

Development of Activated Carbon Using Vine Shoots (*Vitis Vinifera*) and Its Use for Wine Treatment

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An abundant and low-cost agricultural waste such as vine shoots (*Vitis vinifera*) (VS), which is generated by the annual pruning of vineyards, has been used as raw material in the preparation of powder activated carbon (AC) with a view to develop a new fining agent for white wines. A commercial activated carbon, S5X-Agrovin, was used for comparison purposes. From VS size-reduced pieces, AC was prepared using phosphoric acid as activating agent. The concentration of the H₃PO₄ solution, the impregnation temperature, and the carbonization conditions were controlled. The carbons were texturally characterized by gas adsorption (N₂, -196 °C), mercury porosimetry, and density measurements. FT-IR spectroscopy was used in the analysis of the surface functional groups and structures of the carbons. Three varieties of white wine (i.e., cv. Cayetana, cv. Macabeo, and cv. Sauvignon Blanc) were treated with the activated carbons. Color changes were monitored by UV–vis spectrometry. Significant differences in the degree of uptake of polyphenols were observed depending on the wine variety and on the method of preparation of activated carbon. The carbon prepared by first impregnation of VS with the 60 vol% H₃PO₄ solution at 50 °C and by then carbonization of the resultant product at 400 °C for 2 h presents a higher ability to discolor the white wines. The action of this carbon is comparable to that shown by the commercial product. Both carbons possess a well-developed porosity in the macropore range.

KEYWORDS: Vine shoots; chemical activation; activated carbon; white wines

INTRODUCTION

Activated carbon is a porous carbon material, which is usually produced from a large number of abundant and low-cost materials with high carbon content and low levels of inorganic impurities. The growing environmental concern and interest in the utilization of wastes have prompted the development of new processes for producing carbonaceous adsorbents based on agricultural and forest wastes (1–12). Vine shoots (*Vitis vinifera*) (VS) are a major source of vineyard waste, produced in the annual pruning process. Yearly, between 2 and 4 tons of VS are generated in a vineyard (13). This agricultural byproduct poses a problem to farmers who usually burn it in the field. This solution is the fastest one but not the best one, economically and environmentally. As an alternative, VS can be used as fuel, organic fertilizer, or feed. However, these uses of VS, among

others, have drawbacks associated with the low density of the material and transportation cost.

Activated carbon can be prepared by physical or chemical activation or, occasionally, by combination of both methods (14–16). Chemical activation consists of carbonization of the precursor at relatively low temperature in the presence of a chemical agent such as H₃PO₄ (9, 7), ZnCl₂ (5, 17), NaOH (18), KOH (18, 19), and so on. The common feature of these activating agents is their dehydrating action, which influences the thermal decomposition and inhibits the formation of tar (20). The activation processes develop pores of molecular dimensions within the carbon particle. The extended number of pores in each particle gives the carbon extremely high internal porosity and surface area. Adsorption characteristics and efficiency in adsorption processes of activated carbon are determined by its pore structure, magnitude and distribution of pore volume, and surface area. The adsorptive properties of activated carbon are also determined by its chemical composition through the presence of unpaired electrons, chemically bonded elements, and so on (21). Practically, the type of raw material employed

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and the method of preparation dictate the type of porosity and chemical composition of the carbon.

Activated carbon is an extremely versatile adsorbent of major industrial significance. It is used in a wide range of applications which are concerned principally with the removal of species by adsorption from the liquid or gas phase (20, 22). These applications include the use of activated carbon in winemaking as a decolorant and deodorant of white wines (22, 23). In the literature, there are also recent studies dealing with the reduction of the ochratoxin A levels in red wines (24).

Browning, which decreases wine quality and lowers the shelf life of wines, represents an important problem for the making of white wines. Among the various reactions involved, the most important ones are oxidation of the different phenolic compounds (i.e., catechins, proanthocyanidins, and hydroxycinnamic acids and their derivatives) and formation of oligomers (23). One technological preventative measure is to decrease the amount of polyphenols present in white wines. For this, traditionally, the oenological industry has used bentonite, activated carbon, polyvinylpyrrolidone, casein, or yeasts (23, 25–30), their choice being conditioned by the nature of the wine and compounds that are intended to be eliminated from the wine. Activated carbon tends to bind to weakly polar molecules, in particular when these contain benzene rings or their derivatives such as the phenolic compounds that are ubiquitously present in white wines (23, 30). By the use of activated carbon, the phenolic compounds can be effectively removed from wines. Usually, oenological carbons are powdered activated carbons with a specific surface area ranging between 1000 and 1300 m² g⁻¹ and pore volumes between 2.3 and 2.7 cm³ g⁻¹ (31).

