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Assessing the effect of salinity on the oil quality parameters of Indian mustard (*Brassica juncea* L. *Czern & Coss*) using Fourier Transform Near-Infrared Reflectance (FT-NIR) spectroscopy

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SUMMARY: Calibration models were developed for Fourier Transform Near Infrared Reflectance spectroscopy using PLS method and coefficients of determination (r^2) for oil, protein, erucic acid and crude fiber contents were estimated 0.907, 0.922, 0.902, 0.903, respectively. Effects of the salinity on these traits were studied under normal and saline environments in the field (ECe 10.7dS·m^{-1}) and nethouse using saline irrigation levels (EC_{iw} 0, 9, 12, 15, 18 dS/m) during 2011–12 and 2012–13. At higher salinity; oil, protein and crude fiber contents decreased by 7.27, 14.78, 34.25% and 5.78, 29.31, 20.45% in nethouse and field conditions respectively, whereas erucic acid content increased by 72.43 and 12.20%. Thus, FT-NIRS may be useful for quick and nondestructive estimations of oil quality parameters in Indian mustard.

KEYWORDS: *Brassica juncea; Erucic acid; Oil; Protein; Quality; Salinity*

RESUMEN: ***Efecto de la salinidad sobre parámetros de calidad del aceite de mostaza india (Brassica juncea L. Czern & Coss) utilizando espectroscopía de Transformada de Fourier de reflectancia en el infrarrojo cercano (FT - NIR)***. Se han desarrollado modelos de calibración, con espectroscopía de reflectancia en el infrarrojo cercano, mediante transformada de Fourier utilizando el método PLS; los coeficientes de determinación (r^2) para el aceite, proteína, ácido erúcico y contenidos de fibra bruta se estimaron en: 0,907, 0,922, 0,902, 0,903, respectivamente. Se ha estudiado durante 2011–12 y 2012–13 el efecto de la salinidad sobre las características estudiadas, en entornos normales y salinos en el campo (ECe 10.7dS·m^{-1}) y en condiciones controladas bajo irrigación salina (EC_{iw} 0, 9, 12, 15 y 18 dSm^{-1}). Con altos niveles de salinidad los contenidos de aceite, proteína y fibra cruda se redujeron a 7,27, 14,78, 34,25 % and 5,78, 29,31, 20,45 % en el estudio controlado y en condiciones de campo respectivamente, mientras que el contenido de ácido erúcico incrementó a 72,43 y 12,20 %. Por lo tanto, FT-NIRS puede ser de gran utilidad para las estimaciones rápidas y no destructivas de los parámetros de calidad del aceite de mostaza de la India.

PALABRAS CLAVE: *Aceite; Ácido erúcico; Brassica juncea; Calidad; Fibra cruda; Proteína; Salinidad*

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1. INTRODUCTION

Around the globe, a 932.2 million hectare area is affected with salinity and sodicity stresses (Metternicht and Zinck, 2003), out of which, an area of nearly 6.73 million hectare is affected by these stresses in India. Further, the arid and semi-arid areas in different states are associated with underground saline water, which have to be used for irrigation, due to the unavailability or diversion of good quality water to other than agricultural purposes. The use of such water is further rendering the soils unfit for crop cultivation. Rapeseed mustard is the third most important source of vegetable oil in the world and is grown in more than 50 countries across the globe. China, Canada, India, Germany, France, UK, Australia, Poland and USA are the major cultivators of its different species of *Brassica*. During 2012–2013, the estimated area, production and yield of rapeseed mustard in the world was 30.74 mha, 60.43 mt and 1.95 tonnes/ha, respectively. Globally, India accounts for 21.7% area and 10.7% production (USDA 2013). *Brassica rapa*, *B. napus* and *B. juncea* are grown predominantly for oil and seed meal. India is the second largest country in rapeseed mustard production and more than 85% of its area under rapeseed mustard is occupied by Indian mustard *B. juncea* (L.) alone, because, compared to the more widely grown *brassica* species *B. napus* and *B. rapa*, *B. juncea* is more tolerant to heat and drought stress, has high yield potential and wide adaptability. The species does not shatter as readily as *B. napus* and so it can be straight cut or swathed and combined.

