Chemical and Thermal Analysis of the Biopolymers in the Lavandin

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ABSTRACT: Who does not know the lavender's perfume so characteristic of the Provence? The lavandin presents a better yield in essential oil that is used mainly in perfumes and cosmetics, but also in washing powders and cleaning materials. The chemical and thermal study, made on the same stalk of the lavandin, during the period from January to August, responds to two goals. First for economic appearance, we observed a higher yield of essential oil in open or wilted flowers. The automation of the flowers gathered has induced a decreasing of the essential oil in distillation, on account of the recovery of the branches without oil. Moreover, the water, mineral ashes, cellulose, lignin, holocellulose, and hemicellulose contents are computed in all the aerial parts (new and old leaves, branches). Second, the wild lavender, like other plants of the land of Provence, could be at the start of the forest fire. The inflammability risk can be observed by thermal analysis at about 300°C: presence of an exothermic peak by DTA, weight loss by TG, and determination of the maximum decomposition rate by differential thermogravimetry (DTG). In high-heating rates (about 50°C/min), the decomposition of the aerial parts of the plant increases mainly with the cellulose level. © 2000 John Wiley & Sons, Inc. J Appl Polym Sci 77: 1629–1641, 2000

Key words: cellulose; chemical analysis; decomposition; essential oil; lavandin; thermal analysis

INTRODUCTION

The lavender is a very popular aromatic plant in Provence. It plays an important part in cosmetics and perfumes, but also in pharmaceutics where one discovers every day some ancestral virtues. The lavender, always present in a wild state in the plains and the hills, like thyme, rosemary, sage, gorse of Provence (or argeras), and kermes-oak, is an important factor in the spreading of the forest fire.

The ignition of the mediterranean plants in forest fires corresponds to the volatilization of heated flammable volatiles: either essential oil, or evolved gas from the decomposition of the less volatile components, like biopolymers.

On the other hand, a search for new and cleaner methods of electric power generation has developed, mainly by using the biomass feed, flash-pyrolysis process. The engineering design of modern biomass gasifiers and flash pyrolysis reactors requires a deep knowledge of biomass pyrolysis kinetics. Because dry biomass fuel typically consists of about 20–50% cellulose by weight, the kinetics of the pyrolysis biopolymers are often the primary interest of those responsible for reactor design.

The quantity of cellulose produced each year is greater than all other organic polymers; the understanding of its thermal decomposition is an important goal of the scientific community.

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Table I Chemical Analysis of the Lavandin

Lots	Samples	Desiccation Weight Loss (%)	Essential Oil (mL/100 gDM)	Mineral Ashes (%/DM)	Extractives (%/DM)	Lignin (%/DM)	Cellulose (%/DM)	Holocellulose (%/DM)	Hemicellulose (%/DM)
1	g leaves	68.5	0.81	7.80	15.0	21.5	13.3	23.1	9.8
	g branches	56.6	0.03	4.57	6.8	21.0	29.6	37.2	7.6
	b branches	43.9	0	3.57	3.7	27.2	40.0	48.7	8.7
2	g leaves	65.8	0.42	6.98	13.4	22.1	12.0	28.0	16.0
	g branches	57.3	0	5.08	8.1	22.9	26.7	43.9	17.2
	b branches	46.9	0	3.65	3.8	27.4	38.3	52.8	14.5
3	g leaves	67.5	0.77	7.26	17.8	22.2	15.2	26.1	10.9
	g branches	60.3	0	5.30	4.7	22.3	31.4	49.1	17.7
	b branches	52.5	0	4.26	2.2	29.6	40.1	57.6	17.5
4	g leaves	67.4	0.39	7.57	11.0	21.0	11.7	25.8	14.1
	g branches	66.0	0	5.39	7.2	23.4	27.1	41.4	14.3
	b branches	53.8	0	3.47	3.9	29.4	35.2	52.0	16.8
5	flowers	76.5	7.99	8.89	12.7	21.0	20.0	30.2	10.2
	g leaves	77.4	0.54	9.52	15.2	20.9	17.4	23.1	5.7
	g branches	69.4	0	6.20	6.6	20.1	40.0	53.2	13.2
6	flowers	71.8	9.74	8.38	12.3	27.2	22.1	34.2	12.1
	g leaves	80.4	0.49	10.29	17.7	15.2	15.7	19.4	3.7
	g branches	68.2	0	4.97	9.2	20.9	42.7	57.0	14.3
	b branches	58.4	0	4.13	4.8	29.1	43.3	55.9	12.6
7	flowers	63.8	9.44	7.20	12.9	22.7	25.1	40.5	15.4
	g leaves	75.2	ND	9.52	19.4	15.2	17.5	19.1	1.5
	g branches	63.8	0	4.42	6.8	22.2	44.8	56.5	11.8

DM = dry matter; g = green; b = brown; ND = not determined.

