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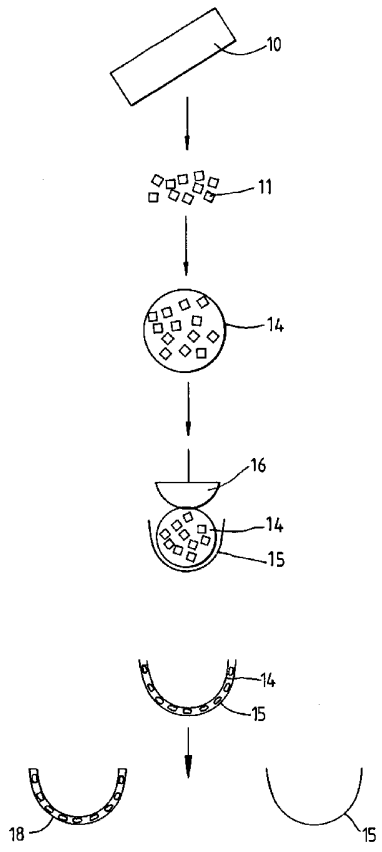
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(54) Title: IMPROVEMENTS IN OR RELATING TO BIODEGRADABLE COMPOSITES



(57) Abstract: A method of producing a biodegradable composite from plant material comprising the steps of converting the plant material into smaller pieces and mixing the plant material with a binding agent to form a substantially non-liquid or liquid composite, and articles produced therefrom.

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IMPROVEMENTS IN OR RELATING TO BIODEGRADABLE COMPOSITES

This invention is concerned with improvements in or relating to biodegradable composites produced from plant material.

This invention is especially, but not exclusively, concerned with biodegradable composites that are suitable for use in the production of packaging.

According to one aspect, the present invention provides a method of producing a biodegradable composite from plant material comprising the steps of converting the plant material into smaller pieces and mixing the plant material with a binding agent to form a substantially non-liquid composite.

According to another aspect, the present invention provides a method of producing an article from a biodegradable composite comprising the steps of converting the plant material into smaller pieces, mixing the plant material with a binding agent to form a substantially non-liquid composite and moulding the composite into an article.

Preferably the plant material is converted into smaller pieces before it is mixed with the binding agent.

The plant material may be converted into smaller pieces by grinding, crushing, cutting, milling, rolling, refining and/or shredding the plant material.

Preferably the plant material is solid, and is not a liquid or paste.

Preferably the smaller pieces of plant material produced are not powder.

According to the British Pharmacopeia powder is defined as follows:

Coarse Powder: in which all the particles will pass through a sieve with a nominal mesh aperture of 1700μm and not more than 40.0% by weight will pass through a sieve with a nominal mesh aperture of 355μm.

Moderately Coarse Powder: in which all the particles will pass through a sieve with a nominal mesh aperture of 710μm and not more than 40.0% by weight will pass through a sieve with a nominal mesh aperture of 250μm.

Moderately Fine Powder: in which all the particles will pass through a sieve with a nominal mesh aperture of 355μm and not more than 40.0% by weight will pass through a sieve with a nominal mesh aperture of 180μm.

Fine Powder: in which all the particles will pass through a sieve with a nominal mesh aperture of 180μm and not more than 40.0% by weight will pass through a sieve with a nominal mesh aperture of 125μm.

Very Fine Powder: in which all the particles will pass through a sieve with a nominal mesh aperture of 125μm and not more than

40.0% by weight will pass through a sieve with a nominal mesh aperture of 45μm.

Micro Fine Powder: in which not less than 90% by weight of the particles will pass through a sieve with a nominal mesh aperture of 45μm.

Super Fine Powder: A powder of which not less than 90% by weight of the particles are less than 10μm in size.

Preferably, substantially no powdered plant material is used in any aspect of the invention. Preferably less than about 10% by weight of the plant material used is powder, more preferably less than about 5% by weight of the plant material used is powder, more preferably still less than about 2% by weight of the plant material used is powder. Although some powder may arise due to the process used to prepare and process the plant material, this is not useful in the invention.

Preferably no powder other than very fine, micro fine or super fine powder is used in any aspect of the invention. Ideally, no powder would be present however due to difficulties in removing very fine, micro fine or super fine powder this cannot always be avoided.

If powder is produced during the process of converting the plant material into smaller pieces it is preferably substantially all removed before the final composite is produced, however very fine, micro fine or super fine powder may remain.

Preferably the invention uses fibres of plant material. Fibres of plant material are preferably not dimensionally symmetrical and have a length and diameter.

Preferably a material is defined as biodegradable if it undergoes degradation by biological activity under specific environmental conditions to a defined extent and within a given time. In Europe the criteria for biodegradability is set out in the standard BS EN 13432, 2000. EN 13432 requires that a material or product fulfils the following criteria:

- biodegradation - over 90% compared with standard (cellulose) in 180 days under conditions of controlled composting using respirometric methods (ISO 14855);
- disintegration - over 90% in 3 months (ISO FDIS 16929);
- ecotoxicity - test results for aquatic and terrestrial organisms (*Daphnia magna,* worm test, germination test) as for reference compost; and
- absence of hazardous chemicals included in the reference list.

Preferably material produced according to the invention is home compostible, that is it will biodegrade on a garden compost heap or in a garden compost bin in 18 months or less.

Preferably the substantially non-liquid composite has a dough-like consistency which forms a workable paste. Preferably the non-liquid composite has a consistency similar to that of bread dough. Preferably the non-liquid composite cannot be easily poured. Preferably, the non-liquid composite can be kneaded and is pliable, and thus can be moulded into a desired article. Preferably the non-liquid composite is easy to handle and does not

stick significantly to the mould when used. Preferably the non-liquid composite is of a consistency which allows it to be self supporting, such that it can be placed on a flat surface and will substantially retain its form, and does not need to be contained.

The advantage of a substantially non-liquid composite is that it is easy to work with, there is less wastage through spillage, and it can be easily moulded into articles. A substantially non-liquid composite generally requires the use of less energy, typically applied in the form of heat or pressure, to produce a finished article as less liquid, such as water, needs to be removed from the composite in order to form the article. Articles may be formed by moulding the composite, preferably without a high-energy input. An article may be produced by cold forming the composite under pressure and/or vacuum.

Using a non-liquid composite allows small scale, low-pressure production of articles. Such production can be performed on farm side factories where the plant material is sourced, or in craft workshops. Low-pressure wooden, metal or plaster of Paris formers may be used to produce articles from the non-liquid composite. The articles produced could be used in any number of sectors including housewares, horticulture, food, home decorations and medical disposables.

Preferably the moisture content of the non-liquid composite is between about 5% and about 30% by weight, more preferably the moisture content is between about 15% and about 20%. However, during the production process to produce a non-liquid composite the water content may vary. Preferably the between about 5% and about 30% by weight moisture content referred to

relates to added moisture, preferably water, and not to moisture held within the plant material.

In a preferred embodiment a substantially non-liquid composite according to the invention comprises between about 65% and about 95% by weight plant material. More preferably the substantially non-liquid composite comprises between about 70% and about 80% by weight plant material.

Preferably the non-liquid composite comprises more than about 60% by weight plant material.

Non-liquid composites comprising less than about 60% by weight plant material do not give the strength required to produced shaped items/moulded articles without the addition of expensive additives, such as cellulose from a separate source. The addition of additives may affect the final appearance of articles produced from the composite.

An article produced from the substantially non-liquid composite according to the invention preferably comprises between about 70 and about 100% plant material, a substantial part, or indeed all, of the moisture content of the non-liquid composite having been removed.

Preferably the plant material used is selected from the group comprising banana (Musa sapientum), corn (Zea), maize, rice, sugarcane, Remi, grasses of the Miscanthus type, switchgrass, wheat, linseed straw and leguminous plant material. More preferably the plant material used is selected from the group

comprising banana, corn/maize, linseed straw and leguminous plants.

Preferably the non-liquid composite also comprises between about 1% and about 40% by weight binding agent, more preferably between about 1% and about 30% be weight binding agent.

Preferably the non-liquid composite also comprises cellulose fibres, preferably between about 5% and about 25% by weight cellulose fibres are included in the composite.

Preferably an article produced from a non-liquid composite according to the invention comprises between about 70% and about 80% by weight plant material (crop material), between about 5% and about 22% by weight cellulose from a different source and between about 3% and about 20% starch (binding agent). Alternatively, an article produced from a non-liquid composite according to the invention may comprise between about 70% and about 80% by weight plant material, about 17% by weight cellulose fibres from a different source and about 3% starch. Alternatively, an article produced from a non-liquid composite according to the invention may comprise between about 70% and about 80% by weight plant material, about 20% by weight starch and less then 10% by weight cellulose form a different source, this composite is particularly useful for horticultural applications such as plant pots and basket liners.

Preferably the aforementioned articles are produced from a non-liquid composite which originally comprised between about 15% and about 20% by weight moisture, substantially all of which has been removed in the finished article.

Preferably the plant material is converted into smaller pieces, such as fibres, granules or flakes, with a size of about 20mm ± 5mm, preferably if the material is a granule this size will refer to the diameter, however if the material is a flake this size will refer to the length of one side, however if the material is fibre this size will refer to the length of the fibre. When the flakes are wet they may curl up, however when they are dried they are typically flat. Preferably the size of the pieces of plant material produced will be about 15mm ± 3mm. More preferably the size of the pieces of plant material is about 8mm ± 2mm. More preferably the size of the pieces of plant material is about 2mm ± 1mm. Preferably the dimensions relate to pieces of plant material produced from pre-dried and flattened plant material that is ready for use.

The composite material may also include pieces of plant material that are about 250 microns, these pieces may fill any gaps between the larger fibres, flakes or granules when the composite is moulded.

Preferably the conversion of the plant material into smaller pieces for use in any aspect of the invention does not require the addition of any chemicals, only water.

Preferably the plant material is converted into smaller pieces using mechanical means.

Preferably the plant material is not the by-product of another plant processing system, more preferably the plant material is not the by-product of producing bean curd.

Preferably the plant material is material that would otherwise be waste, obtained once the crop has been harvested from the plant. For example, in the case of the banana plant once the bananas have been harvested the stem and leaves are usually cut down and left to rot. While some of this waste material may be used to fertilise the soil in the banana plantations most is never used, and such waste material may be used in the method of this invention. In the case of corn, whilst the cob of the corn is used as a foodstuff the rest of the plant including the husk is usually discarded, and some or all of this material may provide the plant material for use in this invention. In an alternative embodiment, substantially the entire plant can be used including the cob, thus for example the plant could be grown specifically for the purpose of producing biodegradable composites. Similarly, for leguminous plants the entire plant may be used, or, if preferred, the fruit/vegetable may be harvested first and the rest, or some of the rest, of the plant may be used in the method of this invention.

The use of plant material, and in particular the use of plant material which would otherwise be waste, offers great environmental savings and ecological benefits both in the manufacturing process and in the generation of waste. The biodegradable products produce no issues with landfill; the composites will simply degrade. The intention is to use the biodegradable composite to produce articles which are usually made of plastic, polystyrene, PVC (polyvinylchloride), acrylic, biopolymers such as PLA or other starch derived polymers that are biodegradable, cardboard or paper. Such articles include packaging such as disposable containers, for example for products such as fresh food, such as fruit and vegetables; fast food; frozen

food; or cosmetics such as toiletries; or stationary items. Other uses include for horticultural items such a plant pots, weed suppressant mats, hanging basket liners, plant guards and tree shelter. Another use is for tableware such as tablemats and coasters. In the medical domain disposable urinals, bedpans, vomit bowls, trays etc which are currently made from paper can be made from such plant material. The material may be used to produce crockery, such as plates, bowls and cups. Another use is the production of decorative material, such as wrapping paper, wall paper or picture mounts.

Products made from a composite according to the invention can be used and discarded and will readily compost as if they were the unprocessed plant material simply left to degrade in the field. The products after use can also be used to generate energy, such as to generate biofuels and biogas, or to produce fuel pellets which can be used as a fuel source.

The binding agent may be an adhesive. Preferably the adhesive is biodegradable, such as a starch-based adhesive, for example oat starch glue (such as Etistar 610™) or an adhesive made from *Tamarind* seeds. Alternatively, the adhesive may be a natural gum, such as a polysaccharide gum, or a sugar derivative adhesive. The adhesive may also be a synthetic glue, for example *Evostik*® wood glue or PVA, or a synthetic gum, preferably such glues are biodegradable. Where the articles to be made from the composite are likely to be exposed to water the adhesive may also be moisture resistant. The use of the aforementioned glues has the advantage that the finished products are not brittle.

The preparation of the plant material for use in a method of the invention may follow one of two routes. In the first route, the plant material is taken from the soil and converted immediately to smaller pieces with no moisture removal. Preferably this is done locally, in the field or on the farm, where the plant is grown thus reducing transport costs and CO_2 emissions. In the second route the plant material is dried to remove moisture before the material is converted into smaller pieces, in this route the moisture level may be controlled throughout the material preparation. This has the advantage that if the dried material has to be transported to a factory away from the farm/field the costs for transport are for moving only dry matter which is lighter and has less volume than the undried plant.

The plant material may be dried by air-drying, in a conventional oven and/or by the use of a microwave oven. It has been found that the plant material can be dried more quickly and evenly by the use of microwaves, thereby accelerating the drying time and increasing the product throughput. Plant material dried by microwaves retains its colour better than other known drying methods.

Maize plant material left in the field to dry may show a reduction in moisture from 70% to about 20% or about 30%. Linseed straw is much easier to dry than maize, and thus lends itself well to this invention.

The non-liquid composite may also include wax. Products made from this composite will then be impregnated with wax. Alternatively, wax may be applied as a coating to an article made out of the composite. An article may be coated in wax by

dipping it in molten wax. The wax may render the composite material waterproof or at least serve as a moisture barrier. The extent of waterproofing provided by the wax may be determined by the amount of wax used and the type of wax used. The wax may also provide a smooth surface to a product produced from the composite. Preferably the wax is biodegradable. The wax may be natural such as beeswax or a paraffin-based wax. Alternatively PLA (polylactic acid) or PCL (polycaprolactone, such as Kappa™ manufactured by Solvay) may be used.

Alternatively a layer of shellac in a biodegradable/organic liquid such as a natural oil may be used instead of wax to produce a moisture repellent surface. The composite may also include, or be coated with, agents, such as cashew nut oil or linseed oil, added to improve the hydrophobicity of any product produced from the composite. Cashew nut oil has the advantage that it has no odour and no flavour. Preferably the cashew nut oil is refined.

In addition to the pieces of plant material and the binding agent other products, such as cellulose fibres, may also be included in the composite. Such additional cellulose fibres may serve to reinforce the composite. Preferably the additional products are biodegradable. Such products may include flax, hemp, jute, sugar cane molasses, cotton, paper fibres and/or grass fibrous material, such as miscanthus. Articles made using reinforced composites may have a greater wet strength than articles made using non-reinforced composites; this increased wet strength may help to prevent disintegration of articles made from the composite if they get wet.