Salinity affects the growth and development of brassica juncea in various ways. The most common adverse effects of salinity on *Brassica* are the reduction in plant height, size and yield as well as deterioration of the product quality (Zamani *et al.*, 2011). Soil salinity markedly affected the lipid components of mustard seeds (*Brassica juncea*). With increasing salt levels, total and neutral lipids declined considerably, while phospholipids and glycolipids increased. The fatty acid profiles of total, neutral and polar lipid fractions were affected substantially. Erucic acid in total and neutral lipids decreased, while it was absent in the polar lipid fraction. In total and neutral lipids, oleic and linoleic acids increased. The amounts of linoleic and linolenic acids in the polar lipid fraction increased with rising salinity. Plant dry weight drastically declined at higher salinity levels (ECe 8 and 12) whereas the maximum weight was observed at ECe 4 (Parti *et al.*, 2003). Brassica cultivars showed comparatively lower percentages of oil content in seeds under saline sodic soil conditions (Ece=13.02 dS m and SAR=12.70). It might be due to an excessive absorption of toxic ions disturbing metabolic processes. Furthermore, nutritional imbalance as a result of depressed uptake of nutrients, shoot transport, chlorophyll breakdown and impaired distribution of mineral ions retarded the development of seeds and early maturity of plants under high salinity treatments might be responsible for the reduced oil content (Ali *et al.*, 2013, Mahmood *et al.*, 2007).

In addition to a decrease in the mobilization of photosynthates towards developing siliqua, salinity also adversely affects the deposition of lipids. Fatty acid composition has revealed that erucic acid decreased marginally and this reduction was accompanied by an increase in linolenic acid and eicosenoic acid (Sharma and Manchanda, 1997, Sureena *et al.*, 1999).

The irrigation of mustard with saline water (3500 ppm) raised the values of erucic acid followed by oleic acid to 40.98 and 20.49% respectively, as compared to 30.82 and 15.59% in the controlled treatment (Abd El-Wahab, 2013).

Improved genotypes of mustard with tolerance to high salt along with consumer acceptance and good oil quality are required for obtaining optimum yield and expansion of the cultivated area under such stress situation. These concerns prompted an intensive breeding program to develop high yielding cultivars with salinity tolerance at the Central Soil Salinity Research Institute (CSSRI).

CSSRI has developed three high yielding salt tolerant varieties of Indian mustard (*Brassica juncea*) i.e. CS 52, CS 54 and CS 56. Further, information on the effect of salinity on the oil quality, nutritional and anti-nutritional make-up of mustard oil would be quite useful for the breeders in the quality improvement programme to make this crop globally competitive.

Indian mustard varieties exhibit quite high contents of erucic acid in oil (more than 40%) (Chauhan *et al.*, 2007). A high amount of erucic acid in edible oils has been reported to impair myocardial conductance, causes lipidosis in children and increases blood cholesterol (Ackman *et al.*, 1977). Because of the adverse effects of high erucic acid in the oil of Indian mustard varieties, the varietal improvement programme in India aims at reducing the erucic acid level up to internationally accepted norms (less than 2%) which necessitates the screening of a large number of samples with limited seed availability especially in potential germ plasm.

In addition, the high fiber content (12–13%) in the seed meal reflects lower values of metabolizable energy and may negatively influence protein digestibility and the bioavailability of minerals such as magnesium and zinc (Simbaya *et al.*, 1995; Ahuja and Bajaj, 1999; Chauhan *et al.*, 2002).

In order to utilize or develop genotypes with high contents of oil and protein and low contents of fiber and erucic acid, a rapid and reliable screening of existing genotypes is required.

Plant breeding programs usually involve extensive evaluations of the quality components of interest. Thus, large numbers of screenings by the standard analytical methods of seed lines are usually performed in order to detect target genotypes. Currently, chemical analytical methods are generally used to estimate oil, erucic acid, protein and crude fiber contents. Although the standard analytical techniques usually offer a high level of accuracy and precision, these methods are expensive, time consuming, and require the destruction of seed samples which could be a handicap in the case of valuable and scarce materials.

In recent decades, the development of low cost, non-destructive, high output equipments featuring improved electronic and optical components, the advent of computers capable of effectively processing information contained in spectra and the development of powerful chemo-metric applications has facilitated the expansion of spectroscopic techniques in an increasing number of fields, allowing for an efficient management of spectral and chemical data. The screenings of materials and applications of such selection techniques would increase breeding efficiency.

