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Synthesis and evaluation of organic pigments.
3. Studies based on nonmutagenic twisted benzidines

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Abstract

Bis-chromophoric pigments prepared using nonmutagenic benzidine analogs with high dihedral angle across the biphenyl linkage are reported. The mutagenic properties of twisted bisazomethine, disazoacetoacetanilide, disazopyrazolone, disazobenzimidazolone and disazonaphthol pigments were established using the standard Ames *Salmonella* mammalian mutagenicity assay and the Prival modification. Results from these tests and from the evaluation of hue, color strength and photostability of the pigments prepared are reported. Some of the new pigments are potential viable alternatives to those derived from 3,3′-dichlorobenzidine and other genotoxic analogs of benzidine. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Pigments; Azomethine; Azoacetoacetanilide; Benzimidazolone; Pyrazolone; Azonaphthol; Mutagenicity; Benzidine; Dihedral angle

1. Introduction

Bis-chromophoric benzidine-based pigments are known to possess higher color strength, better thermal stability and solvent resistance, and absorb at longer wavelengths than their mono-chromophoric counterparts [1,2]. The commercial significance of benzidine-based colorants has caused the search for viable nonmutagenic analogs of benzidines to continue to be an important research problem. Significant progress in this area was made by Shahin et al. [3], who found that the mutagenicity of aromatic *meta*-phenylenediamine could be lowered or removed by placing bulky alkyl or alkoxy substituents *ortho* to an amino group in the molecule. This discovery was followed by patents [4,5] describing the synthesis of nonmutagenic benzidines **I**. These diamines were reported to be useful in the synthesis of water-soluble dyes [6] and pigments [7].

In a previous paper [8], we reported the synthesis and evaluation of a series of new bisazomethine pigments prepared by condensation of oxo- and thiopyrimidines with nonmutagenic 3,3′-disubstituted benzidines (**I**) in the presence of a formylating agent, triethyl orthoformate. The focus of that work was the replacement of genotoxic 3,3′-disubstituted benzidine congeners, such as 3,3′-dichlorobenzidine and *o*-tolidine, as intermediates for bisazomethine pigments. Although high performance nonmutagenic bisazomethine pigments were produced using diamines of type **I**,

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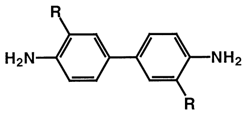
incorporation of bulky alkyl or alkoxy substituents in the *ortho*, *ortho′* positions of the benzidine intermediate limited the color gamut to yellow to golden yellow. The development of nonmutagenic, bright greenish yellow pigments with high fastness and color strength is desirable. Hence, strategies were developed for extending the color gamut of bisazomethine and other classes of organic pigment prepared from benzidine congeners, whilst maintaining nongenotoxic behavior.

The approach considered in the present study involved the incorporation of groups in the benzidine intermediate that reduce the π orbital overlap across the biphenyl linkage, thereby producing hypsochromic shifts in the resultant pigment.



I

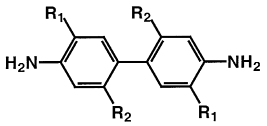
R = $C_{3\text{-}5}$ alkyl/alkoxy

In part one of this series of papers [9], we described the synthesis and evaluation of 2,2′,5,5′-tetrasubsituted benzidine analogs (**II**). Substituents in the 2,2′-positions were introduced to produce steric strain across the biphenyl linkage, thereby increasing the dihedral angle and reducing the bond order of the biphenyl linking bond relative to when protons are present in these positions. The tetrasubstituted diamines were found to be nonmutagenic. Since diamines **IIa** and **IIb** were prepared in good yield and required minimum purification, they were employed as pigment precursors. In this regard, the present paper pertains to the synthesis and evaluation of bisazomethine (**IIIa–d**), disazoacetoacetanilide (**IVa–j**), disazopyrazolone (**V**), disazobenzimidazolone (**VI**), and disazonaphthol (**VII**) pigments prepared from **IIa** and **IIb**.

2. Results and discussion

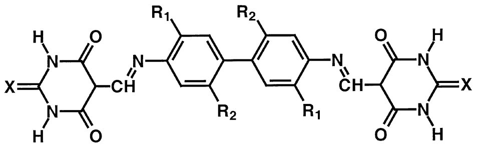
2.1. Synthesis

The synthesis and evaluation of the tetrasubstituted twisted benzidine analogs have been



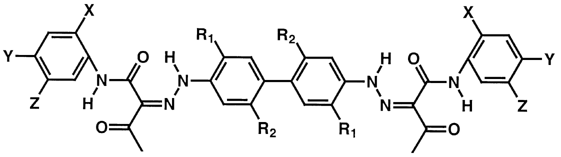
II

	R_1	R_2
a	OPr	Me
b	OPr	OMe
c	OPr	Cl
d	Cl	Cl



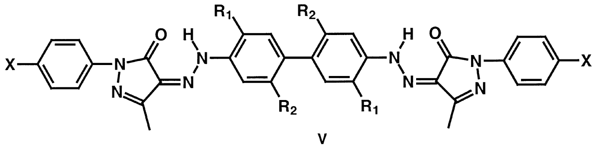
III

	R_1	R_2	X
a	OPr	Me	O
b	OPr	Me	S
c	OPr	OMe	O
d	OPr	OMe	S
e	Me	H	O
f	OMe	H	O
g	OPr	H	O



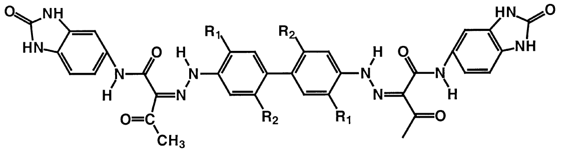
IV

	R_1	R_2	X	Y	Z
a	OPr	Me	H	H	H
b	OPr	Me	OMe	H	H
c	OPr	Me	Me	H	H
d	OPr	Me	H	OMe	H
e	OPr	Me	H	Cl	H
f	OPr	Me	Cl	H	Cl
g	OPr	OMe	H	H	H
h	OPr	OMe	OMe	H	H
i	OPr	OMe	Me	H	H
j	OPr	OMe	H	Cl	H
k	Cl	H	H	H	H
l	OMe	H	H	H	H
m	OPr	H	H	H	H
n	OPr	H	OMe	H	H
o	Cl	Cl	CH_3	CH_3	H
p	Cl	Cl	CH_3	Cl	H



V

	R_1	R_2	X
a	OPr	Me	H
b	OPr	Me	Cl
c	OPr	Me	NO_2
d	OPr	OMe	H



VI

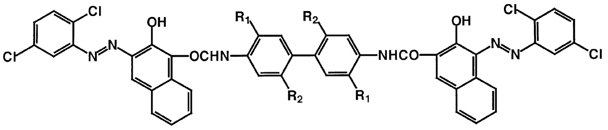
	R_1	R_2
a	OPr	Me
b	OPr	OMe

reported previously [9]. Bisazomethines **IIIa–d** were synthesized by reacting the free base of **IIa–b** with barbituric or thiobarbituric acid and triethylorthoformate (TEOF) in DMF [10]. The pigments were produced in good yield and were greenish yellow to yellow in hue.