The composite may also include oils, such as rapeseed oil, coconut oil, other fractionated oils that are stable and/or egg white. The oil and/or egg white is preferably included in proportions of between about 1% by weight and about 20% by weight. More preferably, between about 3% by weight and about 10% by weight. The oil and/or egg white, like the hemp or flax, serves to increase the wet strength of the dough. In addition, or as an alternative, to be being mixed in with the composite the oil or egg white may be sprayed onto an article made from the composite. The addition of the oil and/or egg white increases the moisture resistance of an article made from the composite material and thus increases the wet strength of the article when it is placed in contact with a wet or moist material. Some of the oils and the egg white are not able to withstand the temperatures used during the composite production and article manufacture processes, and by spraying them onto an article post production these materials can be used without affecting the manufacturing process.

The additional products include in or applied to the composite may also include pulped paper. The pulped paper may be in the form of small fibres of about 250μm in length. The pulped paper may be chemically or mechanically crushed or shredded. The pulped paper may also include enzymes, such as peptic enzymes. The advantage of including pulped paper in the composite material is that it makes the composite easier to mould.

The composite may also include enzymes, such as peptic enzymes, which help to soften the plant material and to break up the fibres.

The plant material may be treated with a mould-inhibiting agent, for example sodium hypochlorite or metabisulphite in suitable concentrations to ensure that mould growth is inhibited. Unwanted mould growth can have a deleterious effect upon the plant material, for example unattractive or excessive discolouration.

Dyes may be added to the composite to modify the natural colour of the composite. Preferably natural, biodegradable dyes are used. Food dyes have been shown to be suitable for this purpose.

An article made from the composite may include printing on the surface. The printing may be for decorative effect or to brand an article with a corporate logo or other insignia. Screen-printing, laser jet printing or ink jet printing may be used to print on an article.

A coating may also be applied to articles made according to the invention to provide a desirable finish, such as a smooth surface, and/or a heat resistant surface. Preferably any coating applied will be biodegradable.

The composite according to the invention may also be used in combination with a laminated product. For example, a laminated product may be made according to the teaching of GB2285406 and may also include a coating of composite according to the present invention. The coating may be for aesthetic purposes only or may be to improve the properties of the laminate, say to improve the strength of an article made of laminate.

Preferably the methods of the invention are undertaken in a 'mobile factory' allowing the methods to be undertaken at the site of the plant material production without the need to transport the material to be processed. The mobile factory containing all the equipment necessary to perform the invention may be located in a lorry which can be easily moved to where the plant material is, rather than bringing the plant material to the factory.

Preferably the following steps are followed in order to make a non-liquid composite.

Firstly, the plant material is chopped up into pieces which are about 20mm+/- about 5mm in length. Preferably about 15mm+/- about 3mm, more preferably about 8mm+/- about 2mm, more preferably about 2mm+/- about 1mm, or more preferably about 2mm to about 250 microns.

If the plant material is dry, that is it has a moisture content less than about 65%, then it is soaked in water for 48 hours prior to subsequent processing. The moisture content will depend on how and when the plant material was harvested. Preferably the plant material is soaked in alkaline water, at a temperature of up-to about 50 degrees Celsius. Preferably the water has a pH of between about pH9 and about pH10.5. Soaking in these condition helps to loosen up the primary wall of the plant fibres which are water repellent, and to separate the lignin and other impurities. The soaked plant material is then washed in fresh water to remove loose particles, powder, grit and soil. Preferably no chemicals are added prior to refining.

This wet/moist plant material is then put through a conical refiner (preferably with one, two or three plates). The conical refiner may be similar to that used in the paper industry. The conical refiner is used to break down and separate, as much as possible, the primary outer walls of the fibres and to provide access to the inner fibrils of cellulose material. This operation may alternatively be performed using a beater such as a valley beater as used in the paper industry, if used on its own this process can take a longer period of time, than if used in combination with a hydra pulper and beater. The hydra pulper and beater may be similar or the same as those used in the paper industry, and preferably uses water as the medium to carry the plant material.

A very dilute mixture of plant material is then made in which the plant material content is between about 5% and about 8% by weight, the rest of the mix is water.

This dilute stock or slurry comprises plant fibres of up to about 1mm in length and about 15 microns in diameter after the refining and/or beating process. Preferably the processing is controlled to give a freeness of between about 250 CSF (Canadian Standard Freeness) and about 350 CSF. Powder is of no use in the method and is preferably strained off.

To make a non-liquid composite according to the invention the water content of this dilute slurry is then drained off, preferably by sieving, to remove about 80 to about 90% of the water. The remaining plant material and water may then be mixed with a binding agent, such as starches and/or tamarind glues. Preferably the non-liquid composite produced comprises about 70 to about

80% by weight of plant material and about 1% to about 20% of a binding agent, the rest of the composite may be water.

The amount of binding agent added will depend on the application. For example, horticultural uses may require more binding agent so that the end product is more solid. Whereas vaccum moulding techniques for medical and food item production will require less binding agent (for example about 10%), and non-weight carrying or non-load bearing applications, such as in padding material for envelopes, may only require about 3 to about 8% binding agent. The composite may also comprise oils and/or waxes which may impart hydrophobic properties to an article produced from the substantially non-liquid composite.

This composite is then suitable for making shaped items, using low cost tooling medium to low volume shaped containers for different applications can be produced.

In an alternative embodiment the following steps are followed in order to make a non-liquid composite containing varying amounts of cellulose fibres.

The plant material is chopped to same size pieces as above i.e. the plant material is chopped up into pieces (fibres, flakes and granules) with about 20mm+/- about 5mm in length. Preferably the pieces are about 15mm+/- about 3mm, more preferably the pieces are about 8mm+/- about 2mm, more preferably still the pieces are about 2mm+/- about 1mm and granules of up to about 250 microns.

Again the plant material if dry, that is with less than about 65% moisture, is soaked in water for 48 hours prior to subsequent processing. Preferably the plant material is soaked in alkaline water, at temp of up-to about 50 degrees Celsius. Preferably the water has a pH of between about pH9 and about pH10.5. The soaked material is then washed in fresh water to remove loose particles, powder, grit and soil. Preferably no chemicals are added prior to refining.

The plant material is then refined and/or beaten as previously described using a conical refiner, or a beater, or a hydra pulper and a beater.

A very dilute mixture of plant material is then made in which the plant material content is between about 5% and about 8% by weight, the rest of the mix is water.

At this stage between about 10% and about 50% by weight of cellulose fibres preferably extracted from cotton, flax, recycled paper, hemp, jute, sugarcane, baggass, grasses such as miscanthus, organic fibres such as chicken feathers or wool are mixed with the dilute mix of plant material and blended in a mixer/hydra pulper as used in the paper industry to make a dilute slurry with about 2% to about 8% solid material.

To make a non-liquid composite according to the invention the water content of this dilute slurry is then drained off, preferably by sieving, to remove about 80% to about 90% of the water. The remaining mix is then mixed with a binding agent, such as starches and/or tamarind glues to about 10% to about 20% by weight, the mix may then be blended with oils/waxes to give

hydrophobic properties in different proportions, to gives a substantially non-liquid composite. This composite is then suitable for making shaped items, low tooling cost may be used to produce medium to low volume shaped containers for different applications.

According to another aspect, the present invention provides a biodegradable substantially non-liquid composite obtainable by any of the above described methods.

According to another aspect, the present invention provides a biodegradable substantially non-liquid composite comprising small pieces of plant material and a binding agent.

With regard to the preferred features of the above composites, the skilled man will appreciate that the preferred features discussed with reference to the above method also apply to the above composites.

According to another aspect, the present invention provides a method of producing a biodegradable composite from banana, corn/maize, sugar cane, rice, grasses of the Miscanthus type, switchgrass, wheat, linseed straw and/or leguminous plant material comprising the steps of converting the plant material into smaller pieces and mixing the plant material with a binding agent to form a substantially liquid composite slurry.

Preferably, a liquid composite slurry can be poured and is sufficiently viscous that on a flat surface it has to be contained otherwise it will form a puddle, like water, which cannot easily be recovered for use.

According to yet another aspect, the present invention provides a method of producing an article from a biodegradable composite material comprising the steps of converting banana, corn/maize, sugarcane, Remi, rice, grasses of the Miscanthus type, switchgrass, wheat, linseed straw and/or leguminous plant material into smaller pieces, mixing the plant material with a binding agent to form a substantially liquid composite slurry and forming an article from the composite.

Preferably the plant material is converted into smaller pieces before it is mixed with the binding agent.

The plant material may be converted into smaller pieces by grinding, crushing, cutting, milling, rolling and/or shredding the plant material.

Preferably the plant material is solid, and is not a liquid or paste.

Preferably, substantially no powdered plant material is used in any aspect of the invention. Preferably less than about 10% by weight of the plant material used is powder, more preferably less than about 5% by weight of the plant material used is powder, more preferably still less than about 2% by weight of the plant material used is powder. Although some powder may arise due to the process used to prepare and process the plant material, this is not useful in the invention.

All the preferred features relating to powder discussed previously apply to this and all aspects of the invention.

This method, which uses a composite slurry or pulp, has the advantage that it allows well established paper making and moulding technology to be used to produce articles out of the pieces of banana, corn/maize, sugar cane, Remi, rice, grasses of the Miscanthus type, switchgrass, wheat, linseed straw and/or leguminous plant material, without having to go through the full processing cycle of paper production.

Preferably, the plant material is material that would otherwise be waste, obtained once the crop has been harvested from the plant. For example, in the case of the banana plant once the bananas have been harvested the stem and leaves are usually cut down and left to rot. While some of this waste material may be used to fertilise the soil in the banana plantations most is never used, and such waste material may be used in the method of this invention. In the case of corn, whilst the cob of the corn is used as a foodstuff the rest of the plant including the husk is usually discarded, and some or all of this material may provide the plant material for use in this invention. In an alternative embodiment, substantially the entire plant can be used including the cob, thus for example the plant could be grown specifically for the purpose of producing biodegradable composites. Similarly, for leguminous plants the entire plant may be used, or, if preferred, the fruit/vegetable may be harvested first and the rest, or some of the rest, of the plant may be used in the method of this invention.

Preferably the plant material is not a by-product of the production of bean curd.

The use of plant material, and in particular the use of plant material which would otherwise be waste, offers great

environmental savings and ecological benefits both in the manufacturing process and in the generation of waste. The biodegradable products produce no issues with landfill; the composites will simply degrade. The products after use can also be used to generate energy, such as to generate biofuels and biogas. The intention is to use the biodegradable composite to produce articles which are usually made of plastic, polystyrene, PVC (polyvinylchloride), acrylic, cardboard or paper. Such articles include packaging, such as disposable containers, for example for products such as fresh food, fast food, frozen food, or cosmetics; or stationary items. Other uses include for horticultural items such a plant pots, weed suppressant mats, hanging basket liners, plant guards. Another use is for tableware such as table mats and coasters. The material may be used to produce crockery, such as plates, bowls and cups. Another use is the production of decorative material, such as wrapping paper or wall paper, or medicinal products such as urinals, bedpans, vomit bowls and trays.

Preferably a liquid composite slurry comprises between about 1% and about 20% plant material, more preferably a liquid composite slurry comprises between about 1% and about 10% plant material, more preferably a liquid composite slurry comprises between about 2% and about 8% plant material.

The binding agent may be an adhesive. Preferably the adhesive is biodegradable, such as a starch-based adhesive, for example oat starch glue (such as Etistar 610™) or an adhesive made from *Tamarind* seeds. Alternatively, the adhesive may be a natural gum, such as a polysaccharide gum, or a sugar derivative adhesive. The adhesive may also be a synthetic glue, for example

Evostik® wood glue or PVA, or a synthetic gum. Where the articles to be made from the composite are likely to be exposed to water the adhesive may also be moisture resistant. The use of the aforementioned glues has the advantage that the finished products are not brittle.

The preparation of the plant material for use in the method of the invention may follow one of two routes. In the first route, the plant material is taken from the soil and converted immediately to smaller pieces with no moisture removal. In the second route the plant material is dried to remove moisture before the material is converted into smaller pieces, in this route the moisture level may be controlled throughout the material preparation.

The plant material may be dried before it is used in a composite according to the invention. The plant may be dried where it is grown and harvested. The plant material may be dried by air-drying, in a conventional oven or by use of a microwave oven. It has been found that the plant material can be dried more quickly and evenly by the use of microwaves, thereby accelerating the drying time and increasing product throughput.

Alternatively, the plant material may be used without drying, this may reduce the processing costs.

In order to produce the composite slurry or pulp the plant material is converted to produce particles of about 150μm to about 250μm in diameter or along one side. The particles may be planar or granular.

The slurry or pulp may also or alternatively include flakes of plant material which are larger than the about 150μm to about 250μm particles. The flakes may be between about 1mm and about 20mm on any side. The flakes may give an article manufactured from the slurry or pulp a more attractive appearance. By using a mixture of the small particles and larger flakes in the slurry or pulp the finished product may have a more attractive appearance whilst still retaining a relatively smooth surface as the small particles may fill in any gaps between the flakes.

The plant material used may also or alternatively comprise fibres the fibres are preferably 1 to 10mm more preferably 1 to 5mm in length. Preferably the fibres used have been fibrillated to produce microfibres on the surface. The fibrillisation preferably exposes cellulose which may be used to cross-link the fibres to themselves or to other reinforcing fibres.

Preferably, substantially no powdered plant material is used. Although some powder may arise due to the process used to prepare the plant material, this is not useful in the invention.

Preferably the slurry produced has a CSF (Canadian Standard Freeness) of 250 to 350. This is similar to paper pulp.

The formation of the slurry into a desired shape may take place under pressure and/or a vacuum, and at either an ambient or an elevated temperature.

Preferably, to make an article according to this aspect of the invention a slurry or pulp is prepared by mixing banana,

corn/maize, sugar cane, Remi, rice, grasses of the Miscanthus type, switchgrass, wheat, linseed straw and/or leguminous plant material, which has been converted to a size of between about 150μm and about 250μm, with a binding agent to a consistency which can be readily poured. The slurry/pulp is made in, or poured into, a tank. A male die or mould is immersed in the slurry, preferably the die has multiple cavities each cavity reflecting the product to be made. The male die is then lifted from the tank bringing with it the pulp. A female die /mould is then placed over the male die and suction is applied to the female die. The female die is then removed bringing with it the pulp product and the male die is returned to the tank. The product is then placed, with or without the female mould, on a drying conveyor. The product is dried on the conveyor which passes the product through a series of ovens or drying areas at different temperatures. The drying area may take the form of a heat tunnel. The heat tunnel may have a temperature profile extending from room temperature of about 20°C at one end to about 130°C at the other end. Filter tooling which permits a vacuum to be used to extract water from the fibre material may be used. By using ceramic dies and higher vacuum levels to filter out the water in the moulds the cycle time in the tunnel can be reduced from about 18 minutes to about 1minute. The surface finish of the moulded item may be improved by a second press and hold tool before drying.

The liquid composite slurry may include wax. Products made from such a composite will then be impregnated with wax. Alternatively, wax may be applied as a coating to an article made out of the composite. An article may be coated in wax by dipping it in molten wax. The wax may render the composite

material waterproof or at least serve as a moisture barrier; the extent of waterproofing provided by the wax may be determined by the amount of wax used and the type of wax used. Preferably the wax is biodegradable.

The wax may be beeswax or a paraffin-based wax. Alternatively, PLA (polylactic acid) or PCL (polycaprolactone, such as Kappa™ manufactured by Solvay) may be used.