Newer technological advances have brought about a rapid, lower cost analytical technique called Fourier Transform Near Infrared Reflectance (FT-NIR) spectroscopy. The use of FT-NIR spectroscopy has already been reported for the non-destructive screening of oil, fatty acids, protein, amino acid, and individual and total glucosinolate contents of rapeseed mustard seeds (Petisco *et al.*, 2010; Chen *et al.*, 2011) in large breeding populations.

Moreover, FT-NIR spectroscopy is a fast, accurate, and non-destructive technique which requires minimal or no sample preparation and can be used as a replacement of conventional time-consuming chemical methods. It is also interesting to note that NIRS does not require the use of solvents, thus is environmentally friendly, which is currently a major concern. To date, no attempt has been made to assess the impact of salinity on oil quality parameters for mustard on intact seeds by FT-NIR spectroscopy.

Keeping in view the potential advantages of NIRS over chemical methods, the present study was undertaken to develop calibration models and to assess their application in estimating the effects of salinity on oil quality parameters of Indian mustard genotypes and to explore its applicability in identifying variability for these traits.

2. MATERIALS AND METHODS

The experiment was conducted at the Research Farm Karnal (Non-saline field) and out station experimental farm, Nain (Saline field) of the Central Soil Salinity Research Institute (CSSRI), during *Rabi* 2011–12 and 2012–13. The experimental materials for the present investigation consisted of 97 salt tolerant Advance Breeding germ plasm lines of the Indian mustard developed by CSSRI.

All the materials were evaluated in a randomized block design with three replicates in two environments *viz.* normal (*p*H=7.6 and ECe 3.9 dSm^{-1}) and saline (*p*H=8.3 and ECe=10.7 dSm^{-1}) and irrigated with water having pH=7.7 and EC_{iw} 3.8 dSm^{-1} at both Research farms; Karnal and Nain. The salinity of the saline soil is above the threshold limit for mustard under field condition ECe 8.2 dSm^{-1} reported by Minhas and Gupta (1992). The seed analysis for oil, protein, erucic acid and crude fiber content was conducted using a pre-standardized Fourier Transform Near Infrared Reflectance Spectrometer (FT-NIR, Perkin Elmer, Massachusetts, USA). Further, the best performing advanced breeding lines out of 97 along with national check (CS 54) for salinity evaluation trials were evaluated under controlled condition in pots in the laboratory.

The plants were grown in 20 kg capacity plastic pots in sand culture and irrigated with five levels of salinity (EC_{iw} 0, 9, 12, 15 and 18 dSm^{-1}) throughout the experiment during 2011–12 and 2012–13. Saline irrigation water was prepared by adding NaCl, $CaCl_2$ and Na_2SO_4 and maintaining Na: Ca and Cl: SO_4 ratio as 4:1 respectively. The pots were arranged in a factorial experiment based on a completely randomized block design (CRBD) with 4 replicates. The seeds were surface-sterilized for 5 minutes in 10% sodium hypochloride solution and then rinsed with distilled water. Five seeds of each genotype were sown at 1 cm depth in each plastic pot (20 Kg capacity) filled with thoroughly washed river sand. The bottom of each pot was delved for drainage of extra water. The pots were irrigated with a nutrient solution (Hoagland's solution) and maintained at full strength field capacity till germination. After germination, the number of plants was reduced to two seedlings per pot. Salinity stress was imposed at the four leaf stage and different levels of salinity were achieved by step-wise addition of saline solution to each pot so as to avoid shock. Thereafter, the salinity levels were maintained throughout the experiment by flushing the salt daily from the pots. At harvest seed yield was recorded. The whole seeds obtained were subjected to the above mentioned analysis using FT-NIR.

2.1. NIRS calibration

Sixty-nine seed samples of mustard genotypes were obtained from the Indian Agricultural Research Institute, New Delhi, Directorate of Rapeseed and Mustard Research, Bharatpur and Punjab Agricultural University, Ludhiana, India during 2012–13. These samples were pre-analyzed in the laboratory for oil, protein, erucic acid and crude fiber

contents with chemical methods. The oil content (%) was estimated using nuclear magnetic resonance (NMR), according to the protocol of the AOCS (1980). The protein content (%) was estimated by determining the nitrogen content using Kjeldahl's analysis. Protein content was estimated by multiplying h a factor 6.25 (AOAC, 1990). The erucic acid content was determined through gas-liquid chromatograph (Nucon Model 5765) equipped with SP 2300+2310 SS column. Crude fiber content (%) in seed meal was estimated using modified AOAC method (Ahuja and Bajaj, 1999).

