Environmental Progress
& Sustainable Energy

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Journal:	*Environmental Progress*
Manuscript ID:	Draft
Wiley - Manuscript type:	Original Manuscript
Date Submitted by the Author:	n/a
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Keywords:	Biorefinery, Biomass, Agricultural Wastes, Green Chemistry
Alternate Keywords:	

Maximizing furfural concentration from Wheat Straw and *Eucalyptus globulus* by non-isothermal autohydrolysis

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SUMMARY

The autohydrolysis process as method for selective extraction of hemicelluloses and conversion to furfural was proposed for lignocellulosic raw materials. Samples of Wheat Straw and *Eucalyptus globulus* were subjected to non-isothermal autohydrolysis, defined by: temperature: 180-240ºC. The effect of the temperature on the sugar yield and composition of both liquid and solid phases obtained after the treatments has been studied. The furfural concentration and composition has been determined. For *Eucalyptus globulus,* the increase in the hydrolysis temperature (240ºC) yielded liquor with higher contents of furfural (4.45 g/100 g raw material, 25% of the initial xylan), for wheat straw, a faster dehydration is found. In that form, 4.25 g/100 g raw material (26% of the initial xylan) could be found at 220ºC, an increase temperature (240ºC) yielded 4.54 g/100 g raw material, 28% of the initial xylan).

Key words: autohydrolysis, furfural, glucan, oligomers, *Eucalyptus globulus,* wheat straw.

INTRODUCCIÓN

An efficient approach for LCM processes is the “biomass refinery” philosophy [1-2] . In that form, LCM is sequentially fractionated to obtain the main components (cellulose, hemicelluloses and lignin) in separated streams for an individualized profit of each. Several technologies based on hydrothermal treatments have been used for this fractionation [3]. An effective process seems to be the steam and aqueous treatments, which separate the feedstock into two main fractions: an aqueous extract composed mainly of hemicellulose derivatives along with some water-soluble lignin, and a solid fraction composed of cellulose and an easily extractable lignin [4]. Biorrefinery is an overall concept of an integrated and diversified processing plant where lignocellulosic biomass feedstocks are converted into a wide range of valuables products, much likewise to petroleum refineries [5, 6]. A number of methods enabling increasingly efficient use of forest products or agro-industrial residues such as eucalyptus wood or wheat straw in recent years. These residues provide low-cost raw materials for the obtainment of end-products with a high added value [7].

One of these products is furfural. Furfural is an important organic chemical, produced from agro industrial wastes and residues [8] and it is used mainly in the production of resin, which is then used as a binding agent in foundry technologies. The second main use is as a selective solvent in petroleum production of lubricants. Moreover, furfural has got other main applications like in grinding and abrasive wheels, in pharmaceuticals and in the manufacture of phenolic resins [8] and it is highly regarded for its thermosetting properties, physical strength and corrosion resistance [9]. It is also used. for the production of a wide range of important non-petroleum derived chemicals, such as furan, tetrahydrofuran, and furfuryl alcohol; it is also used as an extractive, fungicide, nematocide, in oil refineries, as well as in the plastics, food, pharmaceutical and agricultural industries [10]. There is no synthetic route available for furfural production in chemical industry. Furfural is exclusively produced from hemicelluloses of lignocellulosic biomass [11].

Furfural is produced from the dehydration of pentoses (mainly from xylan and arabinan) and their subsequent acid-catalyzed dehydration into furfural This reaction would occur with or without mineral acids addition due to the liberation of acetic acid from the acetyl groups of the hemicelluloses. Industrial production of furfural requires a minimum content of 15–20% of pentosans and only a third of this amount can be converted into furfural [12]. With the perspective of raw material, lignocellulosic materials (LCM) show several advantages such as their abundance, renewable character and relatively low cost, which make them useful for their utilization in chemical and food industries. The application of various catalysts in the furfural conversion has been well documented in the literature, including mineral acids, organic acids and solid acids [13]. In one-stage technology, depolymerization of xylans in xylose and dehydration into furfural occur simultaneously. As industrial use, the most prominent sources of furfural are corn/maize cobs, bagasse, paper-pulp residue, bamboo, kenaf, grain hulls, rice straw, nut shells, cottonseed and wood (soft and hardwood) [14]. Eucalyptus wood is a well known industrial material. Wheat straw, which is an abundant residue in many countries, has the potential for use as a low-cost raw material for the industrial production of higher-added value products. Europe alone is estimated to produce more than 170 million ton of wheat straw each year [15]. This amount is large enough for straw to be used as a source of renewable materials (particularly for the production of chemical derivatives of cellulose, hemicellulose and lignin [16].

