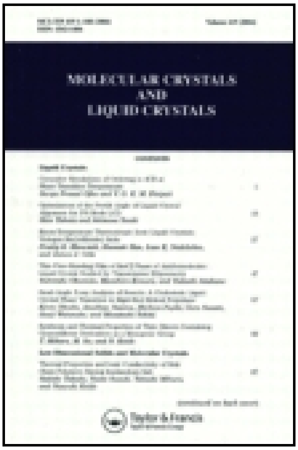


Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl19

Inventory of World Fibres and Involvement of FAO in Fibre Research

Ryszard Kozlowski [a] & Maria Mackiewicz-Talarczyk [a]

[a] Institute of Natural Fibres, Ul. Wojska Polskiego 71b, 60-630, Poznan, Poland

Version of record first published: 24 Sep 2006

Mol. Cryst. and Liq. Cryst., 2000, Vol. 353, pp. 133-148
Reprints available directly from the publisher
Photocopying permitted by license only

Inventory of World Fibres and Involvement of FAO in Fibre Research

RYSZARD KOZLOWSKI and MARIA MACKIEWICZ-TALARCZYK

Institute of Natural Fibres, Ul. Wojska Polskiego 71b, 60–630 Poznan, Poland

Linen and hemp fabrics are among the oldest in the world; their history goes back to ca 8000 BC. In Central Europe, among the most notable discoveries of Polish archaeologists were linen textiles and fibres dating from 4000 BC, i.e. from the period known in archaeology as the Neolithic Age[1]. The fibres were used not only for textile applications but also as a reinforcement of ceramics as early as ca 6500 BC. Most of plants growing on earth are typical biotechnology products made of lignocellulosic natural polymer. They could be classified into three groups: annual, biannual and perennial plants. The lignocellulosic material of perennial plant origin is wood. In addition to wood, other lignocellulosic materials accompanied mankind for centuries, being used for constructing houses, making means of transport, furnishing, textiles. Nowadays, we apply not only natural fibres, but from the twentieth century man-made fibres as well. The world inventory of natural and man-made fibres in the aspect of their classification, potential and statistical data are presented. The involvement of the FAO Network in fibre research as well as the FAO programs are described.

Keywords: lignocellulosic fibres; bast fibres; fibre inventory; natural polymers; biocomposites; FAO involvement

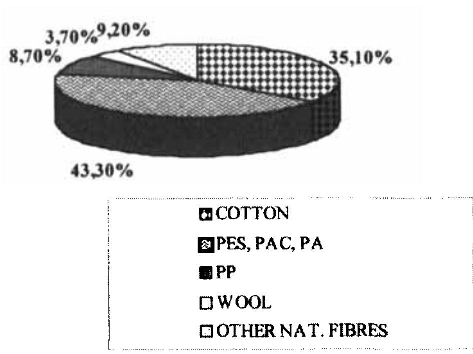
INTRODUCTION

An increase is observed in the awareness of the need for the production of more fibres and materials for rapidly growing world population. At present the rate of population growth is such that 1 billion people are added every eleven years. It was forecast that the world population will increase from 3.7 in 1980 to 11 billion in 2050.

The general classification of fibres includes natural and chemical (man-made) fibres. The natural fibres are divided into animal, vegetable and mineral ones.

WORLD INVENTORY OF FIBRES

The present world inventory of fibres is estimated at 54.2 million tons (100 %) and the share of major classes of fibres is given in Fig. 1.



TOTAL - 54.2 MILLION TONS - 100%

FIGURE 1. Contribution of major groups of fibres to the world fibre inventory

The inventory of major potential world fibrous raw materials from agricultural crops could be estimated at ca 2,535.400 thousands tons and it is presented in Table I.

The natural fibre inventory, including wood resources and natural cellulosic fibres, consists of following raw materials: wood, straw (wheat, rice, oats, barley, rye, oil flax, grass), stalks (corn, sorghum, cotton), sugarcane, bagasse, reeds, bamboo, cotton staple, core (jute, kenaf, hemp), papyrus, bast (jute, kenaf, hemp), cotton linters, esparto and sabai grass, leaves (sisal, abaca, henequen, ramie - called hard fibres), other hard fibres: coir, caroa, cabuya, letona, maguey, banana, doum, aloe etc.

