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Preliminary Feasibility Study of Colorimetric Properties as An Assessment Tool for Cost-Effective Dye Impregnated Paper Gamma Dosimeters

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Abstract

Gamma radiations are known to bring about radiolysis of myriad compounds / dyes which is used to measure of the energy of the incident radiation on the system. The use of various dye solutions for chemical dosimetry is reported in literature. Various thin film dosimeters, semi-conductor dosimeters are also reported and widely used. Similarly γ - dose quantification using paper or polymer impregnated with dyes has also been reported. In the present study, decolouration due to gamma radiation of various dye impregnated papers viz. Gentian Violet (GV), Malachite Blue (MB), Malachite Green (MG), Brilliant Yellow (BY) and Congo Red (CR) has been investigated using device independent colour parameters. The colour analysis was done by standard procedures of *Commission Internationale de l'Eclairage* CIE. Color has mind dependency so to eliminate the errors in determination colour parameters are evaluated.

Keywords: colour analysis, dye impregnated paper strips, gamma radiation

Article Highlights

- Paper based dosimeters are economical and easy to prepare.
- The colour parameters studied are device independent and requires minimal instrumentation.
- The method can be developed as rugged method for dose determination.

1.0 Introduction

Gamma radiations are used for terminal stage sterilization of various commodities like food, medicines, surgical equipment and medical implants etc. Terminal sterilization is beneficial in many ways. Rigorous maintenance of aseptic conditions is not required and sterilization can be effectively done after final packaging. Moreover, such sterilization technique does not leave any chemical residue which may induce toxicity as in case of chemical sterilizing agents. Moreover, gamma radiation is also used effectively to treat wastewater. The organic impurities are known to mineralize by these high energy radiations. These applications generally require high dose of energy of about 25 kGy. Thus, it is of utmost importance that the energy of these radiations be quantified. The dosimeters are the tools used to assess the amount of energy absorbed by the particular system.

The primary dosimeters measure the energy by the ionization of the known quantity of gas present in the ionization chamber. The secondary dosimeters are generally chemical dosimeters. They work on the principle that gamma radiations bring about changes in chemical structure on which the radiation is incident. The high energy radiation may lead to formation or degradation of a particular chemical species depending on the material on which it is incident. If these chemical changes show linear response with the energy absorbed then such systems can be used as chemical dosimeters. Most commonly these radiations cause radiolysis of the compounds/dyes i.e. degradation due to the radiations. The colour intensity of the dye generally decreases due to either bleaching (formation of leuco-base) or degradation of the dye species. The use of various dye solutions for chemical

dosimetry is well-known (Vereshchinski and Pikaev, 1964; el–Assy et. al., 1991; Melendez-Lopez, et. al., 2018). Also, γ - dose quantification using paper / polymer impregnated with dyes have been reported (Gupta and Bhat, 1983; Saisomboon and Siri-Upathum, 1987; Malav, 2014).
In the present study, decolouration due to gamma radiation of Gentian Violet (GV), Methylene Blue (MB), Malachite Green (MG), Brilliant Yellow (BY) and Congo Red (CR) dye impregnated paper has been investigated. The colour parameters of these dye impregnated papers were analyzed. The Commission Internationale de l'Eclairage (CIE) approach was used for description of various colour parameters.

