



Synthesis and correlation analysis of spectral data of some (*E*)-2-benzylidenehydrazine carbothioamides

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ABSTRACT

A series containing ten substituted (*E*)-2-benzylidenehydrazinecarbothioamide were synthesized by condensation between thiosemicarbazide and various substituted benzaldehydes. The synthesized (*E*)-2-benzylidenehydrazinecarbothioamide were characterized by their physical constants and spectral data. The UV C=N λ_{max} (nm), infrared ν C=N (cm^{-1}), ^1H NMR δ (CH= N) and ^{13}C δ (C=N) spectral data have been correlated with Hammett substituent constants and *F* and *R* parameters using single and multi-linear regression analysis. From the results of statistical analysis, the effect of substituents on the above Spectral data has been studied.

Keywords: Thiosemicarbazide; Benzaldehyde; Hydrazones; UV; IR & NMR spectral data and substituent effect

1. INTRODUCTION

Hydrazones constitute important class of medicinal compounds due to their wide variety of pharmacological and analytical applications [1-3]. They have proved their application in analytical chemistry, they have been used as chelating agents for the quantitative estimation of transition metal ions [4].

In analytical chemistry, hydrazones found many applications as multidentate ligands for transition metals in colorimetric or fluorimetric determinations [5,6]. The presence of heterocyclic ring in the synthesized hydrazones plays a major role in deciding the extent of their pharmacological properties [7-9]. In hydrazone moiety the nitrogen atom behaves as nucleophilic nature and carbon atom behaves as nucleophilic as well as electrophilic nature [10-12].

They are generally synthesised by the reaction of hydrazine with carbonyl compounds such as aldehydes or ketones in ethanol [13-14].

Spectral data of organic compounds are useful for the prediction of their structure, stereo-chemical and physicochemical properties [15-16]. The quantitative structure activity relationship and quantitative property relationship of the organic substrates are studied from the spectral data associated with their molecular equilibration [17].

If the molecules possess substituent in the aromatic ring, corresponding absorption frequencies in IR and the chemical shift in NMR vary from ketone to ketone depending upon the type of substituents whether they are electron donating or electron withdrawing in nature. From these data the effect of substituents can be studied on the particular functional group of the molecules by means of regression analysis [18-21].

Further these data are employed for the study of transition state reaction mechanism [22], structure activity of biological potentials [23], normal coordinate analysis [24,25], theoretical study of long range interactions in the beta sheet structures of oligo peptides [26], enone-dienol tautomerism [27], density functional theory [28], rotational barriers in selenomides [29] and gas phase reactivity of alkyl sulfides [30].

The out of plane and in-plane deformation frequencies in fingerprint region are also used for QSAR and QPR study [31]. These potentials are also applied for the study of structure activity relationships [32]. Similarly, Suresh et al had synthesized some imine compounds containing $\delta\text{CH}=\text{N}$ moiety have been correlated with Hammett substituent constants and F and R parameters [33]. Several researchers studied the correlation of $\delta\text{CH}=\text{N}$ moiety with Hammett substituent constants and F and R parameters [34-35]

Survey of literature shows that there is no report available regarding the UV, IR and NMR spectral correlations of substituted (*E*)-2-benzylidenehydrazinecarbothioamides. Hence the author synthesized a series of ten number of substituted hydrazone compounds by condensation reaction of *meta*- and *para*- substituted benzaldehydes with thiosemicarbazide. The completion of the reaction was monitored by TLC.

These synthesized compounds have been characterized by their physical constants, UV, IR and NMR spectral data. These UV, IR and NMR spectral data have been correlated with Hammett constants and Swain-Lupton's F and R parameters using single and multi-linear regression analysis. From the results of spectral correlation analysis the effect of substituents have been discussed.

2. EXPERIMENTAL

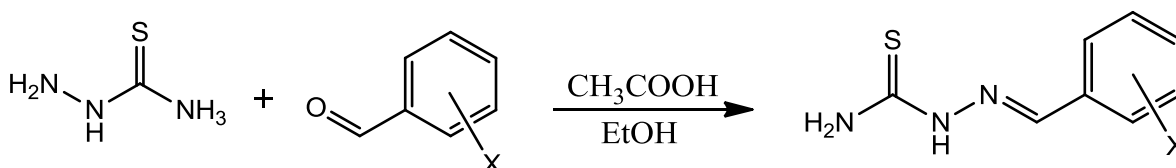
2. 1. General

All chemicals used have been purchased from Sigma–Aldrich and Hi-media chemical companies. Melting points of all substituted (*E*)-2-benzylidenehydrazinecarbothioamides have been determined in open glass capillaries on a Mettler FP51 melting point apparatus and are uncorrected.

The UV spectra of all the substituted (*E*)-2-benzylidenehydrazinecarbothioamides synthesized have been recorded with SHIMADZU- 1650 spectrophotometer (λ_{\max} nm) in spectral grade methanol solvent. Infrared spectra (KBr, 4000–400 cm^{-1}) have been recorded on AVATAR-300 Fourier transform spectrophotometer. Bruker AV400 NMR spectrometer operating at 400 MHz has been utilized for recording ^1H NMR spectra and 100 MHz for ^{13}C NMR spectra in DMSO solvent using TMS as internal standard.

2. 2. Synthesis of substituted (*E*)-2-benzylidenehydrazinecarbothio amides

A solution of benzaldehydes (0.01 mol) and thiosemicarbazide (0.01 mol), acetic acid (few drops) and 10 ml of ethanol were shaken occasionally for 1 hour [36] as shown in scheme1. The completion of the reaction was monitored by TLC. The resulting precipitate was filtered and washed with cold water. The product appeared as pale yellow solid. Then the products are recrystallized using ethanol to obtain pale yellow glittering solid melting at 157-158 $^{\circ}\text{C}$.