Alternatively a layer of shellac in a biodegradable/organic liquid such as a natural oil may be used instead of wax to produce a moisture repellent surface. The composite may also include agents, such as cashew nut oil or linseed oil, added to improve the hydrophobicity of any product produced from the composite. Cashew nut oil has the advantage that it has no odour and no flavour. Preferably the cashew nut oil is refined.

In addition to the pieces of plant material and the binding agent other products may also be included in the composite. Such additional products may serve to reinforce the composite. Preferably the additional products are biodegradable. Such products may include flax, hemp, jute, sugar cane molasses, cotton, paper fibres and/or grass fibrous material, such as miscanthus. Articles made using reinforced composites have a greater wet strength than articles made using non-reinforced composites; this increased wet strength helps to prevent disintegration of articles made from the composite if they get wet.

The additional products may also include pulped paper. The pulped paper may be in the form of small fibres of about 250μm. The pulped paper may be chemically or mechanically crushed or

shredded. The pulped paper may also include enzymes, such as peptic enzymes. The advantage of including pulped paper in the composite material is that it makes the composite easier to mould.

The composite may also include enzymes, such as peptic enzymes, which help to soften the plant material and to break up the fibres.

The composite may also include oils, such as rape seed oil and/or coconut oil, and/or egg white. The oil and/or egg white is preferably included in proportions of between about 1% by weight and about 20% by weight. More preferably, between about 3% by weight and about 10% by weight. The oil and/or egg white, like the hemp or flax, serves to increase the wet strength of the dough. In addition, or as an alternative, to be being mixed in with the composite oil or egg white could be sprayed onto an article made from the composite. The addition of the oil and/or egg white increases the moisture resistance of an article made from the composite material and thus increases the wet strength of the article when it is placed in contact with a wet or moist material. Some of the oils and the egg white are not able to withstand the temperatures used during the composite production and article manufacture processes, and by spraying them onto an article post production these materials can be used without affecting the manufacturing process.

The plant material may be treated with a mould-inhibiting agent, for example sodium hypochlorite or metabisulphite in suitable concentrations to ensure that mould growth is inhibited. Unwanted mould growth can have a deleterious effect upon the

plant material, for example unattractive or excessive discolouration.

Dyes may be added to the composite to modify the natural colour of the composite. Food dyes have been shown to be suitable for this purpose.

An article made from the composite may include printing on the surface. The printing may be for decorative effect or to brand an article with a corporate logo or other insignia. Screen printing, laser jet printing or ink jet printing may be used to print on an article.

A coating may also be applied to articles made according to the invention to provide a desirable finish or a smooth surface. Preferably any coating applied will be biodegradable.

The composite according to the invention may also be used in combination with a laminated product. For example, a laminated product may be made according to the teaching of GB2285406 and may also include a coating of composite according to the present invention. The coating may be for aesthetic purposes only or may be to improve the properties of the laminate, say to improve the strength of an article made of laminate.

Preferably any method of the invention can be undertaken in a 'mobile factory' such that the methods can be undertaken at the site of the plant material production without the need to transport the material to be processed. The mobile factory containing all the equipment necessary to perform the invention may be located

in a lorry which can be easily moved to where the plant material is.

Preferably the following steps are followed in order to make a liquid composite slurry.

Firstly, the plant material is chopped up into pieces (flakes and granules) which are about 20mm+/- about 5mm in length. Preferably about 15mm+/- about 3mm, more preferably about 8mm+/- about 2mm, more preferably about 2mm+/- about 1mm and granules of up to about 250 microns.

If the plant material is dry, that is has a moisture content less than about 65%, it is soaked in water for 48 hours prior to subsequent processing. The moisture content will depend on how and when the plant material was harvested. Preferably the plant material is soaked in alkaline water, preferably the water has a pH of between about pH9 and about pH10.5, at a temperature of up to about 50 degrees Celsius. Soaking in these condition helps to loosen up the primary wall of the plant fibres which are water repellent, and to separate the lignin and other impurities. The soaked plant material is then washed in fresh water to remove loose particles, powder, grit and soil. Preferably no chemical are added prior to refining.

This wet/moist plant material is then put through a conical refiner (preferably with one, two or three plates). The conical refiner may be similar to that used in the paper industry. The conical refiner is used to break down and separate, as much possible, the primary outer walls of the fibres and to provide access to the inner fibrils of cellulose material. This operation may

alternatively be performed using a beater such as a valley beater as used in the paper industry, if used on its own this process can take a longer period of time, than if used in combination with a hydra pulper and beater. The hydra pulper and beater may be similar or the same as those used in the paper industry, and preferably uses water as the medium to carry the plant material.

A very dilute mixture of plant material is then made in which the plant material content is between about 5% and about 8% by weight, the rest of the mix is water.

This dilute stock or slurry comprises plant fibres of up to about 1mm in length and about 15 microns in diameter after the refining and/or beating process. Preferably the processing is controlled to give a freeness of between about 200 CSF (Canadian Standard Freeness) and about 350 CSF. Powder is of no use in the method and is preferably strained off.

Preferably a binding agent is added to the slurry as it is passed through the mixer or hydra pulper.

Preferably the slurry comprises between about 5 to about 8% by weight plant material.

The dilute slurry can be used in vacuum moulding machines to produced shaped containers for various applications.

The slurry may be used in industry standard vacuum moulding machines using 600mm mercury vacuum pressure.

If required waxes, dyes etc can be added to the slurry at the same time as the binding agent, and then passed through the hydra pulper.

In an alternative embodiment the following steps are followed in order to make a non-liquid composite containing varying amounts of cellulose fibres.

The plant material is chopped to same size pieces as above, that is the plant material is chopped up into pieces (fibres, flakes and granules) with about 20mm+/- about 5mm in length. Preferably the pieces are about 15mm+/- about 3mm, more preferably the pieces are about 8mm+/- about 2mm, more preferably still the pieces are about 2mm+/- about 1mm and granules of up to about 250 microns.

Again the plant material if dry, that is with less than about 65% moisture, is soaked in water for 48 hours prior to subsequent processing. Preferably the plant material is soaked in alkaline water at a temperature of up to about 50 degrees Celsius. Preferably the water has a pH of between about pH9 and about pH10.5. The soaked material is then washed in fresh water to remove loose particles, powder, grit and soil. No chemicals are added prior to refining.

The plant material is then refined and/or beaten as previously described, using a conical refiner, or a beater, or a hydra pulper and a beater.

A very dilute mixture of plant material is then made in which the plant material content is between about 5% and about 8% by weight, the rest of the mix is water.

At this stage between about 10% and about 50% by weight of cellulose fibres extracted from cotton, flax, recycled paper, hemp, jute, sugarcane baggass, grasses such as miscanthus, organic fibres such as chicken feathers or wool are mixed with the dilute mix of plant material and blended in a mixer/hydra pulper as used in the paper industry to make a dilute slurry with about 2% to about 8% plant material during processing.

Preferably the slurry comprises between about 5 to about 8% by weight plant material.

This slurry can be used directly for vacuum forming/moulding. This is a high volume fast production technique that runs continuously and is used for making packaging shapes out of paper pulp.

According to another aspect, the present invention provides a biodegradable liquid composite slurry obtainable by any of the above described methods.

According to another aspect, the present invention provides a biodegradable liquid composite slurry comprising small pieces of banana, corn/maize, sugar cane, Remi, rice, grasses of the Miscanthus type, switchgrass, wheat, linseed straw and/or leguminous plant material and a binding agent.

Preferably the slurry comprises between about 3% and about 8% plant material.

With regard to the preferred features of the above composites the skilled man will appreciate that the preferred features discussed with reference to the above method of making or using a liquid composite slurry may also apply to the above composites.

According to another aspect, the present invention provides a biodegradable article made using a composite according to the invention.

According to another aspect, the present invention provides a biodegradable article comprising corn/maize, banana stem, sugar cane, Remi, rice, grasses of the Miscanthus type, switchgrass, wheat, linseed straw and/or leguminous plant material converted into pieces with a length or diameter of from about 150μm to about 20mm ± about 5mm and a binding agent.

According to another aspect of the invention a composite material, such as a non-liquid composite or a liquid composite slurry according to the invention, may be used in an extrusion process to form a biodegradable product. For example, biodegradable tubes, which are hollow, solid or flat, may be extrudes, as may a form of bubble wrap. The extruded product will depend on the nature of the extrusion nozzle and die.

Preferably a composite for extrusion is made by producing a liquid slurry of plant fibres, drawing off excess water, adding cellulose fibres to a concentration of about 10% to about 20% by weight, adding biodegradable biopolymers such as PLA or other

starch derived polymers up to about 30% by weight and adding about 2% of a binding agent which is preferably starch derived. This composite may then be extruded. Preferably the concentration of plant material in the composite for extrusion is from about 60 to about 80%. More preferably from about 70 to about 80%.

Preferably the extruder has temperatures along the extrusion screw ranging from about 60°C at the top of the screw to about 70°C and back to about 60°C at the nozzle.

The skilled man will appreciate that other extrusion conditions may be used.

A composite according to any aspect of the invention may be used to make a padding material. Preferably the padding material comprises a layer of composite material, which is between about 1mm and about 2cm thick. More preferably the composite material is about 5mm to about 1cm thick. The layer of composite material may be from about 1cm to about 10metres wide, more preferably the layer of composite material is between about 10cm and about 1metre wide.

The layer of composite material may be made from the slurry composite using a die system or by spraying the slurry onto a surface, such as a sheet of paper; or from a substantially non-liquid composite by passing the composite through rollers or by pressing the composite to form a layer.

The padding material may comprise a layer of another material, such as paper, on one or both sides of the layer of composite material.

Air may be blown into the composite during production of the padding material to improve its cushioning properties.

The padding material may be formed into a roll for ease of use.

The padding material according to the invention may be used as the padding in a padded envelope; as packaging in boxed goods, for example as an alternative to bubble wrap; as animal bedding; or it may be used as sound and/or thermal insulation, in this embodiment insulating wool may also be included. Such padding material has an environmental advantage in that it is biodegradable, it is also good for waste management as it can be disposed of in compositing or green waste.

Currently padded envelopes typically contain bubble wrap or wool insulating material to provide cushioning. No consideration has been given to the biodegradability of the envelope. A padded envelope according to the invention will be fully biodegradable, whilst there may be differences in the composting rate of the paper compared to the plant material the envelope will all preferably biodegrade.

According to another aspect, the present invention provides a padded envelope or bag in which the padding is made from plant material.

Preferably the plant material is derived from corn/maize, banana stem, sugar cane, Remi, rice, grasses of the Miscanthus type, switchgrass, wheat, linseed straw and/or leguminous plants. Preferably the plant material used is material that would otherwise be waste. Preferably the plant material used is solid. Preferably the plant material is not the by-product of another processing system, such as the production of bean curd.

Preferably the plant material is in the form of strips. Preferably the strips of plant material area dried and flattened.

Preferably the plant material is dried and flattened before being cut into strips. Preferably the plant material is dried in a conventional oven or by the use of microwaves.

The plant material may be woven into a mat. Preferably the mat is the size of the envelope to prevent movement of the material, and to improve the protective effect conferred by the padding.

Preferably the outer layer used in the padded envelope or bag is also biodegradable and compostible as previously discussed, for example, the outer layer may be also made of plant material such as paper made from jute, hemp or straw from a wide range of crops.

Preferably the outer layer of the envelope or bag is hydrophobic in nature, thereby protecting the envelope or bag contents from moisture. Hydrophobicity may be innate in the material used or conferred by adding an agent to the material, for example, adding cashew nut oil or by applying a wax coating to the surface. Wax may be applied by spraying or dipping the material in the wax.

Preferably the adhesive or glue used to seal the envelope or bag is also biodegradable and compostible.

The envelope or bag may also include gussets on the side which allow the envelope or bag to expand.

The envelope or bag may be of a single piece construction, such that the envelope/bag is cut from a single piece of material and folded into the form required.

The padding used may simply by crushed plant material optionally some starch may be added.

Alternatively the padding may be a dried pulp/slurry of plant material such banana stems, maize stems and leaves, rice crop stems and leaves, sugarcane stem and leaves and/or the stems and leaves of leguminous plants and/or grasses of the Miscanthus type, and/or Remi and/or switchgrass, and/or wheat, and/or linseed straw. This material may be used with jute, cotton, flax, or hemp, straw, switchgrass or a mix thereof. Again the dried pulp/slurry may be aerated to enhance the cushioning effect of the material.

Preferably the plant material used is fibrillated to produce micro fibrils on the fibre surface. This process may expose the cellulose in the plant material. The cellulose may be used to crosslink the fibres to each other or to reinforcing fibres.

The plant material used may be formed into a paper for use as padding, the paper may be randomly embossed to improve the

fibre strength. More specifically the plant material may be made into a sheet of about 3 mm to about 8mm thick, preferably not greater than about 12.5mm thick, with a moisture content of up to about 15%, and no more than about 20%. The sheet may then be passed between rollers that have protrusions, which are preferably semi-spherical, to produce a sheet with dents/embossing on it. If semi-spherical protrusions are used the dents/embosses will be semi-spherical. The embossed paper may be used for wrapping goods, such as electronic goods, for shipping.

The embossed paper may comprise about 80% plant material, preferably selected from the group comprising maize, banana, sugar cane, Remi, rice, grasses of the Miscanthus type, switchgrass, wheat, linseed straw and leguminous plant material, about 10% to about 12% reinforcing fibres and about 2 to about 4% starch, the paper may also comprise waxes, oils or surface sealant sprays.

The padding material may be formed of one or more layers of plant material. Each layer may be the same or different. Each layer may be a layer of paper made from plant material.

To provide heavier duty padding, more layers or more material may be used.

According to another aspect, the invention provides a method of preparing plant material for processing comprising drying the material using microwaves.

The use of microwaves to dry the plant material has the advantage that the material dries more quickly, thus reducing the time and cost of product production. For example, to reduce the moisture content from about 80% to about 60% by air drying takes about 2 days, whereas the moisture content can be reduced from about 80% to about 10% in minutes using a microwave.

Preferably the plant material to be processed is sourced from plants of the genus *Musa* (banana), *Zea* (corn or maize), sugar cane, Remi, rice, grasses of the Miscanthus type, switchgrass, wheat, linseed straw and/or leguminous plants. Preferably, the plant material is material that would otherwise be waste, obtained once the crop has been harvested from the plant. For example, in the case of the banana plant once the bananas have been harvested the stem and leaves are usually cut down and left to rot. While some of this waste material may be used to fertilise the soil in the banana plantations most is never used, and such waste material may be used in the method of this invention. In the case of corn, whilst the cob of the corn is used as a foodstuff the rest of the plant including the husk is usually discarded, and all or some of this material may provide the plant material for use in this invention. In an alternative embodiment, the entire plant can be used including the cob, thus for example the plant could be grown specifically for the purpose of producing biodegradable composites. Similarly, for leguminous plants the entire plant may be used, or, if preferred, the fruit/vegetable may be harvested first and the rest, or some of the rest, of the plant may be used in the method of this invention.

All the preferable features discussed above with reference to any aspect of the invention can be applied to all other aspects of the invention.

Preferred embodiments of the present invention will now be described, merely by way of example, with reference to the following drawings and examples.

