Pak. J. Bot., ., 57(1): DOI: http://dx.doi.org/10.30848/PJB2025-1(17)

ASSESSMENT OF SEED, BIODIESEL AND OIL YIELD OF CASTOR BEAN (*RICINUS COMMUNIS* L.) UNDER DIFFERENTIAL PHOSPHORUS DOSES

MUHAMMAD AMJID[1*], MUHAMMAD SAJID[1], IQRA IBTAHAJ[2], FARHAN RIAZ[1], MUHAMMAD AKHLAQ MUDASSAR[3], AHSAN RASHID CHUGHATTA[1] AND MUHAMMAD USMAN IBRAHIM[1]

[1]*Department of Agronomy, University of Agriculture Faisalabad, Pakistan*
[2]*Department of Botany University of Agriculture Faisalabad, Pakistan*
[3]*Senior Scientist Agronomy, Sugarcane Research Institute, AARI Faisalabad, Pakistan*
**Corresponding author's email: amjidm70@gmail.com*

Abstract

Daily energy demand in Pakistan is increasing due to industrialization and growth in different sectors. Wastage and improper use of energy also exert a high pressure on energy resources and the environment, which can be overcome by discovering new alternative energy resources like biofuels. Therefore, a study was planned to minimize the cost of production through sustainable agronomic approaches to get the maximum biodiesel from castor beans. This investigation was executed by employing a randomized complete block design (RCBD) under factorial arrangements with four phosphorus levels (0, 30, 60, and 90 kg P_2O_5 ha^{-1}) and two castor bean varieties (NIAB-Gold and DS-30) and replicated three times. Concluding the findings of the study, the highest number of capsules (109.0), the maximum seed yield (1336.00 kg ha^{-1}), the maximum oil percentage (42.45%), and the maximum oil yield (839.0 kg ha^{-1}) were recorded when 60 kg of phosphorus fertilizer were applied in NIAB-Gold as compared to the DS-30 variety. However, DS-30 exhibited the highest oil calorific value (44.0 K j g^{-1}) as compared to NIAB-Gold with respect to combustion of the unit value of fuel. In conclusion, applying 60 kg of phosphorus fertilizer to the NIAB-Gold variety resulted in the highest oil and seed yield, as well as the highest oil content percentage, indicating its potential as a sustainable agronomic approach for maximizing biodiesel production from castor beans.

Key words: Biodiesel, Castor bean, Energy source, Oil yield, Phosphorus, Yield.

Introduction

The lack of an approach to energy resources is the key element that confirms the consequences of the energy crisis in developing countries for economic development. An unremitting supply of food and energy is vital to supporting human activities such as agriculture, industrialization, and transportation. There is a dire need to produce energy from non-conventional sources due to a lack of conventional resources to overcome the energy shortfall throughout the world (Singh *et al*., 2019). The finite nature of fossil fuels, combined with the need for more sustainable and economically viable energy resources, has led to a shift towards environmentally friendly alternatives as the depletion of these non-renewable resources becomes imminent (Chen *et al*., 2012; Javed *et al*., 2021; Mahmood *et al*., 2021). One of the proposed solutions to the energy shortage is to use crop biomass to make biofuel, which is a renewable energy device (Yusuf *et al*., 2015). Biomass for bioenergy is a divisive and frequently debated topic. Researchers can help overcome the problem by independently evaluating the opportunities of biomass use for bioenergy and its implications for food security (Vanaj *et al*., 2008; Englund *et al*., 2020). The production of biofuel is very important for developing countries to overcome the energy crises (Adekanbi *et al*., 2021). Edible and non-edible oil are sustainable energy sources that are dynamically similar to petro-diesel (Ahmad *et al*., 2022).

Biodiesel is an environmentally friendly, nontoxic, fewer greenhouse gas emissions as compared to other petro-diesel and renewable energy sources. It can be employed as an alternative in any diesel engine (Zahan *et al*., 2018). Biodiesel produced from non-conventional crops retains the potential to revolutionize the petroleum industry and simultaneously mitigate environmental damage (Carvalho *et al*., 2020; Muanruksa *et al*., 2020). It is a good alternative to petro-diesel due to rising petroleum prices, diminishing fossil fuel reserves, and the environmental benefits of lowering net CO_2 emissions, biodiesel is becoming more significant. After the existing supply of crude oil runs out, diesel engines will be unusable. Biodiesel has the potential to address current and future energy shortages while also helping to clean up the environment, boost economic growth, and increase farmer income (Shrirame *et al*., 2011).