TABLE I Estimated world-wide tonnage of fibrous raw materials from agricultural crops in thousands tons

Crop	Plant Component	Availability
Cereals		
barley	straw	218.500
oats	straw	50.800
rice	straw	465.200
rye	straw	41.900
wheat	straw	739.700
Corn	stalks	727.300
Cotton	lint	18.000
	linters	2.300
	stalks	35.900
	mote	900
Oil flax	straw	2.000
Seed grass	straw	3.000
Sorghum	stalks	104.700
Sugarcane	bagasse	100.200
Bast plants	straw	25.000*
Total		**2.535.400**

Source [2] *estimated by INF

Green fibres such as flax, hemp, ramie, jute, sisal, coir, abaca, henequen, curaua, etc. are produced by nature in lavish abundance. Giant chemical companies have recognised this fact recently and turned to „agrobusiness".

Biomass including these green fibres can be produced every day and everywhere causing neither pollution nor disturbance of CO_2 balance around our planet. In textiles the share of clean, biodegradable cellulosic fibres in the world fibre production makes about 50% and currently is decreasing due to fierce competition between natural and synthetic textile polymers. The most known natural fibres and their potential production are listed in Table II. The types of lignocellulosic fibres are described in Table III. The main consumer of fibres is textile industry; the consumption of fibres in major industrialised countries is presented in Table IV. Approximate content of main chemical compounds (in %) is shown in Table V.

TABLE II Comparison of the world production of major natural fibres

Natural Fibre*	Production in 1998 (in million tons)
Cotton	19,700,000
Flax fibre and tow	641,155
Hemp fibre and tow	69,567
Jute and jute-like fibres	3,700,700
Sisal	332,454
Total, hard fibres	342,800
Primary production of world fibre crops	24,061,480

Source: [3] *Natural fibre share in the total production of fibres was ca 46%

TABLE III Types of lignocellulosic fibres

Type of Fibre						
Wood	Seed	Bast	Leaf	Cane	Straw	Grass
Coniferous	Cotton	Flax	Abaca	Bagasse	Corn	Esparto
Deciduous	Kapok	Hemp	(Manila)	Bamboo	Oat	Elephant
		Jute	Date-palm		Linseed	grass
		Kenaf	Henequen		Rape	
		Ramie	Pineapple		Rice	
		Reed	Sisal		Rye	
		Roselle			Wheat	

Source: [4]

TABLE IV Estimated consumption of fibres in major industrialised areas of the world

Application	U.S.A.	Europe	Japan	Korea
Apparel	24.5	47	31	70
Household textile	45.7	35	57	30
Industrial use	29.8	18	12	30
Total:	100.0	100.0	100.0	100.0

TABLE V Approximate content of main chemical compounds in fibre raw materials

	Approximate Content of Main Chemical Compounds [%]		
Material	Cellulose	Lignin	Pentosans
Coniferous wood	40-45	26-34	7-14
Deciduous wood	38-49	23-30	19-26
Cotton	90-95	-	-
Kapok	65-70	5-15	2-10
Flax fibres	64-71	2-15	2-5
Flax shives	36-47	24-30	21-30
Hemp fibres	60-67	3-14	5-10
Hemp shives	40-52	22-30	17-25
Kenaf	31-39	15-19	22-23
Jute	55-65	10-15	15-20
Ramie	60-70	1-10	5-12
Abaca (Manila)	55-65	7-10	16-19
Sisal	63	7.5	22
Date-palm	58	15.3	20
Pineapple	69.5	7.5	21.8
Bagasse	32-44	19-24	27-32
Esparto	33-38	17-19	27-32
Elephant grass (Miscantus)	35-40	10-15	10-20
Bamboo	33-45	20-25	30
Reed Phragmites communis	44.75	22.8	20
Grain Straws	27-37	12-21	20-34

Source: [5]

Although at present a fierce competition between natural and chemical fibres is observed, the recommended solution is, however, to find and introduce harmonious coexistence. The challenges facing natural and man-made fibres in their competition are described in Table VI.