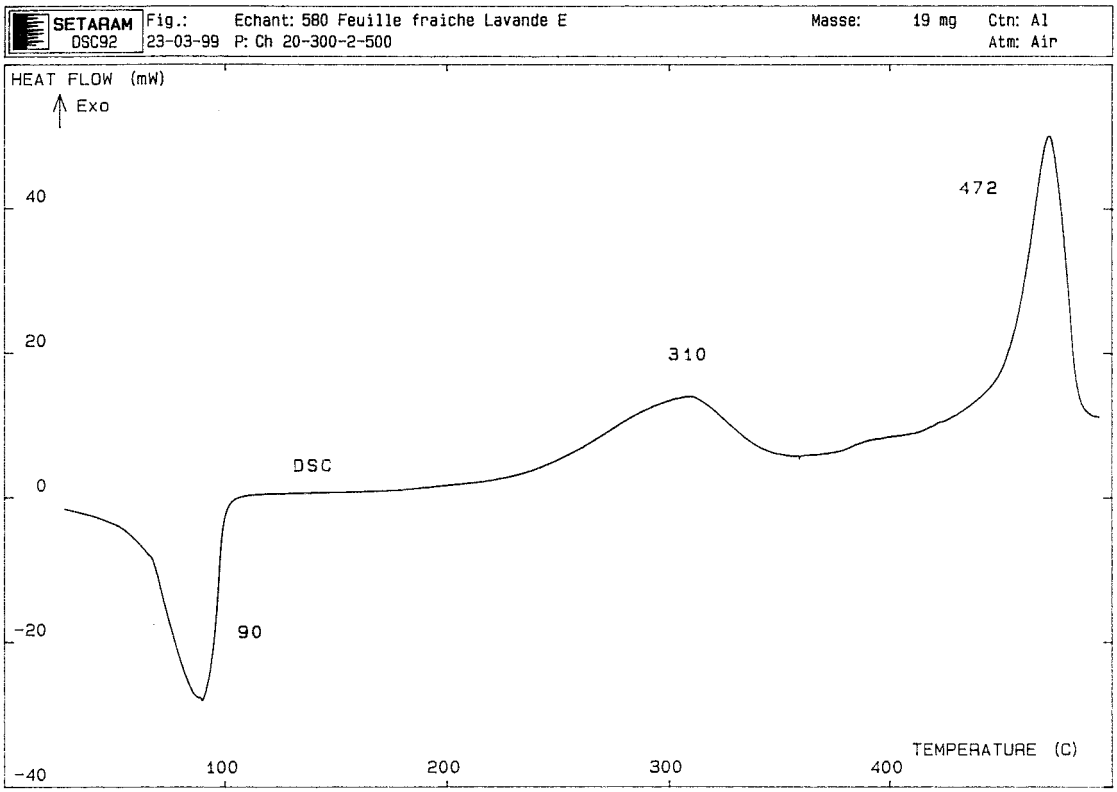


Figure 1 DSC curve of the new green leaves of the lavandin.

For all these reasons, the kinetics of cellulose and other pyrolysis biopolymers (holocellulose, lignin) are currently a topic of great interest worldwide.

So, the thermal analysis technics (TG, DTG, DTA, DSC) play an important role in the determination of the kinetics in the plant's decomposition.

The lavandin (hybrid lavender obtained from *Lavandula officinalis* and *Lavandula aspica*) presents an economic interest for the Provence, thanks to the essential oil issued from the flowers and the leaves in summer. We point out that during this hot period, the forests are often destroyed by fire.

Therefore we gathered samples on the same plant of hybrid lavender during its biological cycle. We realized the chemical analysis of the main components (economical aim), the thermal analysis, and at last the study of the decomposition rate, during heat, to evaluate the flammability risks.

SAMPLING, PROCEDURE, APPARATUS

The gathering was done on the same plant of lavandin, in the town of Aix en Provence, between January and August 1998, according to the following dates (DD/MM/YY): lot 1: 04/01/1998; lot 2: 01/02/1998; lot 3: 15/02/1998; lot 4: 08/03/1998; lot 5: 07/06/1998; lot 6: 02/07/1998; lot 7: 25/08/1998. The results obtained, from these lots, are representative for this plant.

After gathering, we separated the flowers (when they existed), the new green leaves, the new green branches of the year, and the old brown branches from the preceding year. We determined, in the beginning, the essential oil on a part of the freshly picked plant, according to the European Pharmacopea. The sample of about 50 g (weighed accurately) was put in a 1-L flask with 0.5 L of water. The time of distillation was 5 h. This time was sufficient to recover all the oil. Another part was dried at 110°C for 15 h with the calculation of the weight loss. More than 99% of the essential oil was volatilized during the heating at 110°C. Then, the samples were pounded and sieved. The powder was accepted by the 1-mm side sieve. We determined on these powders: the mineral ashes obtained after 1 h at 650°C; the cellulose by gravimetry, after the action of a 1 : 4 volume mixture of concentrated nitric acid and ethyl alcohol[1]; the extractives by

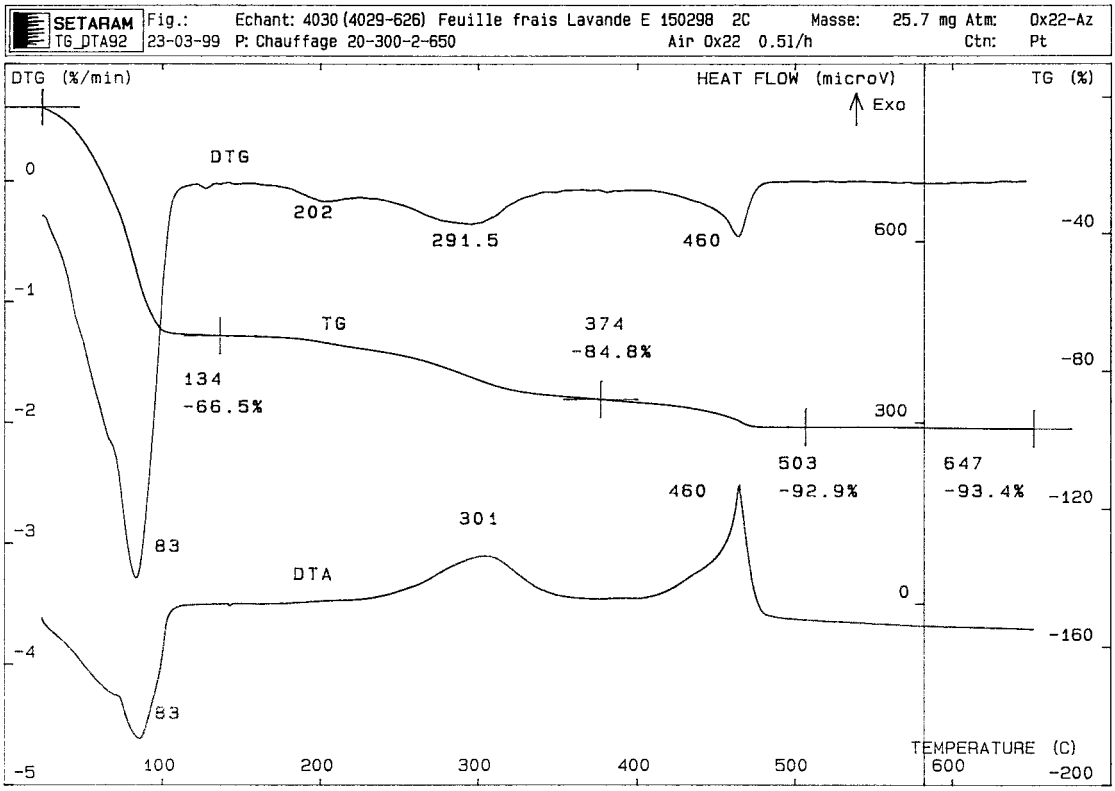


Figure 2 DTA, TG, and DTG curves of the new green leaves of the lavandin.