Diarylides **IVa–j**, disazopyrazolones **Va–d**, and disazobenzimidazolone pigments **VIa–d** were synthesized by tetrazotization of diamines **IIa–b** followed by coupling with an acetoacetanilide, 1-phenyl-3-methyl-5-pyrazolone or 5-acetoacetylaminobenzimidazolone. In most cases, the coupling was carried out at 0–5°C; however, couplings involving 5-acetoacetylaminobenzimidazolone required room temperature. Also, to produce pure samples of **IVe**, **f**, **j** and **VIa**, **b**, Triton X-100 and Surfynol 104 PG-50 were added to a suspension of coupling component before adding the tetrazonium compound.

Disazonaphthol pigments **VII** were synthesized by the reaction of diamines **IIa–b** with the corresponding azo dye acid chloride. The required acid chloride was obtained by coupling diazotized 2,5-dichloroaniline with 3-hydroxy-2-naphthoic acid, followed by chlorination with $SOCl_2$. To purify the pigments and optimize their crystalline form, they were boiled several times in hot water. For pigments **VIa–b**, a treatment step involving hot DMF was also used. While the hot DMF treatment did not influence the color of **VIa**, pigment **VIb** underwent a change of color from dull orange to yellow. Prolonged DMF treatment of this yellow pigment produced a red colorant. Combustion and FDMS analyses showed the two products to have the same chemical structure, while X-ray analysis revealed the formation of different crystalline forms. It is well known that the colorimetric properties (hue, chroma, and lightness) may be altered upon modification of both the crystal form and habit of organic pigments [11]. Data from X-ray analysis will be reported separately.

While it was not possible to use ^1H NMR to characterize each pigment, due to low solubility, it



VII

	R_1	R_2
a	OPr	Me
b	OPr	OMe

Table 1
Data pertaining to pigments **III**–**VII**

Pigment	Yield	M.p.	Light fastness	λ_{max}[a]	ε_{max} 10^4
IIIa	88	372[b]	Good	Insoluble	
IIIb	95	368[b]	Good	Insoluble	
IIIc	79	392[b]	Good	Insoluble	
IIId	64	370b	Good	Insoluble	
IVa	89	254	Poor	428	5.53
IVb	78	252	Poor	429	6.27
IVc	78	260–262	Poor	428	5.66
IVd	81	246–248	Poor	433	6.38
IVe	71	258–260	Poor	431	6.36
IVf	82	300–302	Poor	433	5.63
IVg	66	256–258	Poor	455	5.27
IVh	60	258–260	Poor	455	5.00
IVi	65	256–258	Poor	455	5.20
IVj	75	266–267	Poor	Insoluble	
IVm	70	283–284	Poor	452	6.26
Va	75	238–239	Poor	456	4.87
Vb	81	258–260	Poor	461	4.20
Vc	91	296–298	Poor	473	4.82
Vd	74	260–261	Poor	495	4.80
VIa	75	346–348	Good	Insoluble	
VIb	84	358–360[c]	Good	Insoluble	
		364–365[d]	Good	Insoluble	
VIIa	69	360[b]	Good	Insoluble	
VIIb	68	360[b]	Good	Insoluble	

[a] *ortho*-Dichlorobenzene used as the solvent.
[b] Decomposition temperature.
[c] Yellow form.
[d] Red form.

was possible to confirm their structures using field desorption mass spectrometry (FDMS). The spectra recorded were characterized by intense parent ion peaks $[M^{+\cdot}]$ and a relatively intense $[M^{+}]/2$ peak [12].

2.2. Colorimetric and photostability data

Table 1 lists the pigments produced in this study and some key data. Table 2 summarizes the photostability for each pigment in terms of overall color change (using CIELAB DE) following light exposure of standard draw-downs.

Absorption spectra indicate that the use of **IIb** instead of **IIa** resulted in a large bathochromic shift (27–39 nm). In addition to differences in the electronic effects of the substituents in the 2,2′-positions, it is possible that the dihedral angle of 2,2′-dimethoxy-5,5′-dipropoxybenzidine-based pigments is significantly different from that of pigments derived from 2,2′-dimethyl-5,5′-dipropoxybenzidine.

2.2.1. Bisazomethine pigments

Since the bisazomethine pigments were highly insoluble, solution absorption spectra were not obtained. However, draw-downs of the twisted pigments **IIIa**–**d** and bisazomethine analogs **IIIe**–**g** were analyzed colorimetrically. Compounds **IIIe**–**g** were used as prototypes, because they contain protons in the 2,2′-positions of the biphenyl linkage and can be assumed to be ‘non-twisted’ about the biphenyl linkage. Furthermore, **IIIe**–**f** are based on intermediates commonly employed in pigment synthesis.

Fig. 1 shows CIE a^*b^* data for each of the bisazomethine pigments, where a^* value represents the degree of redness (positive) and greenness (negative) and b^* represents the degree of yellowness (positive) and blueness (negative). The bisazomethine pigment based on 3,3′-dipropoxybenzidine and barbituric acid (**IIIg**) possessed approximately the same yellowness but was redder than pigments based on *o*-tolidine (**IIIe**) and *o*-dianisidine (**IIIf**). Visually, the increased redness is significant and is a limiting factor in the color gamut of pigments prepared from nonmutagenic 3,3′-dialkoxybenzidine congeners. However, the bisazomethine pigments based on 2,2′-dimethyl-5,5′-dipropoxybenzidine, i.e. **IIIa** and **IIIb**, were greener relative to **IIIg**, although not as green as **IIIe**–**f**. Pigments **IIIa**–**c** were also bluer than **IIIe**–**g**. In the case of bisazomethine pigments, the hypsochromic shift due to the presence of methyl substituents in the 2,2′-positions of the biphenyl linkage is significant. However, when a methoxy group was used in lieu of methyl in the 2,2′-positions a bathochromic shift was observed, possibly due to both the electronic contribution of the methoxy groups and a different dihedral angle across the biphenyl linkage. As expected, pigments based on thiobarbituric acid were slightly bathochromic relative to when barbituric acid was employed.