TABLE VI Juxtaposition of advantages offered by natural and man-made fibres of importance to their competition

Naturals	Synthetics
Biodegradability	Lower price?
Comfort and health-providing fibres	Easy care products
Green production using CO_2 and sun energy	Constant fibre qualities
Clean processing	
Economic development of rural areas, retardation of the exodus to slums around world metropolis	Special properties in the case of special fibres (carbon, aramide, nano-fibres and other)

Source: [6]

FUNCTIONAL FIBRES

Coexistence and competition mentioned above resulted in creation of new more sophisticated man-made fibres. The latter include such fibres which have new unconventional characteristics and are called „functional fibres". They are high technology products and are distinguished by high strength, high elasticity and high heat resistance. Most frequently encountered literature reports concern aromatic polyamides (aramide), aromatic polyesters (polyarylate), ultra-high molecular weight polyethylene, phenol fibres, carbon fibres, silicon carbide fibres, alumina fibres, ceramic fibres and whiskers, etc.

Taking into consideration their unique properties functional fibres could be classified into following categories: high performance mechanical and morphological characteristics, electrical – electronic, optical, acoustic – vibration, magnetic, thermal, separation- adsorption, hydrophilic -
lyophilic, adhesion, physiology related[7]. Products made of fibres are characterised by the following properties: electric antistatic, electric conductive, flame retardant and flame proof, ultraviolet cutting fibres (ultraviolet shielding fibres), insect-free and mite-repellent fibres, antibacterial and odour-preventing fibres, deodorising fibres, shin-gosen (finely textured fibre)[8].

The role and importance of chemical fibres and those obtained from natural polymers is increasing. The world is looking forward to new chemical fibres and their new applications as well as to the natural fibres obtained by using biotechnological methods (e.g. biosilk, biocellulose).

Man-made fibres are produced in stationary factories and fibres represent high degree of homogeneity. The quality is constant and thanks to robotisation and huge amount of produced fibres, the prices are rather law, except for special fibres.

ADVANTAGES AND DRAWBACKS OF NATURAL AND MAN-MADE FIBRES

The natural fibres are produced around the globe in different climatic and soil conditions, therefore it is difficult to obtain homogeneous fibres and this fact creates problems in their processing. Production of natural fibres has positive impact on the environment and reduction in pollution. They are biodegradable, provide excellent comfort, when used in for apparel and household purposes. Results of the latest research on flax fibre and fabrics carried out by Nara Women University, Department of Environmental Health, Japan, in collaboration with the Institute of Natural Fibres, have explained why linen fabrics are so healthy and comfortable, when used as bedding linen. It was discovered in the above studies that the level of immunoglobulin A in the human body is highest, when body is in contact with linen bedding and this results in reduction in body temperature, thus ensuring the best rest and relaxation.

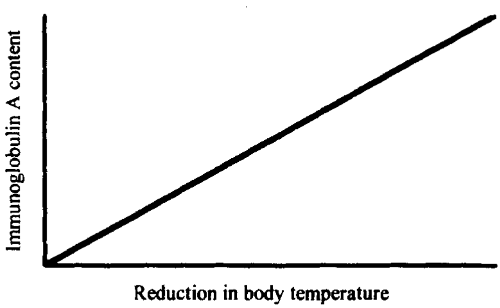


FIGURE 2 The effect of immunoglobulin A level on body temperature

Natural fibres have been well-known for centuries as raw materials for apparels. From the point of view of comfort, when natural fibres are used for apparel application, of importance are such their properties like heat of wetting from zero regain, water absorption, half time of discharging, tenacity of fibres, permeability and some other qualities (see Figs. 3-4).

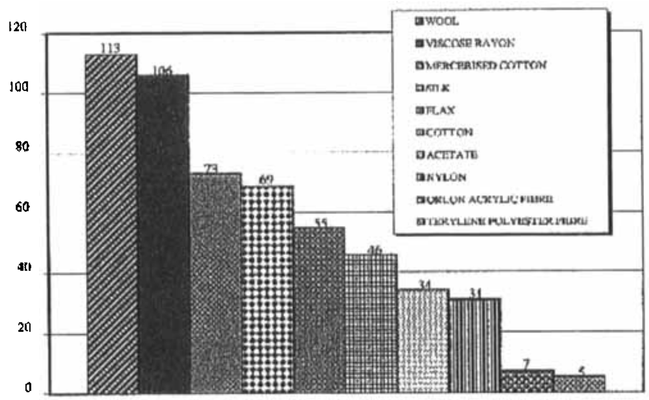


FIGURE 3 Heat of wetting from zero regain for a number of natural and man-made fibres