All the samples were representing the spectral and chemical variability in the mustard in the calibration and validation groups used for preparation of the library and standardization of FT-NIR.

Seed samples were analyzed as intact and NIR spectra were recorded in reflectance mode using an FT-NIR spectrometer (Perkin Elmer, Massachusetts, USA) equipped with an integrative sphere, over the range of 10000 - 4000 cm^{-1} at 1 nm interval. The seeds were then stored. The spectrum of each sample was the average of 32 scans. Spectrum10 software (Perkin Elmer, Massachusetts, USA) was used for spectral acquisition and instrumental control.

Data pre-treatment using mathematical transformations (e.g. derivatives, multiple scatter correction, smoothing) of the NIR spectra was applied to enhance spectral features and/or remove or reduce unwanted sources of variation. The spectral data sets were correlated with oil, protein, erucic acid and crude fiber content using partial least squares (PLS) regression algorithm. Calibrations were performed using Spectrum Quant+ software (v.4 60). To evaluate the calibration performance of the developed models, a cross validation was used and also a test set validation was performed using coefficients of determination (r^2). The precision of calibration is represented by the standard error of estimation (SEE) and the standard error of prediction (SEP). Consistency, which is the ratio of the SEE and SEP, should be as close as possible to 100. The consistency is used to ensure that the number of factors selected for developing the best calibration model is optimum. The coefficient of determination (r^2) expresses the relationship between the measured and the predicted values and describes the quality of quantitative calibration. The coefficient of determination (r^2) shows the proportion of the variance in reference data that can be explained by the variance in the predicted data. When the value of r^2 is higher than 0.83, the robustness of the prediction of calibration model is maintained. The relative prediction deviation (RPD) is a ratio of SEP to SD of the reference values in the validation set. RPD was used to verify the accuracy of the calibration models developed. The higher the value of the RPD the greater the probability of the model to predict the chemical composition in samples set accurately. An RPD value range between 2.4 and 3.0 is considered poor and the models could be applied only for very rough screening, while an RPD value greater than three (range 3.1–4.9) and greater than five (range 5–6.4) could be considered fair and recommended for screening purposes and good for quality control, respectively (Williams and Norris, 2002).

2.2. Statistical analysis

The mean, standard deviation and coefficient of variability for different characters among quality characters were worked out following SAS 9.2 software.

3. RESULTS AND DISCUSSION

3.1. Calibration for oil, protein, erucic acid and crude fiber content

During the process of development of the calibration model and its validation, a certain number of samples was excluded in order to obtain the most reliable model possible. Therefore, the number of samples used for developing calibration (Table 1) was lower than the initial number of samples. To develop the calibration models, initially calibration was started with a group of 69 samples selected according to their spectral variability to make up the calibration set. To detect outliers, Student's residual and leverage values plot were analyzed as suggested by Hein *et al.* (2009). Four outliers were detected for oil content, 7 for erucic acid, one for protein content and none of the outliers was detected for crude fiber contents. Samples classified as outliers were not included in the model calibration or validation phase. When validation was done using 57 samples, the efficiency of models for the quality parameter/traits studied was an average RPD value ranging from 2.0 to 2.4. In order to obtain the best results, the data was pre-processed with standard normal variate (SNV) and straight line subtraction. A cut-off of H=0.8 was used, resulting in the selection of a set of 32 samples constituting an actual representative and used for validation. These spectral data sets were correlated with oil, protein, erucic acid and crude fiber content by using partial least squares (PLS) regression algorithm.

The results of the statistics related to the PLS calibration model using full cross validation obtained by FT-NIR technology for the oil, protein, erucic acid and crude fiber contents are shown in (Table 1).