the 2 : 1 volume mixture benzene and ethyl alcohol with the Soxhlet apparatus.[2]

On the residue that remained after the Soxhlet method, we calculated the lignin and the holocellulose. The lignin was analyzed by gravimetry after 24*N* sulfuric acid attack.[2] The holocellulose (i.e., cellulose and hemicellulose) was also determined by gravimetry after the reaction of the powder with sodium chlorite in acetate buffer at pH 4.9.[1] The hemicellulose was the difference between holocellulose and cellulose. All results were expressed according to the dry matter (%/DM).

Thermal analysis was run on DTA–TG simultaneous apparatus (Setaram 92, Scientific & Industrial Equipment, France) with a heating rate of 60–3000°C/h from the ambient temperature to 800°C, under 0.5 L/h air sweeping, platinum crucibles, and on DSC apparatus (Setaram 92) with 120°C/h heating rate from ambient temperature to 550°C, under air static, and aluminum crucibles.

The sample mass was about 20 mg, and kaolin was used as an inert thermal reference. We worked on freshly cut samples and on 110°C dried powders. The standards used to calibrate DSC and TG, in temperature, were indium, tin, lead, and aluminum, and in weight loss, calcium oxalate monohydrate. For all samples, we will present successively the chemical analysis results, then, those of the thermal analysis.

CHEMICAL ANALYSIS

Results

The results of the chemical analysis on the hybrid lavender gathered between January and August 1998 on the same plant are presented in the Table I. We express the values in percentage weight-to-weight according to the dry matter (%/DM): desiccation weight loss, mineral ashes, extractives, lignin, cellulose, holocellulose, and hemicellulose. In the last study, we observed good standard deviations, and correlation coefficients $< 2\%$. We indicated the essential oil in mL/100 g DM. The lots are classified in two periods: winter (1–4) and summer (5–7).

Discussion

Flowers

The flowers were present only for the lots 5, 6, and 7. They were scarcely opened for lot 5, completely opened for lot 6, and faded for lot 7.

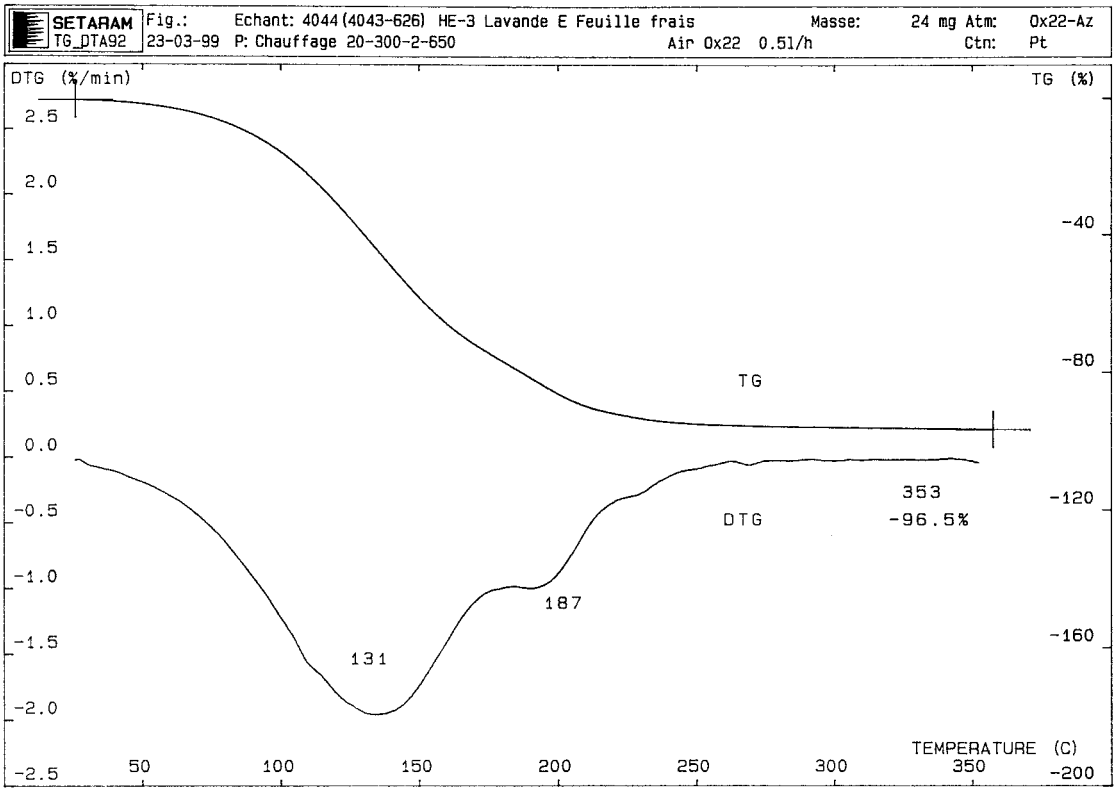


Figure 3 TG and DTG curves of the essential oil obtained from the green leaves of the lavandin.

We observed a decrease in the desiccation weight loss from 77 to 64%, respectively, for lots 5 to 7. The essential oil was highest for lot 6 (9.74 mL/100 g DM). The mineral ashes were higher than 7%/DM, and the extractives 12%/DM. The amount of cellulose, holocellulose, and hemicellulose increased according to the flower's aging. On the other hand, the lignin level was between 21 and 27%/DM. The lignin was present mainly in the gathered small peduncles at the same time as the flowers.