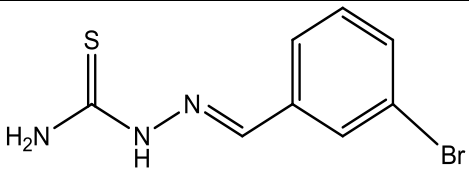
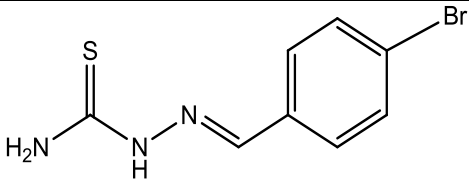
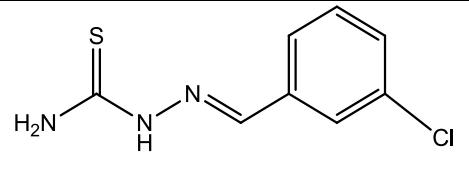
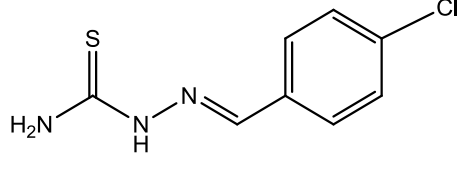
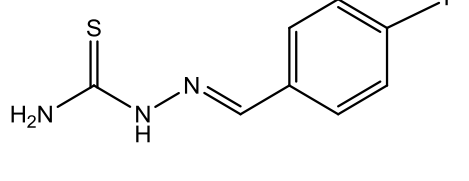
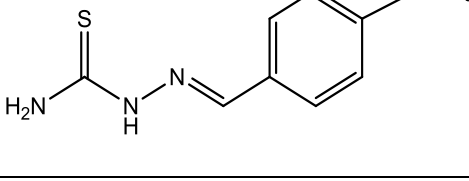
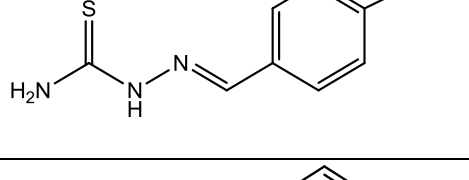
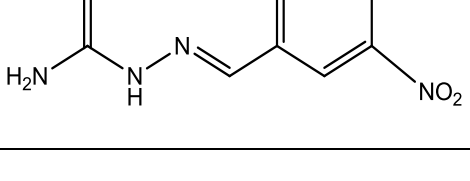
Scheme 1

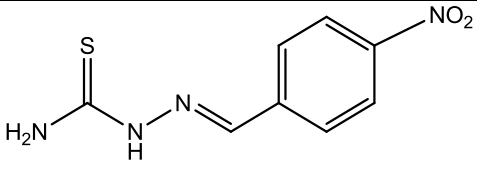
where, X = H, 3-Br, 4-Br, 3-Cl, 4-Cl, 4-F, 4-OCH₃, 4-CH₃, 3-NO₂, 4-NO₂

The physical constants and yields are presented in **Table 1**. The ultraviolet absorption maxima (λ_{\max} , nm), infrared absorptions (ν , cm^{-1}) and NMR chemical shifts (δ , ppm) of substituted (*E*)-2-benzylidenehydrazinecarbothioamides are presented in and **Table 2**.

Table 1. Physical constants and yields of substituted (*E*)-2-benzylidenehydrazine-carbothioamides

Entry	Product	M. F.	M. W.	Yield (%)	m.p. (C)
1		C ₈ H ₉ N ₃ S	179.24	89	158

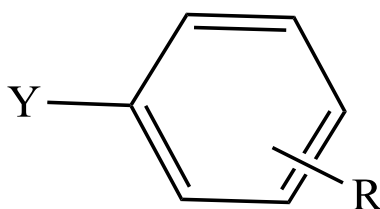
2		$C_8H_8BrN_3S$	258.13	91	210
3		$C_8H_8BrN_3S$	258.13	88	197
4		$C_8H_8ClN_3S$	213.68	94	198
5		$C_8H_8ClN_3S$	213.68	92	211
6		$C_8H_8FN_3S$	197.23	87	195
7		$C_9H_{11}N_3OS$	209.26	84	183
8		$C_9H_{11}N_3S$	193.26	90	169
9		$C_8H_9N_4O_2S$	224.23	95	215

10		$C_8H_8N_4O_2S$	224.23	91	224
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3. RESULTS AND DISCUSSION

3. 1. Spectral linearity

The Hammett equation (37) has been used for many years to assess the electronic effects of substituents (R) through an aryl system on a reaction site (Y). Substituents located in the 2- position with respect to Y



are normally not studied to avoid any complication by steric effects. The equation normally takes the form:

$$\log k = \sigma\rho_R + \log k_o$$

where k is the rate constant of the reaction being studied with different R substituents present, and k_o is the corresponding rate constant of the unsubstituted compound (R = H). The substituent constant σ_R is a value determined from a standard reaction and is characteristic of the nature and position of the substituent. If the substituent is electron withdrawing σ_R has a value > 0 , and a value < 0 indicates an electron donating substituent.

The reaction constant ρ is characteristic of a given reaction and denotes the sensitivity of the reaction to substituent effects. It has a positive value if the reaction is enhanced by electron withdrawing substituents and a negative value if the reaction is facilitated by electron releasing groups. Thus, insight into the polar nature of the transition state of the rate controlling step of a reaction may be obtained. A value for ρ may be determined graphically by plotting $\log k$ vs. the known value for σ_R and calculating the slope of the line.

There have been many successful as well as unsuccessful attempts to correlate properties other than reaction rates with the Hammett σ_R values [38]. Properties such as ultraviolet and infrared absorption frequencies and intensities as well as biological activities have met with only limited success.

However, correlations of 1H NMR data with substituent constants have generally proved more rewarding [39].

Most relevant to this study is the reported correlation of substituent effects in a series of substituted acetanilides and phenylureas. [40]. In the present study the spectral linearity of synthesized substituted (*E*)-2-benzylidenehydrazinecarbothioamides has been studied by evaluating the substituent effects.

The observed UV λ_{\max} (nm), infrared $\nu_{\text{C=N}}$, the proton chemical shifts δ (ppm), of CH=N and carbon chemical shifts of C=N spectral data of all the substituted (E)-2-benzylidenehydrazinecarbothioamides have been correlated with various Hammett substituent constants.

3. 2. UV–Vis spectral study

The assigned UV absorption maxima λ_{\max} (nm) values of synthesized substituted (E)-2-benzylidenehydrazinecarbothioamide compounds are presented in **Table 2**. These UV absorption maxima λ_{\max} (nm) values have been correlated with Hammett substituent constants and F and R parameters using single and multi-linear regression analysis [41-43]. Hammett equation employed, for the correlation analysis, involving the absorption maxima is as shown below in equation (1).

$$\lambda = \rho\sigma + \lambda_0 \quad \dots(1)$$

where λ_0 is the frequency for the parent member of the series.