2.0 Materials and method

2.1 Samples-GV (colour index 42535), MB (colour index 52015), MG (colour index 42000), BY (colour index 24890) and CR (colour index 22120) were obtained from BDH / Qualigen and used without further purification. Strips of Whatman paper no. 1 of dimensions 2.5 cm $\times$ 5.0 cm were soaked in aqueous solutions having various concentrations of the above dyes / indicator for 20 minutes and then air dried in dust free environment at room temperature (30°C). The solutions used had dye concentrations of w/v $6.25x10^{-4}$ %, $1.25x10^{-3}$%, $2.50x10^{-3}$% and $5.00x10^{-3}$%.
2.2 Irradiation-The strips were exposed to various gamma doses at dose rate of 0.90 kGy hr^{-1}. The irradiation was performed in GC-900 ^{60}Co source housed in Department of Chemistry, R. T. M. Nagpur University, Nagpur. The dose rate of the source was calibrated by Fricke dosimeter.
2.3 Diffuse Reflectance Spectra-The reflectance spectra were recorded using integrating sphere assembly (sphere diameter: 63 mm, port / sphere area ratio: 8%, sample incident angle: 8°) of Cintra 20e (GBC, Australia) spectrophotometer against standard plate.
2.4 Colour Analysis-The post irradiation decolouration was evaluated using device-independent colour parameters. The standard procedures of CIE were used for colour analysis. This is required as there is mind dependency of colour.
Correct evaluation of the colour can be done by converting reflectance spectrum data to colour parameters which truly represents human eye capabilities. The colour emerges due to interaction of three components i.e. light source, object's reflectance characteristics, and human vision system. The CIE XYZ color space is suitable because, in this colour space, CIE XYZ tristimulus values are calculated from CIE 2° observing field (standard observer function) considering illumination and reflectance spectrum of object's surface. The standard illuminant source is D65, which is actual spectral measurement of daylight having correlated colour temperature of 6,504 K. Under daylight condition, the vision process is mainly dependent on the fovea, a part of the retina occupying the area where the visual angle of observation is equal to 2° in the centre of vision field (Wyszecki and Stiles, 1967). Hence, the hypothetical observer used is 2° CIE standard observer. The calculation for XYZ is performed using the following equations:

$$X = K\sum_{380}^{780} \rho_\lambda H_\lambda \bar{x}_\lambda \Delta\lambda$$

$$Y = K\sum_{380}^{780} \rho_\lambda H_\lambda \bar{y}_\lambda \Delta\lambda$$

$$Z = K\sum_{380}^{780} \rho_\lambda H_\lambda \bar{z}_\lambda \Delta\lambda$$

where

ρ_λ spectral reflectance of the object at λ

H_λ illuminant function (D65) at λ

$\bar{x}_\lambda, \bar{y}_\lambda, \bar{z}_\lambda$ colour matching functions of standard observer at λ

$\Delta\lambda$ spectral resolution or data interval (1 nm)

The tristimulus values X, Y, and Z are coordinates of a three-dimensional vector space and mathematically describe a colour. This colour system does not form a physiologically equivalent colour space. So, it cannot mimic the nonlinear response of human eye but the values obtained do form the starting point for the calculation of other colour parameters that are closer to human response.

2.4.1 CIE Lab and ΔE^*_{ab}

The human perception of chromaticity follows a space in which the two axes are redness vs greenness and yellowness vs blueness. Considering this, a new colour space called CIE Lab which is very close to human response was formulated. Traditionally the colour space is designated as L*a*b*, where the asterisks indicates nonlinearity of the variables. It is computed from CIE XYZ tristimulus as shown below (Nassau, 1998).

$$L^* = 116 \cdot Y^* - 16; \quad a^* = 500 \cdot (X^* - Y^*); \; b^* = 200 \cdot (Y^* - Z^*)$$

$$Considering, U \in \{X, Y, Z\}$$

$$U^* = \begin{cases} \sqrt[3]{\dfrac{U}{U_n}} & \text{for } U/U_n > 0.008856 \\ 7.787\dfrac{U}{U_n} + 0.138 & \text{for } U/U_n \le 0.008856 \end{cases}$$

The subscript n indicates the tristimulus values of the perfect diffuser for the given illuminant and standard observer. The exponential 1/3 in equation for tristimulus values greater than 0.008856 provides the nonlinearity. For values less than 0.008856, linearity is maintained to simplify conversion of Lab to XYZ

The CIE Lab expresses color as three values namely L* for lightness i.e., from black to white, a* from green to red and b* from blue to yellow. The space is a three-dimensional real number space as shown in Fig. 1. The spatial distribution is usually mapped onto a three-dimensional integer space and thus L*, a*, and b* values are generally absolute having pre-defined range. The lightness value, L* represents the darkest black at L* = 0, and the brightest white at L* = 100. The color coordinates, a* and b* represent true neutral grey at a* = 0 and b* = 0. The a* axis represents the green-red component, with green in the negative direction and red in the positive direction. Similarly, b* axis represents the blue-yellow component, with blue in the negative direction and yellow in the positive. The scaling and limits of the a* and b* axes also depends on specific implementation as shown in Fig. 1.