Fig. 2 shows CIE L^*C^* data for the bisazomethine pigments, where L^* is a measure of the lightness (the higher the L^* value the lighter the color) and C^* is a measure of chroma or color

Table 2
Mutagenicity and lightfastness (DE) of pigments **III**–**VII**

Pigment	R_1	R_2	X	Y	Z	DE[a]	Ames[e]		Prival
							+S9	−S9	TA98
IIIa	OPr	Me	O	–	–	2.54	N	N	N
IIIb	OPr	Me	S	–	–	6.80	N	N	N
IIIc	OPr	OMe	O	–	–	2.50	N	N	N
IIId	OPr	OMe	S	–	–	13.00	N	N	N
IVa	OPr	Me	H	H	H	80.5	N	N	N
IVb	OPr	Me	OMe	H	H	43.8	N	N	N
IVc	OPr	Me	Me	H	H	(100)[d]	N	N	N
IVd	OPr	Me	H	OMe	H	55.0	N	N	N
IVe	OPr	Me	H	Cl	H	(73.1)[d]	N	N	N
IVf	OPr	Me	Cl	H	Cl	(70.0)[d]	N	N	N
IVg	OPr	OMe	H	H	H	67.9	N	N	N
IVh	OPr	OMe	OMe	H	H	(73.9)[b]	N	N	N
IVi	OPr	OMe	Me	H	H	64.5	N	N	N
IVj	OPr	OMe	H	Cl	H	(74.4)[c]	N	N	N
IVm	OPr	H	H	H	H	34.3	N	N	N
IVn	OPr	H	O	H	H	74.7	N	N	N
Va	OPr	Me	H	H	H	57.4	N	N	N
Vb	OPr	Me	Cl	H	H	39.7	N	N	N
Vc	OPr	Me	NO_2	H	H	72.8	P	P	P
Vd	OPr	OMe	H	H	H	70.6	N	N	N
VIa	OPr	Me	Benzimidazolone			6.39	N	N	N
VIb	OPr	OMe	Benzimidazolone			4.44	N	N	N
VIIa	OPr	Me	Condensed			9.72	N	N	N
VIIb	OPr	OMe	Condensed			0.80	N	N	N

[a] After 40 h exposure.
[b] After 30 h.
[c] After 20 h.
[d] After 10 h.
[e] TA98; N, negative, P, positive.

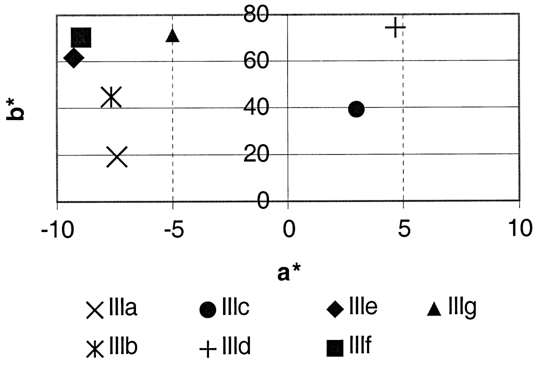


Fig. 1. CIE a^*b^* data for bisazomethine pigments **IIIa**–**g**.

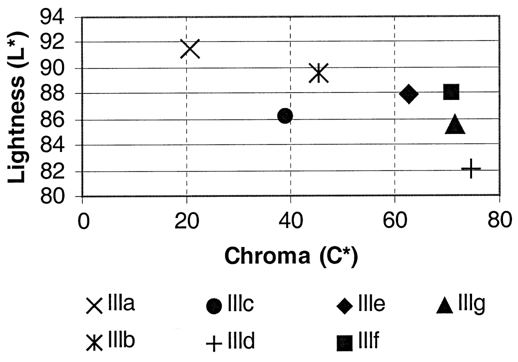


Fig. 2. CIE L^*C^* data for bisazomethine pigments **IIIa**–**g**.

strength. Pigments prepared from thiobarbituric acid exhibited significantly higher chroma compared with their counterparts prepared from barbituric acid. However, compounds **IIIa** and **IIIb** were significantly lower in chroma and were slightly lighter than the non-twisted pigments

IIIe–g. The decrease in color strength is consistent with predicted PPP MO analysis when the dihedral angle of the biphenyl linkage is increased [1]. Interestingly, compound **IIId** displayed the highest chroma of all the bisazomethine pigments tested. Presumably, incorporation of a methoxy group in the 2,2′-position results in both steric and electronic interactions that favor increased color strength. Also, the crystal form and habit may have been optimum for this pigment [11].

Photostability of draw-downs of each of the pigments was determined. Fig. 3 shows the effect of light exposure on the chroma and Fig. 4 shows the effect of light exposure on the overall color change (DE). For each of the twisted pigments, photostability was excellent and comparable to pigments prepared from *o*-tolidine and *o*-dianisidine. Surprisingly, however, the ‘non-twisted’ pigment **IIIg** displayed lower photostability than the twisted analogs.

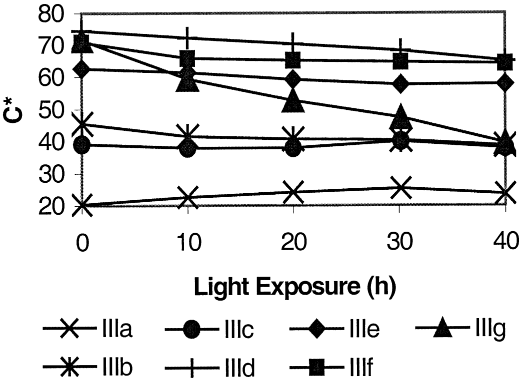


Fig. 3. Effect of light exposure on CIE chroma value for bisazomethine pigments.

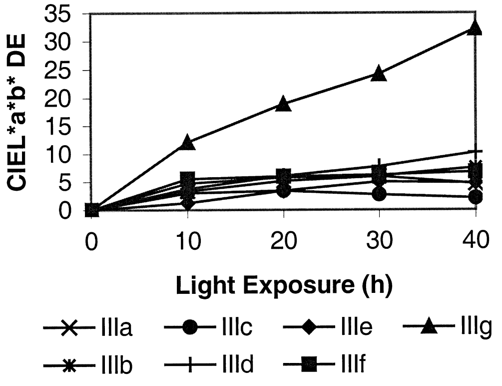


Fig. 4. Effect of light exposure on CIE DE value for bisazomethine pigments.