Table 2. The ultraviolet absorption maxima (λ_{\max} , nm), infrared absorptions (ν , cm^{-1}) and NMR chemical shifts (δ , ppm) of substituted (E)-2-benzylidenehydrazinecarbothioamides

ENTRY	X	UV (λ_{\max})	IR vcm^{-1} (CH=N)	^1H CH=N (ppm)	^{13}C CH=N (ppm)
1	H	309.50	1643.35	8.048	142.29
2	3-Br	318.00	1641.42	8.117	140.75
3	4-Br	317.50	1641.42	8.015	140.23
4	3-Cl	315.00	1685.79	8.041	140.55
5	4-Cl	316.50	1689.64	8.060	140.90
6	4-F	311.00	1638.43	8.051	140.39
7	4-OCH ₃	320.50	1625.99	8.101	142.26
8	4-CH ₃	313.50	1698.00	8.150	142.23
9	3-NO ₂	311.50	1643.35	8.041	140.03
10	4-NO ₂	322.00	1641.42	8.211	140.77

These observed spectral data of all the synthesized substituted (*E*)-2-benzylidenehydrazinecarbothioamides have been correlated with Hammett constants and *F* and *R* parameters and are shown in Table 3.

Table 3. The results of statistical analysis of UV absorption maximum λ_{max} values (nm), infrared frequencies $\nu(\text{cm}^{-1})$ of $\text{CH}=\text{N}$, ^1H NMR chemical shift $\delta\text{C}=\text{N}$ (ppm) and ^{13}C NMR chemical shift $\delta\text{C}=\text{N}$ (ppm) value of substituted (*E*)-2-benzylidenehydrazinecarbothioamides with Hammett constants σ , σ^+ , σ_I & σ_R and *F* and *R* parameters.

Frequency	constants	r	I	ρ	s	n	correlated derivatives
λ_{max} nm	σ	0.900	315	2.122	4.33	8	H, 3-Br, 4-Br, 3-Cl, 4-Cl, 4-F, 4-CH ₃ , 4-NO ₂
	σ^+	0.900	315.42	0.471	4.395	8	H, 3-Br, 4-Br, 3-Cl, 4-Cl, 4-F, 4-CH ₃ , 4-NO ₂
	σ_I	8.032	313.3	5.586	4.159	10	H, 3-Br, 4-Br, 3-Cl, 4-Cl, 4-F, 4-OCH ₃ , 4-CH ₃ , 3-NO ₂ , 4-NO ₂
	σ_R	0.801	315.46	-0.284	4.401	10	H, 3-Br, 4-Br, 3-Cl, 4-Cl, 4-F, 4-OCH ₃ , 4-CH ₃ , 3-NO ₂ , 4-NO ₂
	<i>F</i>	0.852	314.09	3.438	4.304	10	H, 3-Br, 4-Br, 3-Cl, 4-Cl, 4-F, 4-OCH ₃ , 4-CH ₃ , 3-NO ₂ , 4-NO ₂
	<i>R</i>	0.805	315.32	-0.091	4.395	10	H, 3-Br, 4-Br, 3-Cl, 4-Cl, 4-F, 4-OCH ₃ , 4-CH ₃ , 3-NO ₂ , 4-NO ₂
$\nu\text{CH}=\text{N}$	σ	0.812	1656.68	-7.701	27.09	10	H, 3-Br, 4-Br, 3-Cl, 4-Cl, 4-F, 4-OCH ₃ , 4-CH ₃ , 3-NO ₂ , 4-NO ₂
	σ^+	0.903	1655.15	-1.654	27.23	7	H, 3-Br, 4-Br, 4-F, 4-OCH ₃ , 3-NO ₂ , 4-NO ₂
	σ_I	0.830	1667.52	-32.16	25.95	10	H, 3-Br, 4-Br, 3-Cl, 4-Cl, 4-F, 4-OCH ₃ , 4-CH ₃ , 3-NO ₂ , 4-NO ₂
	σ_R	0.807	1656.21	9.732	27.15	10	H, 3-Br, 4-Br, 3-Cl, 4-Cl, 4-F, 4-OCH ₃ , 4-CH ₃ , 3-NO ₂ , 4-NO ₂

	<i>F</i>	0.835	1669.84	-36.66	26.94	10	H, 3-Br, 4-Br, 3-Cl, 4-Cl, 4-F, 4-OCH ₃ , 4-CH ₃ , 3-NO ₂ , 4-NO ₂
	<i>R</i>	0.814	1657.82	15.489	26.94	10	H, 3-Br, 4-Br, 3-Cl, 4-Cl, 4-F, 4-OCH ₃ , 4-CH ₃ , 3-NO ₂ , 4-NO ₂
$\delta C=N$	σ	0.824	8.077	0.025	0.063	10	H, 3-Br, 4-Br, 3-Cl, 4-Cl, 4-F, 4-OCH ₃ , 4-CH ₃ , 3-NO ₂ , 4-NO ₂
	σ^+	0.852	8.083	0.001	0.064	10	H, 3-Br, 4-Br, 3-Cl, 4-Cl, 4-F, 4-OCH ₃ , 4-CH ₃ , 3-NO ₂ , 4-NO ₂
	σ_I	0.805	8.088	-0.013	0.064	10	H, 3-Br, 4-Br, 3-Cl, 4-Cl, 4-F, 4-OCH ₃ , 4-CH ₃ , 3-NO ₂ , 4-NO ₂
	σ_R	0.837	8.094	0.079	0.062	10	H, 3-Br, 4-Br, 3-Cl, 4-Cl, 4-F, 4-OCH ₃ , 4-CH ₃ , 3-NO ₂ , 4-NO ₂
	<i>F</i>	0.804	8.088	-0.011	0.064	10	H, 3-Br, 4-Br, 3-Cl, 4-Cl, 4-F, 4-OCH ₃ , 4-CH ₃ , 3-NO ₂ , 4-NO ₂
	<i>R</i>	0.821	8.093	0.052	0.062	10	H, 3-Br, 4-Br, 3-Cl, 4-Cl, 4-F, 4-OCH ₃ , 4-CH ₃ , 3-NO ₂ , 4-NO ₂
$\delta C=N$	σ	0.907	141.47	-1.841	0.634	9	H, 3-Br, 4-Br, 3-Cl, 4-Cl, 4-F, 4-OCH ₃ , 4-CH ₃ , 3-NO ₂
	σ^+	0.900	141.27	-1.382	0.611	7	3-Br, 4-Br, 3-Cl, 4-Cl, 4-F, 4-OCH ₃ , 3-NO ₂
	σ_I	0.908	142.3	-3.212	0.432	8	H, 3-Br, 4-Br, 3-Cl, 4-Cl, 4-F, 4-CH ₃ , 3-NO ₂
	σ_R	0.814	140.59	-0.634	0.923	10	H, 3-Br, 4-Br, 3-Cl, 4-Cl, 4-F, 4-OCH ₃ , 4-CH ₃ , 3-NO ₂ , 4-NO ₂
	<i>F</i>	0.948	142.26	-2.994	0.483	7	H, 3-Br, 4-Br, 3-Cl, 4-Cl, , 4-CH ₃ , 3-NO ₂
	<i>R</i>	0.815	140.93	-0.569	0.922	10	H, 3-Br, 4-Br, 3-Cl, 4-Cl, 4-F, 4-OCH ₃ , 4-CH ₃ , 3-NO ₂ , 4-NO ₂