A lot of literature is written about different pretreatment methods to enhance the extraction of carbohydrates in the process from lignocellulosic materials. Hot water or weak acid hydrolysis at an elevated temperature is the first step that is typically used to hydrolyze carbohydrates from lignocellulosic materials. Steam explosion and dilute acid pretreatment are the two most commonly used methods because of their effectiveness and inexpensiveness [10]. Among the hydrothermal treatments of lignocellulosic biomass at moderate conditions, autohydrolysis is an effective and simple process for producing hemicelluloses-derived oligosaccharides with reasonable yield and purity. In this sense, hemicelluloses could be solubilized almost quantitatively by autohydrolysis [17].

The aim of this study is to optimize furfural processing technology to enable higher yields and improved productivity from *Eucalyptus globulus* and wheat straw by autohydrolysis. Improved yields, under low cost technologies, can improve the cost competitiveness of furfural as an intermediate chemical. For this purpose, hydrothermal treatments were carried out, so the operational variable (temperature) was varied in the ranges of 180 to 240°C. Material balances and compositions of solid and liquid phases were evaluated, with especial attention to furfural concentration and liquid phase composition.

MATERIALS AND METHODS

Raw material

Eucalyptus globulus and wheat straw samples from local plantations (Huelva, Spain) were milled to pass an 8 mm screen, since in preliminary studies no diffusional limitations were observed for this particle, air-dried, homogenized in a single lot to avoid differences in compositions among aliquots, and stored.

Analysis of raw material and solid residues from hydrothermal treatment

Aliquots of raw material or solid residue were milled to particle size < 0.5 mm and subjected to moisture and determination of extractable compounds (TAPPI T-264-

om-88) and to Quantitative Acid Hydrolysis with 72% H_2SO_4 following standard methods (T-249-em-85). The solid residue after hydrolysis was recovered by filtration and considered as Klason lignin. The compounds (glucose, xylose and arabinose, furfural and hydroxymethylfurfural [HMF]) and acetic acid contained in the hydrolysates were determined by HPLC, so the HPLC features are below mentioned**.** Ashes were determined by calcination (T-244-om-93). Compositions of both raw materials are shown in Table 1. In this table, hemicelluloses content (H) was calculated following Eq 1.

$$H = AcG + Arn + Xn \quad \text{(Eq 1)}$$

Where: Gn = glucan content; AcG = acetyl groups content; Arn = araban content and Xn = xylan content.

Hydrothermal processing of wood samples

Raw material and water were mixed in the desired proportions and treated in a 600 cm^3 stainless steel reactor (Parr Instruments Company, Moline, Illinois, USA) using a liquid/solid ratio (LSR) of 8 kg water/kg raw material, on dry basis (the moisture content of material was considered as water). According to previous works, the influence of LSR is relatively low [17]. The reactor was fitted with four-blade turbine impellers, heated by an external fabric mantle and cooled by cool water circulating through an internal loop. The reaction media stirred at 150 rpm and heated to reach the desired temperature, time zero was considered to be the beginning of the isothermal stage. Figure 1 show heating profile of the reactor.

After treatment, solid residues were recovered by filtration, washed with water, air-dried, weighted for yield determination. Aliquots of the solid residues were assayed for moisture and composition (duplicate) using the same methods as for raw material analysis. An aliquot of the liquors was oven-drying to constant weight to determine the dry content (DC, g non-volatile compounds/g liquid phase). A second aliquot was filtered through 0.45 mm membranes and used for direct HPLC determination of monosaccharides, furfural, hydroxymethylfurfural (HMF) and acetic acid. A third aliquot was subjected to quantitative posthydrolysis with 4% H_2SO_4 at 121 ºC for 45 min, before 0.45 mm membranes filtration an HPLC analysis. The increase in monosaccharide and acetic acid concentration caused by posthydrolysis provided a measure of the oligomer concentration. HPLC analyses were performed using a BioRad Aminex HPX-87H colum at 30º C eluted with 0.01 M H_2SO_4 at a flow rate of 0.6 $mL·min^{-1}$.using a Refractive Index detector to quantify glucose, xylose, arabinose, acetic acid, HMF and furfural.

RESULTS AND DISCUSSION

Raw material composition

The composition of the raw materials, *Eucalyptus globulus* (EG) and wheat straw (WS) was analyzed as described in the experimental section, and the results are detailed in Table 1.