New Green Leaves

The desiccation weight loss, during the winter period, was included between 66 to 68.5%, whereas values between 75 to 80% were obtained during the summer period.

The humidity content in the plant was more important during the summer, thus it was regarded as an inhibitor for the flammability risks. The essential oil was included between 0.39 and 0.81 mL/100 g DM. The amount of mineral ashes were $< 8\%$ during the cold period, whereas in the hot period, values of 9.5–10.3%/DM were obtained. The other parameters did not present significant variations. Only the hemicellulose was very weak in the summer period (1.5–6%/DM).

We observed from dry brown leaves gathered on another plant of hybrid lavender some variations for the desiccation weight loss (19%), the mineral ashes (17%/DM), the lignin (35%/DM), and the holocellulose (39%/DM).

New Green Branches

During aging, the water content increased regularly from 57 to 69% and decreased to 64% at the end of the summer. The essential oil was always missing. The mineral amount of ashes were included in the interval 4–6%/DM. The cellulose content presented significant variations between the cold (27–31%/DM) and the hot period (40–45%/DM). It was the same for holocellulose: $< 50\%$ for the first period, greater for the second period. This was not surprising, indeed, the content the cellulose and holocellulose products took part in the structural development of the plant.

Table II DTA and TG Results of the Lavandin

Samples (powder)	First Exothermic DTA Peak (°C)	First DTG Peak (°C)	Second DTG Peak (°C)	Third DTG Peak (°C)
New green leaves				
M	299	198	282	433
SD	6.4	1.9	11.6	10.8
Old brown leaves				
M	308	—	297	408
SD	1.5		2.3	2.4
New green branches				
M	295	—	266	409
SD	13.2		2.6	3.9
Old brown branches				
M	304	—	281	385
SD	10.0		4.7	8.8
Flowers				
M	304	—	294	414

M = average; SD = standard deviation.

Old Brown Branches

The desiccation weight loss increased regularly from 44 to 58% during aging, but this quantity remained always in the limits widely lower than the quantities obtained for new green branches. The mineral ash and extractive amounts were lower for old brown branches than for the new green branches. Opposite behavior was observed for the lignin content which varied from 27% for the winter period to 20–23% for the summer period for the lignin. For the cellulose, variations were observed only during the cold period (35–40%/DM).

In conclusion, the essential oil amount in the flowers of the hybrid (chosen as our standards) was maximum when the flowers were wholly opened and even faded. This period was optimum for the gathering and the distillation of the oil. Oppositely, the branches that were gathered at the same time as the flowers, never had oil and decreased the yield of the distillation.

The high level of cellulose in the branches explains their use for the distillation boilers.

THERMAL ANALYSIS: DTA, TG, DSC

Description of the Curves

By thermal analysis,[3] the aerial parts of the plants (leaves, branches, flowers, fruits) showed several specific temperature intervals, during the heat. The first interval, from the ambient temperature until about 150°C, corresponded to the volatilization of water in the plant. We determined the weight loss by thermogravimetry (TG), the endothermic reaction by differential thermal analysis (DTA), and by differential scanning calorimetry (DSC). The second interval, from 150 to about 350°C, was characterized by a weight loss and an exothermic reaction. The third interval, from 350 to about 500°C, was also specific with weight loss and exothermic peaks.

In a previous work,[3] we showed that the exothermic peak observed by DTA on cellulose and located at a temperature close to 300°C was characteristic of its decomposition. This phenomenum was followed by the oxidization of volatile products such as alcohols, aldehydes, ketones, and acids.

This decomposition was a depolymerization of the cellulose with a break of the 1–4 glucosidyl links and led to a weight loss of 80%. This reaction took place, indifferently, in air or nitrogen sweeping, and led to the formation of levoglucosan,[4,5] which, in its turn, decomposed in many flammable volatiles.[6–12] The burning started if the oxygen content in air was $> 15\%$.

We noted that this degradation was higher in air than in nitrogen: the DTA exothermic peak appeared at 316°C in air ambience and an endotherm at 341°C in nitrogen ambience.[13] The heat flow at 300°C allowed the flammability of the plants.[14,15] The lignin, present in the plants and degenerated at about 300°C, had less significance in the fire risks, because its evolved products were

Table III Comparison of the Three Vegetal Species

Samples	Desiccation Weight Loss (%)	Cellulose (%/DM)
Green thorns of *Ulex parviflorus*	40.2	38.8
New branches of *Ulex parviflorus*	40.4	34.7
Green needles of *Pinus halepensis*	54.3	25.5
New branches of *Pinus halepensis*	51.9	23.0
Green leaves of lavandin	80.4	15.7
New branches of lavandin	68.2	40.0

in the majority, at high molecular mass (substituted phenols, etc.) and so, less volatile than the cellulose ones.[16] This decomposition was less important.[3,17]

In Figure 1, the DSC curve of the new green leaves of the hybrid (lot 3) showed clearly the endothermic peak at 90°C (evolved water) and two exothermic peaks at 310 and 472°C. The first exothermic peak corresponded to the decomposition of the biopolymers. The second was the kind of combustion of the carbonaceous char formed. This hypothesis was recently confirmed by Weber,[18] by infrared spectroscopy [diffuse reflectance FTIR (DRIFT) procedure] performed on cellulose samples.