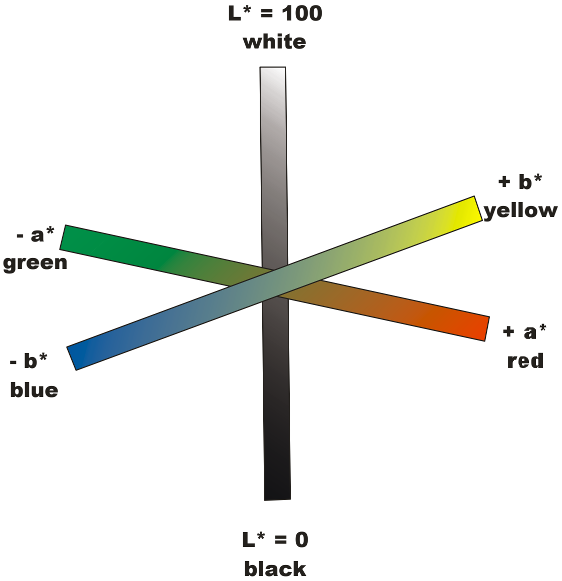


Fig: 1 Spatial representation of CIE Lab colour space

From CIE Lab values of pre- and post- irradiated dye strips color difference (ΔE^*_{ab}) is calculated using following equation [7]

$$\Delta E^*_{ab} \approx \sqrt{(L^*_u - L^*_i)^2 + (a^*_u - a^*_i)^2 + (b^*_u - b^*_i)^2}$$

The subscripts u and i refer to the pre - and post- irradiated dye strips respectively. The ΔE^*_{ab} value is useful for quantitation of colour difference.

2.4.2 Yellowness Index (ASTM Method E313)

The yellowness index shows a degree where the hue leaves white or achromatic colour toward yellow. If it takes a negative value, it moves in the blue direction. The yellowness index for 2° observer and D65 illuminant is calculated as

$$YI = \left[100\frac{(1.2985X - 1.1335Z)}{Y}\right]$$

The change of yellowness index is shown as the difference in yellowness indices of pre- and post-irradiated dye strips.

$$\Delta YI = YI_i - YI_u$$

where, subscripts i and u denotes post- and pre-irradiated dye strips respectively.

2.4.3 Whiteness Index (ASTM Method E313)

Whiteness is measure of how closely a surface matches the properties of a perfect reflecting diffuser, i.e. an ideal reflecting surface that neither absorbs nor transmits light, but reflects it at equal intensities in all directions. For the purposes of this standard, the color of such a surface is known as preferred white.

It is calculated as –

$$W_2 = Y_2 + 800(x_{n,2} - x_2) + 1700(y_{n,2} - y_2)$$

where

Y is the Y tristimulus value (relative luminance),

(x,y) is the chromaticity coordinate in the CIE 1931 color space

(x_n,y_n) is the chromaticity coordinate of the perfect diffuser (reference white)

The 2 in the subscript indicates 2° observer for the CIE 1931.

The change of whiteness index is shown as the difference in whiteness indices of pre- and post-irradiated dye strips.

$$\Delta W = W_i - W_u$$

where, subscripts i and u denotes post- and pre-irradiated dye strips respectively.

2.4.4 Dominant Wavelength

The dominant wavelength of a color correlates in an approximate way with what would be called as the hue of the color as observed under everyday conditions (Singh, et. al, 2009). In other words dominant wavelength is the single wavelength that is perceived by the human eye. Single light source consists of multiple wavelength rather than one single wavelength. Human brain compiles these multiple spectra into a single color of light consistent with a single specific wavelength which is known as dominant wavelength, perceivable to human eye.