Considering color strength and photostability, pigment **IIId** was comparable to, or better than, the corresponding pigments prepared from nontwisted benzidine analogs (cf. **IIIe–g**). These data, when combined with the nonmutagenic properties of both the pigment (see discussion below) and the benzidine intermediate employed, make this colorant a potential alternative to bisazomethine pigments prepared from mutagenic benzidine congeners. On the other hand, the weak color strength of the bisazomethine pigments prepared from 2,2′-dimethyl-5,5′-dipropoxybenzidine make these colorants less suitable replacements for bisazomethine pigments, even though the hypsochromic shift obtained by incorporation of methyl groups in the biphenyl linkage may be desirable.

2.2.2. *Disazoacetoacetanilide pigments*

The majority of the commercial yellow pigments belong to the disazoacetoacetanilide (diarylide) class, with the most important diarylides (e.g. C.I. Pigment Yellow 12, **IVk**) prepared using the genotoxic diamine 3,3′-dichlorobenzidine [1,13]. It is well known that incorporation of alkoxy substituents in the 3,3′-positions of the benzidine structure produces diarylide pigments that are orange. In fact, the most widely used diarylide orange is C.I. Pigment Orange 16 (**IVl**), which is based on a mutagenic dialkoxybenzidine. Consequently, diarylide pigments prepared from nonmutagenic benzidine precursors that possess bulky alkoxy substituents in the 3,3′-positions also produce orange pigments. Since the design of yellow diarylide pigments prepared from nonmutagenic benzidines was a primary objective of the present study, tetrasubstituted diamines **IIa–b** were investigated as potential nonmutagenic precursors for this pigment class. It was anticipated that the bulky propoxy groups in the 3,3′-positions would assure nonmutagenic characteristics and certain groups in the 2,2′-positions would produce a hypsochromic shift from an orange to a yellow hue.

Interestingly, the use of tetrasubstituted benzidines in diarylide synthesis is not new. There are at least two commercial manufactured disazoacetoacetanilide pigments based on tetrasubstituted benzidine congeners [14]: C.I. Pigment Yellow 81 (**IVo**) and C.I. Pigment Yellow 113 (**IVp**). Both are prepared using 2,2′,5,5′-tetrachlorobenzidine (**IId**).

The color attributes and photostabilities of disazoacetoacetanilide pigments **IVa–j** were compared to C.I. Pigment Yellow 12 (**IVk**) and C.I. Pigment Orange 16 (**IVl**). In addition, disazoacetoacetanilide pigments (**IVm–n**) based on 3,3′-dipropoxybenzidne were prepared to compare the effect of methyl and methoxy substituents in the 2,2′-positions of the biphenyl linkage on the properties of diarylide pigments.

Following synthesis and purification, the pigments were formulated into draw-downs and each was analyzed colorimetrically. Fig. 5 shows hue attributes in a CIE *a*b** graph and Fig. 6 shows a comparison of lightness and chroma of draw-downs of selected diarylide pigments. Pigments **IVk** and **IVl** provided a reference point for the color attributes of each pigment, since **IVk** is a strong yellow and **IVl** is a strong orange. The pigments based on 3,3-dipropoxybenzidine (**IVm** and **IVn**) were golden yellow and thus the *a*b** graph shows these pigments to be bathochromic compared with **IVk** and hypsochromic relative to **IVl**. Apart from **IVb** and **IVc**, pigments based on diamine **IIa** (i.e. **IVa–d**) displayed similar hues both to each other and to C.I. Pigment Yellow 12 (**IVk**). In fact, pigment **IVa** was almost identical in hue to **IVk**. Hence, the presence of methyl substituents in the 2,2′-positions produced the desired colorimetric effect. The hue shifts are also evident from solution spectral data (Table 1).

The colorimetric properties of the pigments based on diamine **IIb** (i.e. **IVg–j**) were similar, as indicated in Table 1. Data from pigment **IVg** are provided in Fig. 5. Also, pigments based on **IIb** were significantly bathochromic relative to those based on **IIa**.

Surprisingly, except for **IVb**, the chroma of **IVa–g** and **IVk–m** were all high. This is in contrast to the predicted reduction in extinction coefficient following an increase in the dihedral angle across the biphenyl linkage [1]. A possible reason for the unexpected high color strength of pigments **IVa–b** is that the crystal habit and particle size for these compounds was an optimum. Interestingly, comparison of solution spectral data (see Table 1) for diarylide pigments prepared from **IIa** with **IVm** shows smaller differences in extinction coefficient than expected.

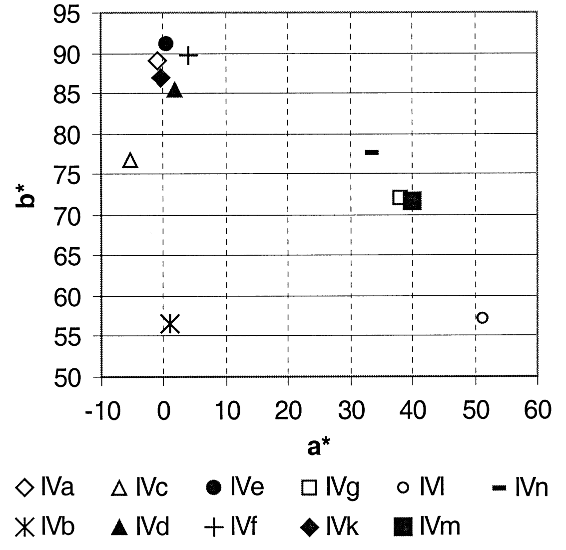


Fig. 5. CIE *a*b** data for selected disazoacetoacetanilide pigments.

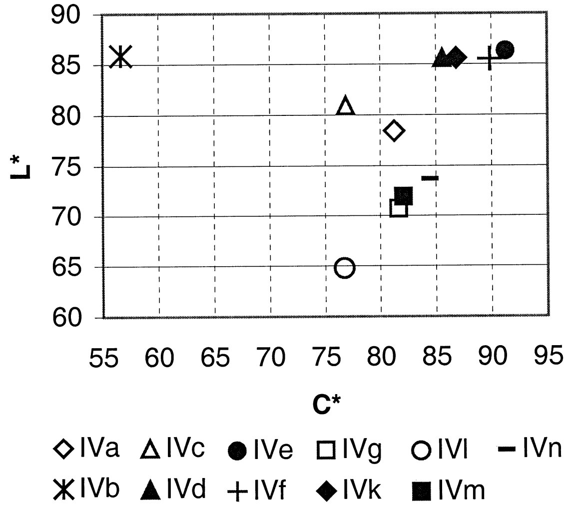


Fig. 6. CIE *L*C** graph for selected disazoacetoacetanilide pigments.