The sample, exhibited in Figure 1 (DSC curve), was also tested by DTA and TG (Fig. 2). The DTA curve was the same, however, with minor variations in the maximum temperature peaks, which was easily explained by the slightly different procedures (nature and geometry of the crucibles, gas sweeping, etc.). We also observed in Figure 2 the TG curve with weight loss and the DTG curve, derived curve of TG, in percent per minute, corresponding to the decomposition rate. The first and the fourth DTG peaks and the corresponding

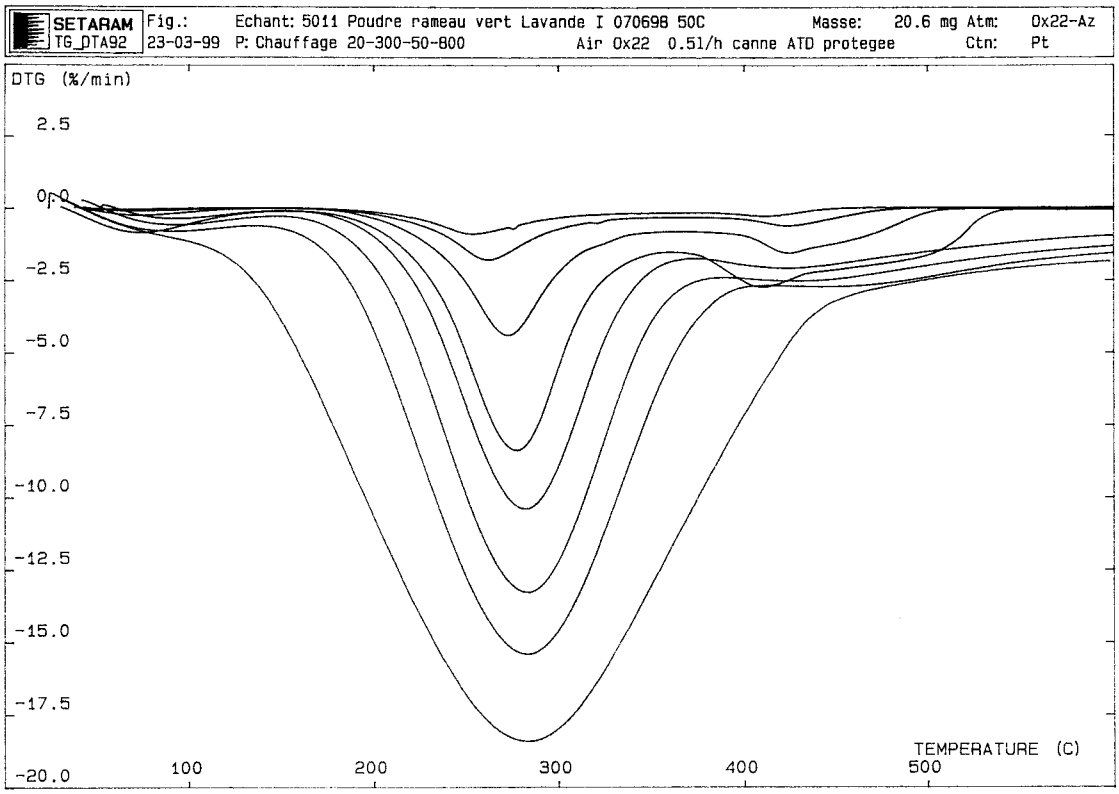


Figure 4 DTG curves of the new green branches of the lavandin (lot 5): raw powder (from top to bottom: 60, 120, 300, 600, 900, 1320, 1800, and 3000°C/h).

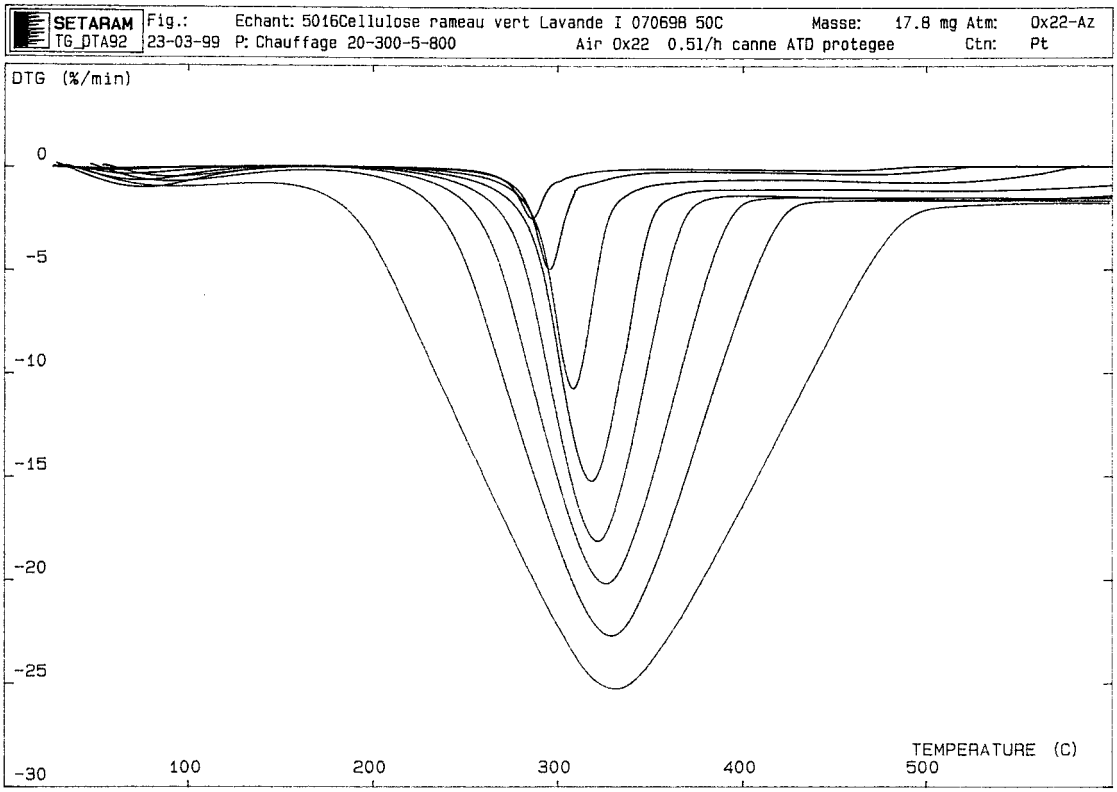


Figure 5 DTG curves of the new green branches of the lavandin (lot 5): cellulose (from top to bottom: 60, 120, 300, 600, 900, 1320, 1800, and 3000°C/h).