For EG, the amounts of lignin and cellulose, measured as Klason lignin and glucan, respectively, were 21.2% and 42.8% of the total material. In the case of WS, the lignin content, near to 14.2%, and the cellulose (glucan) content are lower (32.8%) than that obtained for EG. The composition of xylan, represented 17.1% of the EG and 21.4% of WS. Moreover, the composition of arabinan (0.4%) and acetyl groups (3.5%) for EG, and arabinan (2.0%) and acetyl groups (1.9%) for WS. As can be seen, the compositions of the selected materials were similar to others furfural raw materials reported in the literature.

Effect of hydrothermal treatment on *Eucalyptus globulus* solubilization

Having a prior knowledge of the degree of fractionation after the hydrothermal treatment it would be interesting to study this as it would it enable us to carry out an initial evaluation of the treatment efficiency. The variation of the solid yield (SY) in the course of temperature increment is shown in Table 2. In that form, SY varies among 84.2 % at 180 ºC and 61.4 % at 240 ºC. This can be essentially justified by the solubilization of the extractable compounds (13.8 -36.6 % of the raw material). The solubilised fractions are similar than those found in EG usually employed in the autohydrolysis treatments [18-21] .

In the solid fraction, the SY decreases rapidly up (180-200ºC) to values of about 64 %, then it decreases more slowly, so a minimal value of 61.4 % is reached at T=240ºC. The solubilised fractions are hemicelluloses (21 % of raw material, calculated as the sum of xylan, arabinan and acetyl groups) and extractable compounds (9.9 %). This verifies that cellulose (42.45-41.66%) and lignin (22.99-22.6%) are not significantly solubilizied by the hydrothermal treatment. The raw material solubilization is affected by the temperature, so SY decreases more rapidly at higher temperatures. Table 2 evidences the variation of hemicelluloses (arabinan, xylan, acetyl groups) in the solid fraction. In that form all of them decrease from its initial values (0.03, 11.78, 2.09% for arabinan, xylan, acetyl groups respectively) at 180ºC and subsequently a descent in the afore mentioned values is observed (0.03, 2.69, 0.00% for arabinan, xylan, acetyl groups respectively) at 240ºC.

Effect of hydrothermal treatment on wheat straw solubilization

Similar behaviour to that found for EG is detected in WS (Table 3). As can be observed, in the case of cellulose, around 90% remained unaltered for WS. The reaction condition does not affect this behaviour. In the case of EG, this percentage was lower, (80%), again independent of the reaction conditions. In both cases, the amount of the cellulose recovered in the solid was significant, so can be considered that the cellulose remaining in the solid could be separated in subsequent processes. The lignin remaining in the solid shows a different behaviour. In the case of WS, the lignin that remained after the reaction varied from 16.36 to 15% of the original, showing a depolymerization. The lignin depolymerisation could be related to the lignin structure and extractives content present in the original raw material. The extractives content was around 2.7% for EG, and 5.2% for WS. That indicates that the increase in the lignin and extractives content of the solid contributes making the material less accessible to the reaction, yielding less lignin derived products in the liquid [15]. This aspect is important because these products derived from lignin constitute impurities in the liquid fraction.

The hemicelluloses remaining in the solid showed similar behaviour on both raw materials. For the higher temperatures, it was possible to solubilize up to 60% of the original xylan in WS. For temperatures between 200°C and 220°C, the levels of xylan in the solid fraction fell very rapidly, and around 50% of the xylan reacted for temperatures less than 20ºC. In the case of lower temperatures (180°C and 200°C), the solubilization was smaller. These results showed good agreement with the trends reported for the autohydrolysis of annual plants, agriculture residues and hardwoods, both in hydrothermal processes [17,22,23]. However, the extracted xylan contents for EG were higher (in percentage) than that observed for WS.

With respect to, the solubilised fractions, for WS, are hemicelluloses (26% of raw material) and extractable compounds (28%). This data also verifies that cellulose (30.34-33.46%) and lignin (16.36-15.00%) are not significantly solubilizied by the hydrothermal treatment. Furthermore, for WS a similar evolution that observed for EG, is produced. All of compounds decrease from its initial values (1.8, 19.0 and 0.4% for arabinan, xylan, acetyl groups respectively) at 180ºC to (0.56, 7.99, 0.00% for arabinan, xylan, acetyl groups respectively) at 240ºC.