r = correlation coefficient; I = intercept; ρ = slope; s = standard deviation; n = number of correlated derivatives

The results of statistical analysis are presented in **Table 3**. From the **Table 3**, the results of statistical analysis [44-47] of these UV absorption maxima (λ_{max} , nm) data with Hammett substituent constants, except those with 4-OCH₃ and 3-NO₂ substituent have shown satisfactory correlations with Hammett substituent constant σ ($r = 0.900$). The Hammett constant σ^+ ($r = 0.900$) parameter has also shown satisfactory correlation for all the substituents except those with H, 4-OCH₃ and 3-NO₂.

However UV absorption maximum λ_{max} (nm) values of all the substituted (*E*)-2-benzylidenehydrazinecarbothioamides compounds have shown poor correlations ($r < 0.900$) with the remaining Hammett substituent constants σ_I & σ_R and *F* and *R* parameters.

This is due to the incapability of inductive, field and resonance effects of the substituents for predicting the reactivity on the UV absorption maximum λ_{max} (nm) values through resonance as per the conjugative structure shown in **Figure 2**.

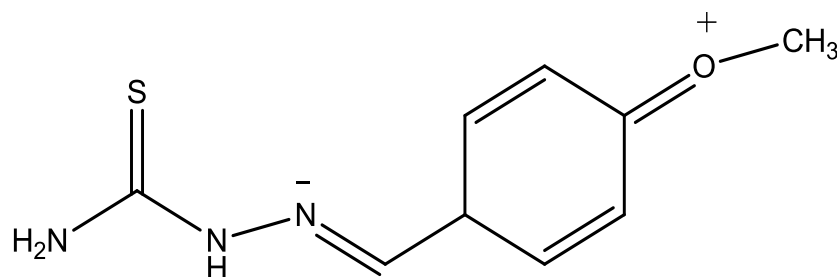


Fig. 2. The resonance-conjugative structure

Some of the single regression analyses have shown poor correlations with Hammett substituent constants σ_I & σ_R and *F* and *R* parameters, it is decided to go for multi regression analysis.

The multi regression analysis of the UV absorption maximum λ_{max} (nm) values of all the substituted (*E*)-2-benzylidenehydrazinecarbothioamides compounds with inductive, resonance and Swaine-Lupton's [48] parameters produce satisfactory correlations as shown in equations (2) and (3).

All the correlations have shown positive ρ values except σ_R and *R* parameter. This indicates the operation of normal substituent effect with respect to UV absorption maximum λ_{max} (nm) values of all the substituted (*E*)-2-benzylidenehydrazinecarbothioamides compounds.

$$\text{UV } (\lambda_{max} \text{ nm}) = 313.09 (\pm 3.063) + 5.71(\pm 1.139)\sigma_I - 1.15 (\pm 0.204)\sigma_R \quad \dots(2)$$

(R=0.933, n = 10, P > 90%)

$$\text{UV } (\lambda_{max} \text{ nm}) = 313.96 (\pm 3.076) + 3.40 (\pm 1.093) F - 0.78(\pm 0.215)R \quad \dots(3)$$

(R=0.921, n = 10, P > 90%)

The single linear plot of UV absorption maximum λ_{max} (nm) values against Hammett constant σ and σ^+ is shown in the following **Fig. 3**.

