decreased specific conductivity (k_s or k_h per leaf area) and aboveground biomass. Flexural rigidity, wood specific gravity, and xylem transverse area at point of flexure increased while MOE and MOR decreased in most of the mechanically perturbed stems. Surprisingly, in comparing differences among hybrids, k_s was positively correlated with MOE (r^2=0.60, P=0.001), with some hybrids having both great mechanical strength and water conduction while others were deficient in both properties.

Water flow through junctions in Douglas-fir roots

Paul Schulte

Department of Biological Sciences, University of Nevada, Las Vegas, NV 89154-4004 USA

Abstract: Roots are important conduits for the redistribution of water within the rooting zone. Root systems are often highly branched and flow between regions undoubtedly involves passage through junctions of individual roots. This study considered junctions in roots of Douglas fir with regard to the resistances encountered by flow. Flow into a root branch and distally along the main root encountered much greater resistance than flow between the branch and the main root proximally. When the main root proximal to the junction was gradually shortened, the resistance to flow between the branch root and distally along the main root increased dramatically. Thus flow in this manner appears to depend on lateral flow within the root over many centimeters proximal to the junction and not just a direct connection at the junction. These results suggest that the hydraulic nature of junctions will be an important aspect of hydraulic redistribution utilizing flow through roots.

Do plants obey Murray's law?

Katherine McCulloh and John Sperry

Department of Biology, University of Utah, Salt Lake City, UT 84112, U.S.A.

Abstract: Murray's law describes the optimal design of a vascular system that maximizes hydraulic conductivity per investment in vascular tissue. The law states that the optimal structure will conserve the sum of the conduit radii cubed at every level of the vascular system. Although the law was derived for the cardiovascular systems of animals, it should apply to plants and surprisingly has not been examined extensively. We hypothesized that the xylem conduits of plants would obey Murray's law when they are not providing the plant with structural support in addition to transporting water. We tested this in a variety of systems, which varied in the amount of structural support provided by the xylem. We found that when the xylem of a plant or organ was not expected to provide large amounts of structural support, it obeyed Murray's law.

Elucidating the role of turgor pressure in forcible ascospore discharge

Luis Velasquez and Frances Trail

Department of Plant Biology, Michigan State University, East Lansing, MI 48824 U.S.A.

Abstract: Ascomycetes disperse their spores predominantly by active discharge from asci. This dispersal mechanism allows the spores to breach the boundary layer of air and escape into air currents. Forceful discharge of ascospores has long been speculated to be driven by turgor pressure, but the mechanism has not been elucidated. We have been investigating the mechanism of forcible ascospore discharge in the perithecial fungus *Gibberella zeae* (anamorph, *Fusarium graminearum*). We will present a model for the generation of turgor pressure within the perithecium based upon physiological and genetic studies.

Poster #36: Tyloses and water conductance in *Gliricidia sepium*

Alejandra Quintanar [1], Guillermo Ángeles [2], Frank Ewers [3], Jorge López-Portillo [4]

[1]Departamento de Biología, Universidad Autónoma Metropolitana, México
[2]Departamento de Productos Forestales, Instituto de Ecología AC, México.
[3]Department of Plant Biology, Michigan State University, East Lansing, MI 48824.
[4]Departamento de Ecología Vegetal, Instituto de Ecología AC. México

Abstract: *G. sepium* develops tyloses in young, healthy vessels next to the vascular cambium. This event could be due to low water potential values. Functional vessels and tyloses were counted in transverse sections of double-stained stems, and hydraulic conductivity and embolism were measured by the hydraulic method. Tylose formation was induced in sap vessels by means of branch dehydration, and it was correlated with low water potentials and embolism. The PLC_{50} (50% loss in conductivity) was at -1.85 MPa and most tyloses occurred at still lower water potentials in the dehydration experiment. Based on a bimonthly sampling of native plants, the number of functional vessels was always higher than those with tyloses, and, throughout the year, average water potential values were not lower than -1.2 MPa. Tyloses in *G. sepium* may be a response to pressure differences between vessels and axial parenchyma, or it may occur following embolism events.