2.4.5 RGB Color Gamut and Color Palette

Most of the visible spectrum is represented by mixing three basic coloured light, red, green and blue in various proportions. The primary colour space is used in monitor display and the fill colour options of most of the softwares. For 2° observer and D65 illuminant, the XYZ to RGB conversion is given as

$$X' = X/100$$

$$Y' = Y/100$$

$$Z' = Z/100$$

$$R' = X' \times 3.2406 + Y' \times (-1.5375) + Z' \times (-0.4986)$$

$$G' = X' \times (-0.9689) + Y' \times 1.8758 + Z' \times 0.0415$$

$$B' = X' \times 0.0557 + Y' \times (-0.2040) + Z' \times (1.0570)$$

$$U' \in \{R', G', B'\}$$

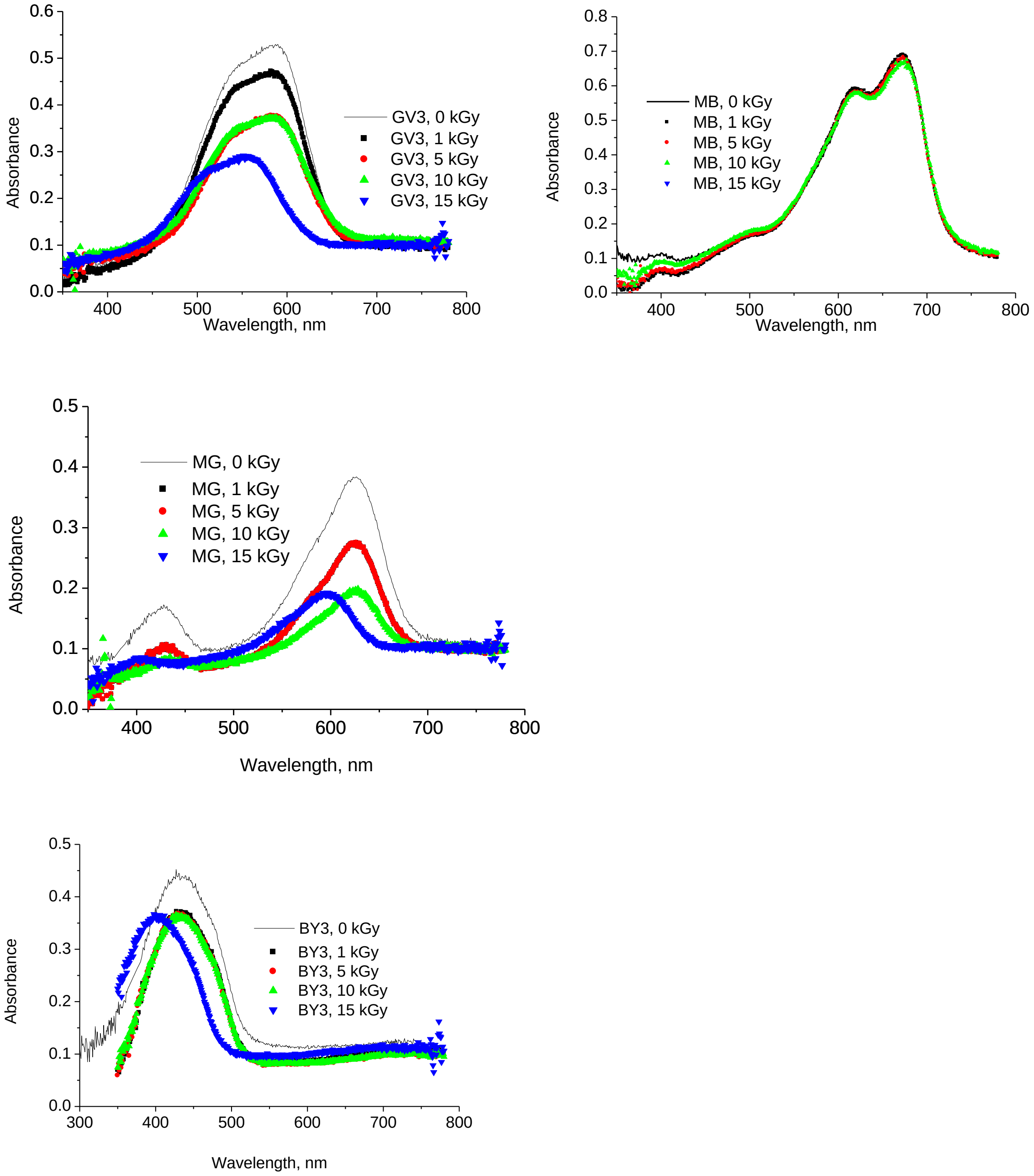
$$if\,(U' > 0.0031308),\quad U' = 1.055 \times (U'\wedge(1/\ 2.4)) - 0.055\ \ \text{else}\ U' = 12.92 \times U'$$