The equations developed for *Brassica* seeds showed sufficient accuracy for using this technique as a valuable tool for the analysis of these components [Table 1 (adapted and modified from Singh *et al.*, 2013)]. The r^2 shown by the equations for oil content (0.907), protein content (0.922), erucic acid

Table 1. Calibration and validation statics in FT-NIR models for the estimation of oil, protein, erucic acid and crude fibers content in mustard

	Oil %		Protein %		Erucic acid %		Crude fiber %	
Statistics	**Calibration**	**Validation**	**Calibration**	**Validation**	**Calibration**	**Validation**	**Calibration**	**Validation**
No. Sample	69	32	69	32	69	32	69	32
Mean	39.24	39.20	19.45	19.30	39.61	39.10	10.91	10.50
Range	37.0–41.5	37.1–41.3	17.6–20.2	17.0–20.0	0.0–57.30	0.02–57.0	6.3–16.7	6.1–17.1
SD	4.720	4.750	3.200	3.100	3.720	3.720	2.040	2.100
CV	12.029	12.117	16.452	16.062	9.392	9.514	18.698	20.000
r^2	0.900	0.907 (Y=0.290x+ 27.82)	0.910	0.922 (Y=0.607x+ 7.711)	0.910	0.902 (Y=0.869x+ 3.402)	0.910	0.903 (Y=0.235x+ 7.835)
SEE	0.70	–	0.50	–	0.73	–	0.36	–
SEP	–	1.01	–	0.68	–	0.80	–	0.43
RPD		4.67		4.71		4.65		4.74

SD: Standard deviation, CV: Coefficient of variation, r^2 Coefficient of determination, SEE: Standard error of estimation or calibration, SEP: Standard error of performance or cross validation, RPD: Relative prediction deviation.

content (0.902) and crude fiber (0.903) determinations in mustard seeds indicated excellent quantitative information (Shenk and Westerhaus, 1996). On the other hand, on the basis of the statistics RPD, these equations were higher than 3, thus being useful for screening (Williams and Sobering, 1996; Williams and Norris, 1987; Daun *et al.*, 1994; Williams and Norris, 2002).

3.2. Effects of salinity on quality parameters

3.2.1. Analysis of variance

The analysis of variance for both field as well as pot study showed significant mean squares of genotypes for oil, protein erucic acid and crude fiber content, indicating significant differences among the genotypes. Significant mean squares of salinity for all studied traits indicated differences among salinity levels and its influence on these traits. The interaction effects of salinity levels and genotypes were significant for all the traits, indicating the different trend of variations among the genotypes at different salinity levels (Table 2). In addition, the genotypes followed a similar pattern of performance in both cropping seasons (2011–12 and 2012–13) as the mean sum of squares due to year, year × salinity and year × genotype were non-significant for these traits. Therefore, the effect of salinity on quality characteristics was pooled over the two years.

3.2.2. Oil content

The mean seed oil content showed a range of 36.92–39.81% and 36.13–38.34% in the field experimentats and control conditions (pots), respectively and was less variable as seen by the relatively lower values for coefficients of variability (CV= 1.40% in field and 0.70% in pot). With the increase in salinity to ECe 10.7 dSm^{-1} under field conditions, the seed oil content decreased by 7.27%, whereas, the oil content decreased by 5.78% at ECe 18 dSm^{-1} under control conditions (Table 3). The reduction in seed oil content might be due to an increase in the osmotic pressure of the soil solution and imbalances in nutrients and essential elements (Toorchi *et al.* 2011) or the retarded development of seed and early maturity of plants in high salinity treatments (Boern *et al.*, 1997; Flagella *et al.*, 2004; Cucci *et al.*, 2007).

3.2.3. Protein and Crude fiber content

The protein content was more variable, as seen by relatively high coefficients of variability (CV=2.10%) in pot condition and less variable in field condition (CV=4.0%) than the crude fiber content (CV=0.90% in pot and 9.40% in field). Protein and crude fiber contents decreased by 29.31% and 34.25% in pots and 14.78% and 20.45% in field conditions, respectively, at high salinity levels (Table 3). The reduction in the protein content may be due to a failure of the plants to make full use of nitrogen compounds. The accumulation of nitrogen compounds is more rapid than their utilization in building more cells and organs (Olfa *et al.*, 2009).

3.2.4 Erucic acid

The mean erucic acid among the varieties did not vary over the cropping seasons in the pot experiment (CV=0.60%) but in the field study, it was more variable than oil and protein contents (CV=5.30%). It