Fig. 7 shows the effect of light exposure during fading on the chroma and overall color change, respectively, for selected disazoacetoacetanilide pigments. Table 2 provides a summary of the change in color for each pigment. In most cases, the photostability of the pigments based on twisted benzidine congeners was much lower than C.I. Pigment Yellow 12 (**IVk**) and C.I. Pigment Orange 16 (**IVl**). However, the photostability of **IVc** was only slightly lower than that of **IVk**. The photostability of the rest of the new pigments in this group was too low for them to be suitable for applications requiring good photostability.

2.2.3. Disazopyrazolone pigments

Fig. 8 shows hue attributes in a CIE a^*b^* graph and Fig. 9 shows a comparison of lightness and chroma of draw-downs of selected disazopyrazolone pigments. For comparison, data for disazoacetoacetanilide pigments **IVk** and **IVl** are also shown. All of the disazopyrazolone pigments prepared from diamine **IIa** were bathochromic relative to C.I. Pigment Yellow 12 (**IVk**) and were similar in hue to C.I. Pigment Orange 16 (**IVl**). The chroma of pigments **V** was comparable to **IVl**.

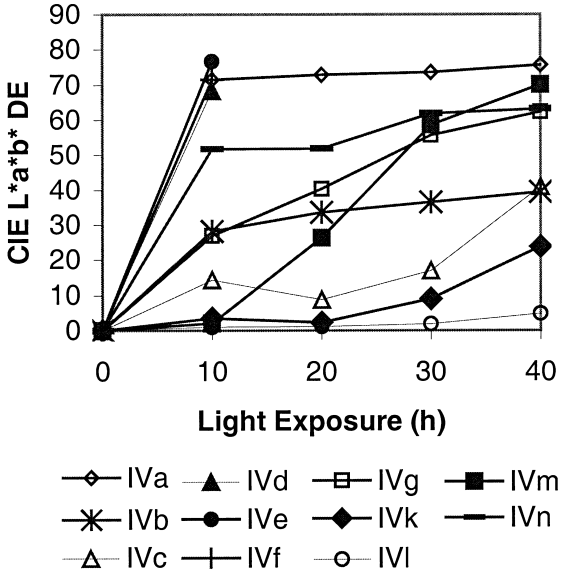


Fig. 7. Effect of light exposure on CIEL$^*a^*b^*$ DE value for disazoacetoacetanilide pigments.

As shown in Fig. 10 and Table 2, the photostability of pyrazolone pigments **Va–d** was lower than **IVk** and **IVl**, although not as low as pigments **IVa–j**. Pigment **Vb** had the highest photostability of the new twisted disazopyrazolone pigments synthesized. The brightness, hue and photostability of the latter pigment, which is prepared from diamine **IIa**, make it a potential replacement

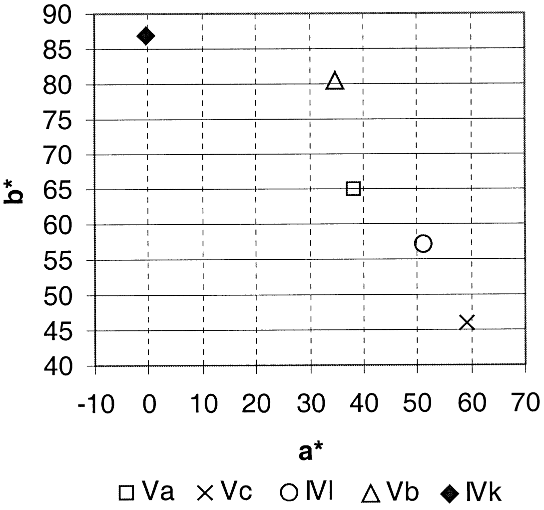


Fig. 8. CIE $L^*a^*b^*$ data for selected disazopyrazolone pigments **Va–c** (**IVk–l** shown for comparison).

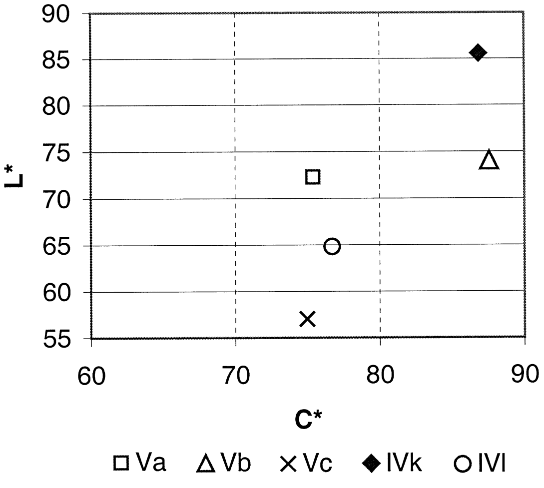


Fig. 9. CIE L^*C^* data for disazopyrazolone pigments **Va–c** (**IVk–l** shown for comparison).

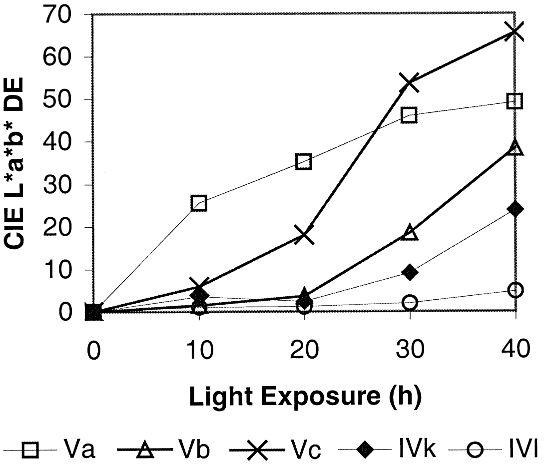


Fig. 10. Effect of light exposure on CIEL**a***b** DE value for selected disazopyrazolone pigments.

for orange disazopyrazolone pigments that are based on mutagenic diamines.