$$U = U' \times 255$$

The RGB values calculated from XYZ tristimulus values were used to display the colour palette. The colour given in the palette may differ from the original colour of the compound, as RGB colour space is not equivalent to human perception but is used for simplification of data.

3.0 Results and Discussion

The diffuse reflectance spectra obtained for the various dyes at different doses are shown in Fig. 2.



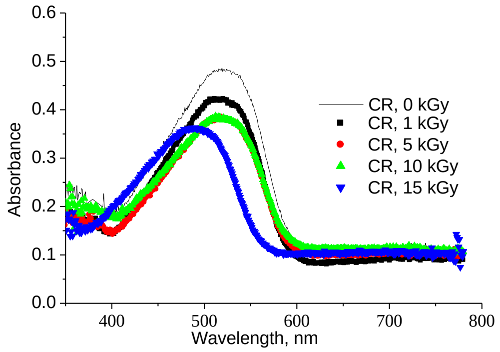


Fig.2 Reflectance spectra of GV, MB, MG, BY and CR strips dyed with 2.5×10^{-3} % w/v solution with respective dyes / indicators

The representative values for various colour parameters such as tristimulus value, CIE L*a*b* values, colour difference, ΔE^*_{ab} , dominant wavelength, Yellowness index as well as difference of yellowness indices, ΔYI for CR3 is given in Table -1.

Table-1 Various colour parameter for CR3.

Colour Parameters	**CR 3, 0 kGy**	**CR 3, 1 kGy**	**CR 3, 5 kGy**	**CR 3, 10 kGy**	**CR 3, 15 kGy**
Tristimulus value	59.2766 49.9165 51.8225	59.5854 50.0836 51.0229	70.0332 60.7803 61.2915	65.4622 55.6948 54.3643	64.0385 57.2344 59.5783
CIE L*a*b*	76.018 30.5535 2.5071	76.1206 30.852 3.4913	82.2605 28.0634 4.2866	79.4398 30.1747 5.8945	80.3113 23.1936 2.479
Dominant Wavelength (nm)	495.64	495.1	494.4	493.78	495.16
ΔE^*_{ab}		1.033576	6.952411	4.829771	8.520642
YI	36.5133	39.0007	35.3072	41.9701	27.2907
ΔYI		2.4874	-1.2061	5.4568	-9.2226
RGB & colour palette	243 166 184	244 166 182	258 185 198	254 176 187	243 184 195

It is expected that with increase in dose the colour intensity of the dye impregnated strips would tend to decrease as higher energy tends to increase radiolysis of the dyes. This is evident from the diffuse reflectance spectra of the five dyes as shown in Fig. 2. The absorbance at absorption maxima tends to decrease with increasing dose. However, the decrease in colour intensity seems to be negligible between 0 to 10 kGy. Thus it is very difficult to find a relationship between dose and absorbance. So, colour analysis is done to investigate the relation between dose and colour intensity.