Poster #37: Tradeoffs among xylem efficiency, safety, and strength in twenty-two species of chaparral shrubs

Anna Jacobsen [1], Stephen Davis [1], Frank Ewers [2], Kristine A. Kern [2]

[1]Pepperdine University, Malibu, California, U.S.A.
[2]Department of Plant Biology, Michigan State University, East Lansing, Michigan 48824, U.S.A.

Abstract: Is resistance to cavitation of water columns in xylem, measured as the water potential at 50% loss in hydraulic conductivity (ψ_{50PLC}), controlled only by the size of pores in pit membranes? Is there a tradeoff between cavitation resistance and xylem conductive efficiency (K_s)? Alternatively, does increased cavitation resistance require increased carbon allocation to xylem, e.g., greater wood density (D) and greater Modulus of Rupture (MOR)? To explore these issues, K_s, ψ_{50PLC}, and minimum seasonal water potential (ψ_{min}) were compared to D and MOR in 22 species of chaparral shrubs in southern California. Both D and MOR were poorly associated with K_s but strongly associated with ψ_{50PLC} and ψ_{min}. This suggests there is a correlation between the biomechanics of chaparral stem xylem and resistance to cavitation. Carbon allocation for structural support, to prevent vessel and fiber implosion, may represent a significant cost associated with resistance to hydraulic cavitation.

Poster #38: The structural and hydraulic tradeoffs associated with cavitation resistance in conifer wood

Jarmila Pittermann, John Sperry

Department of Biology, University of Utah, Salt Lake City, UT, 84112, USA

Abstract: To evaluate the structural and hydraulic tradeoffs associated with mechanical support and cavitation resistance in xylem, we examined the conduit anatomy and cavitation pressures of roots and stems in conifers inhabiting a wide range of environments. Xeric conifers exhibit greater resistance to cavitation, higher mean ratio of wall thickness to lumen diameter [(t/d)^2] and consequently greater wood density, than mesic species. The greater the (t/d)^2, the better the conduit is reinforced against implosion under negative xylem pressure. The cavitation pressures of roots and stems were calculated from each organ's respective (t/d)^2 measurements. The predicted cavitation pressures that best fit the empirical data were associated with a unique safety factor (k) from implosion. Across species, roots and stems have a 'k' of 1.5±0.18 and 3.4±0.3, respectively. This implies that with regard to implosion safety, stems have 'overbuilt' conduits compared to the roots. The higher 'k' in stems is consistent with their canopy support function.

Poster #39: Implications of xylem pressure for conduit wall reinforcement

Uwe G. Hacke and John S. Sperry

Department of Biology, University of Utah, 257 S. 1400 E., Salt Lake City, UT 84112

Abstract: It has long been hypothesized that the evolution of thickened and lignified cell walls was necessary to prevent the collapse of xylem conduits by negative water pressure. This common assumption has not been tested in a quantitative manner. Here we present data showing that conduit wall reinforcement corresponds closely with the xylem pressure range plants experience in nature. Our analysis considered the weakening effect of pits on wall strength. The need to prevent conduit collapse is an important requirement for xylem structure, but there are other requirements as well. Extensive cavitation must be prevented and hydraulic conductivity should be maximized. Angiosperms and gymnosperms differ in how they achieve an optimal compromise between these conflicting tasks. Due to the role of tracheids in providing both transport and structural support, safety margins from conduit collapse were much higher in conifer stems than in angiosperm stems and roots.

MODELING PLANT BIOMECHANICS

KEYNOTE

Structural Modeling in Plant Biomechanics

Bruno Moulia
UEPF-INRA, F-86600 Lusignan, France

Abstract: Modeling is a central tool in structural mechanics, and therefore models have been used in plant biomechanics. The major interest of a mechanical model is to elicit the change in scale from the behavior of a material (characterized by its empirical constitutive law) to the behavior of a structure. Mechanical models applied to plants can span many organizational levels: cell wall models, cell models, tissue models, whole plant model and even plant population models. However, plants are able to perform processes that are lacking in most human built passive structures: they grow by auto-straining and material adjunction, and they sense their mechanical state (mecano- and graviperception), and react to it (thigmomorphogenesis, gravitropism).
Specific biomechanical modeling has thus to be developed to take into account growth and biomechanical regulations. Their peculiarities are presented. Moreover, the introduction of biomechanical modules within more general plant structure-function models is discussed.