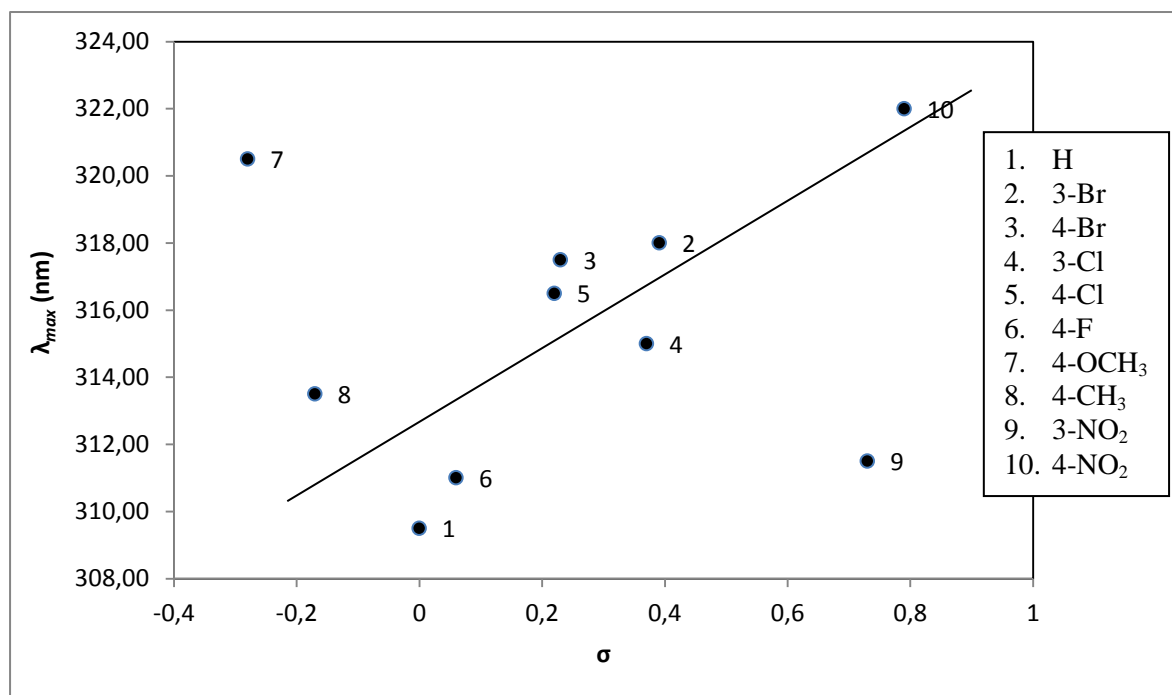


Fig. 3. Single linear plot of λ_{max} (nm) values of substituted (*E*)-2-benzylidenehydrazinecarbothioamides compounds Vs σ

3. 3. IR Spectral study

The infrared $\nu_{C=N}$ stretching frequencies (cm^{-1}) of the synthesized (*E*)-2-benzylidenehydrazinecarbothioamides have been recorded and presented in **Table 2**. These data have been correlated with Hammett substituent constants and Swain-Lupton's [48] parameters. In this correlation the structure parameter Hammett equation employed is as shown in equation (4).

$$\nu = \rho\sigma + \nu_0 \quad \dots (4)$$

where ν_0 is the frequency of the parent compound.

The infrared frequency of all the substituted (*E*)-2-benzylidene hydrazine carbothioamides except those with 3-Cl, 4-Cl and 4-CH₃ substituents have shown satisfactory correlation with Hammett substituent constant σ^+ ($r = 0.903$). When these substituents that have been given exception are included in regression they reduce the correlations considerably.

The remaining Hammett substituent constants σ , σ_I , σ_R and F and R parameters have shown poor correlations ($r < 0.900$). This is attributed to the weak inductive, field and resonance effects of the substituents for predicting the reactivity on the infrared frequency through resonance as per the conjugative structure as shown in **Fig. 2**.

All the correlations have shown negative ρ values (except σ_R and R parameter) with all the Hammett substituent constants and F and R parameters. It indicates that the reverse

substituent effect operates with respect to infrared frequency $\nu_{\text{CH=N}}$ (cm^{-1}) values of all the substituted (*E*)-2-benzylidenehydrazinecarbothioamide compounds.

The single linear plot of IR frequency $\nu_{\text{C=N}}$ (cm^{-1}) values against Hammett constant σ^+ is shown in the following **Fig. 4**.

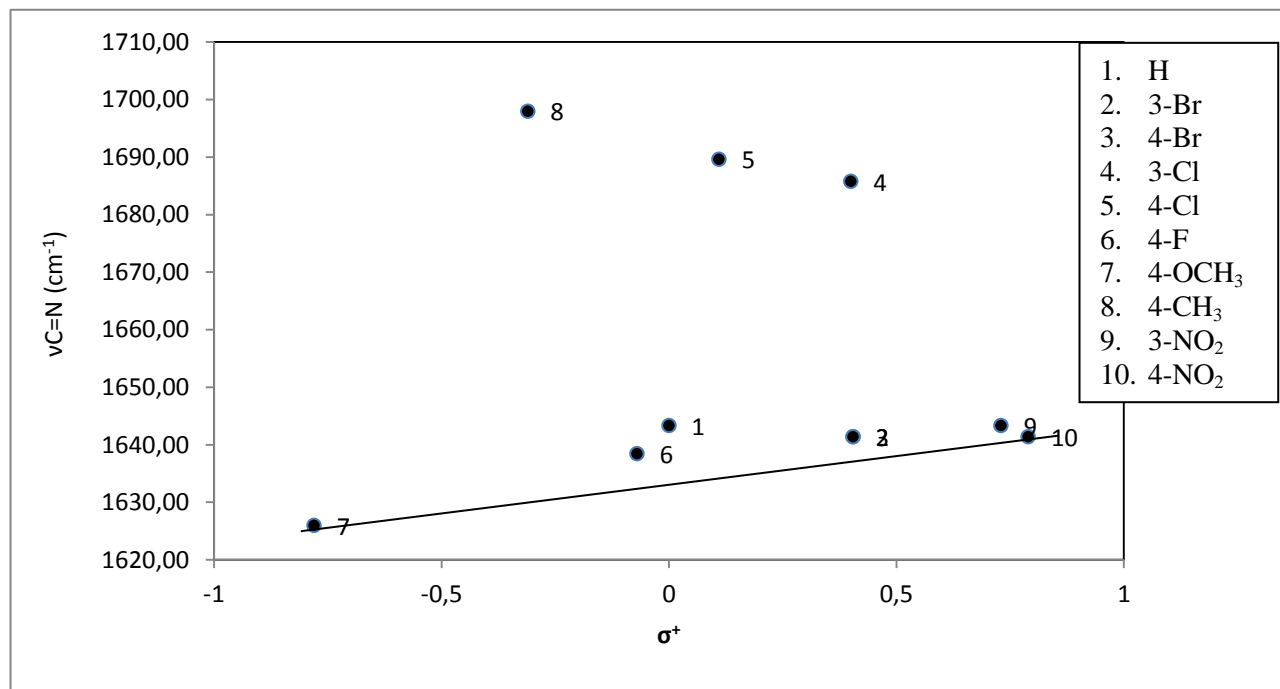


Fig. 4. Single linear plot of IR frequency $\nu_{\text{C=N}}$ (cm^{-1}) values of substituted (*E*)-2-benzylidenehydrazinecarbothioamides compounds Vs σ^+

Most of the single regressions have shown poor correlations. Hence, the author decided to go for multi-regression analysis. The multi regression analyses have shown satisfactory correlations as shown in equations (5) and (6).

$$\nu_{\text{cm}^{-1}}(\text{CH=N}) = 1670.20 (\pm 18.995) - 33.80 (\pm 8.072) \sigma_{\text{I}} + 14.86 (\pm 2.679) \sigma_{\text{R}} \quad \dots(5)$$

(R = 0.932, n = 10, P > 90%)

$$\nu_{\text{cm}^{-1}}(\text{CH=N}) = 1672.29 (\pm 17.996) - 36.13 (\pm 3.65) F + 16.65 (\pm 2.363) R \quad \dots(6)$$

(R = 0.938, n = 10, P > 90%)

3. 4. NMR spectral study

The proton and carbon chemical shifts (ppm) of all the synthesized substituted (*E*)-2-benzylidenehydrazinecarbothioamides (CH=N) compounds have been assigned and are presented in **Table 2**. Attempts have been made to correlate the $\delta_{\text{CH=N}}$ chemical shifts (ppm) with Hammett substituent constants, field and resonance parameters, with the help of single and multi-regression analyses to study the reactivity through the effect of substituents.