This work focuses on the preparation of activated carbon from VS, using phosphoric acid as activating agent. The products obtained are further characterized from the standpoints of porous structure and surface functional groups and structures. Another main objective of this study is to test the resultant products in the discoloring treatment of three white wines. In particular, the effects on phenolic compounds and color parameters are studied by considering the physicochemical properties of the carbons.

MATERIALS AND METHODS

Raw Material. Vine shoots (*Vitis vinifera* variety) (VS) were used as precursor in the preparation of activated carbon. The VS were obtained from a vineyard located in the zone named Tierra de Barros (Badajoz province, Spain).

VS Conditioning. The VS, as received already air-dried, were size-selected, ground (a manual mechanical mill was used in this operation), and sieved to obtain particle sizes smaller than 1 mm. Subsequently, the material was washed with a dilute (5 vol%) H₂SO₄ solution to partially, at least, dissolve inorganic impurities (32). Washing was then carried out with distilled water until neutral pH was attained in the residual liquid. Finally, the product was oven-dried at 120 °C overnight.

VS Impregnation. Approximately 50 g of conditioned VS was added to a 100 mL solution of H₃PO₄, and the system was stirred at a pre-set temperature for 2 h. After being mixed, the solution was evaporated to dryness.

Carbonization Treatments. About 10 g of impregnated VS was placed in a stainless steel reactor (240 mm length and 35 mm i.d.) and, using a vertical cylindrical furnace, heated from room temperature to a pre-set carbonization temperature in flowing nitrogen (flow rate = 200 mL min⁻¹). The heating rate was 10 °C min⁻¹. The time at maximum heat treatment temperature was 2 h. Once this time elapsed, the system was cooled to room temperature under the same flow of nitrogen. The product thus obtained was washed with distilled water to pH 6 and oven-dried at 120 °C for 10 h. The concentration of the

Table 1. Preparation of Activated Carbon by Chemical Activation of Vine Shoots

sample	[H ₃ PO ₄] (vol%)	chemical activation		yield (wt%)
		impregnation temperature (°C)	carbonization temperature (°C)	
C1	35	85	400	52
C2	60	50	400	50
C3	60	50	200 + 400	51
C4	60	50	450	48

H₃PO₄ solution, impregnation and carbonization temperatures, yield values for the carbonization process, and notations of the samples can be seen in **Table 1**. In the carbonization of VS, heating was effected in one step for C1, C2, and C4 and in two successive steps for C3. In this instance, VS were heated first from room temperature to 200 °C and, after 2 h isothermal time at this temperature, then at 400 °C also for 2 h.

For a further comparison purpose, a commercial activated carbon (S5X-Agrovin, CC) was used. The selected activated carbon is widely employed at present in most of the wine cellars located in the Autonomous Community of Extremadura (Spain).

Textural Characterization. The activated carbons were characterized in terms of their texture (surface area, porosity, and pore-size distribution) and surface functional groups and structures. The textural characterization was carried out by gas adsorption, mercury porosimetry, and density measurements. Regardless of the analysis tool used, the samples were always first oven dried at 120 °C for 12 h. The adsorption isotherms for N₂ (purity >99.998%) at -196 °C were determined using a semiautomatic adsorption apparatus (Autosorb-1), Quantachrome. About 0.15 g of sample was used in each adsorption experiment. The adsorbent was placed in a glass container and outgassed at 250 °C for 12 h, at a pressure lower than 10⁻³ Torr, prior to effecting adsorption measurements. From the measured adsorption isotherms, the specific surface area was estimated using the Brunauer, Emmet, and Teller (BET) equation (33), S_{BET} . The micropore volume (W_0) was obtained by applying the Dubinin–Radushkevich equation (34) and also by taking it to be equal to the volume of N₂ adsorbed at $p/p^0 = 0.10$ (V_{mi}). The mesopore volume V_{me} was also obtained from the N₂ isotherm ($V_{\text{me}} = V_{0.95} - V_{\text{mi}}$, $V_{0.95}$ being the volume adsorbed at $p/p^0 = 0.95$). V_{mi} and V_{me} were expressed as liquid volumes. The values of S_{BET} , V_{mi} , and V_{me} are set out in **Table 2**. A mercury porosimeter (Autoscan-60), Quantachrome, was used in the experiments of mercury intrusion. The values of surface tension and contact angle used in the computational program of the porosimeter were 0.480 Nm⁻¹ and 144°, respectively. From porosimetry data, the macropore volume (V_{ma}) and the mesopore volume ($V_{\text{me-p}}$) of the samples were obtained. V_{ma} was regarded to be the cumulative pore volume at the pore radius of 250 Å, and $V_{\text{me-p}}$ that at 10 Å minus V_{ma} . The values of V_{ma} and $V_{\text{me-p}}$ are listed in **Table 2**.