Phosphatic fertilizer plays a significant role in enhancing agricultural productivity and soil quality. The addition of phosphorus as a fertiliser to the soil is necessary for energy metabolism and the development of plant structural components, which ultimately enhance seed production in various crops. Moreover, nitrogen and phosphorus enrichments in the soil can potentially improve the nutritional quality of plants for both human and animal consumption (Yousefi *et al*., 2020; Gupta *et al*., 2020). An adequate amount of phosphorus fertilization stimulates root development, establishes a vigorous plant stand, enhances flowering, increases physiological maturity, improves seed formation, enhances grain yield, and increases resistance against cold stress. It performs an integral role in many reactions and metabolic functions of the cell, such as protein synthesis, fats and the formation of structures such as phospholipids, which are part of several cell components (Mitran *et al*., 2018). The uptake of phosphorus in plants regulates several metabolic processes such as respiration, photosynthesis, the transfer of energy in the form of ADP and ATP, and nucleic acid biosynthesis (Malhotra *et al*., 2018). Castor bean is extensively cultivated in Brazil, and the global situation indicates that castor bean is an excellent choice for biodiesel production. Chemically, its oil contains almost 90% ricinoleic acid, which offers some helpful properties due to its alcohol solubility at 30 degrees Celsius (Silva *et al*., 2006).

Generally, in an arid and semi-arid area, one hectare of castor beans produces 355-660 kg per hectare, making it an attractive crop. Castor bean is grown commercially all over the world, as well as in developed countries. India, China, Brazil, Ethiopia, Paraguay, Vietnam, and Thailand are the leading producers of castor beans, which make up 97% of the world's production (Anon., 2012). Castor bean is one of the most important oilseeds that has acclimated well to Pakistani climates. Castor-bean seed contained 30-50% oil. In order to achieve the full potential output of oilseeds, there are various obstacles that need to be overcome, including the high cost and low quality of seeds, competition with other non-oilseed crops, the need for significant labour input, unstable market conditions, inadequate planting density, and improper fertilization (Cheema *et al*., 2013; Reza *et al*., 2020).

Castor bean is a very important crop that provides raw material in many industries and is used in by-products like cosmetics, lubricants, and paints. Pakistan spends a lot of money on the import of castor oil to fulfil the industry's need (Anon., 2018). Castor bean is an annual oilseed crop, and its seed comprises 80-90% glycerides of ricinoleic acid. Owing to the presence of these glycerides, castor oil is widely used in biodiesel production (Kumar & Sharma, 2011). Keeping in view the above-mentioned facts this study was arranged to assess the effect of phosphorus on two castor bean varieties with respect to growth, seed yield, oil yield and oil percentage. Moreover, phosphorus dose optimization was also done regarding aforementioned traits.

Table 1. Soil analysis traits.

Analysis	Determination	Value	Unit
Structural analysis	Sand	65.5	%
	Silt	17.6	%
	Clay	16.9	%
	Texture class	Sandy loam (Hydrological group A)	-
Chemical analysis	Nitrogen	0.046	%
	Phosphorus	9.2	ppm
	Potassium	141	ppm
	Sulfur	9.05	ppm
	Organic matter	0.65	%
	E.C	1.4	dS m^{-1}
	pH	7.9	-

Material and Methods

The investigation was executed at the Agronomic Research Farm, University of Agriculture, Faisalabad (31.26° North latitude, 73.06° East longitude, and altitude of 184.4m) on July 15, 2021. Before one week of sowing, soil samples at 0-30 cm were collected from different locations using an auger and mixed to form a composite soil sample. Soil analysis was done at the Ayyub Agriculture Research Institute Faisalabad (AARI) and is shown in (Table 1). The experimental site was subtropical in nature and characterized by moderate rainfall, a dry summer, and a cold winter. The weather data collected from the University of Agriculture, Faisalabad metrological observatory during the growing season is given in (Figs. 1 & Fig. 2). The study was carried under randomized complete blocks design (RCBD) under factorial arrangements having two castor bean varieties (NIAB-Gold and DS-30) and four phosphorus levels (0, 30, 60 and 90 kg P_2O_5 ha^{-1}) using the SSP source. NIAB-Gold seed was purchased from Nuclear Institute for Agriculture and Biology (NIAB), Faisalabad, Pakistan and DS-30 castor bean was purchased form Ayub Agricultural Research Institute, Faisalabad. Net plot size was 4m×3m and row to row and plant to plant distance was kept 56 cm and 24 cm, respectively. Total three irrigation was employed during the whole crop season (1st irrigation of 4-acre inches was applied after 2nd week of germination, 2nd and 3rd on flowering and seed filling stage respectively). Moreover, 100 kg/ha nitrogen (urea as a source of nitrogen) and 30 kg/ha potassium (K_2O_5 as a source) was applied. Phosphorus, potassium and ½ nitrogen were applied during field preparation at seedbed preparation whereas, the rest half of nitrogen was used at stem elongation. Agronomic traits including, plant height of five plants was measured with the help of meter rod at the time of harvesting whereas, number of branches and number of capsules/plants also counted on the selected five plants. Hundred seed weight was recorded on analytical balance whereas, seed yield was calculated of each experimental plot and converted into yield kg ha^{-1}. Oil content was determined by using electric Soxhlet apparatus. A 200 g seed was collected, de-husked and placed in oven to dry. Seed was ground and powder was packed into thimble. Thimbles were fixed in device. For the extraction of oil, N-hexane solvent was utilized, and the temperature was maintained at 65°C for five hours. Following this, the mixture of N-hexane and oil was separated from Soxhlet once the apparatus had cooled down to room temperature. The oil was subsequently isolated from the N-hexane using a rotary evaporator, and its content was quantified using the formula given below and unit was kg ha^{-1} (Velioglu *et al*., 2017).