SiGRAT: a biomechanical model to Simulate Growth and Reorientation of Axes in Tree

Catherine Coutand [1], Jean-Denis Mathias [2], Jean-François Destrebecq [2], M. Fournier [3] and G. Jeronimidis [4]

[1]Piaf, INRA, Clermont-Ferrand, France
[2]Lermes, University Blaise Pascal, Clermont-Ferrand, France
[3]Umr ECOFOR, Kourou, France
[4]Centre for Biomimetics, Dept. of Engineering, University of Reading, Reading, UK

Abstract: SiGRAT is a biomechanical model to simulate reorientation process and to predict the location of the sectors of tension wood in a hardwood axis through time. It is a mechanical model linked to a biological regulation hypothesis for the formation of tension wood. The mechanical problem is solved at the cross section scale and uses beam theory. But, as radially growing structures are loaded by continuously changing forces during growth, a differential expression using Eulerian formalism is required Heterogeneities of wood are explicitly taken into account by working in the composite structure field. Eccentricity of radial growth is also taken into account. The mechanical problem was first solved in the frame of linear elasticity theory and then in the frame of linear visco-elasticity theory.
Simulations of the righting up process of tilted young polar were compared to experimental data. As the regulation of the formation of tension wood in trees is not well known yet, simulations using different regulation hypotheses were compared.

Respective Effect of Variations in Maturation Strain, Modulus of Elasticity and Radial Growth on the Restoration of Verticality in Various Tree Species

Joseph Gril [1], Tancrède Alméras [1] and Marie-Françoise Prévost [2]

[1]Laboratory of Mechanics and Civil Engineering, University Montpellier 2, CC48, Place E. Bataillon, 34095 Montpellier, France
[2]Institute for Research and Development (IRD), Cayenne, French Guyana

Abstract: Reaction wood production in trees was analysed from a biomechanical viewpoint. On 14 angiosperms and 3 gymnosperm trees in a stage of active re-orientation, the longitudinal growth strain (α_L), distance to pith and MOE (modulus of elasticity) were measured at 8 peripheral positions. Assuming regular and homogeneous wood production in each angular sector, we characterized the biomechanical efficiency (BE) of reaction wood by the theoretical curvature change exerted by a given proportion of most recently formed wood. The effect of each isolated factor and interactions between factors were obtained by replacing data by their normal wood value. In angiosperms, α_L alone explained 60% to 95% of BE, depending on the tree, while eccentricity and MOE asymmetry contributed mainly though their interaction with α_L. By contrast, the gymnosperm strategy, where compression wood MOE is lower than in normal wood so that MOE asymmetry competes with other factors, is not as efficient from a biomechanical viewpoint.

Why are big trees from high-density hardwoods more prone to end splitting?

Delphine Jullien, Caroline Loup and Joseph Gril

Laboratory of Mechanics and Civil Engineering, University Montpellier 2, CC048, Place Eugène Bataillon, 34095 Montpellier cedex 5, France

Abstract: Log-end cracks consecutive to tree felling and crosscutting, are a dramatic expression of growth stresses, used by trees to improve their stability and to re-orient growth. We aim at producing a rational explanation of this phenomenon by developing a predictive model of the cracking pattern at log-ends in relation to the growth stresses pre-existing in the standing tree. Crack propagation was simulated numerically based on the Griffith criterion: $G > G_c$, where G is the elastic energy release rate and G_c the material toughness, and illustrated using data for Beech. In addition to explaining some general trends such as the aggravating effect of log size, the drastic influence of tension wood, and the low crack-susceptibility of softwoods, the model predicts a negative effect of wood density on the cracking risk, which ought to be verified through systematic field work in tropical forests where the widest range of species density can be observed.

The influence of shape, size, and embedment depth on the uprooting resistance of bulbs

Slobodan B Mickovski, Roland A Ennos

School of Biological Sciences, University of Manchester, 3.614 Stopford Building, Oxford Road, Manchester M13 9PT, U.K.