The density of the samples was obtained by mercury and helium displacement. The mercury density (ρ_{Hg}) was measured just before carrying out the experiment of mercury porosimetry. The sample holder, containing about 0.5 g, was evacuated until the pressure of 13.33 Pa was reached in the filling apparatus, Quantachrome. The helium density (ρ_{He}) was measured in a Quantachrome steropycnometer, using around 3 g of sample. From ρ_{Hg} and ρ_{He} , the total pore volume (V_{T}) was calculated by the expression $V_{\text{T}} = 1/\rho_{\text{Hg}} - 1/\rho_{\text{He}}$ (22). The values of ρ_{Hg} , ρ_{He} , and V_{T} are listed in **Table 2**.

Infrared Analysis. A Perkin-Elmer 1720 spectrometer was used. The spectra were recorded in the range of wavenumbers 4000–450 cm⁻¹. 50 scans were taken at 2 cm⁻¹ resolution. Pellets were prepared by thoroughly mixing carbon and KBr at a 1:400 sample/KBr weight ratio in a small size agate mortar. The resulting mixture was placed in a Perkin-Elmer manual hydraulic press, and a force of 10 tons was applied for 3 min. The background spectrum and a reference spectrum were subtracted from the spectrum of each individual sample. The reference spectrum was obtained previously for a KBr pellet with identical mass and thickness as for the carbon sample.

Table 2. Textural Properties of the Activated Carbons

sample	N ₂ adsorption				mercury porosimetry		density measurements		
	S _{BET} (m ² g ⁻¹)	V _{mi} (cm ³ g ⁻¹)	W ₀ (cm ³ g ⁻¹)	V _{me} (cm ³ g ⁻¹)	V _{me-P} (cm ³ g ⁻¹)	V _{ma} (cm ³ g ⁻¹)	ρ _{Hg} (gcm ⁻³)	ρ _{He} (gcm ⁻³)	V _T (cm ³ g ⁻¹)
C1	1007	0.48	0.51	0.09	0.33	0.13	0.79	1.75	0.69
C2	1160	0.45	0.48	0.30	0.43	0.63	0.49	1.79	1.48
C3	1666	0.72	0.77	0.31	0.53	0.36	0.54	1.78	1.29
C4	1573	0.64	0.67	0.44	0.61	0.33	0.59	1.94	1.18
CC	1329	0.48	0.52	0.83	0.60	1.38	0.33	1.67	2.43

Wines Used. They were three unclarified white wines, i.e., cv. Cayetana, cv. Macabeo, and cv. Sauvignon Blanc, from the 2003 harvest, as supplied by a wine cellar located in Almendralejo D. O. "Ribera del Guadiana" (Extremadura region, Spain).

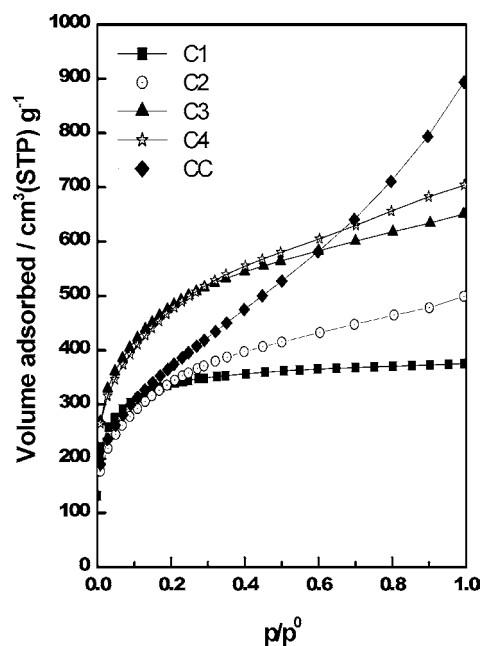
Wine Analysis. The wines, which had not been subjected to previous clarification and stabilization treatments, were first vigorously aerated for a better appreciation of the effects associated with the treatment with activated carbon. Then, a carbon dose of 0.1125 g was added to 75 cL of each wine (i.e., the carbon/wine ratio was 15 g hL⁻¹) in duplicate, the system being maintained under slight agitation at 25 °C for 72 h. After that, the wine was centrifuged. The presence of particles in suspension was not observed in the resulting wines. These were also free from CO₂. The color and phenolic compounds were analyzed by UV-vis spectrometry using a Perkin-Elmer Lambda 3 B apparatus, with 1 cm path length quartz cells. Absorbance measurements were taken between 380 and 750 nm. All analyses were carried out in duplicate both on the control wine and on the wine after its contact with carbon.