Composition of solid phase after hydrothermal treatments

The variation of the composition of the solid phase with respect to temperature after the hydrothermal treatment for EG and WS is shown in Table 2 and 3 respectively (in weight percent). In that form, the glucan recovery shows that glucan and lignin keeps back in the solid phase in a practically quantitative way in both raw materials. The minor difference in EG, which is equivalent to 0.8 glucan/100 raw material, could be caused by the solubilization produced by the treatment or the presence of low contents of polymer with glucose. On the contrary, an increment in glucan content for WS is found (3.1 glucan/100 raw material), this fact could be due to the high solubilised fraction (49.3%) observed in this material.

The other three measured fractions (xylan, arabinan and acetyl groups) show more affected by autohydrolysis. The content of these fractions decrease as temperature increases, so lower values are found at high temperatures. Xylan decreases from 11.8 at 180ºC to 2.7 % at 240ºC in EG. In WS, xylan, decreases from 19.00 to 7.99% under the same temperature range. Arabinan decreases from about 0.03 to 0.00 in EG, although there is still some amount of arabinan WS (0.56%) at 240 ° C, so has not been achieved a complete solubilization of this component under high temperature. Acetyl groups decreases from 2.09 to 0.00% in EG and from 0.43 to o.00% in WS. Therefore, a similar behaviour for this compound, in both materials, has been obtained.

Comparative composition of liquid phase obtained in hydrothermal treatments: sugars

The liquid phase is mainly composed of solubilization products from polisaccharides. The variation of glucose, arabinose, xylose, acetic acid, furfural and hydroxymethylfurfural (HMF) concentration in liquid phase for EG and WS with respect to temperature are shown in Table 3 and 4 respectively. Concentrations of different compounds are expressed as g /100 g raw material, on a dry basis to let an easy comparison with the rest of the data of this work.

The glucose content increases rapidly from 0.03 g/100 g at 180ºC to maximum values at 0.74% at 240ºC for EC and 0.06 g/100 g at 180ºC to 0.76% at 240ºC. An increase in temperature implies an increase in glucose content this fact could be justified by the hydrolysis reactions in α-cellulose to produce monosacharides (glucose) under high temperature [1]. If glucose concentration passed on to the liquid phase due to the cellulose fraction, its concentration would probably increase with temperature. However, the glucose concentration must be higher than those found in liquid phase, which is probably caused by its degradation to HMF.

Arabinose is very susceptible to hydrolytic degradation (García-Martín et al., 2008). Its content increases from 0.38 g/100g at 180ºC to values of 0.40 g/100 g at 240ºC, which can be considered as a relatively high value if it is compared with the content of the raw material 0.4 g/100 g, for EG and from 0.25 g/100g at 180ºC to values of 0.07 g/100 g at 240ºC for WS. For WS, a evident decrease at high temperatures (240ºC) is found probably due to its degradation to furfural.

For EG, the xylose concentration increases with temperature, from 0.59 g/100g (180ºC) to maximum values of 1.81 g/100g at higher temperatures (240ºC). The xylose increase is higher from 200-220ºC. The maximum values are much lower than those found for the raw material (17.1 g/100 g), which is justified by the important concentration of oligomers in the liquid phase and the degradation of xylose to furfural. For WS, a similar trend, in lower range, a decrease is observed up to values of 0.79 to 0.47 g/100 g at the highest temperature (240ºC). In both raw materials, the xylose content increases from its initial to its maximum value at 220ºC, and then decreases up to low values. The pattern of EG is similar to that find for WS, but a greater influence of the temperature is found for EG.

The acetic acid content increases very rapidly from values of about 0.47 g/100 g at 180ºC to maximum values of 4.49 g/100 g at 240ºC for EG and from 0.50 to 2.10 g/100 g in the same temperature range. It is remarkable that acetic acid maximum content is obtained at highest temperature in both raw materials, so it increases with temperature.

The found data shows similar trend to that found in other raw materials [18 ,23 ,24,25] . In this form, xylan is considered to be a polymer made up of three constitutive monomers: xylose, arabinose and acetic acid. Moreover, a model a model which assumes that xylan are hydrolyzed to a mixture of water□soluble oligomers, which are then hydrolyzed in the liquid phase to monomers: xylose, arabinose and acetic acid and only xylose and arabinose are dehydrate to furfural [25] could be a valid model for the studied raw materials.