Abstract: The anchorage mechanics of bulbs has never before been studied, even though common sense suggests that bulbs could help prevent plants being uprooted by grazing animals or during gardening practice. Uprooting resistance might be influenced by several factors. To explore these possibilities, model bulbs of different sizes and shapes were embedded at different depths in an agricultural soil or sand and pulled out using a universal testing machine. The failure mechanism in each soil medium is described, as is the effect of the different factors on uprooting resistance. Conical models resisted uprooting most strongly followed by bulb-shaped ones and cylinders. Uprooting resistance increased with both model size and depth, but more strongly with bulb size in agricultural soil and more strongly with depth in sand. The results are compared with the behavior of real bulb plants - garlic and onion - grown in a greenhouse.

Simulation of the fractionation of the wheat endosperm

Frederic Mabille [1], Lothar Brendel [1], Farang Radjai [2]

[1]UTCA-INRA 2 Place Viala, 34060 Montpellier; France
[2]LMGC Place E Bataillon, 34000 Montpellier; France

Abstract: The INRA-UTCA and the LMGC have developed an original method to describe the fractionation of the wheat grain. The program's purpose is to simulate the quasi-static solicitation of the heterogeneous system "endosperm". The latter is modeled in the simplified (two-dimensional) way of consisting of only starch grains and the embedding protein matrix which does not need to fill the interstice between the starch grains perfectly, and therefore, the third phase "void" (i.e. air) is present. Additionally, the interface between grains and matrix is assigned its own properties. The modeling in terms of elastic, damageable materials is explained in detail and will be illustrated by a parametric approach of the endosperm mechanical properties such as matrix density, starch / protein rigidity ratio, large / small starch granules ratio etc.

Determination of the parameters and validation of a tangential contact force model using a rheometer device

M. Van Zeebroeck, E. Dintwa, E. Tijskens, J. De Baerdemaeker and H. Ramon

Laboratory for Agromachinery and –Processing, Catholic University of Leuven
Kasteelpark Arenberg 30, 3001 Leuven, Belgium

Abstract: A computer model based on Discrete Element Modelling (DEM) can simulate damage to fruit during handling. A contact force model is one of the basic ingredients of a DEM. A rheometer device was used to measure and to validate a tangential contact force model during oblique impacts of apples. The Mindlin and Deresiewicz model for torsion was used to simulate quasi-static torsion and a viscous term was added in order to simulate dynamic torsion. The measured parameters were the dynamic friction coefficient, the shear modulus and the viscosity of the apples. In order to validate the model also the angular deformation, the torque, the contact surface and the normal force were measured. The model could describe on a satisfactory way the phenomena of slip-stick at the contact surface of the apples. By adding the viscous term, the model could be improved.

Poster #40: Centric Diatom Valve Shape Enables these Cells to Contain Turgor and Free Daughter Cells During Reproduction

Guy L. Steucek

Department of Biology, Millersville University, Millersville, PA 1755l, USA

Abstract: Diatoms are single celled algae. Centric diatoms are bipartite and have a drum shape. Each half of the wall is called a theca; the epitheca overlaps the hypotheca. A diatom valve is comprised of a theca and girdle bands. Why do centric diatoms have a drum shape? The cell walls of diatoms are made of silica. Once deposited, siliceous walls cannot be remodeled. Hence, daughter cells can only escape from a mother cell wall if the valves of the mother cell separate. How are the valves held together under a turgor load? Finite element models of diatom valves were made using ANSYS. Turgor distends the valves such that they clasp in the region of the girdle band. Also, once cells reproduce, and turgor is relaxed, the valves are free to separate and release daughter cells. The role of the girdle bands in this mechanical mechanism will be discussed.

Poster #41: Biomechanics of the Pollen Tube: A Finite Element Model

Jean-Francois Bolduc [1,2], Laurent Lewis [2], Anja Geitmann [1]

[1]Institut de Recherche en Biologie Végétale, Université de Montréal, 4101, rue, Sherbrooke est, Montréal, Québec H1X 2B2, Canada
[2]Physics Department, Université de Montréal, 2900, boul. Édouard-Montpetit Montréal, Québec H3T 1J4, Canada

Abstract: Pollen tubes are plant cells that exhibit extremely rapid tip growth with the purpose of delivering the male gametes to the egg apparatus of a receptive flower. On their way to the ovule, pollen tubes have to penetrate the transmitting tissue and to resist lateral deformation forces to allow for the passage of the gametes.
We investigate the mechanical properties of the pollen tube experimentally with the help of micro-indentation techniques. The results are compared to a computer model created using finite element analysis (FEA). Our objective is to characterize and quantify the influence of different structural molecules present in the cell wall and the cytoplasm on the pollen tube's resistance to deformation. The FEA model represents a simulation of the micro-indentation experiment. Starting from a simple model for the pollen tube assuming a solid homogenous elastic body we attempt to refine it by adding structural elements such as the cell wall, microtubules and actin filaments.