Spectral Analysis of Phenolic Compounds. Since, during the discoloring process of white wines by action of carbonaceous adsorbents, the progressive disappearance of the yellow color occurs due to the adsorption of phenolic compounds present in the wine, the total phenolic index (TPI) and total hydroxycinnamates (TH) were estimated. The TPI is defined as (A₂₈₀ - 4) and the TH as (A₃₂₀ - 1.4) (35), A₂₈₀ and A₃₂₀ being the absorbance readings at 280 and 320 nm, respectively, multiplied by a dilution factor. The correction factors 4 and 1.4 are introduced to allow for the absorption caused by nonphenolic compounds at such absorbance readings.

Color Evaluation. The standard parameters (color density and tint) and the chromatic coordinates CIELAB were used to characterize the wine's color. Color density (CD) gives one idea of how much color a wine has. A measure of CD was achieved by summation of the absorbance readings at 420 (A₄₂₀) and 520 (A₅₂₀) nm (35). Color tint (CT) shows the importance of yellow color relative to red color. It was measured as the quotient A₄₂₀/A₅₂₀ (35). Color definition was also made by the CIELAB space (36), using the D65 illuminant and a 10° observer. Hue angle (H*) and chroma (C*) spherical coordinates were obtained from the chromatic coordinates L*, a*, and b*, which were derived from the so-called tristimulus values (23). The vertical axis, L*, is a measure of lightness, from completely opaque (0) to completely transparent (100), a* is a measure of redness (or -a* of greenness), and b* of yellowness (or -b* of blueness) (28). C* is related to the coloring intensity. It indicates the contribution of a* (redness) and b* (yellowness) to the wine color. H* was calculated as [arctan(b*/a*)] and C* as [(a*)² + (b*)²]^{0.5}. The variation in the color of a wine, ΔE*, is defined as [(ΔL*)² + (Δa*)² + (Δb*)²]^{0.5} (37).

RESULTS AND DISCUSSION

Preparation of Activated Carbon. From the yield values (Table 1), it follows that the method of preparation of activated carbon slightly influences the mass loss produced in the carbonization of H₃PO₄-impregnated VS. Thus, on average, the yield is 50% (w/w). The yield is only somewhat higher when the dilute H₃PO₄ solution is used in the impregnation of VS. Conversely, it is a little lower when the carbonization temperature is 450 °C, instead of 400 °C. Finally, the fact that impregnated VS are heated in one or in two successive steps

**Figure 1.** Adsorption isotherms (N₂, -196 °C) of the activated carbons.

from ambient temperature to the maximum heat treatment temperature does not affect the process yield.

Textural Characterization. The N₂ isotherms measured for the activated carbons prepared in the present study are shown in Figure 1. The isotherm obtained for C1 is a typical type I isotherm of the BDDT classification system (38). Accordingly, C1 is an essentially microporous solid. Because the isotherms for C3 and C4 stand over the isotherms of C1 and C2, the degree of development of the microporosity is larger in the former couple of activated carbons. The rather open isotherm knees for C1-C4 indicate that the activated carbons possess a wide pore size distribution in the micropore range. For C2, C3, and C4, in addition, the gradual increase in the amount of N₂ adsorbed to p/p⁰ = 1.0 demonstrates the presence of mesopores of different sizes in these carbons. These statements on the porosity of the carbons are corroborated by the values of V_{mi}, W₀, and V_{me} listed in Table 2. As expected, in view of the V_{mi} and W₀ values, S_{BET} is higher for C3 and C4 than for C1 and C2. The values of S_{BET} of 1666 m² g⁻¹ for C3 and of 1573 m² g⁻¹ for C4 are even larger than those reported previously for oenological carbons (31), which is worth mentioning. Figure 2 displays the curves of the cumulative pore volume (CPV) against pore radius (r) for the activated carbons. The derived values of V_{me-P} also show that the development of the mesoporosity is greater in C2, C3, and C4 than in C1. The systematically higher V_{me-P} than V_{me} for the series of carbons, in particular for C1, indicates that a significant fraction of their porosity is accessible to mercury under compression but not to N₂ at -196 °C. Such a porosity may be made up of blind pores or pores created by compacting of the carbons. In the first