2.2.4. *Disazobenzimidazolone and disazonaphthol pigments*

While the main focus of this study was the synthesis of new bisazomethine, disazoaceto acetanilide, and disazopyrazolone pigments, diamines **IIa** and **IIb** were also converted to benzimidazolone (**VIa**–**b**) and disazonaphthol pigments (**VIIa**–**b**). As shown in Table 2, very good photostability was observed for **VIa**–**b** and **VIIa**–**b**, similar to the bisazomethine pigments.

2.3. *Mutagenicity data*

Pigments **IIIa**–**d**, **IVa**–**j**, and **V**–**VII** were evaluated in the standard Ames [15] *Salmonella* mammalian mutagenicity assay and the Prival [16] modification. The latter assay was developed specifically for evaluating azo dyes and provides enhanced reductive-cleavage of azo linkages. As shown in Table 2, all of the pigments were non-mutagenic in both assays, except for pigment **Vc** which was Ames positive in TA98 in the standard assay, with and without S9 activation, and gave a positive result in TA98 in the Prival assay. It is likely that mutagenicity of **Vc** arises from the nitro substituent.

3. Experimental

3.1. *General*

All chemicals were purchased from Aldrich Chemicals (Milwaukee, WI) and used without further purification. 5-Acetoacetylaminobenzimidazolone was prepared by treatment of 5-aminobenzimidazolone with diketene at 80°C according to published reports [17,18]. ^{1}H NMR spectra were recorded on a General Electric GN 300 MHz spectrometer. CI, EI and FD mass spectra were recorded on a Hewlett Packard 5985B GC mass spectrometer. Ink draw-downs were prepared and photostability assessed using procedures reported previously [9]. A portion of each draw down was exposed to light for 10, 20, 30 and 40 h, or until the pigment was completely decolorized.

Mutagenicity testing was performed using the standard Ames *Salmonella* mammalian assay [15] and Prival modification [16]. *Salmonella typhymurium* strains TA98 and TA100 were employed in the Ames assay, with (+S9) and without (−S9) mammalian microsomal activation system.

3.2. *Colorimetric analysis*

Draw-downs were analyzed colorimetrically using a calibrated X-Rite SP88 spectrophotometer (X-Rite, Inc.) and Sliform® NG software (She-Lyn, Inc.). Reflectance curves of each draw-down were used to calculate CIE *L***a***b***C** values and overall color difference was calculated using the CIELAB DE color difference formula [19].

3.3. *Synthesis*

3.3.1. *Preparation of pigment* **IIIb**

2-Mercapto-4,6-dihydroxypyrimidine (3.87 g, 0.0268 mol) was added to a stirred solution of **IIa** (4 g, 0.012 mol) in 40 ml DMF, at 25°C. After stirring the solution for a further 30 min, triethyl orthoformate (4.10 g, 0.0275 mol) was added. The reaction mixture was stirred for 3 h at 25°C and then heated to 80°C over 30 min. After 1 h, the temperature was raised to 120°C over 30 min, and after 2 h, it was allowed to drop to 80°C. The product was collected by filtration and washed with hot MeOH and with hot H_2O and dried at 40°C.

- Elemental analysis

Theory: %C = 56.59 %H = 5.07 %N = 13.20
Found: %C = 56.30 %H = 5.21 %N = 13.51

FDMS: *m/z* (rel. int.): 636 (100%), 318 (50%).

3.3.2. *Preparation of pigments* **IIIa, c, d**

The synthesis of these colorants was the same as that described above for **IIIb**.

- **IIIa**: Elemental analysis

Theory: %C = 59.60 %H = 5.33 %N = 13.90
Found: %C = 59.61 %H = 5.35 %N = 13.86
FDMS: *m/z* (rel. int.): 604 (100%), 302 (15%).

- **IIIc**: elemental analysis

Theory: %C = 56.60 %H = 5.06 %N = 13.20
Found: %C = 56.73 %H = 5.14 %N = 13.27
FDMS: *m/z* (rel. int.): 636 (100%), 318 (10%).

- **IIId**: elemental analysis

Theory: %C = 58.88 %H = 4.82 %N = 12.56
Found: %C = 58.81 %H = 4.87 %N = 12.52
FDMS: *m/z* (rel. int.): 668 (100%), 334 (30%).

3.3.3. *Preparation of pigment* **IVa**

A suspension of **IIa** (4 g, 0. 01mol) in 20 ml H_2O, 4 ml conc. HCl (0.12 mol), and 4.80 g ice was stirred for 10 min. This mixture was stirred at 0–5°C as $NaNO_2$ (1.38 g, 0.02 mol) dissolved in 12 ml H_2O was added dropwise at the rate needed to maintain a slight excess of HNO_2. The tetrazotization step was continued for 30 min and excess HNO_2 was destroyed by the addition of solid sulfamic acid. The tetrazonium salt was purified using activated carbon and the resultant solution was added dropwise, at 0–5°C and pH = 6, under the surface of a suspension of acetoacetanilide (3.70 g, 0.021 mol) at a rate such that the tetrazonium intermediate was not observed. The latter suspension was obtained by dissolution of acetoacetanilide in 100 ml H_2O containing NaOH (0.64 g, 0.016 mol), followed by precipitation with HOAc (1.60 ml, 0.028 mol) and $NaOAc{\cdot}3H_2O$ (8.64 g, 0.064 mol). The coupling reaction was continued for 12 h and the reaction mixture was heated to the boil. The pigment was filtered hot, boiled several times with hot water, filtered and dried at 40°C.

- Elemental analysis

Theory: %C = 68.16 %H = 6.29 %N = 11.92
Found: %C = 68.15 %H = 6.32 %N = 11.86
FDMS: *m/z* (rel. int.): 704 (100%), 352 (15%).

^1H NMR [$CDCl_3$, δ (ppm), *J* (Hz)]: 14.92, s, (2H); 11.50, s, (2H); 7.10–7.70, m, (12H); 6.74, bs, (2H); 4.07, t, (4H, *J* = 7.2); 2.64, s, (6H); 2.10, s, (6H); 1.98, sx, (4H, *J* = 6.3); 1.17, t, (6H, *J* = 7.2).

3.3.4. *Preparation of pigments* **IVb–j**

The synthesis of each pigment was the same or similar to that described above for **IVa**.