DTA ones had the same temperature; oppositely, a small variation existed between the exothermic DTA peak (301°C) and the third DTG peak (291.5°C). We had, previously, observed this phenomenon for other plants. This gap was attributed to the oxidation (observed in DTA) of the evolved products during the degradation (observed in TG and DTG) of the biopolymers, mainly the cellulose. The water, carbon monoxide, and carbon dioxide weight loss corresponded to about 13% at 364°C, the remainder to the hydroxylated, carbonylated, and etherified products.[19] For instance, the needles of *Pinus halepensis* presented an exothermic DTA peak at 314.4°C and a DTG peak at 300.8°C, that is, a 13.6°C difference.[20] A little DTG peak was always present at about 202°C in the case of the leaves and was attributed to undetermined products. We recall that the sum of the determined constituents was $< 74\%$. The weight loss at 500°C for the plants was always $< 100\%$; mineral ashes were present.

The evaporation of the essential oil (Fig. 3) was characterized by a minimum in DTG at 131°C followed by a shoulder at 187°C.

Results

The thermal analysis led to use specific parameters for the studied plants. In Table II, we noted for the hybrid powder samples and for each thermal characteristic, the averages (M) computed from several tries on each lot, and the standard deviation (SD) from more than five analyses, for the new green and old brown leaves, the new green and old brown branches, and the flowers.

The old brown leaves were issued from another stalk of a lavender. The flowers came from only one lot. We held the thermal parameters: DTA exothermic peak at about 300°C, and DTG peaks between about 200 and 500°C. We preferred work by thermal analysis on powder samples which represented the dry matter (see the sampling for the preparation), because of much more regularity in the curves than the freshly cut plants.

Discussion

For the leaves and the branches, we observed a significant variation of the maximum peak (DTA and DTG) temperatures, from the new green to old brown samples: first exothermic DTA peak:

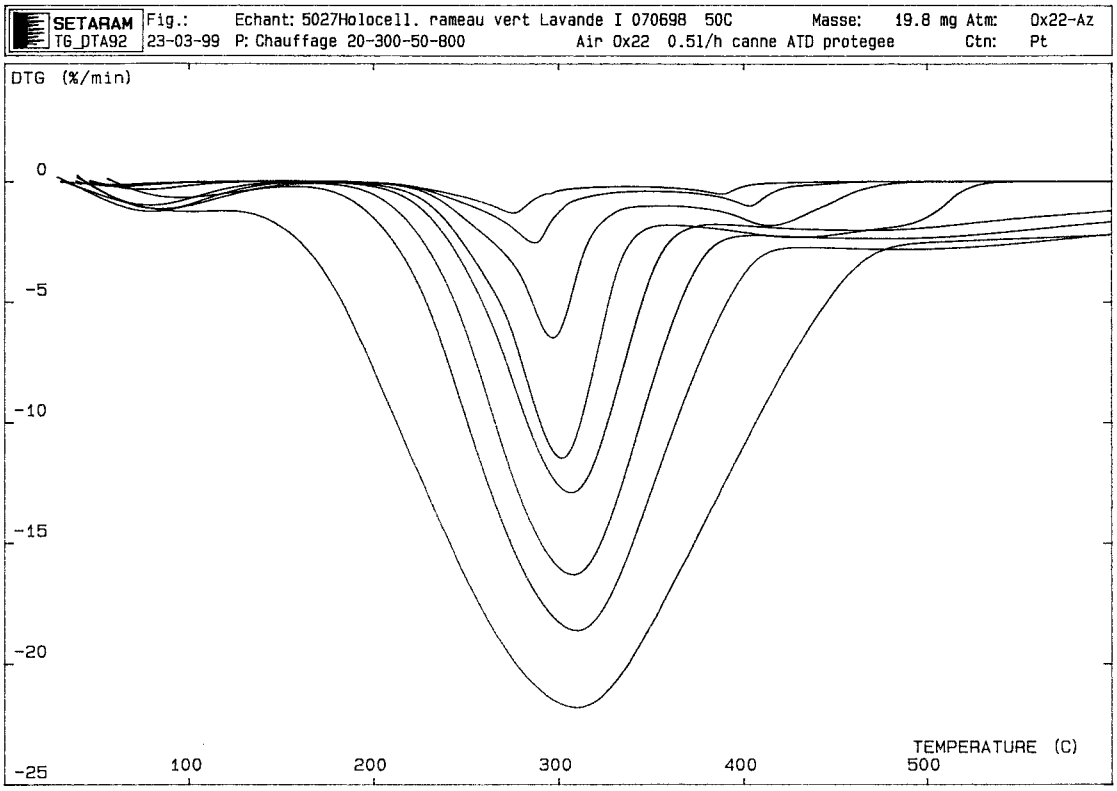


Figure 6 DTG curves of the new green branches of the lavandin (lot 5): holocellulose (from top to bottom: 60, 120, 300, 600, 900, 1320, 1800, and 3000°C/h).

leaves +9°C, branches +9°C; second DTG peak: leaves +15°C, branches +15°C; third DTG peak: leaves −25°C, branches −24°C.

According to us, the development of these variations depended on the increasing levels of cellulose, holocellulose, lignin, and decreasing for the extractives. The decreasing temperatures for the third DTG peak, during the aging, was explained by a lower temperature for pure holocellulose and lignin.[21]

Previously, we described a correlation between the maximum decomposition rate (V_{max}, i.e., the minimum of the DTG peak) and the level of cellulose and holocellulose in the dry matter. The study was performed at 120°C/h.[21,22] Some correlations had been observed between the carbohydrate level in the plant (mainly the cellulose as biopolymer) and the fire statistics (frequency, burnt areas, etc.) during the summer period.[23] The fire began with the brushwood and the litter, then with the evolved exothermicity, the trees dried up and ignited. The risk was important when the ambient air was hot and contained less humidity.[24]

When we observed, for instance, the three species present in Provence and gathered during the dryest period (August), the determination of water and cellulose present in the aerial parts of Argeras (*Ulex parviflorus*), Pine of Aleppo (*Pinus halepensis*), and the hybrid lavender (*Lavandula*) were reproduced in Table III. It is well known in Provence that the *Ulex parviflorus* species is very often at the start of forest fires. In this example, the most flammable part seems to be the thorns (consisting of a small amount of water and high level of cellulose). Oppositely, the leaves of the lavandin are less flammable (80.4% water and 15.7%/DM of cellulose).