CIE L*a*b* values are computed from tristimulus values as they are near to the colour perceived by human eyes. CIE L*a*b* values does show decrease or increase in one of the chromaticity coordinates with increasing dose depending on the colour for instance, incase of CR, a* values changes from 30 to 23 which indicates decrease in red hue and so on. However, it is difficult to establish any linear relationship with change in the co-ordinate values and dose. So, the most common colour difference, ΔE^*_{ab} is investigated.

The colour difference shows quite good response with dose upto 10 kGy beyond which there is marked deviation as is evident from the R-value. The R-value obtained is 0.9524 and 0.9946 for GV3 and BY3 respectively upto 10 kGy. Beyond which the R-value decreases showing non-linearity in the response. This deviation is reflected in dominant wavelength, which generally indicates the hue as shown in Table-5. This is also evident from the change in RGB colour palaette shown in Table-6. The observation is further supported by the diffuse reflectance spectra as shown in Fig. 2.

Fig. 2 depicts shift in absorption maxima for diffuse reflectance spectra with increasing γ-dose (15 kGy) with almost all the dyes which may be attributed to yellowing of paper due to γ radiation. Gamma-radiation is known to cause depolymerization in polymeric chain (cellulose as well as polyethylene) initiating free radical formation (Adamo et. al., 1988; Kömmling, 2017). This induces yellowness in the paper substrate which hampers lightness of the paper (L*) and chromaticity coordinate (b*) shifts to yellow from blue. This consequently affects the colour estimation of the strips. The colour degradation occurs due to γ-radiation reducing the colour intensity however beyond 10 kGy there is severe interference due to yellowing of the paper.

The non-linearity of the ΔE_{ab}^{*} at 15 kGy could be attributed to yellowing of paper due to γ radiations which is evident from increase in ΔYI.

The relation between the gamma dose and ΔYI and ΔW for four different concentrations of BY, GV, MB, MG, CR is given is Table-3 and 4. It is observed that ΔYI shows good correlation in assessing radiation induced decolouration for BY (R= 0.9769), GV (0.9585) and CR (0.9860) upto 10 kGy whereas ΔW incase of MB (R= 0.9999) and MG (R= 1). It is observed that for decolouration of dyes having blue or green hue can be better assessed using whiteness index which is quite evident from the definition of the latter.

4.0 Conclusion

It may thus be concluded that dye strips were effective upto dose of 10 kGy and ΔE_{ab}^{*} may be used as a tool to assess radiation damage. Out of all the dye investigated BY is found to be the most suitable probably could be due to its hue. However, if yellowing of paper due to γ radiation could be avoided then higher dosages could also be studied. This can be achieved by chemical modification of the paper. The analysis done by CIE L*a*b* coordinates which is device independent system, with advent of electronics and software, this system can be easily integrated to form a cheap technology for dose detection.

5.0 Acknowledgement

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6.0 CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

7.0 FUNDING

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8.0 AUTHOR CONTRIBUTIONS STATEMENTS

This is to certify that all the three cuthors have contributed jointly to the paper. The main manuscript was written by I. B . Das Sarma and D. V. Parwate. The data analysis was jointly done by I. B. Das Sarma, D. V. Parwate and D. S. Bhowmick. The figures and data tables (1-6) were prepared by D. S. Bhowmick. All the authors reviewed the manuscript.

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Table 2- ΔE^*_{ab} values as function of dose for various concentrations of BY, GV, MB, MG and CR. Correlation coefficient, R was computed from R^2 value obtained on plotting the ΔE^*_{ab} against dose upto10 kGy.

Dose, kGy	BY1	BY2	BY3	BY4	GV1	GV2	GV3	GV4	MB1	MB2	MB3	MB4
1	1.080	0.500	2.174	4.538	4.221	2.127	3.806	3.952	1.881	1.555	2.441	4.296
5	4.871	5.280	5.128	6.445	12.629	20.949	15.537	21.299	5.202	4.381	2.738	2.970
10	6.269	8.255	7.699	5.199	14.053	20.355	20.159	17.309	0.917	1.569	1.961	5.583
15	1.492	0.932	3.137	5.679	15.199	27.388	34.949	35.405	5.364	4.880	4.856	3.142
R^2	**0.8985**	**0.9615**	**0.9892**	**0.0786**	**0.8082**	**0.6667**	**0.9070**	**0.4763**	**0.0764**	**0.0035**	**0.4373**	**0.2996**
R	**0.9479**	**0.9806**	**0.9946**	**0.2804**	**0.8990**	**0.8165**	**0.9524**	**0.6901**	**0.2764**	**0.0592**	**0.6613**	**0.5474**