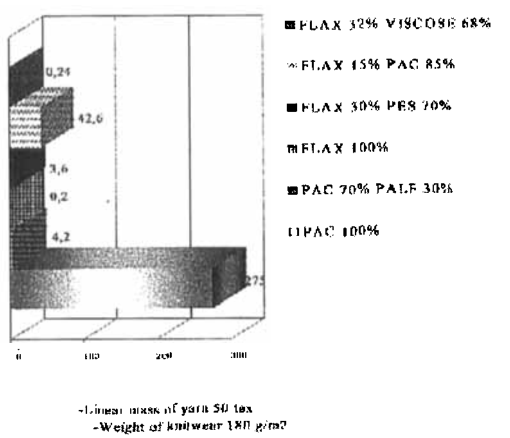


FIGURE 4. Water absorption on some fibres as determined by drop method

On the other hand, the already mentioned lack of homogeneity and differences in fineness of some green fibres complicate multioperational processing technique in spinning and increases manufacturing costs.

Harvesting and primary processing of raw materials used for the manufacture of natural fibres are still not efficient enough and this results in creation of many problems. Promising new trends in the development of natural fibre processing, such as enzymatic, plasma and corona treatments, will have a strong impact on the production of diversified and cheaper products of high quality in the near future.

COMPOSITES CONTAINING NATURAL VEGETABLE FIBRES

The traditional application of man-made and natural fibres is, of course, textile and apparel sector of consumer goods industry, but nowadays it is observed an increasing importance of non-traditional applications of lignocellulosic biocomposites to new, emerging and promising areas of usage, such as e.g. geotextiles, chemotextiles, grass mats (reinforcement of slopes and embankments), particle-boards, filters, pulp, biocomposites applied to furniture and transport industries, etc. It is possible to make completely new types of composite materials based on fibres by combining different resources, e.g. lignocellulosic or agro-based fibres with such materials as glass, metal, plastics and synthetics to produce new classes of composite materials. Data on strength and some other properties of different fibres used in composites are shown in Table VII.

TABLE VII Strength and some other properties of different fibres

Fibre	Density [g/m³]	Diameter [μm]	Elongation at break [%]	Module E_m [%]	Tenacity [G/tex]	Moisture content [%]	Melting point [°C]
Cotton	1.2	11-22/35	7	500	1.3	7	220
Flax	1.3	5-40 (14)	3	1840	0.8	7	Decomposition
Jute	1.5	8-30	2	1750	0.5	12	Decomposition
Sisal	1.45	8-40	2	2500	0.5	8	Decomposition

Fibre	Density	Diameter	Elongation at break	Module B_m	Tenacity	Moisture content	Melting point
Glass	2.25	5-24	2-5	3000	I	I	800
PA 6		>14	30-50	250	6-7	3-5	225
PET	1.2	>12	12-55	1000	2-9	0.4	250
Carbon	1.9	5-7	2	10 000	10	1	
Kevlar	1.44	>12	2-4	4500-8000		4	500
at room temperature and relative humidity of 65%							

Source: [10]

A variety of biocomposites can be obtained by using lignocellulosics and polymers as raw materials. A review of them is presented in Table VIII.

TABLE VIII Biocomposites based on lignocellulosics and polymers as raw materials

Type of Biocomposite	Raw Materials	
	Lignocellulosic and other	Polymer
Structural composites:		
• Glulam beams	wood boards, bamboo, bast fibres	
• Laminated veneer lumber (LVL)	wood veneer, bamboo,	Resins based on: urea, melamine, phenol, resorcinol, isocyanate, vinyl polyacetate
• Parallel strand lumber PSL		
• Oriented strand lumber OSL		
Panels:		
• Plywood	wood veneer, bamboo	
• COM-PLY®	wood veneer and lignocellulosic particles,	
• Particleboards	wood particles, flakes, saw dust;	
	shives of flax, hemp, kenaf, jute, roselle fibres, bagasse, reed, straw, vetiver roots, etc.	Resins based on: urea, melamine, phenol, resorcinol, isocyanates, vinyl acetate. Proteins: casein, soybeans
• Medium density fibreboards MDF	lignocellulosic fibres	Other: lignin and enzyme decomposing lignin
• Oriented strand boards OSB	lignocellulosic strands	
• Insulating (thermal, acoustic, radiation)	vegetable stalks, lignocellulosic particles, wood veneer, paper	