We shall develop, in the next section, the inflammability risks of the different parts of the stalk of lavandin chosen as standard, simply in searching correlations between the V_{max} at about 300°C and the cellulose level in the dried powder samples. The thermogravimetric experiments were performed at high heating rates, near the conditions at the beginning of the forest fire.

THERMAL DECOMPOSITION RATE

The temperature (°C) and the maximum decomposition rate (V_{max} in %/min), determined at the

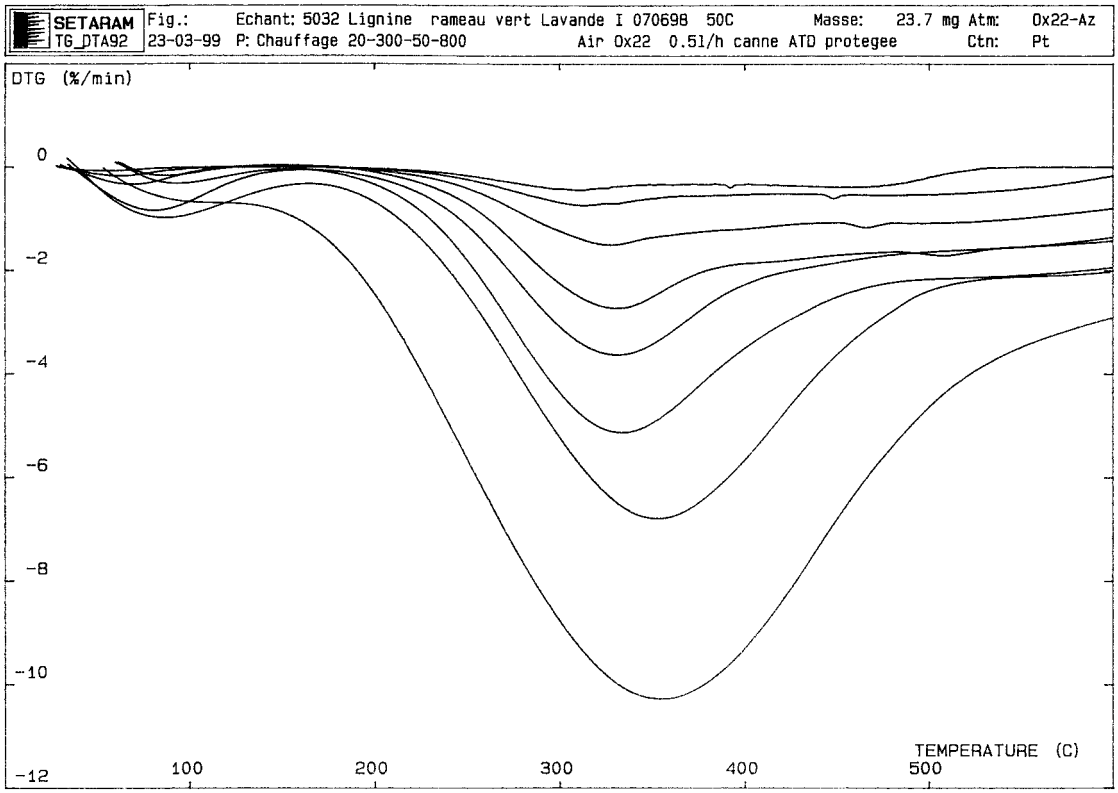


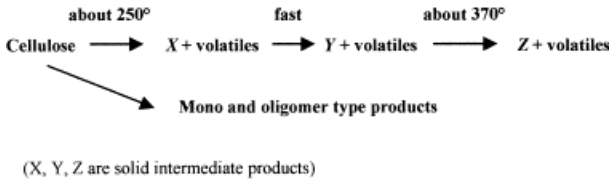
Figure 7 DTG curves of the new green branches of the lavandin (lot 5): lignin (from top to bottom: 60, 120, 300, 600, 900, 1320, 1800, and 3000°C/h).

minimum of the DTG peak, were deduced from the eight tries made by DTA-TG, under air sweeping and heating rate of 60, 120, 300, 600, 900, 1320, 1800, and 3000°C/h. We presented, as examples, for the new green branches of the lavandin (lot 5), the DTG curves in Figure 4, raw powder; Figure 5, cellulose; Figure 6, holocellulose; and Figure 7, lignin.

The smouldering and flaming combustion of cellulose was studied by Broido et al.,[25,26] Bradbury et al.,[27] and Alves and Figueiredo.[28,29] Varhegyi et al.[30] presented the reaction in Scheme 1.

Between 250 and 370°C, a first-order model would be adequate, of the form:

$$-d\alpha/dt = A \exp(-E/RT)(1 - \alpha)$$



Scheme 1

where α is the fraction of volatiles formed at time t, E is the apparent activation energy, and A is the preexponential constant.

According to this model, Cooley and Antal[31] obtained a good fit to the experimental weight loss curves with a value E at about 193 kJ/mol.

We computed the activation energy (E) according to the method described by Kissinger,[32] Ozawa,[33] and Audebert and Aubineau,[34] and by using the slope of the line, logarithm of the heating rate versus the reverse of the minimum DTG peak temperature. Eight tries were done in each case for the biopolymers and the raw powder of the green branches of lot 5. We obtained for the cellulose a correlation coefficient (r) = 0.990 and E = 221.2 kJ/mol, the holocellulose r = 0.958 and E = 270.9 kJ/mol, the lignin r = 0.935 and E = 223.0 kJ/mol, the raw powder r = 0.962 and E = 277.4 kJ/mol.