Dose, kGy	MG1	MG2	MG3	MG4	CR1	CR2	CR3	CR4
1	6.873	6.084	4.599	8.277	0.890	1.684	1.034	1.722
5	10.960	13.831	17.326	17.243	4.993	5.150	6.952	5.259
10	8.362	10.964	14.214	12.647	4.007	3.891	4.830	3.440

15	7.449	12.664	17.708	18.748	4.623	7.989	8.521	5.416
R^2	**0.0897**	**0.3267**	**0.4611**	**0.3267**	**0.3389**	**0.3340**	**0.4655**	**0.1837**
R	**0.2995**	**0.5716**	**0.6790**	**0.5716**	**0.5822**	**0.5779**	**0.6823**	**0.4286**

Table 3- ΔYI values as function of dose for various concentrations of BY, GV, MB, MG and CR. Correlation coefficient, R was computed from R^2 value obtained on plotting the ΔYI against dose upto10 kGy.

Dose, kGy	BY1	BY2	BY3	BY4	GV1	GV2	GV3	GV4	MB1	MB2	MB3	MB4
1	1.194	0.842	2.110	6.301	-6.867	-5.103	-10.487	-12.217	3.772	3.149	6.720	12.866
5	1.158	-1.827	1.788	5.392	-17.550	-35.556	-36.897	-57.858	-1.775	-3.638	1.027	6.515
10	-7.261	-9.764	-8.226	-0.994	-20.145	-36.780	-48.310	-49.078	-0.381	-0.080	0.518	10.901
15	2.369	1.467	4.578	7.919	-22.890	-44.991	-68.944	-85.430	-8.328	-9.983	-12.649	-10.627
R	**0.8979**	**0.9769**	**0.9081**	**0.9411**	**0.9202**	**0.8506**	**0.9585**	**0.7179**	**0.6736**	**0.4183**	**0.8709**	**0.2406**

Dose, kGy	MG1	MG2	MG3	MG4	CR1	CR2	CR3	CR4
1	-11.504	-8.618	-7.070	-13.521	0.335	1.038	2.487	2.773
5	-14.410	-19.916	-27.468	-27.785	-1.227	-0.578	-1.206	-1.934
10	-15.885	-17.936	-25.334	-24.882	-7.158	-4.433	5.457	-7.402
15	-13.798	-19.724	-30.086	-31.861	2.063	7.053	-9.223	5.890
R	**0.9688**	**0.7300**	**0.7757**	**0.7099**	**0.9662**	**0.9860**	**0.5012**	**0.9860**

Table 4- ΔW values as function of dose for various concentrations of BY, GV, MB, MG and CR. Correlation coefficient, R was computed from R^2 value obtained on plotting the ΔW against dose upto10 kGy.

Dose, kGy	BY1	BY2	BY3	BY4	GV1	GV2	GV3	GV4	MB1	MB2	MB3	MB4
1	-5.378	-2.355	-11.227	-25.205	13.280	7.521	14.596	14.571	-9.512	-5.548	-11.215	-17.683
5	-14.496	-3.721	-16.441	-30.930	27.011	56.468	50.643	73.488	-8.856	-3.170	-6.882	-12.502
10	13.526	21.938	18.084	-10.501	33.287	65.554	76.167	64.873	1.201	-1.362	-1.739	-13.295
15	-7.471	-4.106	-17.811	-29.274	45.141	78.758	113.844	124.650	5.150	11.007	15.128	13.282
R	**0.7080**	**0.8743**	**0.8253**	**0.7421**	**0.9621**	**0.9040**	**0.9869**	**0.7495**	**0.9191**	**0.9898**	**0.9999**	**0.7451**