Type of Biocomposite	Raw Materials	
	Lignocellulosic and Other	Polymer
• Lignocellulosic-mineral	wood paper pulp, mineral particles e.g. vermiculite, microspheres, mineral wool, asbestos, glass fibres	Polycondensated product of urea borate and phosphate with silicate, organic resins, inorganic materials like cement, gypsum, lime, magnesium silicate,
• Special functional (water-, fire-, and bio-resistant)	+fire retardants, fungicides, etc.	
Polymers filled or reinforced with lignocellulosics:		
• Thermosetting polymers	lignocellulosic fibres including waste paper, saw dust, flour	urea, phenol, isocyanates, resorcinol, epoxy resins, melamine
• Thermoplastic polymers	wood saw dust, flour, short fibres, waste paper	PP, PE, PVC, PS, PA, LDPE
• Natural polymers	lignocellulosic fibres including waste paper, saw dust, flour	natural rubber, casein, modified starch
Textiles:		
• Lignocellulosic and man-made fibre blends	cotton, flax, hemp, kenaf, roselle, ramie, jute, kapok, coir, pineapple, abaca, sisal, henequen	wool, silk, polyesters, polyamides, polyaramide, acrylic, modacrylic, olefin, lycra®, man-made cellulosic fibres: viscose, rayon
• Textiles upgraded with polymers	as above	starch, gelatin, urea, melamine, resins (sizing), urea, melamine, resins, condensation products of formaldehyde with urea, thiourea, guanidine, melamine, e.g. DMU, DMEU, DMDHEU (abrasion), reactive dyestuffs: triazine or pyrimidine or sulphonated vinyl derivatives
• Textiles coated with polymers	as above	PVC, polyurethane
• Non-woven textiles including geotextiles	as above + wood wool, straw, bentonite, active carbon, vermiculite, silica gel	soybean oil, rape oil
• Absorption chemotextiles including filters and sorbents	as above	urea, phenol, resorcinol, isocyanates, epoxy resins, melamine
Packagings	wood, wood wool, bamboo, paper including wastes	starch, sillicates, urea resins, polyvinyl alcohol, lignin

Source: [5]

Composites containing natural vegetable fibres are usually environmentally friendly materials at all stages of their life, i.e. production, service and disposal. Vegetable materials used for their manufacture are characterised by annual renewability and relatively low energy inputs per unit of product, which causes that the price of composites reinforced with natural fibres is twice as low as that of polymers reinforced with glass fibre. Their advantages include commonly known methods of production; properties comparable with materials reinforced with glass fibre; better elasticity of polymer composites reinforced with natural fibres, especially when modified with crushed fibres, embroiled and 3-dimensional weaved fibres. They make acoustic insulation and absorb vibrations and large amounts of energy at the moment of destruction. Polymer composites reinforced with natural fibres are characterised by lower density compared to those reinforced with glass fibre;

Natural vegetable fibres can be also applied to reinforcing natural polymers such as starch, lignin, hemicellulose and India rubber and the products obtained are 100% biodegradable. When burned, natural fibre-containing polymer composites produce less CO_2 and less CO and other toxic gases.

In addition to the above advantages, the application of vegetable fibres to the manufacture of composites has, of course, also drawbacks. The latter include the dependence of quality and yield on natural conditions and lack of homogeneity in natural fibrous raw materials. Preparation of natural fibres is labour and time-consuming; properties and dimension changes of polymer composites reinforced with natural fibres are dependent on their inherent physical properties. For cultivation of large amounts of natural fibre raw materials vast areas are required and low density of natural vegetable fibres can be disadvantageous at the stage of processing due to the necessity of applying pressure (otherwise the fibres tend to merge on the surface). We have to mention also weak bonding of natural fibres to polymers and insufficient level of knowledge which properties of fibres to be used in composites are the best and how to modify fibre properties to upgrade them.

Selected mechanical properties of composites based on different lignocellulosic fibres compared with those of polypropylene are presented in table IX.