Comparative composition of liquid phase obtained in hydrothermal treatments: furfural and hydroxymethylfurfural

The variation of furfural and HMF concentrations in the liquid phase with temperature is noted in Tables 2 and 3 for EG and WS respectively. The HMF is the component generated by the acid dehydration of the hexoses such as the glucose. It is evident that the concentration of furfural increases in constant turn from 0.00 to maximum values of 4.45 g/100 g at the highest temperature (240ºC) for EG and from 0.00-1.86 g/100 g (240ºC) for WS. The maximum concentration of the produced furfural means about 25% of the initial pentoses for EG and 19% for WS. It can be noted that the behaviour of the HMF is very similar to furfural, so there is an increase from 0 to maximum values of 1.86 and 0.64 g/100 g for EG and WS respectively, which only means about 4.3% % of the initial glucan for EG and 1.95% for WS.

The yield of the measured compounds in the aqueous phase at the four reaction temperatures is shown in Figure 2 and 3 for EG and WS respectively, both figures are expressed as extracted component variation with respect to temperature increment ratio [Δ (g/100 g) /ΔºC] (R) value vs. temperature (T, ºC). The chemical composition of the extracted oligosaccharides was also influenced by temperature. Therefore, the plot R vs. T permits the graphical estimation of the variation of these components among studied temperatures. As can be seen in Figure 2, oligomer content, in EG, increases with temperature up to 220ºC and then decreases, probably caused by breakdown reactions. After that temperature, only in furfural and HMF increases are observed. Among the extracted monomers, xylose content increases considerably with temperature and a slightly increment is observed for the other compounds.

For WS (Fig 3), higher temperature also favoured an increase in the yield of oligosaccharides. Although lower R has been found for WS with respect to EG, dehydration to furfural was faster in WS. In that form a short reaction time (dehydration) had been produced in WS with respect to EG, under high temperature (220ºC). After that, the furfural content in WS is lower at the highest temperature (240ºC) which is unstable at the reaction conditions and forms condensation and other degradation products.

The Figure 4 was used to develop the optimum temperature to obtain maximum furfural content, with respect to initial xylan content in EG and WS respectively and as function of temperature. Data are expressed as g of substance per 100 g of xylan in each raw material on dry basis in order to let a comparative. In that form, WS significantly produced furfural at 220ºC with respect to EG. The furfural content increases up 25%

whereas only 6% have been reached for EG at the same temperature. Thus, higher temperature favoured an increase in the yield of furfural for EG which reached a maximum of 25% of the initial xylan at 240°C. The content of furfural increased steadily with reaction temperature reached a maximum at 220ºC and after that temperature slight furfural degradation is found in WS, reached up 28% of the initial xylan at 240°C.

CONCLUSIONS

Non-isothermal autohydrolysis of Wheat Straw and *Eucalyptus globulus* could be a suitable process for the furfural production.

Autohydrolysis showed that the maximal yield in the production of xylooligosaccharides 220°C for both raw materials. At this temperature Eucalyptus globulus gave a maximum yield of xylose (6.47 g/100 g raw material) and lower content (1.90 g/100 g raw material) for wheat straw is found.

In *Eucalyptus globulus* the increase in the hydrolysis temperature (240ºC) yielded liquor with higher contents of furfural (4.45 g/100 g raw material, 25% of the initial xylan) and acetic acid (4.49 g/100 g raw material) and smaller contents of arabinose and xylan. In wheat straw, a faster dehydration is found. In that form, 4.25 g/100 g raw material (26% of the initial xylan) could be found at 220ºC, an increase temperature (240ºC) yielded 4.54 g/100 g raw material, 28% of the initial xylan).

ACKNOWLEDGEMENTS

The authors acknowledge financial support for this investigation has been provided by CDTI (CENIT-E-CDTI-BioSos-CEN-2009-1040) and supported by Ministry of Economy and Competitiveness, "Local Investment fund for employment" and the business group ACCIONA INFRAESTRUCTURAS, S.A. Also they thank to Spanish Ministry of Science and Innovation by the “Ramón y Cajal” contract, PhD student grant from Agrifood Campus of International Excellence (CeiA3) and Regional Ministry of Innovation, Science and Enterprise. Government of the Junta de Andalucía, Spain (Project number RNM 2323-2012).

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Caption of Figures

Figure 1. Operational time-temperature profile.

Figura 2. Liquid phase composition variation of sugars (see text for variables definition and units; g/100 g raw material) obtained under autohydrolysis for Eucalyptus globulus.

Figura 3. Liquid phase composition variation of sugars (see text for variables definition and units; g/100 g raw material) obtained under autohydrolysis for Wheat Straw.