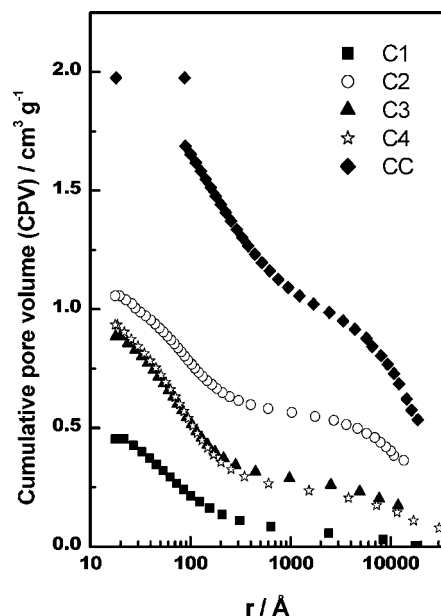


Figure 2. Cumulative pore volume against pore radius for the activated carbons.

instance, the pores should open under compression to enable mercury intrusion and in the second instance the pores should be mesopore-size voids remaining between compressed carbon particles of the sample. Moreover, V_{ma} is significantly higher for C2 than for the other carbons. From the values of V_T , it follows that, of all the carbons prepared here, C2 is the most porous one.

From the above results, it becomes clear that, using VS as raw material and by controlling the method of preparation, it is possible to develop activated carbon with a good development of the porosity in the micro-, meso-, and macropore ranges.

The values of the pore volumes (Table 2) reveal that CC is as microporous as C1 and C2 but less than C3 and C4. However, CC is a more mesoporous and macroporous carbon than C1, C2, C3, and C4. The value of V_{me-p} obtained for CC is increased with regard to the real value of the mesopore volume since, as deduced from Figure 2, breaking of carbon particles surely occurs, owing to the application of high pressures during the porosimetry experiment. Nevertheless, the slope of the CPV- r curve for CC in the mesopore range suggests that the aforementioned effect on carbon particles is not very important, and so the increase in the reported value of V_{me-p} will be of little significance. On the other hand, the isotherm of CC (Figure 1) is situated rather below the isotherms of C3 and C4 over a wide p/p^0 range. Accordingly, the development of the mesoporosity in the region of narrow mesopores is larger for C3 and C4 than for CC. The opposite applies to the wide mesopores. Also notice that S_{BET} is significantly higher for C3 and C4 than for CC, as expected in view of the micropore volume for these carbons. From the results obtained in this characterization study of the carbons, it becomes clear that, except for the large pores (i.e., macropores and wide mesopores), activated carbons prepared in this work have better textural properties than the commercial carbon.

FT-IR Spectroscopy. The spectra registered for the activated carbons prepared from VS (Figure 3) show an intense and broad band located at 3371 cm^{-1} , which is ascribable to $\nu(\text{OH})$ vibration (ν = stretching) in phenolic hydroxyl groups. The position of this band is compatible with the participation of the OH groups in hydrogen bonds because, for nonbonded OH groups, the band is usually located above 3500 cm^{-1} (39). Water

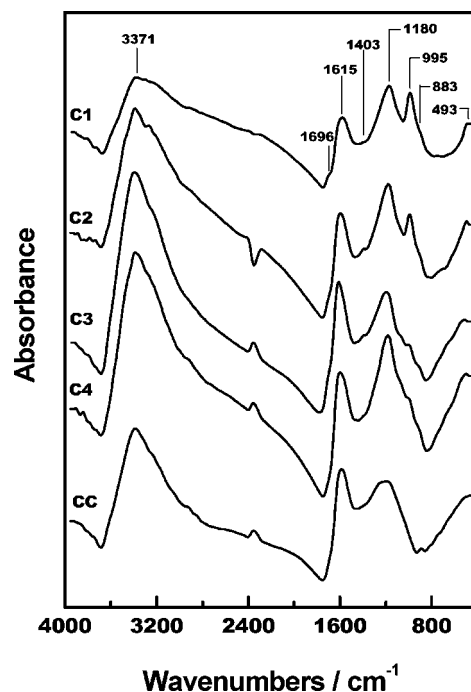


Figure 3. FT-IR spectra of the activated carbons.

may also cause absorption of infrared radiation in this spectral region. In the carbons, such water may be present after interacting with primary adsorption centers through its OH groups and in micropores as volumetric water. The band at 1696 cm^{-1} is associated with $\nu(\text{C}=\text{O})$ vibrations in quinone-type structures. The band centered at 1615 cm^{-1} is likely due to $\nu(\text{C}=\text{C})$ absorption. Since this band is broad and extends below 1600 cm^{-1} , it may embrace not only the stretching vibration of C=C bonds in olefinic structures but also in-plane skeletal C=C vibrations of aromatics. In the former instance, as the band appears at low frequencies in the $1700\text{--}1600\text{ cm}^{-1}$ range, the C=C bonds may be in conjugation with other similar C=C bonds, C=O groups, or aromatic nuclei (40). The broad band at 1180 cm^{-1} is attributed to $\nu(\text{C}-\text{O})$ vibrations in hydroxyl groups and ether-type structures. Finally, the band at 995 cm^{-1} is similarly shaped to a band reported previously at 985 cm^{-1} , which was ascribed to $\nu(\text{P}-\text{O})$ vibrations in inorganic and organic species (41).