Dose, kGy	MG1	MG2	MG3	MG4	CR1	CR2	CR3	CR4
1	9.882	4.378	4.184	10.148	1.058	-0.602	4.793	-2.590
5	3.591	8.672	16.850	17.814	-2.333	-0.517	-2.885	5.409
10	18.647	13.445	22.324	27.455	11.151	10.267	10.486	17.908
15	16.586	14.253	25.310	27.029	2.154	-3.759	-7.570	-0.015

R	**0.6306**	**0.9994**	**0.9585**	**1.0000**	**0.7625**	**0.8993**	**0.4812**	**0.9981**

Table 5- Dominant wavelength as function of dose for various concentrations of BY, GV, MB, MG and CR.

Dose, kGy	BY1	BY2	BY3	BY4	GV1	GV2	GV3	GV4	MB1	MB2	MB3	MB4
0	570.1	570.8	571.7	572.7	456.3	447.5	437.7	566.1	487.1	486.0	484.7	482.4
1	569.8	570.6	571.5	572.2	458.0	445.1	436.2	566.1	486.1	485.5	483.9	481.4
5	569.8	570.7	571.4	572.1	460.8	456.1	430.6	566.2	486.8	485.9	484.3	481.9
10	571.1	571.9	572.7	573.3	461.8	456.7	421.1	566.2	486.8	485.5	484.0	481.3
15	569.7	570.5	571.3	572.0	469.9	467.0	459.1	432.0	485.9	485.5	484.3	482.1

Dose, kGy	MG1	MG2	MG3	MG4	CR1	CR2	CR3	CR4
0	486.2	488.0	487.8	488.0	501.1	497.5	495.6	494.1
1	480.7	486.1	487.1	486.9	500.9	497.3	495.1	494.1
5	480.6	484.1	488.0	488.2	498.3	495.9	494.4	658.2
10	482.7	490.4	490.3	490.1	495.6	494.9	493.8	647.3
15	476.8	477.3	480.9	481.5	500.0	497.1	495.2	493.5

Table 6- RGB Colour palettes as function of dose for various concentrations of BY, GV, MB, MG and CR.

Dose, kGy	BY1	BY2	BY3	BY4	GV1	GV2	GV3	GV4	MB1	MB2	MB3	MB4
0	230 231 206	230 229 189	230 225 163	233 222 138	208 203 237	189 179 232	175 155 229	161 126 218	177 221 231	149 213 233	119 199 229	86 177 220
1	232 233 209	230 230 190	235 231 170	235 227 151	212 209 236	193 182 232	178 160 228	163 131 217	177 222 236	147 211 233	115 197 230	80 171 220
5	244 245 220	244 243 197	244 240 176	248 240 158	229 228 245	221 218 241	198 183 236	185 163 227	192 235 247	163 225 244	125 206 238	87 181 229
10	243 241 206	245 240 185	245 234 160	250 235 147	230 229 242	212 210 231	193 181 223	171 149 215	176 218 230	151 212 232	122 196 227	81 165 213
15	230 231 209	229 229 190	231 228 172	232 225 152	224 226 234	224 224 236	211 209 230	190 179 220	196 225 235	167 215 232	140 201 228	101 177 217

Dose, kGy	MG1	MG2	MG3	MG4	CR1	CR2	CR3	CR4
0	203 225 233	186 223 230	165 217 227	160 216 226	240 202 216	244 184 201	243 166 184	243 146 163
1	226 231 235	207 227 234	182 221 230	190 222 231	238 202 215	245 187 203	244 166 182	244 150 166
5	243 246 248	236 242 245	230 242 245	225 240 243	251 215 226	255 197 210	255 185 198	255 159 170
10	229	225	217	205	250	250	254	245

	231 233	238 239	236 237	227 229	207 216	191 202	176 187	146 157
15	225 227 230	228 231 235	226 230 235	225 230 234	236 208 217	240 197 208	243 184 195	242 156 167