Figure 1 is a schematic chart depicting the production of a composite article from pieces of plant material;

Figure 2 is a schematic chart depicting an alternative method for the production of a composite article from pieces of plant material to that depicted in Figure 1;

Figure 3 is a representation of an article with an outer laminate layer and an inner layer of composite material made from pieces of plant material;

Figure 4a is a schematic chart depicting a method for producing padding material according to the invention;

Figure 4b is a schematic chart depicting an alternative method to that of Figure 4a for producing padding material according to the invention;

Figure 5 is a representation of an envelope padded with a woven mat of strips of plant material;

Figure 6a illustrates the moisture characteristic of corn leaves (top);

Figure 6b illustrates the moisture characteristic of corn leaves (bottom);

Figure 7a to 7d illustrate the moisture variations during drying at 60°C of multilayer cylindrical banana stem sections;

Figure 8 illustrates the drying rates of banana stems at 60°C;

Figure 9 illustrates a comparison between ambient and high temperature drying of banana stem;

Figure 10 illustrates the relationship between sheet weights and drying times;

Figure 11 illustrates the moisture content of whole corn leaf before and after microwave drying; and

Figure 12 illustrates the bending force as a function of moisture content and span for banana stems.

Figure 1 depicts schematically a method for the production of an article from pieces of plant material. A sheet 10 of banana skin is microwave dried and then ground using a conical refiner to produce fibres 11 with dimensions of about 1mm in length and about 15 microns in diameter. The plant fibres are then used to form a non-liquid composite comprising about 70% by weight plant fibres, about 8% by weight of an adhesive (binding agent) derived from tamarind seeds, the remaining volume being water. Optionally, other things may be added to the composite, such as cellulose fibres, dyes, anti fungal agents etc. The non-liquid

composite 14 has a dough-like consistency which is self supporting when placed on a flat surface. The composite 14 is then place in a mould 15 and a die 16 is pushed into the composite 14 to mould it to the shape of the mould 15. The die 16 is then removed from the mould 15 leaving a layer of composite 14 around the mould 15. The mould 15 is then removed from the composite 14 to produce the finished article 18. The finished article 18 is then left to dry if necessary and may be further treated with wax to enhance the moisture proofing and/or a heat barrier material. The finished article may also be decorated as required.

Figure 2 depicts schematically an alternative method for the production of an article from pieces of plant material. A sheet 20 of banana skin is ground using a conical refiner to produce fibres 11 with dimensions of about 1mm in length and about 15microns in diameter. The plant fibres are then used to form a liquid composite slurry 25 comprising between about 5% and about 8% by weight plant fibres. Between about 3% and about 5% binding agent is then added. With the balance being water. The slurry is then placed in a tank 23. A male mould/dye 26 is then placed in the slurry/pulp 25 in the tank. The male mould 26 is then moved up and partially out of the tank 23 bringing with it the slurry/pulp 25. A female mould/dye 29, with water and vacuum suction, is then placed over the male mould 26 to form the article under pressure and vacuum. The pressure and vacuum removes up to 85% of the water content from the article. The female mould 29 and article 28 are removed from the male mould 26 which remains in the pulp 25 in the tank 23. The article 28 is released from the female mould by removing the vacuum (breaking the suction) and is then placed on conveyor 30 passed

through a drier with a temperature gradient of from room temperature to 130°C to reduce the moisture content of the article 28. Again, the article 28 may then be left to dry further if necessary and may be decorated as required. To give this smoother surface finish the article may be again pressed and held for less than 30 seconds in a male female mould and removed. This is called a second press operation.

Figure 3 shows a representation of an article which comprises an outer layer 32 made from laminated plant material and an inner layer 34 moulded from smaller pieces of plant material. The outer laminate layer 32 forms the mould on which the inner layer 34 is formed.

Figure 4a depicts schematically a method for the production of a padding material from composite plant material. A layer of composite material 44 is made by passing substantially non-liquid composite plant material, made according to the method of Figure 1 prior to the moulding step, through rollers 42 and 43. The layer 44 produced is about 1cm thick and is dried before further processing. The layer may be air dried or dried in a conventional or microwave oven. In a separate operation a sheet of paper 54 is sprayed with adhesive 53 dispensed from nozzles 51. The dried layer 44 of composite material is then adhered to the sheet of paper 54, an optional top sheet of paper 54' may also be applied. The resulting material 55 can be used as padding. The material 55 is formed into a roll 58 for ease of use and storage.

Figure 4b depicts schematically an alternative method for the production of a padding material from composite plant material.

A layer of paper 64 is laid out on a conveyor 62 and passed through an adhesive dispense region where adhesive 66 is sprayed onto the paper 64 from nozzles 65. The adhesive coated paper 64 is then passed to a subsequent zone where pulped plant material 71, made according to the method of Figure 2 before the moulding stage, is sprayed onto the paper 64 from nozzles 65. The pulp comprises pieces of plant material of about 250μm, wax and water. The paper 64 and pulp 71 is then passed through a drying zone where hot air 73 is applied to the material 74 to reduce the moisture content. The resultant material 74 can be used as a padding material. An optional top layer of paper (not shown) may be applied. The material 74 is formed into a roll 75 for ease of use and storage.

In an alternative embodiment not depicted the adhesive may be provided just in the pulp and not on the paper, or on the paper and not in the pulp.

Figure 5 shows a representation of a padded envelope 50. The padded envelope 50 includes an upper sealing tab 52 and a main body 53. The main body 53 is illustrated part cut away to allow the padding 54 to be seen. The padding 54 is made from a woven mat of strips 58 of dried plant material. In an alternative embodiment the padding could be about 100% plant material with no added cellulose, if require about 3 to about 5% binding agent could be added. The material could be made by rolling flat the substantially non-liquid dough of plant composite.

EXAMPLES

Example 1 - Method for the Production of a Biodegradable Tray

The following method was used to produce a biodegradable tray. 3 parts by weight of ground banana stem fibres which were 15mm or less by 3mm or less, was mixed with 1 part by weight of a cold glue. The cold glue comprised 30% Tamarind powder and 70% water which was mixed together and had a resulting viscosity measured as 4.20min for 5ml of glue. The resulting dough (substantially non-liquid composite material) comprised about 70 to about 80% by weight plant material. The dough was then rolled to produce a layer of 1.5mm to 2mm in thickness. The layer was then pressed into a mould; the pressure applied was sufficient to remove substantially all the air bubbles. The dough in the mould was then dried for 45 minutes at 130°C. The composite material was then turned out of the mould to provide a biodegradable tray.

A tray produced by the above method may then be optionally coated with a wax, such as paraffin wax, to provide a finish with some degree of waterproofing. The degree of waterproofing being determined by the amount and type of wax applied.

The biodegradation rate of a tray made according to the above method is less than 1 year.

Example 2 - Method for the Production of a Moulded Tray from Dried Sweetcorn Leafs or Banana Stem.

Dried sweet corn leafs or banana stem were ground using a blender to a particle size of 5mm in length or less. 1g of the plant material was mixed with 4ml of Etistar 610™ adhesive. The mixture was placed between 2 layers of cling film and rolled out to form a sheet about 3mm thick. The sheet was then placed between two sheets of aluminium with spacers 2.5mm thick spacers at each corner, a load of 5kN was then applied to the sheet for 30 seconds to flatten the sheet and remove any air. The flattened sheet was then placed in a mould and a 5kN load applied for a further 30 seconds. The mating half of the mould was removed and the resulting tray was dried in the oven for 1 hour at 80°C. The tray was then removed from the mould and left to air dry at ambient temperature for 4 to 6 hours

Example 3 - Production of a Hanging Flower Basket Liner from Ground Banana Stems.

Banana stems were dried in the open for several days. The banana stems were then cut into pieces of about $2cm^2$. The pieces of banana stem were then ground in a blender to obtain fibres of about 250μm (which comprised a grade of fibres ranging from 150μm to 710μm the average of which is 250μm) 750g of the ground banana stem fibres was mixed with 200ml of Etistar 610™ glue or Tamarind glue and water was added to produce a homogenous dough of composite comprising about 70 to about 80% plant material.

The dough was then placed on a piece of plastics sheet, e.g. cling film, another piece of cling film was then placed on top of the dough, and the dough was then rolled out to form a sheet around 3mm in thickness. One of the sheets of cling film was then removed and the sheet of composite was then placed around a mould for the hanging basket which had previously been covered with a sheet of cling film. A small amount of pressure was applied as necessary to join edges and reduce any differences in thickness. Once in position the outer sheet of cling film was removed from the composite.

The mould was then left over night to begin the drying process, by drying the composite slowly the resulting basket retains some flexibility. After over night drying the mould was then placed in an oven at 80°C for 15 minutes.

The composite was then separated from the mould and the cling film and then place in the oven again for a further 30 minutes at 80°C.

Any holes in the basket can be filled with excess dough composite, and left to air dry.

Hanging basket liners can also be made from a slurry of plant material using vacuum moulding methods. The vacuum moulding methods used may be the methods that are well established for making moulder paper pulp items, these methods may allow high volume product production.

Example 4

Mechanical Tests

In order to determine some mechanical properties of the products produced using the method of the invention tests were done to compare a number of samples. The tests carried out included a cutting test, a bending test and a pulling the test. The tests were carried out using an Instron™ Tensile Testing machine (available from Instron™ Corporation)

The Cutting Test

The cutting test is a measure of toughness, and was performed on strips of composite material. Strips of various composition were used, some were laminated (that is, strips glued on top of each other) and others were strips made from a dough composite which had been rolled to about 3mm thick, the composition of the dough composite being varied by varying the amount of water and glue.

The cutting test itself comprised hanging a pair of scissors from a mobile horizontal arm on the Instron™ machine, holding a strip of composite between the two blades of the scissors and then slowly closing the blades on the strip. The machine was stopped when the strip had been cut in two.

The toughness of the strip gives an indication of the resistance of the material to fracture when suddenly stressed. The toughness R and its standard deviation S are defined by

$$R = \frac{\sum W_i - \sum W_{scissors}}{Across-section}$$

where W_i is the area under the load displacement curve and $W_{scissors}$ the friction component, with

$$Across\text{-}section = width thickness$$

and $$S = \sqrt{\frac{\left(\sum X_i - \overline{X}\right)^2}{i-1}}$$

The Bending Test

The bending test was carried out be attaching a vertical bar to the load cell on the cross-head of the Instron™ machine and placing a support on the base of the Instron™ machine. The software on the Instron™ machine was then initiated to position the bar relative to the support. A strip of composite was then placed on the support under the bar perpendicular to the cross head and the experiment was started. Slowly the cross head was lowered, and pressed on the width of the strip to bend it, the amount of curvature was measured. Using this technique the maximum force F_{max}, bending strength (maximum bending stress) σ of the strip as well as the moment of inertia I generated by the strips can be determined. The maximum force F_{max} was read on the curves "load versus extension" while the tensile strength σ and moment of inertia I were defined by:

$$\sigma = \frac{M \cdot thickness}{2 \cdot I}$$

with $M = \frac{F_{max} \cdot d_1 \cdot d_2}{d_3}$

$d_1 = d_2 =$ distance between the bar perpendicular and the extremity of the strip

and $I = \frac{width \cdot (thickness)^3}{12}$

The maximum bending stress σ is the geometrical expression of deformation caused by the action of stress on a physical body which expresses itself as a change in size and/or shape.

The Pulling Test

The pulling test required the placement of an adapter on the cross head and on the base of the Instron™ machine, the adapters were aligned and positioned by the Instron™ software, a strip of composite was positioned between and held by the adapters. The adapters were then moved to stretch the strip until it ruptured.

From the data collected the maximum force F_{max} tensile strength σ of the strip as well as the Young's modulus E generated by the strips of same compositions in material and in adhesive could be determined. The maximum force F_{max} was read on the curves "load according versus extension" while the tensile strength σ and Young's modulus are defined as

$$\sigma = \frac{F\max}{width \cdot thickness}$$

$$E = \frac{\sigma}{\epsilon}$$

with $\epsilon = \frac{\Delta l}{l_0}$

and Δl = extension corresponding to the load in comparison with the tangent at the origin of the curve "load according to extension".

Tensile stress σ is the stress associated with stretching when the material tends to increase in length. The Young's modulus E is a measure of the stiffness of a given material, it is defined as the limit for small strains of the rate of change of stress with strain. The Young's modulus allows you to calculate the behaviour of a material under load.

Results

The various tests carried out above on the sweet corn/maize leafs strips (pulped, laminated - single or double sided, or half pulped - including a mix of flakes of material and fibres of material, each sample comprising about 70% to about 80% plant material) showed that the tensile strength σ of the pulped strips is about twice as large as that of the half pulped and half laminated strips and about four times as large as for the laminated strips (Table 1). This data shows that the more particles of material that are small, the more close to each other they are and consequently the

sample is more resistant. The results for *R* also bear this out, the smaller the particles the tougher the material.

SWEET CORN STRIPS	Bending test	Pulling test	Cutting test
σ (pulped)	2.25MPa	0.3MPa	-
σ (laminated)	0.48MPa	0.1MPa	-
σ (half pulped and half laminated)	0.85MPa	0.2MPa	-
R (pulped)	-	-	0.45MJ.m^{-2}
R (laminated)	-	-	0.26MJ.m^{-2}
R (half pulped and half laminated)	-	-	0.32MJ.m^{-2}

Table 1

The pulling test carried out on banana strips showed the more water in the strip the lower the Young's modulus E (Table 2), as the Young modulus E represents the rigidity of the material, it can be concluded that the material is more flexible in the presence of water.

BANANA STRIPS	Young modulus *E*
100% glue	240.9MPa
75% glue + 25% water	187.18MPa
60%glue + 40% water	118.23MPa
50% glue + 50% water	98.51MPa
40% glue + 60% water	65.8MPa

Table 2

The various tests carried out on banana stem strips showed that the more water there is the smaller the tensile strength σ. Thus the material is more resistant when there is no water (Table 3). This is borne out in the toughness *R* results.

BANANA STRIPS	Bending test	Pulling test	Cutting test
σ (100% glue)	5.04MPa	1.98MPa	-
σ (75% glue + 25% water)	1.46MPa	1.08MPa	-
σ (60%glue + 40% water)	1.44MPa	0.87MPa	-
σ (50% glue + 50% water)	0.78MPa	0.57MPa	-
σ (40% glue + 60% water)	0.68MPa	0.2MPa	-
R (100% glue)	-	-	5.86MJ.m^{-2}
R (75% glue + 25% water)	-	-	3.05MJ.m^{-2}
R (60%glue + 40% water)	-	-	2.9MJ.m^{-2}
R (50% glue + 50% water)	-	-	2.11MJ.m^{-2}
R (40% glue + 60% water)	-	-	1.57MJ.m^{-2}

Table 3

These results in Table 4 show that the Etistar 610™ glue makes a more resistant material than the tamarind glue does because the tensile strength σ is larger. However the tamarind glue makes a more flexible material evidenced by the lower Young's modulus E.

BANANA STRIPS	Dry in the oven
σ (Etistar 610 glue)	1.98MPa
σ (tamarind glue)	0.45MPa
E (Etistar 610 glue)	240.9MPa
E (tamarind glue)	79.33MPa

Table 4

Table 5 shows that wax is a slim barrier against the water and that flax can be used to increase the wet resistance of the material. The flax was added at about 20 to 25% by weight and had the effect increasing the wet strength by about four fold.