The spectra registered for the activated carbons prepared from VS (Figure 3) show the same number of main features but with different band intensities. This suggests the dependence of the content of surface atomic groupings and structures on the method of preparation of the carbons. As an example, in the spectrum of C3, the intensity of the shoulder at 1696 cm^{-1} is higher. In addition, the band at 1615 cm^{-1} is significantly stronger than the band 1180 cm^{-1} , whereas the opposite applies to the other spectra. Therefore, the concentration of C=O-containing structures and of C=C bonds relative to that of C-O bonds is higher for C3. Moreover, the band at 995 cm^{-1} is only readily visible in the spectra of C1 and C2, which reveals that the content of P-O bonds is higher in both carbons heated at $400\text{ }^\circ\text{C}$. However, it is lower when the carbonization of VS is performed at $450\text{ }^\circ\text{C}$ or in two successive steps at 200 and $400\text{ }^\circ\text{C}$. The influence of the concentration of the H_3PO_4 solution used in the impregnation of VS on the formation of P-O bonds is of little significance as the intensity of the aforesaid band is similar in the spectra of C1 and C2.

As far as the spectrum of CC is concerned, as expected, the band at 995 cm^{-1} is absent from it. For this carbon, as for C3,

Table 3. Wine Treatment: Effect on Phenolic Compounds

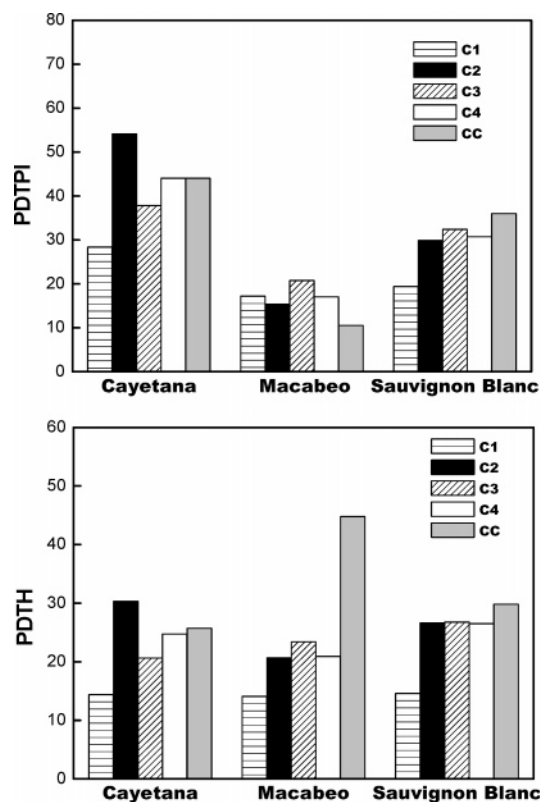
control wine/ carbon	wine		
	cv. Cayetana	cv. Macabeo	cv. Sauvignon Blanc
	TPI		
control wine	2.94	6.08	4.95
C1	2.10	5.04	3.99
C2	1.35	5.14	3.47
C3	1.82	4.82	3.34
C4	1.64	5.04	3.43
CC	1.64	5.42	3.17
	TH (g L ⁻¹)		
control wine	3.18	5.45	3.94
C1	2.72	4.69	3.37
C2	2.22	4.33	2.89
C3	2.52	4.18	2.89
C4	2.39	4.31	2.90
CC	2.36	3.01	2.77

the band at 1615 cm⁻¹ is also more intense than the band at 1180 cm⁻¹. Finally, the latter band is broader than in the spectra of C1, C2, C3, and C4. This is in line with the presence of a larger number of different C–O-containing functional groups and structures in CC than in the other activated carbons.