The assigned proton chemical shifts (ppm) have been correlated with reactivity parameters using the Hammett equation as shown in equation (7)

$$\delta = \delta_0 + \rho\sigma \quad \dots (7)$$

where δ_0 is the chemical shift of unsubstituted system.

3. 4. 1. ^1H NMR Spectral study

The ^1H NMR spectra of the (*E*)-2-benzylidenehydrazinecarbothioamides under investigation have been recorded in deuterated dimethylsulfoxide solution employing tetramethylsilane (TMS) as internal standard. The signals of the (*E*)-2-benzylidenehydrazinecarbothioamides protons have been assigned and are presented in **Table 3**. In nuclear magnetic resonance spectra, the ^1H or the ^{13}C chemical shifts (δ , ppm) depend on the electronic environment of the nuclei concerned. These chemical shifts have been correlated with reactivity parameters. The results of statistical analysis are presented in **Table 3**. These proton chemical shifts (ppm) fail in correlation with Hammett substituent constants and *F* and *R* parameters. All correlations gave positive ρ values. This shows that the normal substituent effect operates in all systems. The failure in correlation is attributed to the conjugative structure shown in **Fig 2**. All the correlations have shown positive ρ values except σ_{I} and *F* parameter, it indicates the operation of normal substituent effect in the synthesized (*E*)-2-benzylidenehydrazinecarbothioamides. In this case all the single regression analyses have shown poor correlations with all the Hammett substituent constants and *F* and *R* parameters. So, it is decided to go for multi regression analysis. The multi regression analysis of the $\delta_{\text{CH}=\text{N}}$ chemical shift (ppm) values of all the synthesized (*E*)-2-benzylidenehydrazinecarbothioamide compounds with inductive, resonance and Swain-Lupton's [48] parameters produce satisfactory correlations as shown in equations (8) and (9).

$$\delta_{\text{CH}=\text{N}} (\text{ppm}) = 8.103 (\pm 0.045) - 0.22 (\pm 0.091)\sigma_{\text{I}} + 0.832 (\pm 0.107)\sigma_{\text{R}} \quad \dots(8)$$

(R = 0.928, n = 10, P > 90%)

$$\delta_{\text{CH}=\text{N}} (\text{ppm}) = 8.090 (\pm 0.045) - 0.11 (\pm 0.008)\text{F} + 0.52(\pm 0.091)\text{R} \quad \dots(9)$$

(R = 0.921, n = 10, P > 90%)

3. 4. 2. ^{13}C NMR spectra

In the present study, the $\delta_{\text{C}=\text{N}}$ carbon chemical shifts (ppm) of all the substituted (*E*)-2-benzylidenehydrazinecarbothioamides compounds have been assigned and are presented in **Table 2**. From **Table 2** the assigned $\delta_{\text{C}=\text{N}}$ chemical shift (ppm) values have been correlate [49] with Hammett substituent constants, field and resonance parameters, with the help of single and multi-regression analyses to study the reactivity through the effect of substituents. The results of statistical analysis are presented in **Table 3**.

From **Table 3**, it is evident that the $\delta_{\text{C}=\text{N}}$ chemical shift (ppm) values of all the substituted (*E*)-2-benzylidenehydrazinecarbothioamides compounds, except with 4- NO_2 substituent have shown satisfactory correlation with Hammett substituent constant σ ($r = 0.907$). The $\delta_{\text{C}=\text{N}}$ chemical shift (ppm) values of all the substituted (*E*)-2-benzylidenehydrazinecarbothioamides compounds, except with parent and 4- NO_2 substituent have shown satisfactory correlation with Hammett substituent constant σ^+ ($r = 0.900$).

The $\delta_{\text{C=N}}$ chemical shift (ppm) values of all the substituted (*E*)-2-benzylidenehydrazinecarbothioamides compounds, except with 4-OCH₃ and 4-NO₂ substituent have shown satisfactory correlation with Hammett substituent constant σ_{I} ($r = 0.908$). The $\delta_{\text{C=N}}$ chemical shift (ppm) values of all the substituted (*E*)-2-benzylidenehydrazinecarbothioamides compounds, except with 4-CH₃, 4-OCH₃ and 4-NO₂ substituent have shown satisfactory correlation with Hammett substituent constant F ($r = 0.908$). When these substituents that have been given exception in each case included in the regression they reduce the correlations considerably.

All the correlations have shown negative ρ values, it indicates the operation of reverse substituent effect in all the substituted (*E*)-2-benzylidenehydrazinecarbothioamides. In This case some of the single regression analyses have shown poor correlation with Hammett constant σ_{R} and R parameters. It is decided to go for multi-regression analysis.

The multi-regression analysis of all the synthesized substituted (*E*)-2-benzylidenehydrazinecarbothioamide compounds have shown satisfactory correlations as shown in equations (10) and (11).

$$\delta_{\text{CH=N}} (\text{ppm}) = 142.27 (\pm 0.318) - 3.19 (\pm 0.637) \sigma_{\text{I}} - 0.15 (\pm 0.074) \sigma_{\text{R}} \dots (10)$$

($R = 0.988$, $n = 10$, $P > 95\%$)

$$\delta_{\text{CH=N}} (\text{ppm}) = 142.14 (\pm 0.321) - 3.02 (\pm 0.635) F - 0.68 (\pm 0.148) R \dots (11)$$

($R = 0.987$, $n = 10$, $P > 95\%$)

The single linear plot of ¹³C chemical shift (ppm) $\nu_{\text{C=N}}$ (cm⁻¹) values against Hammett constant σ , σ^+ , σ_{I} , and F is shown in the following **Figs. 5-8**.