Table 2. Pooled ANOVA of experiments conducted during 2011–12 and 2012–13

		df		Mean Sum of Square	
Source	**Variable**	**Pot**	**Field**	**Pot**	**Field**
Replication	Oil%	3	2	0.05	0.72
	Protein%			0.12	1.31
	Erucic acid%			0.01	11.95
	Crude fiber%			0.01	2.24
Genotype	Oil%	1	96	1.06*	0.40*
	Protein%			0.58*	0.82**
	Erucic acid%			1.06*	38.09**
	Crude fiber%			0.82*	5.01**
Salinity	Oil%	4	1	13.44**	2434.05**
	Protein%			86.59**	2374.95**
	Erucic acid%			1021.12**	5923.16**
	Crude fiber%			32.81**	1650.39**
Year	Oil%	1	1	0.02	0.10
	Protein%			0.05	0.19
	Erucic acid%			0.90	2.73
	Crude fiber%			0.01	0.46
Genotype * Salinity	Oil%	4	96	4.15*	12.57*
	Protein%			2.33*	6.94*
	Erucic acid%			4.23*	28.94*
	Crude fiber%			3.65*	45.56*
Genotype * Year	Oil%	1	96	0.94	0.13
	Protein%			0.01	0.31
	Erucic acid%			0.09	2.73
	Crude fiber%			0.02	0.46
Salinity * Year	Oil%	4	1	0.40	5.03
	Protein%			0.61	3.93
	Erucic acid%			0.14	17.48
	Crude fiber%			0.03	0.01
Genotype * Salinity * Year	Oil%	4	96	0.63*	8.25**
	Protein%			0.36*	4.76**
	Erucic acid%			0.62*	20.55**
	Crude fiber%			0.56*	32.57**
Error	Oil%	60	776	0.25	0.30
	Protein%			0.13	0.52
	Erucic acid%			0.24	4.35
	Crude fiber%			0.21	1.00

*, ** Significant at 5% and 1% levels respectively.

ranged from 27.04%–46.62% and 36.93%–41.47% in pot and field experiments, respectively. The erucic acid content increased by 72.43% in the pots at ECiw 18 dSm^{-1} compared to the non-saline control; whereas, it increased by 12.20% in the field at a high salinity level of ECe 10.70 dSm^{-1} (Table 3). Increasing erucic acid content with higher salinity may be due to changes in the fatty acids and the ratio of the unsaturated/ saturated in brassica (Wu *et al.*, 2005; Mansour and Salama, 2004; Baldini *et al.*, 2002). In addition, under conditions of salt stress, fatty acid contents increased compared with normal conditions probably due to the involvement of some fatty acids in cell wall stability. These fatty acids increase the activity of some of the involved enzymes in salt stress resistance. Different compositions of

Table 3. Summary of the effects of salinity on quality parameters of mustard

Variate	Range over the salinity	Mean over year and salinity	SD	CV%	% decrease or increase over control			
					9 dS·m^{-1}	12 dS·m^{-1}	15 dS·m^{-1}	18 dS·m^{-1}
Pot condition (Salinity levels: control (0), 9, 12, 15 and 18 dS·m^{-1})								
Oil%	36.13–38.34	37.62	0.27	0.70	0.15	–1.82	–2.02	–5.78
Protein%	13.63–19.29	17.19	0.36	2.10	–2.57	–6.06	–16.46	–29.31
Erucic acid%	27.04–46.62	34.46	0.21	0.60	6.08	18.14	40.59	72.43
Crude fiber%	6.00–9.13	8.03	0.07	0.90	–0.16	–2.55	–22.81	–34.25
Field condition [Salinity levels: control (2.0 dSm^{-1}) and 10.70 dS·m^{-1}]								
Oil%	36.92–39.81	38.37	0.54	1.40	–7.27			
Protein%	16.50–19.35	17.92	0.72	4.00	–14.78			
Erucic acid%	36.93–41.47	39.22	2.08	5.30	12.20			
Crude fiber%	9.26–11.64	10.45	0.98	9.40	–20.45			

fatty acids plays an important role in the transport of protective compounds such as glycine- betaine (Willekens *et al.*, 1997; Xu *et al.*, 2001).

4. CONCLUSIONS

The present investigation revealed that FT-NIR is an accurate and powerful technique that could be applied successfully for rapid mass screening of the potential germ plasm for selecting high oil and protein, low crude fiber and erucic acid contents. The threshold limit of salinity for mustard, up to which little or no reduction in yield occur, is 8.2 dSm^{-1} under soil (ECe) and 12 dSm^{-1} for irrigation water (EC_{iw}), and for every increase of 1 dSm^{-1} in EC above the salinity threshold results in a reduction in the oil, protein and crude fiber of about 1–3%, 4–6% and 5–8%, respectively, whereas erucic acid increased by 5–9%.

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