- **IVb**: elemental analysis

Theory: %C = 65.95 %H = 6.32 %N = 10.98
Found: %C = 65.84 %H = 6.26 %N = 10.89
FDMS: *m/z* (rel. int.): 764 (100%), 382 (5%)

^1H NMR [$CDCl_3$, δ (ppm), *J* (Hz)]: 14.94, s, (2H); 11.80, s, (2H); 8.50, m, (2H); 7.56, bs, (2H); 6.91–7.08, m, (6H); 6.72, m, (2H); 4.04, t, (4H, *J* = 7.2); 3.98, m, (6H); 2.63, s, (6H); 2.10, s, (6H); 1.98, sx, (4H, *J* = 6.3); 1.16, t, (6H, *J* = 7.5).

- **IVc**: elemental analysis

Theory: %C = 68.83 %H = 6.60 %N = 11.46
Found: %C = 68.90 %H = 6.58 %N = 11.44
FDMS: *m/z* (rel. int.): 732 (100%)

^1H NMR [$CDCl_3$, δ (ppm), *J* (Hz)]: 14.93, s, (2H); 11.41, s, (2H); 8.24, m, (2H); 7.57, s, (2H); 7.09–7.57, m, (6H); 6.74, s, (2H); 4.04, t, (4H,

$J = 7.20$; 2.64, s, (6H); 2.10, m, (6H); 1.94, sx, (4H, $J = 7.2$); 1.13, t, (6H, J = 7.2).

- **IVd**: elemental analysis

Theory: %C = 65.95 %H = 6.32 %N = 10.89
Found: %C = 65.84 %H = 6.35 %N = 10.89
FDMS: *m/z* (rel. int.): 764 (100%), 382 (10%).

^{1}H NMR [$CDCl_3$, δ (ppm), J (Hz)]: 14.91, s, (2H); 11.36, s, (2H); 7.58, m, (6H); 6.91,m, (4H); 4.03, t, (4H), $J = 6.3$); 3.81, s, (6H); 2.62, s, (6H); 2.08, s, (6H); 1.91, sx, (4H, $J = 7.5$); 1.13, t, (6H, $J = 7.5$).

For pigments **IVe–f**, a small variation in the general procedure was required. Before the addition of the tetrazonium salt to the dispersion of the coupling component, several drops of Triton X-100 and Surfynol 104 PG-50 were added.

- **IVe**: elemental analysis

Theory: %C = 62.13 %H = 5.47 %N = 10.86
Found: %C = 62.11 %H = 5.64 %N = 10.79
FDMS: *m/z* (rel. int.): 772 (100%), 386 (15%)

^{1}H NMR [$CDCl_3$, δ (ppm), J (Hz)]: 14.86, s, (2H); 11.55, s, (2H); 7.56–7.65, m, 96H); 7.31, d, (4H, $J = 8.4$); 6.73, s, (2H); 4.05, t, (4H, $J = 6.3$); 2.62, s, (6H); 2.09, s, (6H); 1.96, sx, (4H, $J = 7.2$); 1.15, t, (6H, $J = 7.2$).

- **IVf**: elemental analysis:

Theory: %C = 57.01 %H = 4.78 %N = 9.97
Found: %C = 57.20 %H = 4.92 %N = 9.68
FDMS: *m/z* (rel. int.): 842 (100%).

- **IVg**: elemental analysis

Theory: %C = 65.20 %H = 6.01 %N = 11.40
Found: %C = 63.17 %H = 5.88 %N = 10.99
FDMS: *m/z* (rel. int.): 736 (100%), 368 (15%).

^{1}H NMR [$CDCl_3$, δ (ppm), J (Hz)]: 14.91 s (2H), 11.47 s (2H), 7.67–7.69 m (4H), 7.15–7.38 m (8H), 6.91 s (2H), 4.04 t (4H, $J = 7.2$), 3.82 s (9H), 2.61 s (6H), 1.98 sx (4H, $J = 7.5$), 1.13 t (6H, $J = 7.5$).

- **IVh**: elemental analysis

Theory: %C = 63.30 %H = 6.06 %N = 10.54
Found: %C = 63.39 %H = 6.10 %N = 10.48
FDMS: (*m/z*): 796 (100%), 766 (10%)

^{1}H NMR [$CDCl_3$, δ (ppm), J (Hz)]: 14.99 s (2H), 11.80 s (2H), 8.50 m (2H), 7.40 s (2H), 6.80–7.20 m (8H), 4.10 t (4H, $J = 7.2$), 4.00 s (6H), 2.80 s (6H), 1.99, sx (4H, $J = 7.2$), 1.18 t (6H, $J = 7.2$).

- **IVi**: elemental analysis

Theory: %C = 65.95 %H = 6.32 %N = 10.98
Found: %C = 65.92 %H = 6.31 %N = 10.91
FDMS: *m/z* (rel. int.):764 (100%), 382 (10%)

^{1}H NMR [$CDCl_3$, δ (ppm), J (Hz)]: 15.00, s, (2H); 12.40, s, (2H); 8.27, d, (2H, $J = 8.5$); 7.50–7.30; m, (6H); 7.18, t, (2H, $J = 7.3$); 7.10, s, (2H); 4.10, t, (4H, $J = 6.0$); 3.98, m, (6H); 2.68, bs, (6H); 2.47, bs, (6H); 1.99, sx, (4H, $J = 7.2$); 1.18, t, (6H, $J = 7.2$).

- **IVj**: Elemental analysis

Theory: %C = 59.62 %H = 5.25 %N = 10.43
Found: %C = 59.67 %H = 5.3, %N = 10.19
FDMS: *m/z* (rel. int.): 804 (100%), 402 (10%).

3.3.5. Preparation of pigment **Va**

The tetrazonium salt was prepared according to the procedure described for **IVa** and added dropwise, at 0–5°C and pH 6, to a suspension of 1-phenyl-3-methyl-5-pyrazolone (3.48 g, 0.02 mol). (The latter suspension was obtained by dissolution of 1-phenyl-3-methyl-5-pyrazolone in 100 ml H_2O containing NaOH (0.64 g, 0.016 mol), followed by precipitation using HOAc (1.60 ml, 0.028 mol) and $NaOAc{\cdot}3H_2O$ (8.64 g, 0.064 mol). The pigment was isolated in the manner described for **IVa**.

- Elemental analysis

Theory: %C = 68.75 %H = 6.05 %N = 16.03
Found: %C = 68.76 %H = 6.05 %N = 16.00

FDMS: *m/z* (rel. int.): 698 (100%), 349 (15%)

^1H NMR [$CDCl_3$, δ (ppm), J (Hz)]: 13.78, s, (2H); 8.00, d, (4H, $J=7.2$); 7.66, s, (2H); 7.43, t, (4H, $J=7.2$); 7.19, t, (2H, $J=7.2$); 6.74, s, (2H); 4.05, t, (4H, $J=6.20$; 2.40, s, (6H); 2.10, s, (6H); 1.96, sx, (4H, $J=7.3$); 1.13, t, (6H, $J=7.5$).