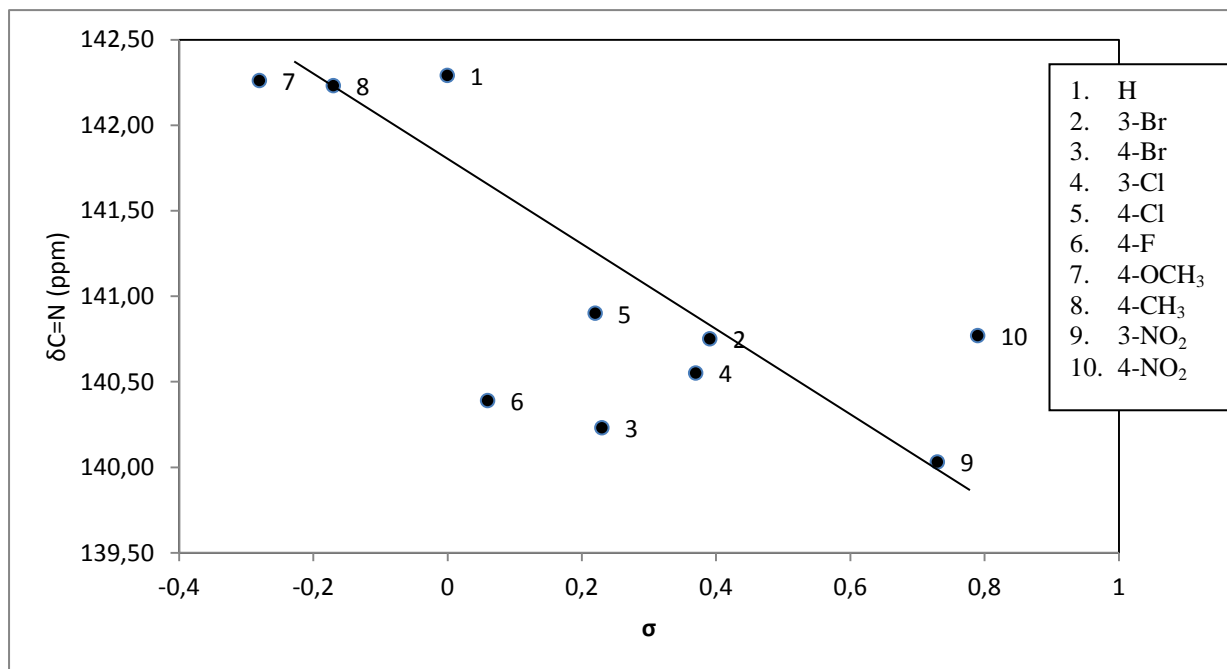


Fig. 5. Single linear plot of chemical shift (ppm) $\delta_{\text{C=N}}$ (ppm) values of substituted (*E*)-2-benzylidenehydrazinecarbothioamides compounds Vs σ

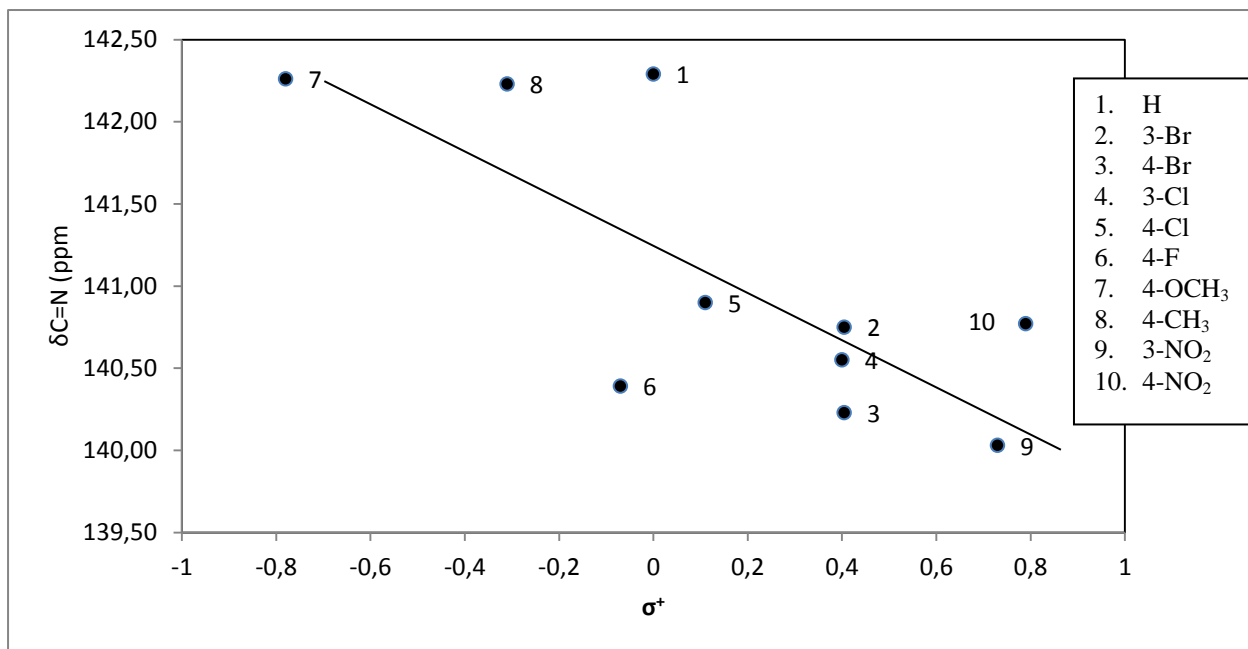


Fig. 6. Single linear plot of chemical shift (ppm) $\nu_{C=N}$ (cm^{-1}) values of substituted (*E*)-2-benzylidenehydrazinecarbothioamides compounds Vs σ^+