Wine Treatment: Effect on Phenolic Compounds. Table 3 lists the values of TPI and TH obtained for the three wines. It was observed that, in comparison to the each control wine, the TPI decreases for the various carbons, which demonstrates the partial removal of polyphenolic compounds from the wines after their treatment with the carbonaceous adsorbents. The lowest TPI corresponds to C2 for cv. Cayetana, C3 for cv. Macabeo, and CC for cv. Sauvignon Blanc. The percentage decrease in TPI, i.e., PDTP = [(TPI_{cw} - TPI_{tw})/TPI_{cw}] × 100, TPI_{cw} being the TPI for the control wine and TPI_{tw} the TPI for the treated wine, is as high as 54.1 for cv. Cayetana, 20.7 for cv. Macabeo, and 36.0 for cv. Sauvignon Blanc (Figure 4a). After treatment of the wines, the lowest TH appears in the case of CC for cv. Macabeo and cv. Sauvignon Blanc and of C2 for cv. Cayetana. The percentage decrease in TH, i.e., PDTH = [(TH_{cw} - TH_{tw})/TH_{cw}] × 100, TH_{cw} being the TH for the control wine and TH_{tw} the TH for the treated wine, is as high as 30.2 for cv. Cayetana, 44.8 for cv. Macabeo, and 29.7 for cv. Sauvignon Blanc (Figure 4b).

Effect on Color. Standard Parameters. The values of the standard parameters (CD and CT) obtained for the three wines are set out in Table 4. The discoloring effect of the wines, as expressed by the decrease in CD, depends on the activated carbon. Usually, it is weaker for C1 and stronger for C2. In addition, the activity of C2 in the discoloring process of the wines is comparable to that of CC. Since C1 is the only carbon of the series C1–C4 for which V_{me} and V_{ma} are very small (Table 2), a well-developed porosity in the region of large pores of the carbons appears to be the essential factor in controlling their effectiveness in the treatment of the wines. It is corroborated with the high V_{ma} for C2 and CC. For C2, in fact, V_{ma} is almost 2-fold higher than for C3 and C4. As expected, the values of CD and CT as a rule are close for C2 and CC and more different for C1, C3, and C4. The activity of the carbons in the treatment of the wines does not run parallel to the contents in surface functional groups and structures. As a whole, the results obtained here suggest then that the porous structure is a more decisive factor than the surface functional groups and structures in connection with the action of the carbons.

Chromatic Coordinates. The values of the chromatic coordinates CIELAB are listed in Table 5. Lightness (L*) significantly increases for the wines subjected to treatment with

**Figure 4.** Percentage decrease in TPI (a) and in TH (b).**Table 4.** Effect on Color: Standard Parameters

control wine/ carbon	wine		
	cv. Cayetana	cv. Macabeo	cv. Sauvignon Blanc
	CD		
control wine	0.30	0.32	0.38
C1	0.09	0.15	0.17
C2	0.05	0.09	0.10
C3	0.06	0.14	0.13
C4	0.06	0.12	0.13
CC	0.05	0.08	0.10
	CT		
control wine	1.50	1.70	1.90
C1	3.50	2.70	3.25
C2	4.00	3.50	4.00
C3	5.00	2.50	3.33
C4	5.00	3.00	3.33
CC	4.00	3.00	4.00

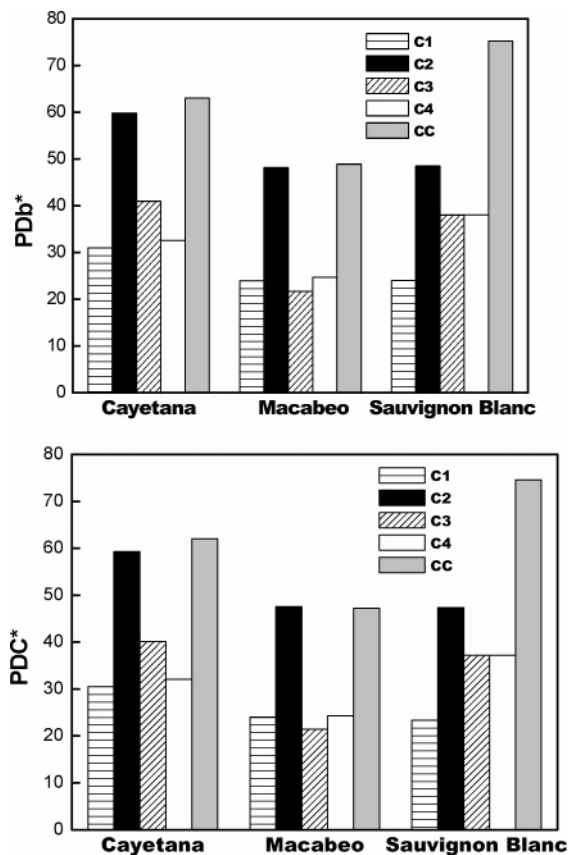
activated carbon, which is attributable to the removal of pigments present in the wines. The increase in L* denotes that the wine changes toward high transparency. Depending on the wine, L* is higher either for CC (cv. Sauvignon Blanc), C2 and C3 (cv. Cayetana), or C2 (cv. Macabeo). For the three wines, the variations produced in a* are slight, whereas those in b* are more marked. These results indicate a reduction in the yellow color of the wines after their treatment with activated carbon. The values of the percentage decrease in b*, i.e., PDb* = [(b*_{cw} - b*_{tw})/b*_{cw}] × 100, b*_{cw} and b*_{tw} being the b* values for the control and treated wines, are shown in Figure 5a. It is seen that for a given carbon the smallest decrease in PDb* appears for cv. Macabeo, which is in line with the lowest TPI for this wine. Irrespective of the wine, the decrease in PDb* is usually smaller for C1 and greater for C2 and CC. The chroma, C*, and hue, H*, parameters also change as a result of the discoloring process since they are combinations of the a*