Figura 4. Comparative evolution for the obtained furfural (percentages with respect to initial xylan in raw material) in Eucalyptus globulus and Wheat Straw as a function of temperature.

Table 1. Average chemical composition for *Eucalyptus globulus* (EG) and Wheat Straw used and other lignocellulosic raw materials *

	EG	**Wheat Straw**	**EG** (Garrote et al., 2002)	**Wheat Straw** (Papatheophanus et al., 1995)	**Tagasaste** (Alfaro et al., 2010)	***Miscanthus*** (Ververis, 2004)	***Arundo donax*** (Caparros et al., 2006)
1% NaOH soluble (%)	13.1	23.1	12.4	-	21.2	-	-
Ethanol extractables (%)	2.7	5.2	1.2	5.3	2.3	4.2	9.1
Ash (%)	0.7	5.9	0.6	9.6	0.7	2.0	3.0
Glucan (%)	42.8	32.8	46.8	55.4	38.9	39.5	34.8
Klason lignin (%)	21.2	14.2	22.9	11.7	19.8		23.0
Holocellulose (%)	78.0	69.6	66.9	76.2	80.3	69.4	64.5
Xylan (%)	17.1	21.4	16.6	34.6	19.9	19.0	19.4
Arabinan (%)	0.4	2.0	0.5	5.6	0.6	1.8	1.5
Acetyl groups (%)	3.5	1.9	3.5	-	4.4	-	3.4
Others (%)	7.2	11.5	10.1	10.5	12.5	33.5	5.8

* Raw material percentages (100 kg dry matter).

Table 2. Product distribution for *Eucalyptus Globulus* in conditions leading to maximum oligomers extraction.

	Temperature (ºC)			
	180	**200**	**220**	**240**
Material balances (g/100 g raw material, dry basis)				
Solid yield (SY)	84.2	71.3	64.1	61.4
Solubilized fraction (SF)	13.8	26.7	34.9	36.6
Solid phase composition (g/100 g raw material, dry basis)				
Glucan	42.45	41.69	39.65	41.66
Klason lignin	22.99	23.84	22.73	22.60
Arabinan	0.03	0.09	0.02	0.00
Xylan	11.78	8.70	6.37	2.69
Acetyl groups	2.09	1.29	0.17	0.00
Liquid phase composition (g/100 g raw material, dry basis)				
Glucose	0.03	0.15	0.55	0.74
Arabinose	0.38	0.37	0.38	0.40
Xylose	0.59	2.59	6.47	1.81
Acetic acid	0.47	1.26	3.46	4.49
Furfural	0.00	0.30	0.87	4.45
Hydroxymethylfurfural	0.00	0.06	0.56	1.86

Table 3. Product distribution for Wheat Straw in conditions leading to maximum oligomers extraction.

	Temperature (ºC)			
	180	**200**	**220**	**240**
Material balances (g/100 g raw material, dry basis)				
Solid yield (SY)	81.6	64.1	56.4	49.7
Solubilized fraction (SF)	17.4	34.9	42.6	49.3
Solid phase composition (g/100 g raw material, dry basis)				
Glucan	30.34	28.96	33.21	33.43
Klason lignin	16.36	15.25	16.06	15.00
Arabinan	1.79	1.70	1.09	0.56
Xylan	19.00	20.23	13.32	7.99
Acetyl groups	0.43	0.71	0.00	0.00
Liquid phase composition (g/100 g raw material, dry basis)				
Glucose	0.06	0.15	0.41	0.76
Arabinose	0.25	0.37	0.20	0.07
Xylose	0.79	0.90	1.90	0.47
Acetic acid	0.50	1.26	2.02	2.10
Furfural	0.00	0.04	4.21	4.54
Hydroxymethylfurfural	0.01	0.04	0.22	0.64