BANANA STRIPS	After 5 minutes of exposure to steam
σ (100% glue)	0.17MPa
σ (100% glue + wax)	0.27MPa
σ (100% glue + flax)	0.71MPa
σ (100% glue + wax + flax)	0.74MPa

Table 5

Example 5 - Drying of Plant Material

To compare conventional drying methods with microwave drying methods experiments were undertaken to compare these drying methods on banana stems and corn leaves.

Press Drying - leaves and stems can be dried by pressing between sheets of blotting paper, studies have shown that this technique has problems relating to the growth of mould on the samples and the rolling up of the sample edges.

Conventional Drying - banana stems were cut into cylindrical sections (dimensions of 12 x 4.5 inches) and dried by using a cabinet dryer with hot air at 60±1°C for 24 hours. Every other layer of the banana stem was sampled, starting from the outermost layer (layer 1) to the inner most layer which is wrapped around the core. On average it was possible to obtain samples from four layers. Samples were collected at the differing times of 0, 2, 4, 6, 8, 10 and 24 hours. Moisture content was determined using a moisture analyser (MA 40).

A second set of experiments involved separating individual layers, and drying at ambient temperature, 20±2°C, for 3 days before determining the moisture content.

Microwave Drying - banana sheets were cut to 10-12 inches in length and 4-4.5 inches in width, out of each layer and subjected to microwaves at different power levels (output power at high level: 1800W, medium level: 900W and low level: 360W) until the moisture content reached about 10-15%.

Corn leaves do not have the same moisture content throughout. Ten leaves were separated from one corn and numbered from 1 to 10, number 10 representing the outermost leaf, and 1 the innermost which is in contact with the kernels. Each leaf was separated into two parts the "top" and the "base". The base was cut off about 5mm from the bottom. The moisture content of each part of every leaf was determined. For microwave drying, a whole leaf was fried for 3 min at low power level and the moisture content was determined. All experiments were duplicated.

Results

Characteristics of Moisture Content

Banana Stems - fresh banana stem had over 90% moisture content. The highest moisture content was about 95% observed in the innermost layer. For the drying experiment, the average of initial moisture content was 89% in the outermost layer.

Corn leaves - before drying, the base part of the corn leaf had higher moisture content than the top part. The highest moisture content of the innermost leaf was about 62% observed in the base, and about 20% in the top part. For the outermost leaf, the moisture content of both the base and the top parts were more

uniform, varying between 12 and 13%. Figures 5a and 5b show the moisture content of the top part (a) and the base part (b) of each leaf. The average moisture content of a whole leaf determined from leaf 5 to leaf 10 (outermost leaf) was 46, 34, 26, 18, 16 and 12%, respectively. With the exception of the outermost leaf, these average values were closer to the moisture content of the respective bottom part, which is relatively high because of the proximity to the kernels. It may be noted that the average moisture content of corn kernels was 71 to 74%.

Drying methods

Conventional drying methods - High temperature(60°C)

By using a cabinet dryer, the initial moisture content of four layers of banana stem taken from outside to inside was 89 to 93% and reduced to 14 to 72% after drying for 24 hrs (Figure 6 a, b, c, d). The moisture contents decreased as a function of time due to diffusion and osmosis. Drying rate of layer 1 (i.e. the outermost layer) was fastest, followed by layers 2, 3 and 4 which were about 1.4, 2.3 and 3.6 times lower, respectively (Figure 7).

Conventional drying methods - Ambient drying (20°C)

For these experiments, the initial moisture content of the four layers of banana stem varied between 89 and 93%. The moisture content of layers 1, 2, 3 and 4 reduced to 15, 39, 64 and 76%, respectively after drying for 3 days (Figure 8). Compared with drying at 60°C, it is clear that the final moisture contents are higher, even though the samples were dried samples; some

samples were also observed to fold due to uneven dimensional changes.

Microwave Drying - Banana Stems

Effect of power levels on moisture contents

The banana sheets which had the same dimension, i.e. 12x4.5 inches, and 88% initial moisture content were dried in a microwave at high power level for 2 minutes and medium power level for 3 minutes. The final moisture contents were 14 and 17%, respectively. To reduce the drying time, a combination of high, medium and low levels were considered. It was found that the low level was unsuitable initially when the moisture content was high (over 93%). The use of high power level reduced the drying time, but microwave application could not be continued beyond 2 minutes because of deterioration in appearance. Medium power level appeared optimum.

Effect of sample weights on drying times and appearances

Eleven banana sheets having different initial thicknesses and weights were dried to 10-13% moisture contents. It is clear from Figure 9 that initial weight and drying times are proportional. The sheet dried for the highest duration using the medium power level (10 minutes), had poor appearance; it was deformed and shrunken, and had a brown colour. It may be noted that this sheet also had a high thickness and weight, and high initial moisture content. The dried sheet was brown and appeared burnt. The banana sheet which had an initial moisture content of around 80-90% gave a good colour. In addition, the rapid removal of

moisture also puffed the sheet which acquired a corrugated appearance. From out studies, the optimum drying time appears to be 4 to 4.5 minutes using medium level for samples which are initially contain 86-88% moisture (the typical weight of a sheet 12x4.5 inches is approx. 49-61 grams).

Microwave drying – Corn leaves

Initial moisture content of a whole corn leaf starting from layer 5 to 10 (which is the outermost layer) varied between 46 and 12%. The final moisture contents, after subjecting the leaves to low power level microwave for 3 minutes varied between 17 and 11%, respectively. Figure 10 shows that the moisture content of dried leaf does not fall below 11%, which may be an equilibrium moisture content. Dried leaves had a good colour, similar to the original leaf.

It is obvious from the results that convective air drying is very slow. On the other hand, microwave drying reduces drying times to the order of a few minutes.

Folding characteristics of corn husk and banana tissue

Preliminary tensile and three point bending tests were carried on single pieces of corn husk, some laminated husks composites and banana stems (VB) in order to assess their "formability" as a function of moisture content. Three spans and five moisture contents (m.c.) were chosen: 80-90% (fresh, highly hydrated tissues), 30-40% (partial free water removal),20-30% (cellulose fibre saturation point), 10-20% (air dried) and 15% (microwave dried). The results for banana stems are shown in Figure 11.

They suggest a minimum of bending force (associated with a minimum of damage in folding) between 25% and 30% m.c. which corresponds with the cellulose fibres saturation point. Above this mc the structure of the stem still contains significant amounts of water and the leaf structure is intact, about 5mm thick. When the tissues are dried, they collapse to about 2 mm thickness, become stiffer and more brittle and the folding force increases.

Waxing and water-proofing

The use of paraffin waxes as coatings for moisture barrier has been investigated and some results are reported here. Paraffin oil and wax are unique as coating materials because they provide excellent moisture barrier properties. Since they are not high molecular weight polymers, they are inherently biodegradable and compost most readily. They are used extensively to coat foods and food packaging materials, providing the advantages mentioned above.

Dried banana which was cut into rectangular sheet

The average moisture content of dried banana sheet is about 10+ 2% on a wet basis. Different types of paraffin were used: oil (liquid) and wax (solid). These paraffin-based coating materials, differ in viscosity and congealing point (oil) and melting point (waxes). Coated banana sheets are left overnight at ambient temperature before determination of moisture holding capability. Thickness of coating is characterised by the increment in weight following the application of the coat. The coated banana sheets are then soaked in water for one hour. The surface water is

removed by using tissue. The moisture barrier capability is measured by determining weight gain as a function of time following immersion in water. As an alternative suitable for film coating, the use of polylactic acid (PLA) has been discussed.

Example 6 - Production of an Article from Pulped Plant Material

Maize plant material was chopped to pieces that were about 10mm in length. These pieces of plant were then further reduced in size to below 4mm in length by putting them through a laboratory grinder of 500cc bowl size. The chopped maize was then disintegrated in a laboratory conical refiner (UEC refiner model number 2019) of 300mm disc size. The speed was 1500 rpm. The power supply was 440V 3ph. 50Hz; and the power consumption was 7.5 to 40Kw.

30kg of starting material was treated in this manner, which due a moisture content of 60% was equivalent to about 11.5kg of dry material. This material was then loaded, hand fed, through the funnel of the refiner with 1500 litres of water (the resulting slurry passing through the refiner having 5 to 6 % by weight of plant material) initially the material was disintegrated for 0.5hours. After 0.5 hours the fiber length was 1.5 to 2 mm and the freeness of the pulp was 200 CSF. After a further 0.5 hours refining of the maize, cellulose fibres from extract from cotton rags were added, such that the cellulose comprised about 25% by weight on the basis of total slurry weight. The cellulose fibres had a CSF of 350. Further refining of the maize and celloluse was undertaken for another 0.5hours. The CSF of the slurry was then 185 CSF. After this 2% starch, 3% Rosin (abetic acid) and 5% of Alum-

Aluminium sulphate was added, the resulting pH was 4.5. The material was then mixed in hydra pulper UEC 2020 of 10 litre capacity (Note- UEC= Universal Engineering Company-www.universalenggcorp.com) for 0.5 hours. A further 1½ hrs mixing was undertaken to prepare a desired slurry.

A hand sheet of 3 gms of above slurry was prepared on a hand sheet making laboratory machine (UEC2005 SCA Type) and was allowed to air dry. The burst factor of the dried paper was 3.01, the breaking length of paper was 263.77, and the final C.S.F. of the pulp was 185 C.S.F.

The slurry thus made was used to produce tomato punnets with 150mm length, 85mm width and 55mm depth and thickness of 2mm.

A male & female tool for molding were made from aluminium alloy. The surface of the tools were fitted with industry standard fine wire mesh size 30 (Stainless steel) for pulp adhesion.

The slurry was poured into the moulding machine (PM5000 Sodaltech™) tank of dimensions 1.2 meters by 0.75 meters by 0.75 meters deep for vacuum molding. The male part of the tool was submerged in the tank filled with the slurry. The submerged male mould was then vertically moved and raised up and out of the slurry in the tank. It could be seen that the plant fibres had adhered to the tool. The female part of the tool was then lowered on to the male mould and vacuum pressure applied (600 mm of mercury). This process forms an article corresponding to the shape of the male mould, for example a punnet for foodstuffs. The male tool is then taken back into the slurry. The moulded

article, for example the punnet, remains attached to the inside of the female tool. On removing the vaccum the article is released from the female mould. Before releasing the vacuum the female mould is placed over a conveyor. The conveyor takes the released article through an oven drier. The temperature in drier increasing from room temperature to above 130 degrees celcius. The conveyor moves at a speed of about 3ft/per minute

Once dried the article is complete. If required the article can be further treated to meet the requirements of the end user. For example, a wax coating could be applied or surface decoration.

Example 7 - Production of an Article from Liquid Slurry

Corn, maize, banana or leguminous plant material if dry are soaked for 48 hours then put through a refiner and/or beater or a combination of hydra pulper and beater, to produce fibre pieces of about 150μm to about 250μm (size control exercised by measuring CSF parameter of handsheets made from the slurry). The slurry has a CSF around 250 and is mixed in the following ratio:

about 5% to about 8% by weight crushed plant material
about 3% to about 4% by weight wax (eg beeswax)
the rest is aqueous material including binding agent, the binding agent comprises 3 to 4% by weight of the composite

The above is mixed at ambient temperature and passed through a known pulped paper vacuum moulding process to produce articles, such as plant pots and hanging basket liners.

Example 8 - Production of an Article from a Non-Liquid Composite

Maize stems, leaves and husks are left in the field to dry. A reduction in moisture content from 70% to 20 to 30% is observed. The plant material is then chopped to 10mm lengths. The chopped plant material is then placed in a hydra-pulper. The chopped pieces are then fibrillated, that is, the outer layers are loosened up to expose and free up inner core cellulosic fibres of 1.5 to 2mm in length by the beating and chopping action in the hydra pulper vessel. This material is blended at about 70% to about 80% by weight with about 15% to about 25% by weight reinforcing cellulose fibres extracted from material such as cotton, jute, flax, straw, switchgrass or hemp or a mixture thereof. Starch is then added to the pulp at about 3 to about 8% by weight. Linseed oil or cashew nut oil may then be added to provide hydrophobicity to the product. This material is then used to substitute pulped paper in a vacuum-molding machine to produce articles such as egg trays and tomato punets.

Example 9 - Production of an Article from a Non-Liquid Composite

Example of production of an article from a substantially non-liquid composite comprising nearly 100% plant fibres.

Maize plant material was chopped into pieces of 10mm or less in length. These were then further reduced in size to below 4mm in length by putting them through a laboratory grinder of 500 cc bowl size. The chopped maize was then disintegrated in a laboratory conical refiner (UEC refiner model number 2019) of

300mm disc size. The speed was 1500 rpm and the power supply was 440V 3ph. 50Hz with a power consumption of 7.5 to 40Kw.

30 Kg of plant material was chopped material, of which about 11.5kg was dry matter and the rest was moisture. The chopped plant material was then loaded, hand fed, through the funnel of the refiner with 1500 litres of water (the slurry in the refiner comprised 5 to 6% plant material). Initially the plant material was disintegrated for 0.5 hours. After 0.5 hours the fibre length was 1.5 to 2 mm and the freeness of the pulp was 250 CSF. 2% starch, 3% Rosin (abetic acid) and 5% of Alum-Aluminium sulphate was then added to the refined pulp. The pH of the pulp was 4.5. The material was then mixed in hydra pulper UEC 2020 with a 10 litre capacity (UEC is the Universal Engineering Company - www.universalenggcorp.com) for 0.5 hours for proper mixing to produced desired slurry.

A hand sheet of 3 gms of above slurry was prepared on a hand sheet making laboratory machine (UEC2005 SCA Type) and was allowed to air dry. The burst factor of the dried material is 1.25, the tensile index N.m/gm is 0.29, the final C.S.F. of the slurry is 250 C.S.F., the Stiffness Taberis 5 and the double folds number is 0 and hence the material is very brittle.

The slurry was then used to produce an A4 size sheet 210mm width and 296mm height and 3mm thickness as padding for envelopes.

A size 35 wire mesh made from stainless steel was fitted to wooden frame (75mm sq. cross section) of 740mm by 450mm to make up a tray.

This was held in water tank of 300mm height, 1 meter length and 600m width and was half filled with water. The tank was fitted with three drain pipes to drain rapidly water from it. The wire mesh tray was immersed in the water so that it was just below the water level in the tank. About 1.5 to 2litres of slurry was poured into the tank and the wire mesh was lifted up and down above the liquid level in the tank about 2 to 4 times and water drained off. This produced a layer of 3mm thick plant material sheet on the wire mesh. The layer of plant material was allowed to dry overnight at ambient temperature of 24 degrees Celcius to give a board like padding material which was cut to size 210mm by 296mm to give padding for envelope padding material.

Example 10 - Production of an Article from maize husk plant material

Maize is harvested from a maize plant, and vast amounts of husks remain. The husks are sorted based on their moisture content and separated. The husks are dipped in sodium hypochlorite/sodium metabisulphate to inhibit mould growth. The husks are flattened and moisture removed from about 70% to about 50% by air drying. Alternatively microwave heating can be used to bring the moisture content down to about 20 to about 40%. Adhesive is then applied to the husks by spraying. The adhesive may be a tamarind glue, a wood glue or a starch base glue. The sheets are then overlaid to form a two or three layer laminate and compressed. The material can then be cut to size for use.