We observed, earlier, a better correlation for cellulose than holocellulose, in the case of *Pinus halepensis*.[35] The correlations for lignin and raw powder were not so good, and sometimes no correlation appeared. This was easily explained by a

Table IV Correlation Between the $V_{max}(Y)$ and the Logarithm of the Heating Rate (X), $Y = a + bX$, and the Regression Coefficient (r)

Lots	Samples	A	B	r	Cellulose (%/DM)	Holocellulose (%/DM)	Lignin (%/DM)
4	New green leaves	−15.456	7.915	0.947	11.7	25.8	21.0
	New green branches	−17.923	9.231	0.953	27.1	41.4	23.4
	Old brown branches	−18.959	10.003	0.975	35.2	52.0	29.4
5	Flowers	−16.432	8.340	0.943	20.0	30.2	21.0
	New green leaves	−16.051	8.098	0.935	17.4	23.1	20.9
	New green branches	−20.091	10.663	0.977	40.0	53.2	20.1
6	Flowers	−17.915	9.285	0.947	22.1	34.2	27.2
	New green branches	−21.537	11.647	0.984	42.7	57.0	20.9

For each sample, eight tries are done; the significance level is always very highly significant.

complex chemical structure of each specific lignin, and also a complex composition of the raw powder.

Our only concern was to find a correlation between, on one side, the levels of cellulose (or holocellulose) and lignin, and on the other side, the raw powder of the lavandin. So, we searched for a correlation between the $V_{max}(Y)$ and the logarithm of the heating rate (X).

For three studied lots, the results of the regression straight line equation $Y = A + BX$ and the regression coefficient r are included in Table IV. The levels of biopolymers (cellulose, holocellulose, lignin) are also indicated.

For each sample, eight tries are done; the significance level is always very highly significant. The regression coefficient is better for the samples with upper level in cellulose and holocellulose (for instance in the new green branches of the lot 6, $r = 0.984$; cellulose = 42.7%/DM, and holocellulose = 57.0%/DM).

Later, we looked up correlations between this slope $B(y)$ and the cellulose (x), and also holocellulose (x') contents in the samples. We obtained in the case of

$$\text{cellulose} \quad y = 6.335 + 0.113x \quad \text{and} \quad r = 0.968$$

$$\text{holocellulose} \quad y = 5.644 + 0.095x' \quad \text{and} \quad r = 0.954$$

The correlations were very highly significant (eight tries done for each sample), and better for the cellulose. Previously, we observed the same fact in the study of the variation of the V_{max} versus the contents of cellulose and holocellulose at 120°C/h heating rate. The volatilization between 150 and 350°C was higher for the cellulose (77.5%) than the holocellulose (70.8%).[21]

If we consider only the dry matter present in the plants, the flammability risk seems more important, because of the upper decomposition, for the green and brown branches than the flowers or the leaves.

We studied some biopolymers (cellulose, holocellulose, lignin) isolated from the new green branches (lot 5). Like previously, the regression straight lines equation were computed, with $Y = A + BX$ ($Y = V_{max}$ and X = log heating rate). The values are in Table V.

If we take into account the sum of the incremented parameters of the biopolymers, we observe for the new green branches (lot 5) a theorical percentage near the observed one:

$$\text{Theorical \%} = 40.0\ (\text{cellulose}) + 20.1\ (\text{lignin}) = 60.1\%$$

Table V Correlation Between the $V_{max}(Y)$ and the Logarithm of the Heating Rate (X), $Y = A + BX$, and the Regression Coefficient (r)

Samples (New green branches of lot 5)	A	B	r
Raw powder	−20.091	10.663	0.977
Cellulose	−23.329	13.972	0.998
Holocellulose	−22.868	12.514	0.987
Lignin	−10.280	5.180	0.905

For each sample, eight tries are done; the significance level is always very highly significant, except for the lignin, highly significant.

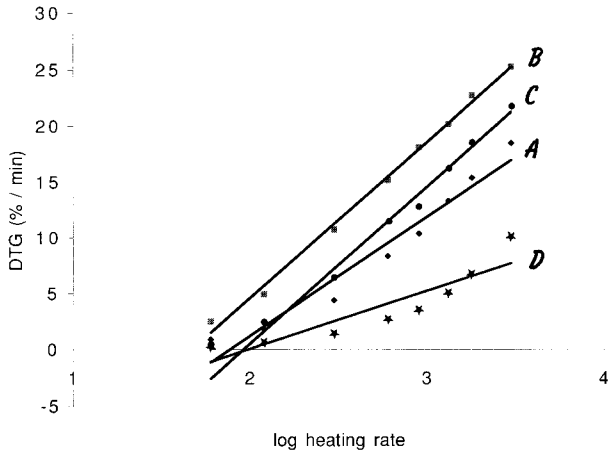


Figure 8 Correlation between the $V_{max}(Y)$ and the logarithm of the heating rate (X): New green branches of the lavandin (lot 5) (A = raw powder; B = cellulose; C = holocellulose; D = lignin).

$$\text{Observed } \% = (13.97) \times (40.0)/100 + (5.18) \times (20.1)/100 = 6.63$$

$$\text{So, } (6.63) \times 100/10.66 = 62.2\%$$

In the same way, for the holocellulose: theorical = 73.3%; observed = 72.2%.

This thermal decomposition of the plant powders corresponds to the sum of the partial decomposition of each biopolymer. But this must be considered as a semiquantitative analysis, because in our procedure, the determination of the slope B in lignin and raw powder is not perfect; the spots seem to be placed on curves (Fig. 8).

In conclusion, we observed a correlation between the V_{max}, at high heating rates near the conditions of the fire spreading in the forests, and mainly the content of cellulose in the dry matter, and secondarily with the holocellulose. This study seems important because it permits a fire risk estimation founded on the presence of biopolymers. The part played by the lignin is minor, compared to the cellulose, but if the decomposition rate of the lignin is higher, more of the V_{max} of the dry matter will decompose, and the risk fire increases.

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