Poster #42: Influence of architectural and mechanical properties of root systems on their anchorage

Lionel Dupuy [1, 2], Patrick Lac [1], Alexia Stokes [1] and Thierry Fourcaud [1]

[1]Laboratoire de Rhéologie des Bois de Bordeaux, Domaine de l'Hermitage
69 Route d'Arcachon, 33610 CESTAS Gazinet, FRANCE
[2]Institut pour le Développement Forestier, 23 avenue Bosquet, 75007 Paris, FRANCE

Abstract: Different finite element models have been developed to understand and simulate the process of windthrow. At the scale of a single root, the modeling took into account the three possible localized failures i.e. in the soil, the root and at the interface. The experimental design was used to analyze the influence of parameters defining the geometry. It was possible to elucidate the influence of architectural parameters including branch angle and number of lateral roots, but also mechanical parameters such as cohesion of the soil or friction coefficient. For a complete root system, simplified FEM models beam element for root axes and bricks for the soil was used. A similar parametric study was carried out to find out the parameters affecting most the tree stability. It could be shown how the loads on the tree crown are transferred in roots and in the soil after mechanical solicitation.

Poster #43: A three-dimensional FE analysis of the sunflower (*Helianthus annuus* L.) fruit under impact. A useful approach for the understanding and improvement of its hullability

L. F. Hernández [1,3], L.I. Lindström [1] and P. M. Bellés [2,3]

[1] Plant Morphology Laboratory, Department of Agronomy, Universidad Nacional del Sur, Bahía Blanca, 8000, Argentina
[2]IMA-Department of Engineering, Universidad Nacional del Sur, Bahía Blanca, 8000, Argentina
[3]Comisión de Investigaciones Científicas (CIC), La Plata, 1900, Argentina

Abstract: For sunflower fruits, hullability (H) defines how easily the hull (pericarp) can break and set apart from the seed after impact during oil extraction. H mainly depends on the fruit structural properties.
A 3-D finite element approach, using mechanical event simulation with a non-linear FE commercial code, was used to analyze the pattern of stresses produced in the hull after fruit impact. The fruit 3-D model was designed in terms of strain incompatibilities between longitudinal strands of parenchyma and sclerenchyma.
The points of contact between those tissues and also areas with longitudinal parenchymatous rays were more likely to mechanically fail. The simulated patterns of failure closely agree with those observed after subjecting fruits to compressive loads on an Instron Universal Testing Machine.
This FE model can be used to define, under different hull structural parameters, the distribution and magnitude of stresses generated during the process that leads to the hull breakage and can be considered the first step of a protocol leading to a genetic improvement of H.

Poster #44: Determination of parameters of a normal contact force model using a pendulum device

M. Van Zeebroeck, E. Tijskens, V. Deli, J. De Baerdemaeker and H. Ramon

Laboratory for Agromachinery and -Processing, Catholic University of Leuven
Kasteelpark Arenberg 30,
B-3001 Leuven, Belgium

Abstract: A computer model, based on Discrete Element modeling (DEM), can simulate damage to fruit during handling. A contact force model is one of the basic ingredients of a DEM. A pendulum device was used to estimate the contact parameters (spring and damping parameter) of a normal contact force model. The contact force, displacement and displacement rate was measured between a metal impactor and the sample, i.e. apples, tomatoes and potatoes. The parameters of the Kuwabara-Kono model were estimated by minimizing an error function between the experimental data and prediction based on the contact force model. A rubber ball was used to validate the measuring procedure. The Kuwabara-Kono model can model non-damaging normal impacts between the samples in a satisfactory way, although the parameters are dependent on the radii of curvature and impact velocity.

AUTHOR INDEX