Example 11 - Properties Achieved With a Maize Slurry and Cellulose From Recycled Paper

The various properties below were achieved in paper sheets produced from a maize slurry with and without cellulose obtained from waster paper.

Parameters	**100% Maize**	**90% Maize + 10% W.P.**	**80% Maize + 20% W.P.**	**70% Maize + 30% W.P.**	**60% Maize + 40% W.P.**	**50% Maize + 50% W.P.**
CFS,ML	**250**	**250**	**250**	**250**	**250**	**250**
Tensile Index, N.m/gm	0.29	0.90	1.10	2.50	5.49	9.90
Burst Factor	1.25	1.75	2.14	2.47	2.71	3.74
Stiffness, Taber	5	10	13	15	18	25
Double Fold, No.	00	2	5	10	15	28

Result of strength properties of the sheets tested under standard conditions of 65± 2% Relative Humidity and 27±1 degree Celsius are recorded in Table.

Here CSF means Canadian standard freeness and WP means cellulose from waste paper. The parameters are typical/standard to the paper industry and the measuring instruments and methodology similar. Double folds test method shows how many times the hand sheets can be folded before breaking.

It is noted that when slurry is made without cellulose fibres-i.e. 100% maize in the above example the tensile strength is low and molded shapes will not have the strength required and will break

at any attempt to fold them. As more cellulose is added higher mechanical strength is achieved.

CLAIMS

1. A method of producing a biodegradable composite from plant material comprising the steps of converting the plant material into smaller pieces and mixing the plant material with a binding agent to form a substantially non-liquid composite.

2. A method of producing an article from a biodegradable composite comprising the steps of converting the plant material into smaller pieces, mixing the plant material with a binding agent to form a substantially non-liquid composite and moulding the composite into an article.

3. A method of producing a biodegradable composite material from plant material from one or more of banana (Musa sapientum), corn (Zea), maize, rice, sugarcane, Remi, grasses of the Miscanthus type, switchgrass, wheat, linseed straw and leguminous plants comprising the steps of converting the plant material into smaller pieces and mixing the plant material with a binding agent to form a substantially liquid composite slurry.

4. A method of producing an article from a biodegradable composite material comprising the steps of converting plant material from one or more of banana (Musa sapientum), corn (Zea), maize, rice, sugarcane, Remi, grasses of the Miscanthus type, switchgrass, wheat, linseed straw and leguminous plants into smaller pieces, mixing the plant material with a binding agent to form a substantially liquid composite slurry and forming an article from the composite.

5. A biodegradable substantially non-liquid composite obtainable by the method of claim 1.

6. A biodegradable substantially non-liquid composite comprising small pieces of plant material and a binding agent.

7. A biodegradable liquid composite slurry obtainable by the method of claim 3.

8. A biodegradable liquid composite slurry comprising small pieces of material from one or more of banana (Musa sapientum), corn (Zea), maize, rice, sugarcane, Remi, grasses of the Miscanthus type, switchgrass, wheat, linseed straw and leguminous plants and a binding agent.

9. A method according to claim 1 or claim 2, or a composite of claim 5 or 6, wherein the substantially non-liquid composite has a dough-like consistency which forms a workable paste and is self supporting.

10. A method according to any of claims 1, 2 or 9, or a composite of claim 5, 6 or 9, wherein the plant material is converted into pieces of a size of about 20mm ± 5mm.

11. A method or a composite according to claim 10 wherein the size of the pieces of plant material is about 15mm ± 3mm.

12. A method or a composite according to claim 10 wherein the size of the pieces of plant material is about 2mm ± 1mm.

13. A method according to any one of claims 1, 2, 9 to 12, A composite according to any one of claims 5, 6, 9 to 12 wherein the plant material is obtained from one or more of banana (Musa sapientum), corn (Zea), maize, rice, sugarcane, Remi, grasses of the Miscanthus type, switchgrass, wheat, linseed straw and leguminous plants.

14. A method according to claim 3 or 4, or a composite of claim 7 or 8, wherein the plant material is converted to produce particles of about 150μm to about 250μm in diameter or along one side.

15. A method or a composite according to claim 14 wherein the particles are fibrous and/or planar and/or granular.

16. A method or a composite according to claim 14 or 15 wherein the plant material also includes flakes of plant material which are larger than the about 150μm to about 250μm particles.

17. A method or a composite according to claim 16 wherein the flakes are between about 1mm and about 20mm on any side.

18. A method or a composite according to any preceding claim wherein the plant material is converted into smaller pieces before it is mixed with the binding agent.

19. A method or a composite according to any preceding claim wherein the plant material is converted into smaller pieces by grinding, crushing, cutting, milling, rolling or shredding the plant material.

20. A method or a composite according to any preceding claim wherein the binding agent is an adhesive.

21. A method or a composite according to claim 20 wherein the adhesive biodegradable.

22. A method or a composite according to claim 20 or 21 wherein the adhesive is selected from the group comprising starch-based adhesives, adhesive derived from *Tamarind* seeds, natural gums, sugar derivative adhesives, synthetic glues and synthetic gums.

23. A method according to any preceding claim comprising drying the plant material being converting into smaller pieces.

24. A method according to claim 19 wherein the plant material is dried by microwave.

25. A method or a composite according to any preceding claim comprising adding wax and/or one or more agents to provide hydrophobic properties.

26. A method or a composite according to claim 25 wherein the wax is biodegradable.

27. A method or a composite according to claim 25 or 26 wherein the wax is selected from the group comprising beeswax, a paraffin-based wax, PLA and PCL, and the optional one or more agents is selected from the group comprising shellac, cashew nut oil and linseed oil.

28. A method or a composite according to any preceding claim comprising adding reinforcing products selected from the group comprising flax, hemp, sugar cane molasses, paper fibres and grass fibrous material, such as miscanthus.

29. A method or a composite according to any preceding claim also comprising rape seed oil and/or coconut oil, and/or egg white.

30. A method or a composite according to any preceding claim wherein the plant material is treated with a mould-inhibiting agent.

31. A method or a composite according to any preceding claim wherein a dye is added to the composite.

32. A composite or a composite made according to the method of any of the preceding claims in combination with a laminated product.

33. An article made from a composite made according to the method of claim 1 or claim 3 or any claim dependent thereon.

34. An article made according to the method of claim 2 or 4 or any claim dependent thereon.

35. An article made from a composite according to claim 5, 6, 7, or 8 or any claim dependent thereon

36. A biodegradable article comprising corn/maize, banana stem and/or leguminous plant material which has been converted into

pieces with a length or diameter of from about 150μm to about 20mm ± 5mm and a binding agent.

37. An article according to any one of claims 33 to 36 which is selected from the group comprising packaging, a disposable container, a plant pot, a weed suppressant mats, a hanging basket liner, a plant guard, a table mat, a coaster, crockery, wrapping paper and wall paper.

38. An article according to claim any one of claims 33 to 37 which also includes a reinforcing product.

39. An article according to claim 38 wherein the reinforcing product is selected from the group comprising flax, hemp, sugar cane molasses, paper fibres, chicken feathers, wool and grass fibrous material, such as miscanthus.

40. An article according to claim 38 or 39 wherein the article has a wet strength at least four times greater than an article without a reinforcing product.

41. A padding material comprising a layer of composite material made according to any preceding method.

42. A padding material according to claim 41 wherein the composite material is in the form of a layer which has a layer of paper on at least one side of the layer.

43. A padding material according to claim 41 or 42 wherein the layer of composite material is from between about 1mm and about 2cm thick.

44. A padding material according to any one of claim 41 to 43 comprising a layer of paper on one or both sides of the layer of composite material.

45. A method of making a padding material comprising applying a slurry composite according to claim 7 or 8 to a layer of paper, and drying the slurry to form padding material.

46. A method of making a padding material comprising applying a layer of substantially non-liquid composite according to claim 5 or 6 to a layer of paper.

47. A padded envelope in which the padding is made from plant material.

48. A padded envelope according to claim 47 wherein the plant material is derived from one or more of banana (Musa sapientum), corn (Zea), maize, rice, sugarcane, Remi, grasses of the Miscanthus type, switchgrass, wheat, linseed straw and leguminous plants.

49. A padded envelope according to claim 47 or 48 wherein the plant material is in the form of strips.

50. A padded envelope according to claim 49 wherein the strips of plant material are dried and flattened.

51. A padded envelope according to any one of claims 47 to 50 wherein the plant material is dried in a conventional oven or by the use of microwaves.

52. A padded envelope according to any of claims 47 to 51 wherein the plant material is woven into a mat.

53. A method of preparing plant material for processing comprising drying the material by microwaves.

54. A method of preparing plant material according to claim 53 wherein the plant material is sourced from one or more of banana (Musa sapientum), corn (Zea), maize, rice, sugarcane, Remi, grasses of the Miscanthus type, switchgrass, wheat, linseed straw and leguminous plants