TABLE IX Mechanical properties of composites based on different lignocellulosic fibres compared to polypropylene

Fibre	Tensile-MOR		Tensile-MOE		Flexural-MOR		Flexural-MOE	
	MPa	%	GPa	%	MPa	%	GPa	%
Wood	30.51	102.31	8.21	463.84	55.31	165.85	7.49	411.53
Bagasse	27.00	90.54	5.42	306.21	47.79	143.30	5.14	282.42
Coir	25.88	86.79	3.60	203.39	46.87	140.54	3.60	197.80
Curauá	48.07	161.20	7.14	403.39	77.56	232.56	6.06	332.97
Flax	36.06	120.93	6.09	344.07	58.37	175.02	5.77	317.03
Hemp	33.51	112.37	6.06	342.37	61.51	174.44	6.23	342.31
Jute-50	34.57	115.92	7.19	406.21	57.78	173.25	6.89	378.57
Jute-60	28.97	97.15	9.11	514.69	55.02	164.98	8.22	451.65
Ramie	43.24	145.00	5.39	304.52	70.15	210.34	5.08	279.12
Sisal	34.27	114.92	7.07	399.44	60.03	180.00	6.57	360.99
PP-recycl.	30.31	101.64	1.89	106.78	35.68	106.99	1.91	104.95
PP-virgin	29.82	100.00	1.77	100.00	33.35	100.00	1.82	100.00

Source: [11]

It is difficult to obtain good composites on the basis of PP matrix and bast fibres. For this reason bast fibres have to be modified before being used for the production of composite. They can be subjected to the following treatments: silane treatment, treatment with polymers containing functional groups, treatment with substances showing hydrophobic properties, producing fibres with modified cellulose chains by transgenic methods, treatment with urea, melamine and formaldehyde. The application area of such composites includes: glue-lam wood, plywood, particleboards, fibreboards, MDF; OSB; lignocellulosic-mineral particleboards and composites, special functional products (water-, fire-, bio-resistant), insulating materials (thermal, acoustic, radiation-absorbing), thermosetting polymer composites; thermoplastic polymer composites; natural polymer composites (based on starch, polyhydroxybutyric and polylactic acid), non-wovens, geotextiles, adsorption chemotextiles (containing bentonite, active carbon, silica gel, linoleum, etc.). A promising direction of the use of natural cellulosic fibres is their application to automotive industry, where they are used as different types of fillings; as reinforcing fibre which in some cases replaces glass fibre; as a component of hybrid composites [12]. It is worth to add that composites made of natural fibres and natural polymers are biodegradable.

Due to the quickly expanding world population, it is obvious that the demand for wood and pulp will increase accordingly. Pulp production has to grow in the next 10 years from 270 to 480 million tons, according to the forecast based on a correlation between population growth and the increase in world demand for pulp.

At the same time the demand for fibre supplies supporting the production of pulp will grow as well. Unfortunately, it involves a reduction in forest area which, according to the forecast, will decrease from 3.44 billion ha to 2.42 billion ha in the year 2050. Facing such a deforestation it is of importance to pay more attention to alternative raw materials for pulp production which include wood and non-wood fibres, e.g. non-wood plant fibres like grass, bast, leaf and fruit fibres; non-plant fibres - animal, mineral, inorganic man-made fibres, organic man-made fibres, etc.

FAO AND FIBRE RESEARCH

Authors represent the Coordination Centre (at INF) of the FAO European Cooperative Research Network on Flax and Other Bast Plants, within FAO ESCORENA system (European System of Cooperative Research Networks in Agriculture). At present the Network brings together 325 experts from 45 countries from the fields of research, economics, marketing and industry. It also includes members from non-European countries such as Argentina, Australia, Brazil, Canada, Chile, China, Egypt, India, Mexico, Pakistan, South Africa, Thailand, and USA. The FAO Network promotes research cooperation, exchange of information, transfer of know-how and methodology advances