Figure 1

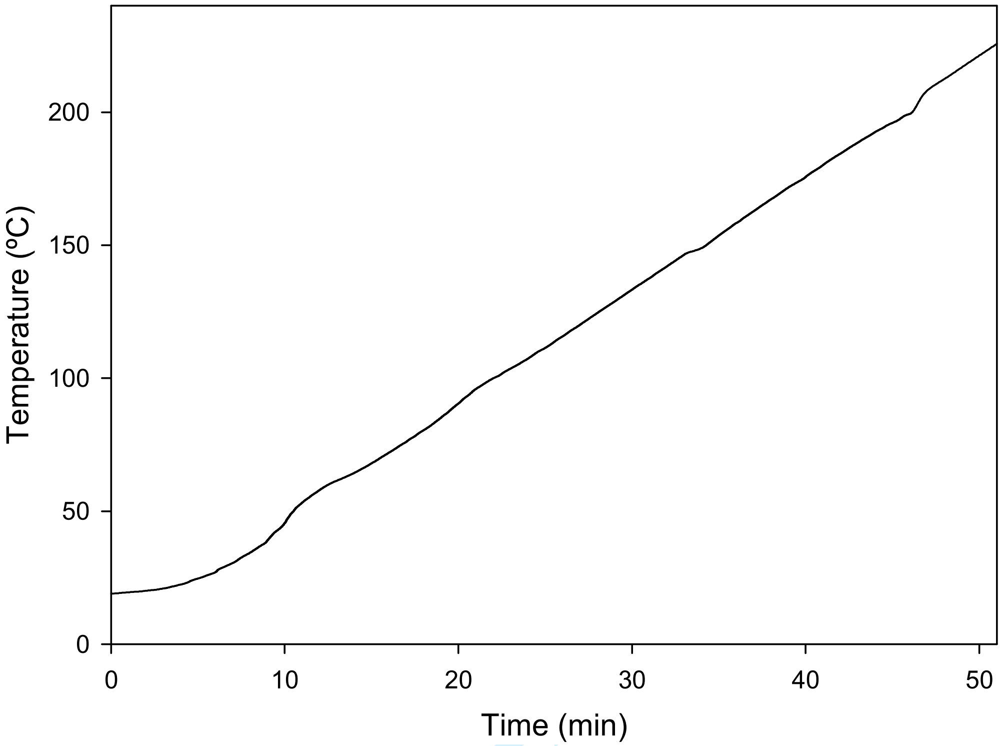


Figure 2

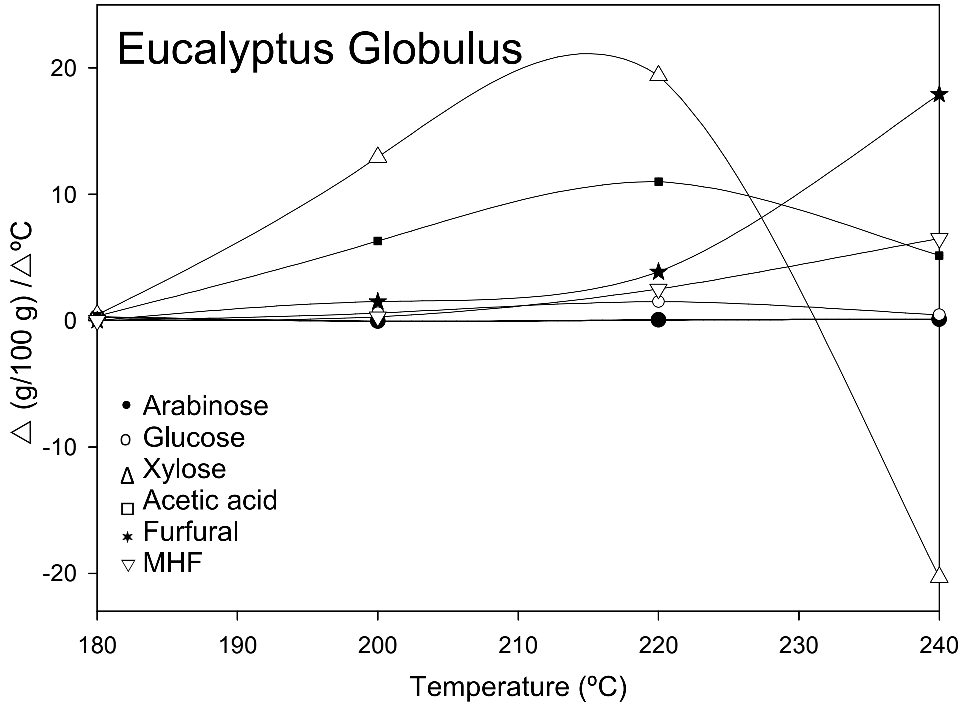

Eucalyptus Globulus
△ (g/100 g) / △ºC
20
10
0
-10
-20
180
190
200
210
220
230
240
Temperature (ºC)
● Arabinose
○ Glucose
△ Xylose
□ Acetic acid
★ Furfural
▽ MHF