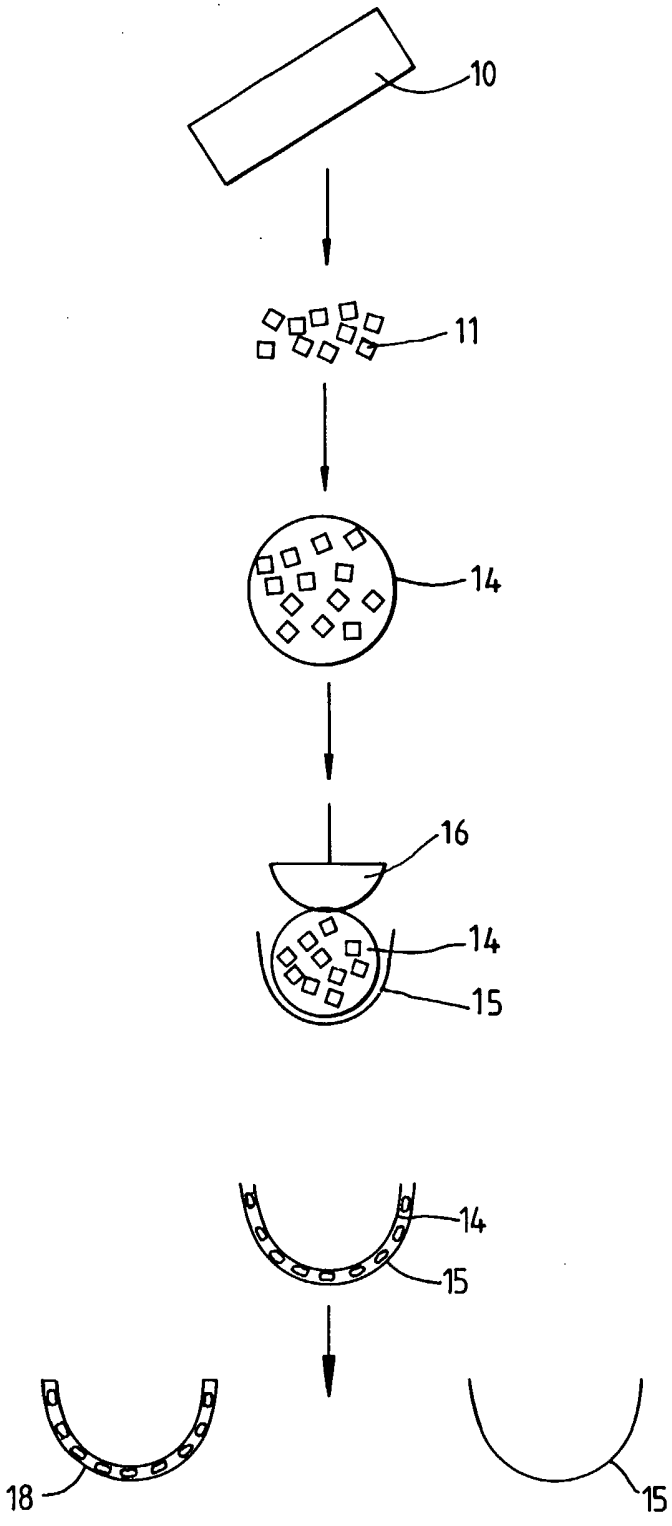


Fig. 1

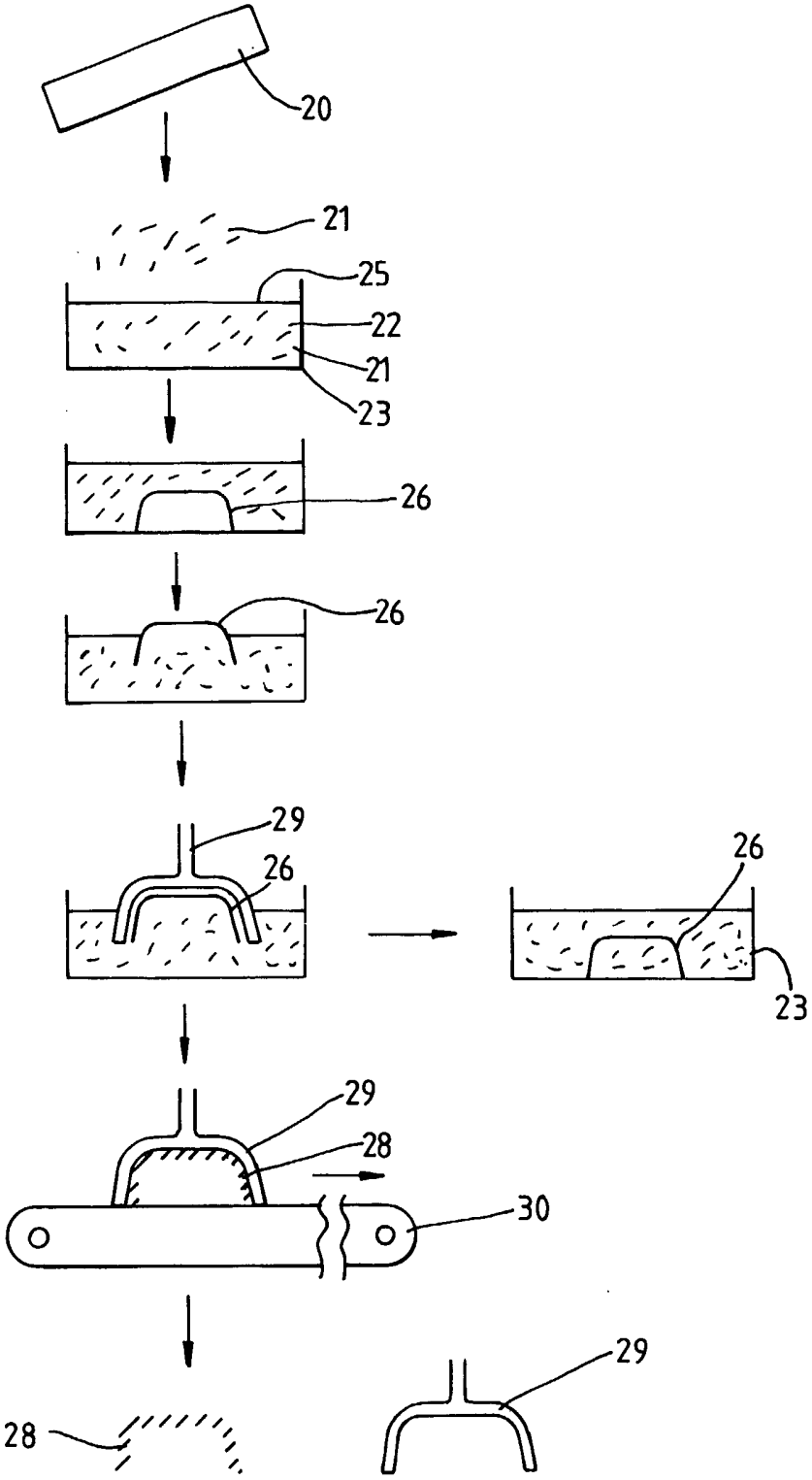


Fig. 2

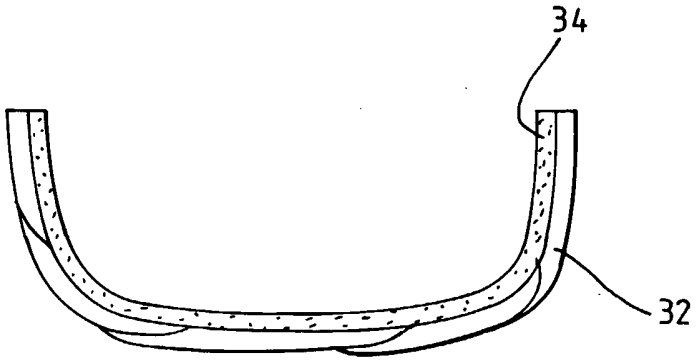
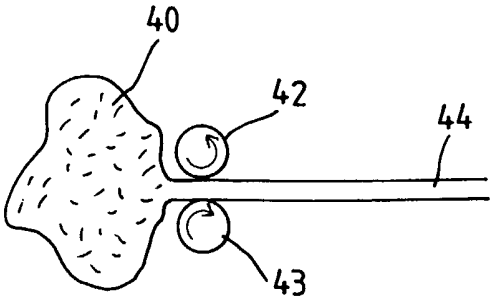
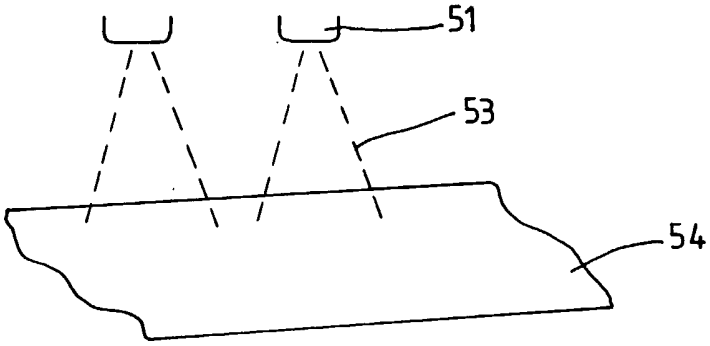
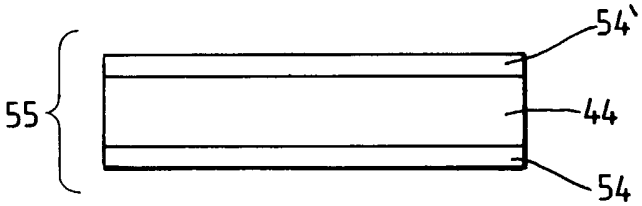