Table 5. Effect on Color: Chromatic Parameters

control wine/ carbon	wine		
	cv. Cayetana	cv. Macabeo	cv. Sauvignon Blanc
	<i>L*</i>		
control wine	90.8	91.0	90.4
C1	99.0	98.1	97.2
C2	99.5	99.1	98.7
C3	99.4	97.4	98.1
C4	99.1	98.4	98.3
CC	99.2	98.9	99.1
	<i>a*</i>		
control wine	-0.52	-0.50	-1.12
C1	-0.57	-0.32	-1.31
C2	-0.47	-0.61	-1.22
C3	-0.62	-0.54	-1.17
C4	-0.57	-0.63	-1.21
CC	-0.51	-0.96	-0.63
	<i>b*</i>		
control wine	5.53	7.11	9.82
C1	3.82	5.41	7.46
C2	2.22	3.69	5.06
C3	3.26	5.57	6.09
C4	3.73	5.36	6.09
CC	2.04	3.64	2.44
	<i>C*</i>		
control wine	5.55	7.13	9.88
C1	3.86	5.42	7.58
C2	2.26	3.74	5.21
C3	3.32	5.60	6.20
C4	3.77	5.40	6.20
CC	2.11	3.76	2.51
	<i>H*</i>		
control wine	-84.6	-86.0	-83.5
C1	-81.4	-86.5	-80.0
C2	-79.8	-80.8	-76.4
C3	-79.2	-84.4	-79.1
C4	-81.2	-83.3	-78.7
CC	-75.8	-75.1	-75.5
	ΔE^*		
control wine	0.00	0.00	0.00
C1	8.42	7.31	7.23
C2	9.30	8.75	9.64
C3	8.91	6.53	8.61
C4	8.56	7.58	8.75
CC	9.10	8.56	11.41

and b^* parameters. For all wine/carbon systems, C^* presents low values, which proves that vivid colors are absent from the wines. Otherwise, the C^* value should be close or higher than 5 (42). Because the incidence of the treatments of the wines with the carbons is greater for b^* than for a^* , the results obtained for PDC^* , as calculated by expression $[(C^*_{cw} - C^*_{tw})/C^*_{cw}] \times 100$, (Figure 5b) are practically identical to those for PDb^* . H^* in absolute value as a rule is also smaller for CC and C2 than for the other carbons. Finally, ΔE^* , which depends also on Δb^* , is higher for C2 than for CC for cv. Cayetana and cv. Macabeo.

Of the activated carbons prepared from VS, C2 exhibits the best behavior in the discoloring treatment of the white wines. The behavior of C2 is comparable to that shown by CC. C2 has been prepared by impregnation of VS using the concentrated H_3PO_4 solution at 50 °C and by carbonization of the impregnated product at 400 °C for 2 h. The textural property that distinguishes C2 from the other carbons of the series C1–C4 is its higher macropore volume. This is even higher for the commercial activated carbon. These facts indicate that a way to increase the effectiveness of activated carbon prepared from VS in the discoloring treatment of white wines may consist of developing the macroporous structure in the material.

**Figure 5.** Percentage decrease in b^* (a) and in C^* (b).**ACKNOWLEDGMENT**

Financial support from MCYT (project BQU2002-03600) is gratefully acknowledged by the authors. We also thank the Instituto Tecnológico Agroalimentario de Extremadura (INTAEX) for valuable assistance in laboratory tasks.

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Received for review July 15, 2004. Revised manuscript received November 9, 2004. Accepted November 16, 2004.

JF048824D