Figure 3

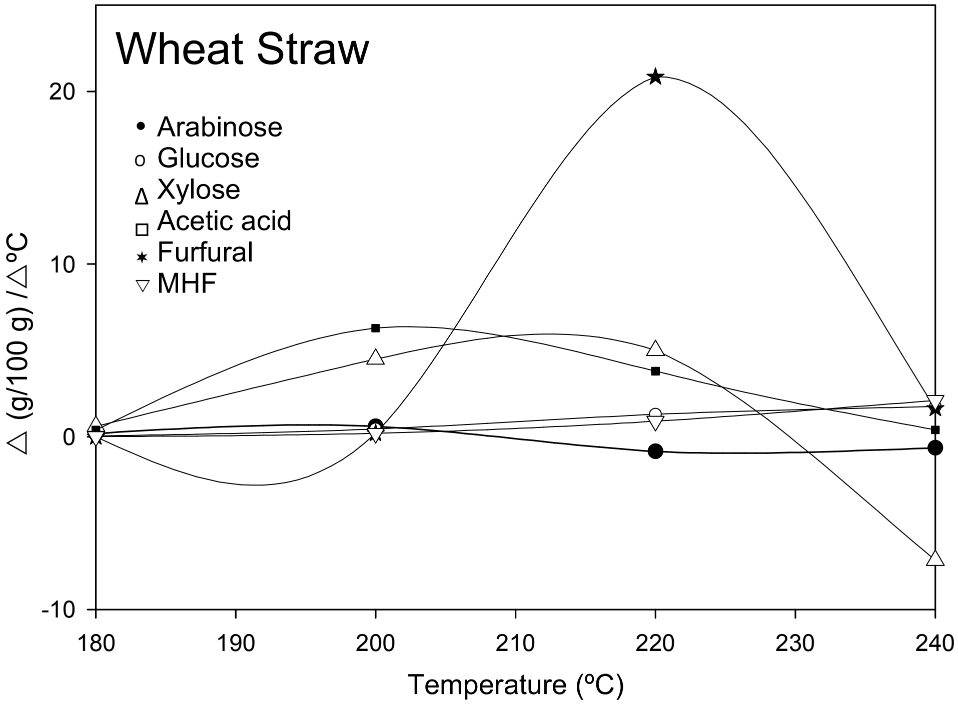
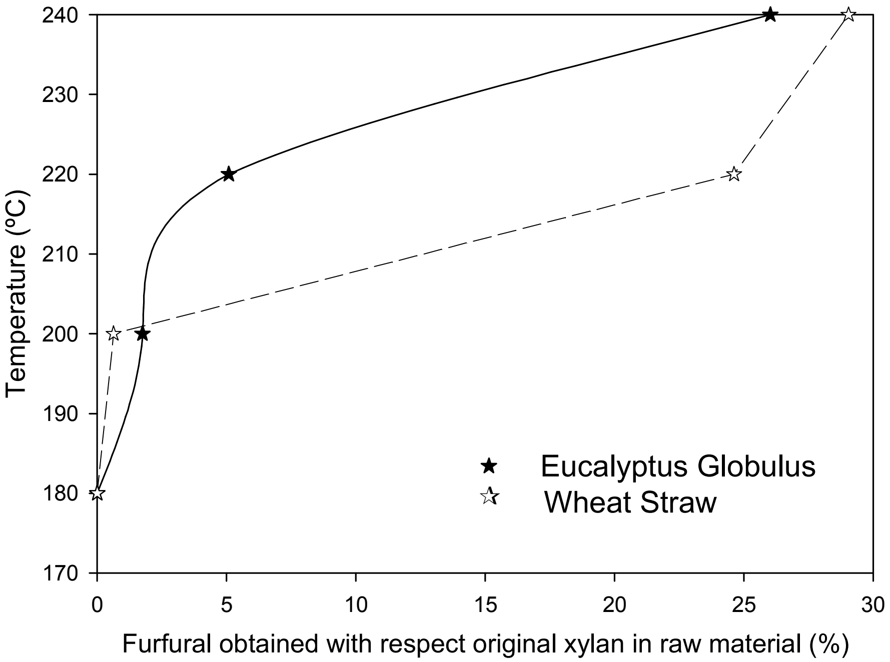

Wheat Straw
● Arabinose
○ Glucose
△ Xylose
□ Acetic acid
★ Furfural
▽ MHF
△ (g/100 g) /△ºC
20
10
0
-10
180
190
200
210
220
230
240
Temperature (ºC)

Figura 4



240
230
220
210
200
190
180
170
Temperature (ºC)
0
5
10
15
20
25
30
Furfural obtained with respect original xylan in raw material (%)
★ Eucalyptus Globulus
☆ Wheat Straw