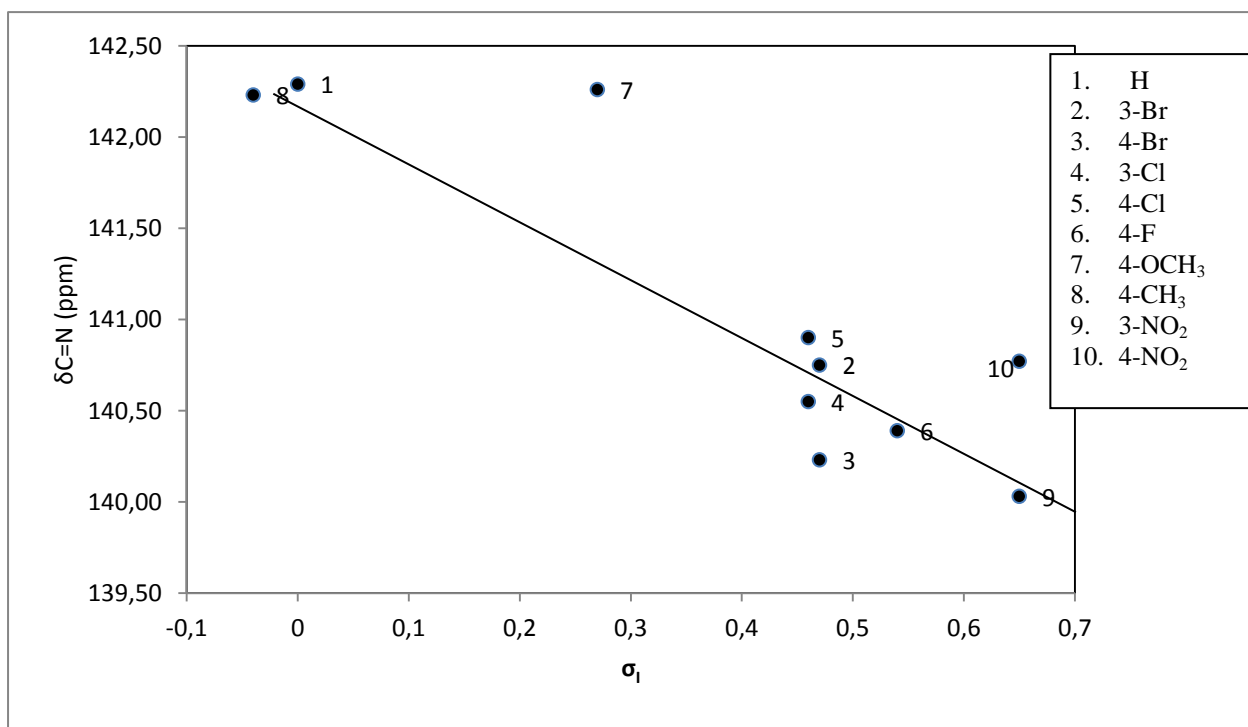


Fig. 7. Single linear plot of chemical shift (ppm) $\delta_{C=N}$ (ppm) values of substituted (*E*)-2-benzylidenehydrazinecarbothioamides compounds Vs σ_1

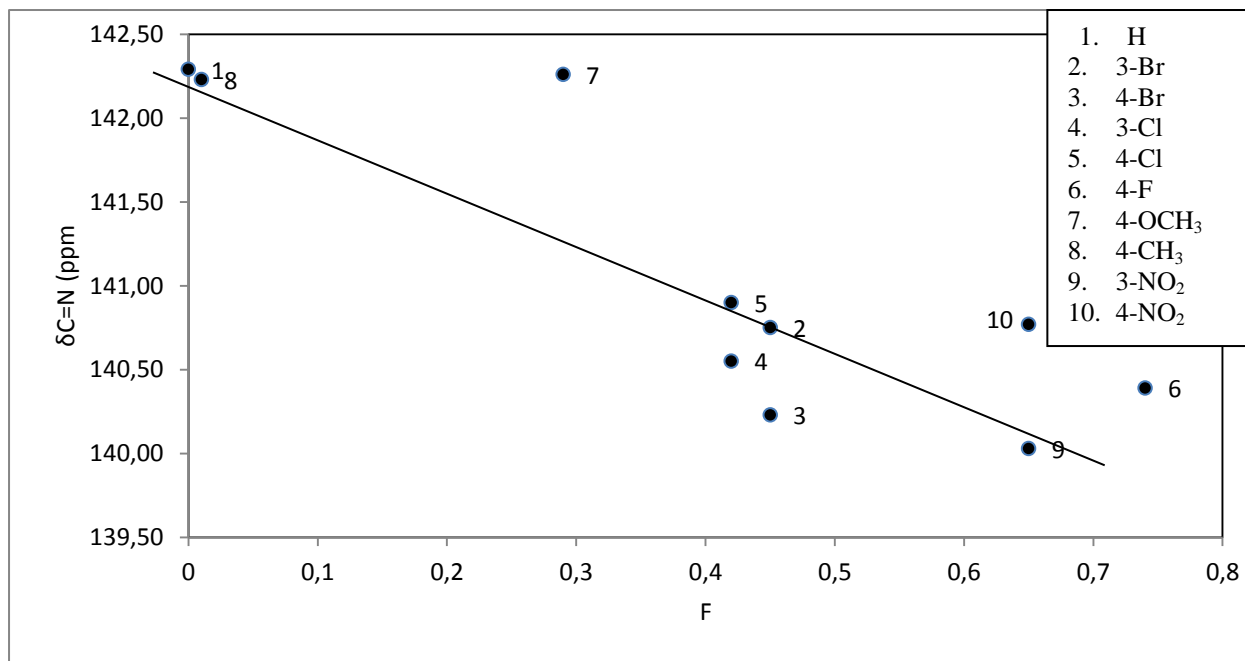


Fig. 8. Single linear plot chemical shift (ppm) $\nu_{C=N}$ (ppm) values of substituted (*E*)-2-benzylidenehydrazinecarbothioamides compounds Vs *F*

4. CONCLUSIONS

The authors have been synthesized some substituted (*E*)-2-benzylidenehydrazinecarbothioamide compounds by condensation of meta- and para-substituted benzaldehyde with thiosemicarbazide using sodium hydroxide catalyst. The synthesized (*E*)-2-benzylidenehydrazinecarbothioamides compounds have been found to be more than 80% yield. The synthesized compounds have been characterized by physical constants, UV, IR and NMR spectral data. From the UV, IR, and NMR spectral data have been correlated with Hammett substituent constant and Swine-Luptan's *F* and *R* parameters using single and multi-regression analysis from results of statistical analysis the effect of substituents have been discussed.

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