Fig. 3







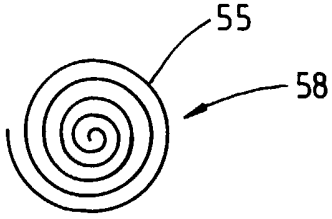


Fig. 4a

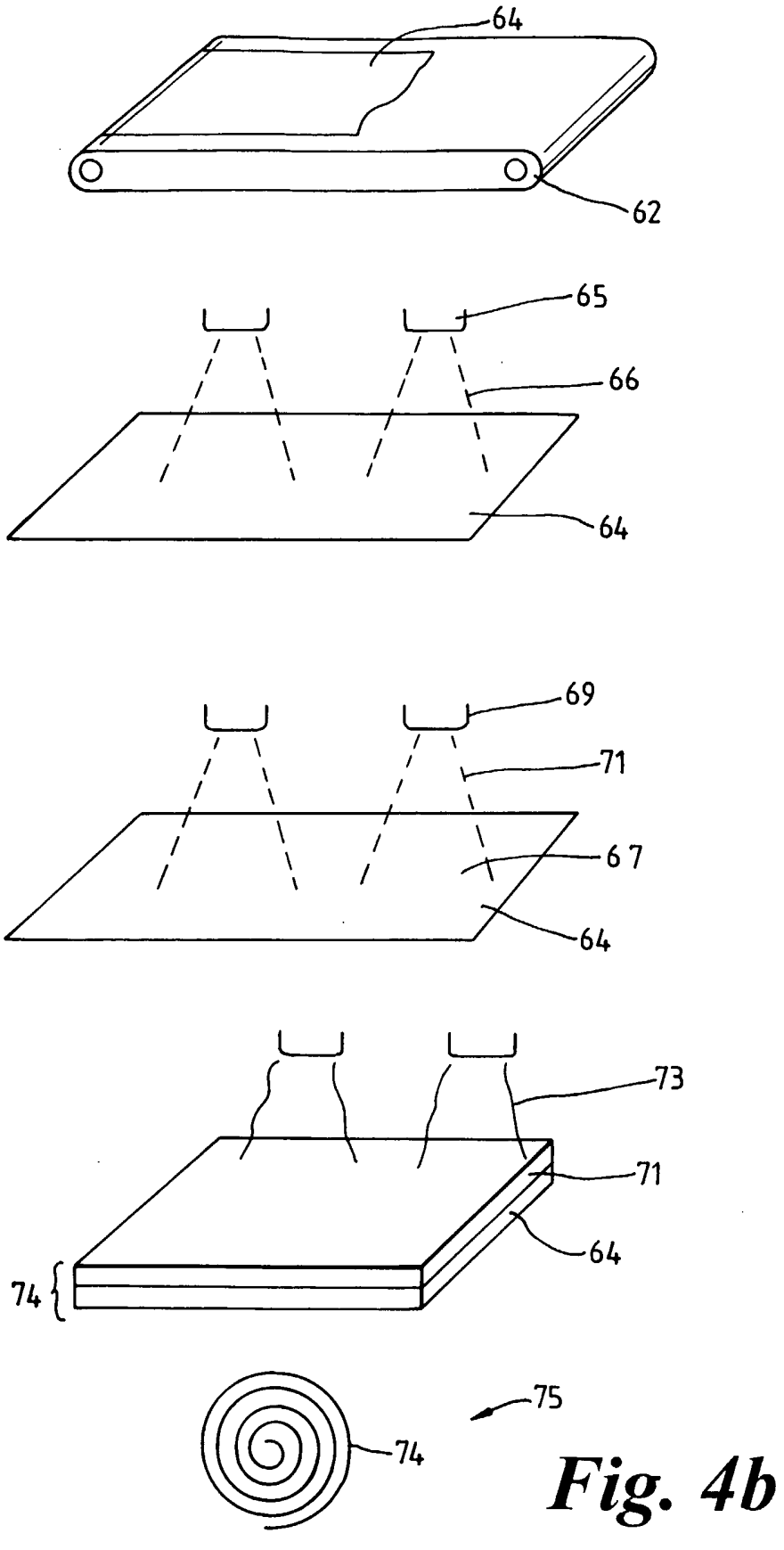


Fig. 4b

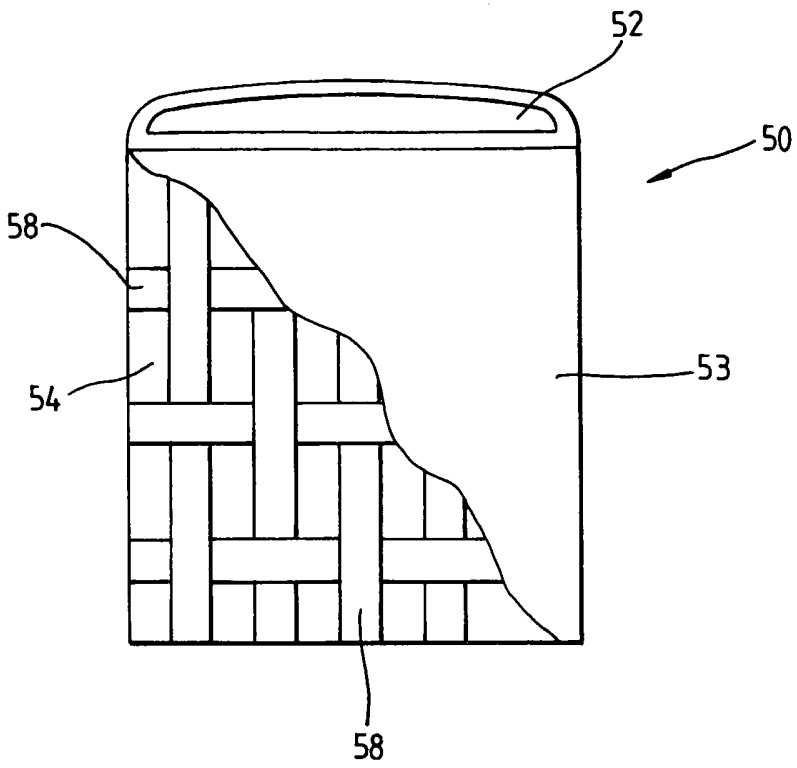


Fig. 5

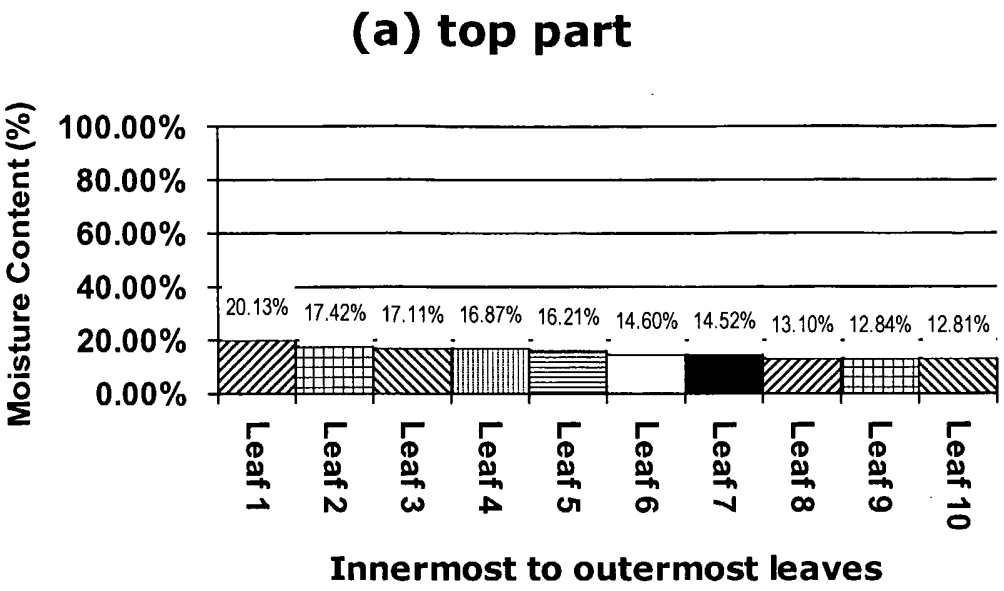


Figure 6a

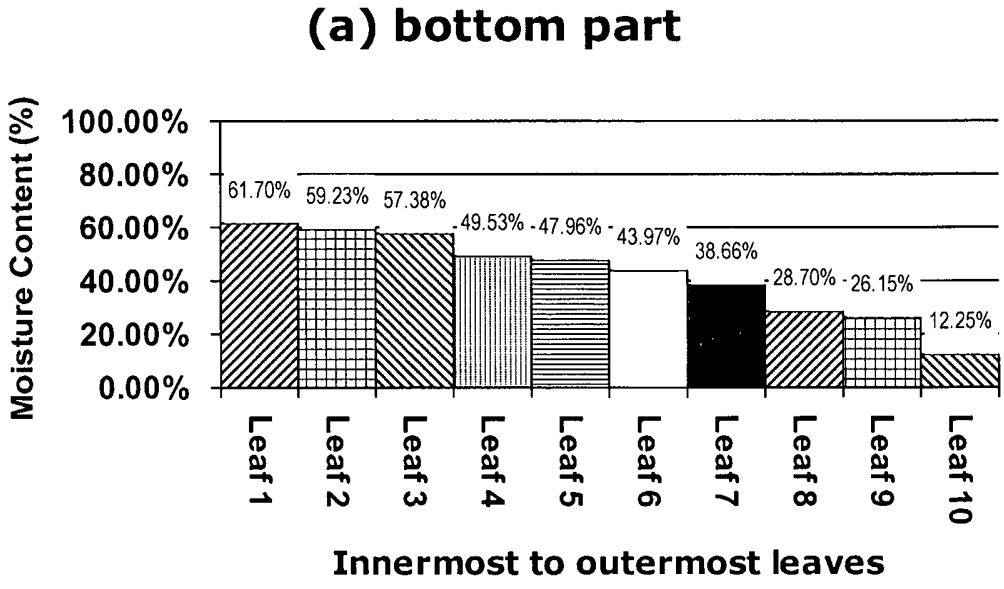


Figure 6b

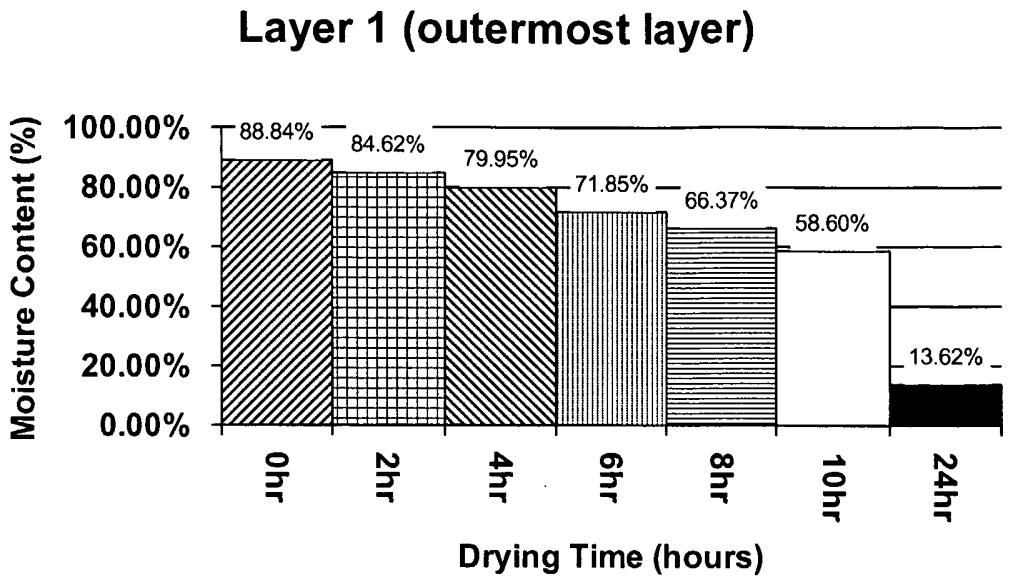


Figure 7a

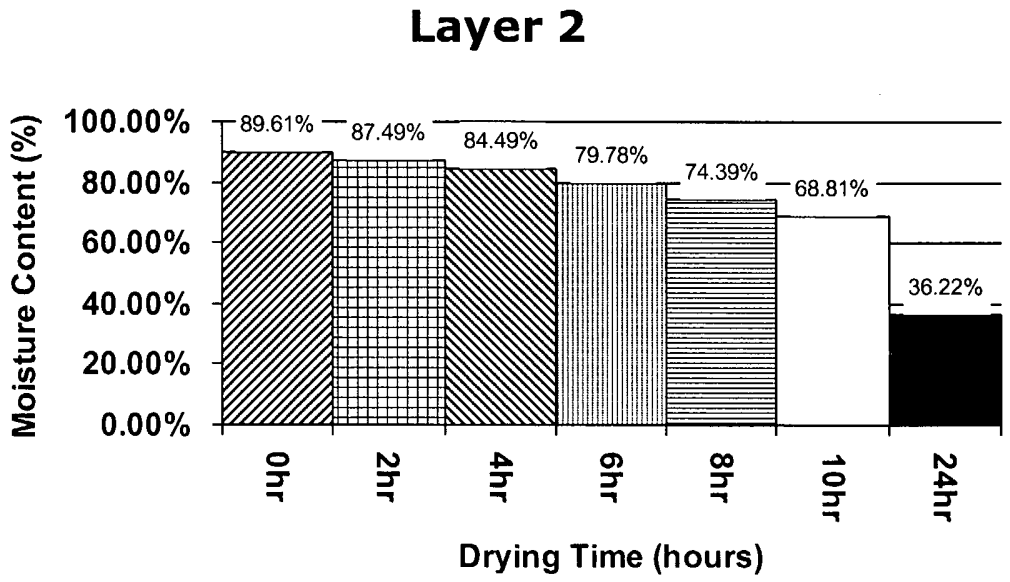


Figure 7b

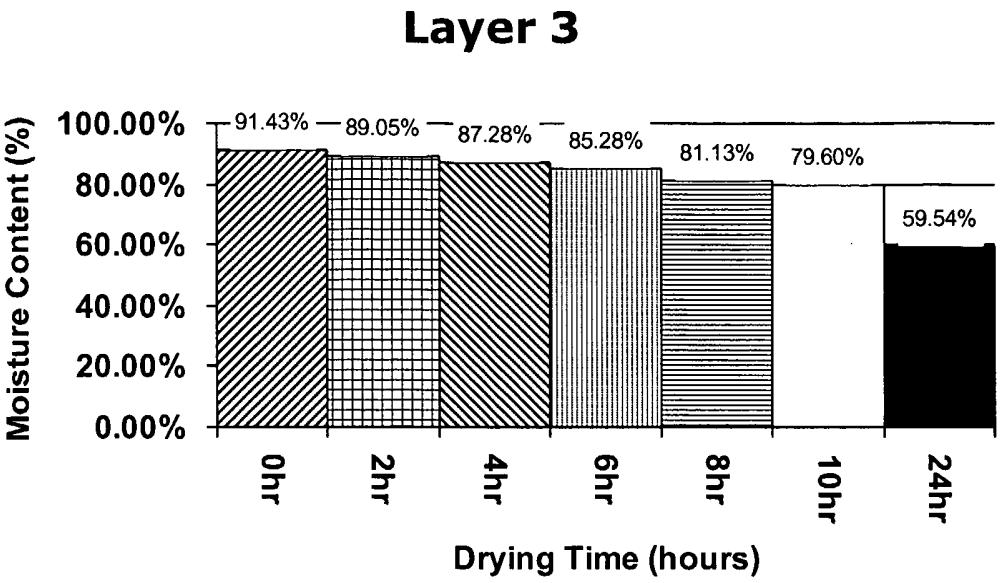


Figure 7c

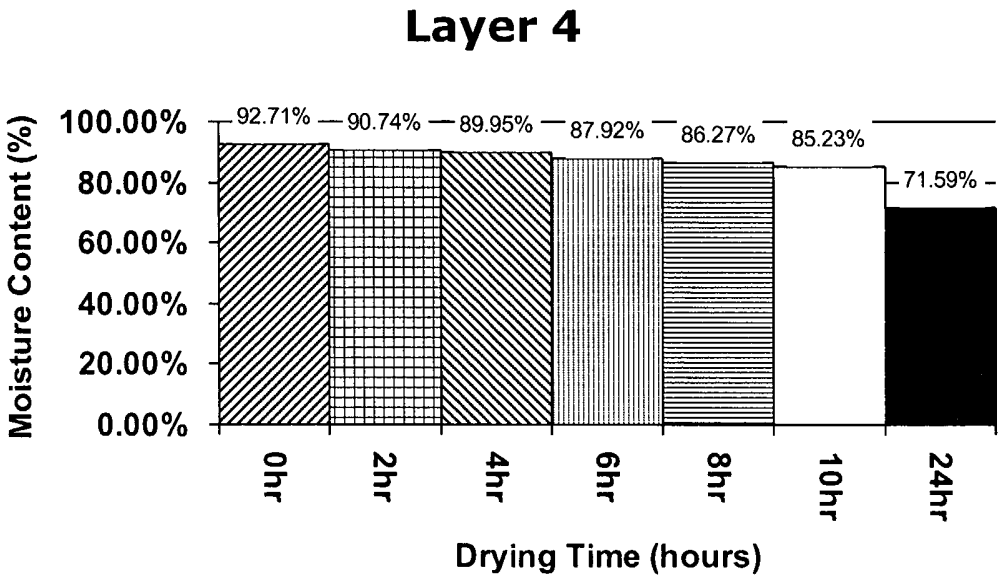


Figure 7d

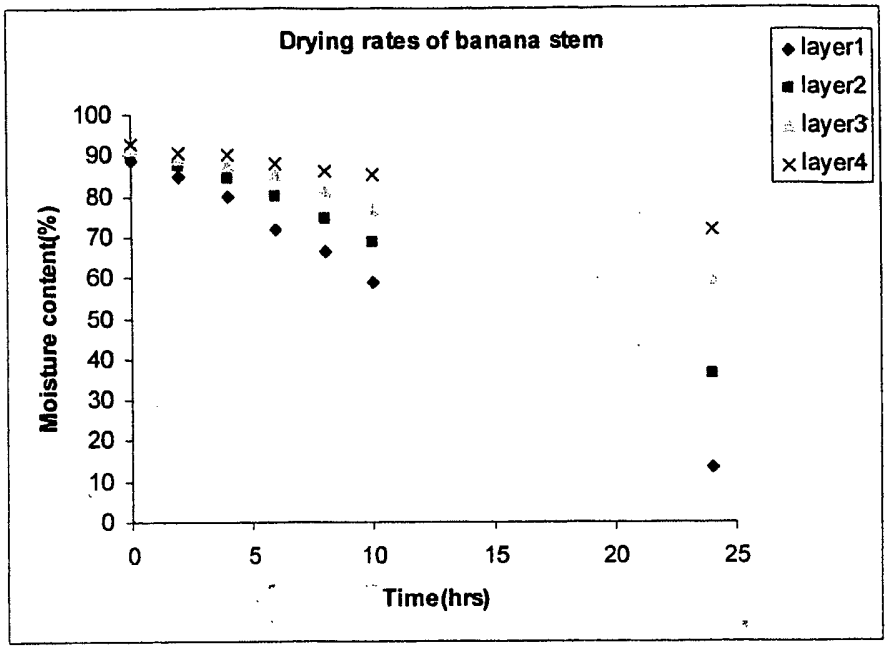

Drying rates of banana stem
layer1
layer2
layer3
layer4
Moisture content(%)
100
90
80
70
60
50
40
30
20
10
0
0
5
10
15
20
25
Time(hrs)

Figure 8

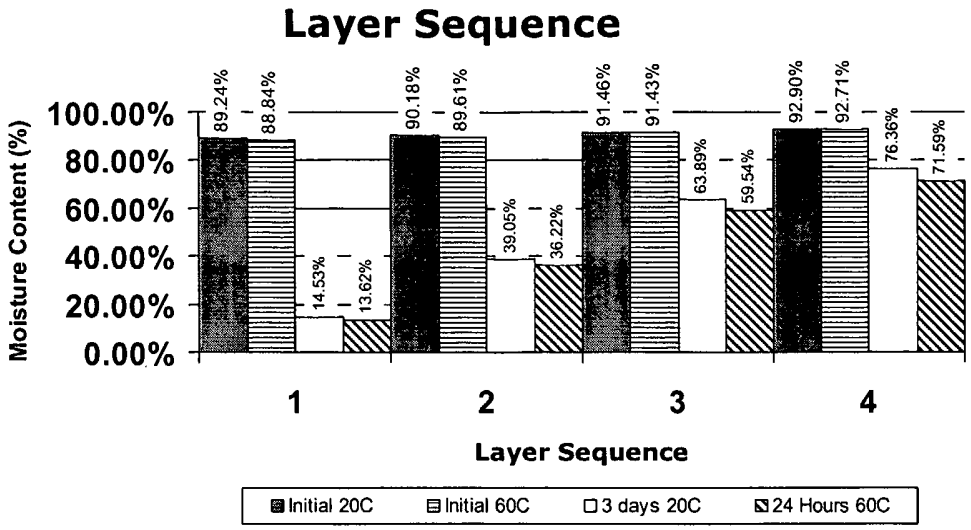

Layer Sequence
Moisture Content (%)
100.00%
80.00%
60.00%
40.00%
20.00%
0.00%
89.24%
88.84%
14.53%
13.62%
90.18%
89.61%
39.05%
36.22%
91.46%
91.43%
63.89%
59.54%
92.90%
92.71%
76.36%
71.59%
1
2
3
4
Layer Sequence
Initial 20C
Initial 60C
3 days 20C
24 Hours 60C

Figure 9

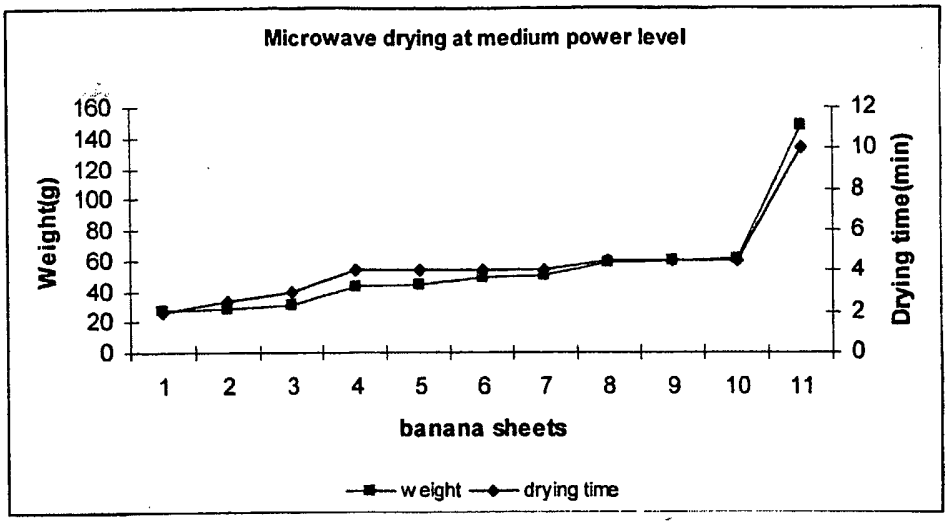

Microwave drying at medium power level
Weight(g)
160
140
120
100
80
60
40
20
0
Drying time(min)
12
10
8
6
4
2
0
1
2
3
4
5
6
7
8
9
10
11
banana sheets
weight
drying time

Figure 10

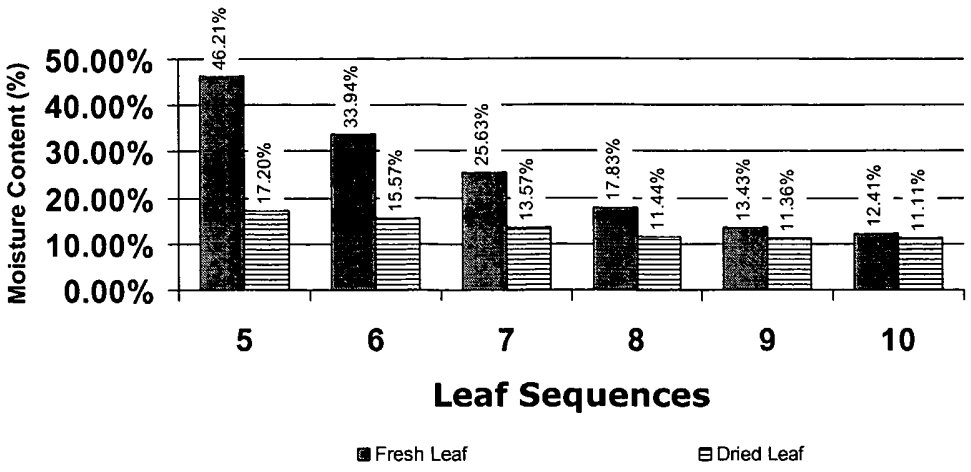

Moisture Content (%)
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
46.21%
17.20%
33.94%
15.57%
25.63%
13.57%
17.83%
11.44%
13.43%
11.36%
12.41%
11.11%
5
6
7
8
9
10
Leaf Sequences
Fresh Leaf
Dried Leaf

Figure 11

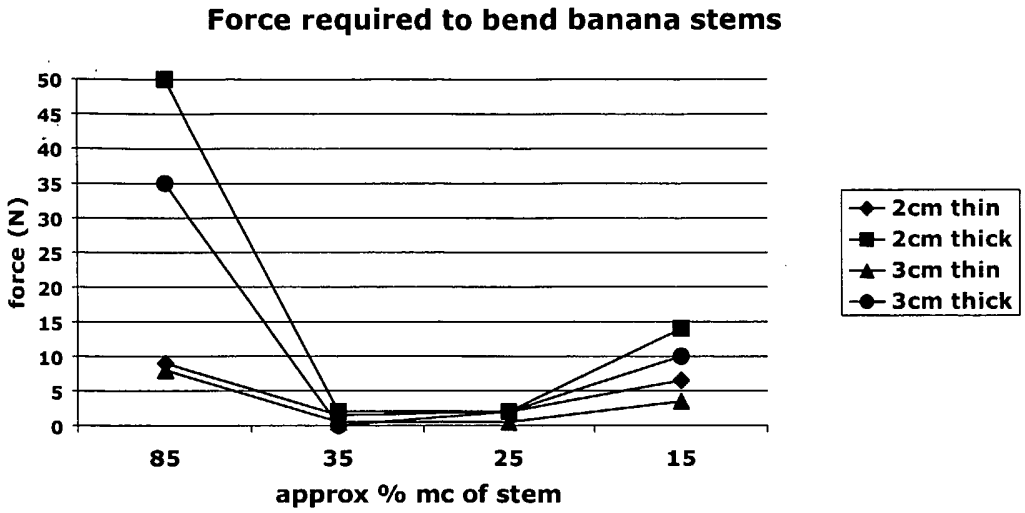

Force required to bend banana stems
force (N)
50
45
40
35
30
25
20
15
10
5
0
85
35
25
15
approx % mc of stem
2cm thin
2cm thick
3cm thin
3cm thick

Figure 12