The Network's scope of activities includes facilitating collaboration and sharing of knowledge among scientists and experts from industry and trade, organising meetings and world-wide circulation of proceedings, performing analyses of linen world market and its future trends, collecting statistical data on flax, offering consulting services and experts data base, focusing on new textile and non-textile applications of flax and hemp and by-products, conducting cooperative research - the activity of WG/4 Quality. and WG/1 on Genetic Resources. The Network has the following Working Groups (WG): WG/1 Breeding and Plant Genetic Resources; WG/2 Extraction and Processing; WG/3 Economics and Marketing; WG/4 Quality; WG/5 Non-Textile Applications of Flax; WG/6 Biology and Biotechnology. During 10 years of its activities, the Network has organised: 4 European Regional Workshops, 7 international conferences, 11 meetings (workshops) of Working Groups, 8 meetings of Coordinating Board and 4 Meetings of Panel of Experts. The Network's Coordination Centre publishes semi-annually Information Bulletin *EUROFLAX Newsletter* –11 issues since 1994, as well as Proceedings of the Network's Meetings and Conferences which are available at the Institute of Natural Fibres (INF), Poznan, Poland.

Natural fibres and natural lignocellulosic raw materials are produced mostly in rural areas and sometimes they are the only source of income for people living there. According to FAO statistics and INF's data, their production frequently does not contribute efficiently enough to the economic development of the rural areas. FAO Network on Flax and Other Bast Plants is involved in the development of the rural areas, in spreading scientific information to increase productivity and processing level. The Network is involved in plant genetic resources protection and development as well. Coordination Centre cooperates actively on the basis of bilateral agreement with the world largest gene bank at the N.I. Vavilov Research Institute of Plant Industry (VIR) in St. Petersburg, Russia.

FAO in Rome is interested in the promotion of research cooperation and realisation of FAO Programs and Initiatives for Technical Cooperation and Partnership. There are fibre-oriented groups within FAO, namely Intergovernmental Group on Hard Fibres and Intergovernmental Group on Jute, Kenaf and Allied Fibres. The Groups conduct certain research on the above

mentioned fibres, organise meetings, consultations and discussions attended by the members, provide relevant statistical data.

FAO promotes transfer of know-how and advances in methodology with clear sustainable development and socio-economic implications under the umbrella of the ESCORENA System.

References

[1] L. Czerniak, R. Kirkowski, R. Kozlowski, and M. Zimniewska, in *Proc. of the Symposium on Hemp, Flax and Other Bast Fibrous Plant Production, Technology and Ecology,* edited by R. Kozlowski (Institute of Natural Fibres, Poznan, 1998), p.18.

[2] G. A. White and Ch.G. Cook, in *Paper and Composites from Agro-Based Resources,* edited by R. M. Rowell, R. A. Young, and J. K. Rowell (Lewis Publishers, New York, London, Tokyo, 1997), Chap. 1, p. 10.

[3] FAOSTAT *Database Results* - http://apps.fao.org, *Current Statistics on Sisal, Jute, Kenaf, Abaca and Coir:* Document CCP: HF 98/3 – JU 98/3 of the FAO in Rome, December 1998.

[4] J.E. McIntyre, P.N. Daniels, *Textile Terms and Definitions,* 10th edition, (Textile Institute, Manchester, 1995).

[5] R. Kozlowski and M. Helwig, in *The Fourth International Conference on Frontiers of Polymers and Advanced Materials,* edited by P.N. Prasad et al. (Plenum Press, New York, 1998), p.679.

[6] R. Kozlowski and S. Manys, in *Proc. of the 79th World Conference of the Textile Institute,* (Heritage Printers, Coimbatore, India, 1999), p.29.

[7] T. Sakai, *A Full View of the Functional Fibre Market* (CMC, 1989), p. 9.

[8] Y. Washino, *Functional Fibres. Trends in Technology and Product Development in Japan* (Toray Research Center, Sonoyama, 1993).

[9] E. Pawula, *Natural Fibres-Wlokna Naturalne* (Instytut Wlokien Naturalnych, Poznan, 1995).

[10] S. Lee, R. M. Rael, *International Encyclopaedia of Composites* (VCH, New York, 1991).

[11] A. L. Leao and H. Tan, in *Proc.of the Symposium on Hemp, Flax and Other Bast Fibrous Plant Production, Technology and Ecology,* edited by R. Kozlowski (Institute of Natural Fibres, Poznan, 1998), p.8.

[12] R. Kozlowski, J. Mankowski, A. Kubacki, in *Proc. of the International Conference on Advanced Composites, icac 98,* edited by Y. Gowayed and F. Abel-Hady, (Hurghada, Egypt, 1998), p. 597.