The synthesis of **Vb–d** was the same as that described above for **Va**.

- **Vb**: elemental analysis

Theory: %C = 62.58, %H = 5.25, %N = 14.59
Found: %C = 62.12, %H = 5.19, %N = 14.46

FDMS: m/z (rel. int.): 766 (100%), 383 (10%)

^1H NMR [$CDCl_3$, δ (ppm), J (Hz)]: 13.80, s, (2H); 8.03, d, (4H, $J=9.6$); 7.71, s, (2H); 7.44, m, (4H); 6.78, s, (2H); 4.11, t, (4H, $J=$ 6.0); 2.45, s, (6H); 2.14, s, (6H); 1.99, sx, (4H, $J=7.2$); 1.19, t, (6H, $J=7.2$).

- **Vc**: elemental analysis

Theory: %C = 60.90 %H = 5.11 %N = 17.75
Found %C = 60.10 %H = 5.07 %N = 17.79

FDMS: m/z (rel. int.): 788 (100%), 394 (15%).

^1H NMR [$CDCl_3$, δ (ppm), J (Hz)]: 13.71, s, (2H); 8.20–8.40, m, (8H); 7.65, s, (2H); 6.74, s, (2H); 4.07, t, (4H, $J=6.0$); 2.42, s, (6H); 2.01–2.23, m, (6H); 1.99, sx, (4H, $J=7.20$); 1.16, t, (6H, $J=7.5$).

- **Vd**: elemental analysis

Theory: %C = 65.73 %H = 5.79 %N = 15.33
Found: %C = 65.62 %H = 5.77 %N = 15.27

FDMS: m/z (rel. int.): 730 (100%), 365 (5%).

^1H NMR [$CDCl_3$, δ (ppm), J (Hz)]: 13.82, s, (2H); 7.99, m, (4H); 7.25–7.45, m, (6H); 7.19, t, (2H, $J=7.2$); 6.91, s, (2H); 406, t, 4H, $J=7.2$); 3.84, s, (6H); 2.55, s, (6H); 1.99, sx, (4H, $J=7.2$); 1.10, t, (6H, $J=7.2$).

3.3.6. Preparation of pigment **VIa**

The tetrazonium component was prepared in the usual way (cf. **IVa**) and added dropwise, at 20°C and pH 6, to a suspension of 5-acetoacetylaminobenzimdazolone (4.90 g, 0.021 mol) containing a small amount of Triton X-100 and Surfynol 104 PG-50. The pigment was isolated by filtration and dried at 40°C. The dry pigment was boiled in DMF for 30 min using 1 ml of DMF/g pigment. After cooling the mixture to 50°C the pigment was collected by filtration, washed with water, and dried at 40°C.

- Elemental analysis

Theory: %C = 61.75 %H = 5.43 %N = 16.51
Found: %C = 60.11 %H = 5.64 %N = 16.50

FDMS: m/z (rel. int.): 816 (100%), 598 (45%), 408 (45%).

- **VIb**

The synthesis was the same as that described above for **VIa**.

Elemental analysis

Theory: %C = 59.42 %H = 5.22 %N = 16.50
Found: %C = 59.37 %H = 5.24 %N = 16.43

FDMS: m/z (rel. int.): 848 (100%), 673 (80%), 630 (25%), 604 (20%).

3.3.7. Preparation of pigment **VIIa**

A mixture of 2,5-dichloroaniline (8.10 g, 0.05 mol) in 10 ml H_2O and 30% HCl (15 ml, 0.46 mol) was stirred at 60°C for 20 min. Next 50 g ice was added, and at 0–2°C $NaNO_2$ (3.45 g, 0.05 mol) dissolved in 15 ml H_2O was slowly added. The diazotization step was continued for 30 min, followed by filtration to remove a small amount of insoluble material. The diazonium salt solution was added dropwise to 3-hydroxy-2-naphthoic acid (10 g, 0.065 mol) dissolved in 200 ml H_2O containing 30% NaOH (5 ml, 0.017 mol) and Na_2CO_3 (17g, 0.16 mol) at a rate needed to maintain the temperature at 0–2°C. The coupling step was continued for 4 h, and the monoazo dye was isolated by acidification with 30% HCl (20 ml, 0.65 mol), filtration, washing with water, and drying at 40°C. The dye was stirred with 50 ml dry chlorobenzene at 40°C. To this mixture were added DMF (0.5 ml, 0.0065 mol) and $SOCl_2$ (2.5 ml, 0.034 mol) and the chlorination step was allowed to proceed for 1 h. At that point, an additional 2 ml (0.027 mol) $SOCl_2$ was added, and the temperature was raised to 70°C and held there for 2 h. The resulting acid chloride was collected by filtration and washed with chlorobenzene. The product was dispersed in 200 ml dry chlorobenzene and added to a solution of **IIa** (6.68g, 0.02 mol) in 300 ml chlorobenzene, at 70°C. The reaction mixture was then heated to the boil over a 1-h period and the condensation step was continued for 8 h. The mixture was filtered hot, and the pigment was washed with chlorobenzene and dried at 40°C.

- Elemental analysis

Theory: %C = 63.91 %H = 4.37 %N = 8.28
Found: %C = 64.37 %H = 4.41 %N = 7.81

FDMS: *m/z* (rel. int.): 1014 (100%), 856 (25%), 508 (10%).

- **VIIb**

The synthesis was the same at that described above for **VIIa**.

Elemental analysis:

Theory: %C = 61.95 %H = 4.24 %N = 8.03
Found: %C = 61.97 %H = 4.25 %N = 7.98

FDMS: *m/z* (rel. int.): 1046 (100%), 1010 (10%), 872 (10%).

4. Conclusions

It has been shown that highly twisted, nonmutagenic benzidines such as 2,2′-dimethyl-5,5′-dipropoxybenzidine and 2,2′-dimethoxy-5,5′-dipropoxybenzidine can be used to prepare yellow organic pigments having good tinctorial and lightfastness properties. It is also clear that the resultant pigments are generally nonmutagenic, and that several of them are potential replacements for commercial pigments prepared from mutagenic benzidine congeners.

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