$$\text{Oil \%} = \frac{\text{Weight of resiude}}{\text{Weight of sample}} \times 100$$

Synthesis of biodiesel: To produce biodiesel from castor bean, the refined oil was first converted into fatty acid methyl esters. In the process of transesterification, a precise amount of potassium hydroxide was combined with a measured quantity of methanol (in a ratio of 5:1 of methanol to oil), and the oil was subsequently added to the resulting mixture. Moreover, this solution was heated at 65°C for three hours, and the sample was centrifuged for three hours continuously at 400 rpm. Stirring was done, which is necessary for assisting the reaction mixture in the production of fatty acid methyl esters. Hereafter, the mixture was put in a funnel and left for 24 hours to settle. Glycerin was settled in the lower portion of the funnel and collected separately. The top layer comprises biodiesel known as FAME (fatty acid methyl esters), shown in (Fig. 3). The calorific value was recorded by an oxygen bomb calorimeter (Model: DSHY-1A+ZHAUHAI Dshing).

Statistical analysis

The data analysis was performed using Statistix 8.1 software (Analytical Software, Tallahassee, FL, USA), and a least significant difference (LSD) test was conducted for mean comparison at a significance level of $p \leq 0.05$. Furthermore, Pearson correlation analysis was conducted with the assistance of Microsoft Excel, employing a two-tailed t-test (df-2).

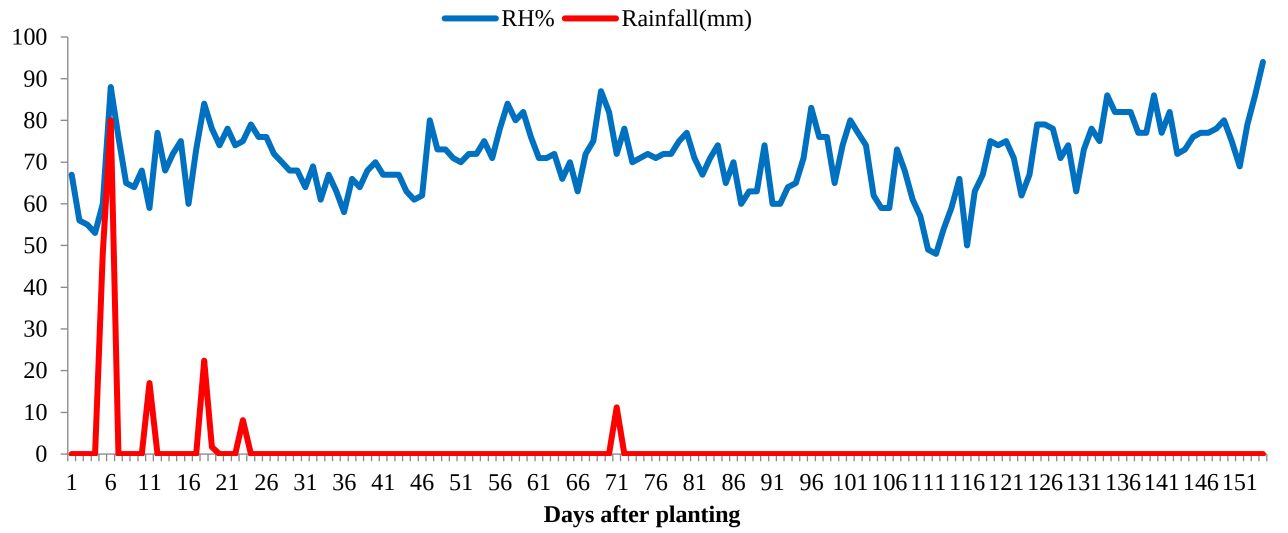

Fig. 1. Max. and Mini. Temp. during course of study.

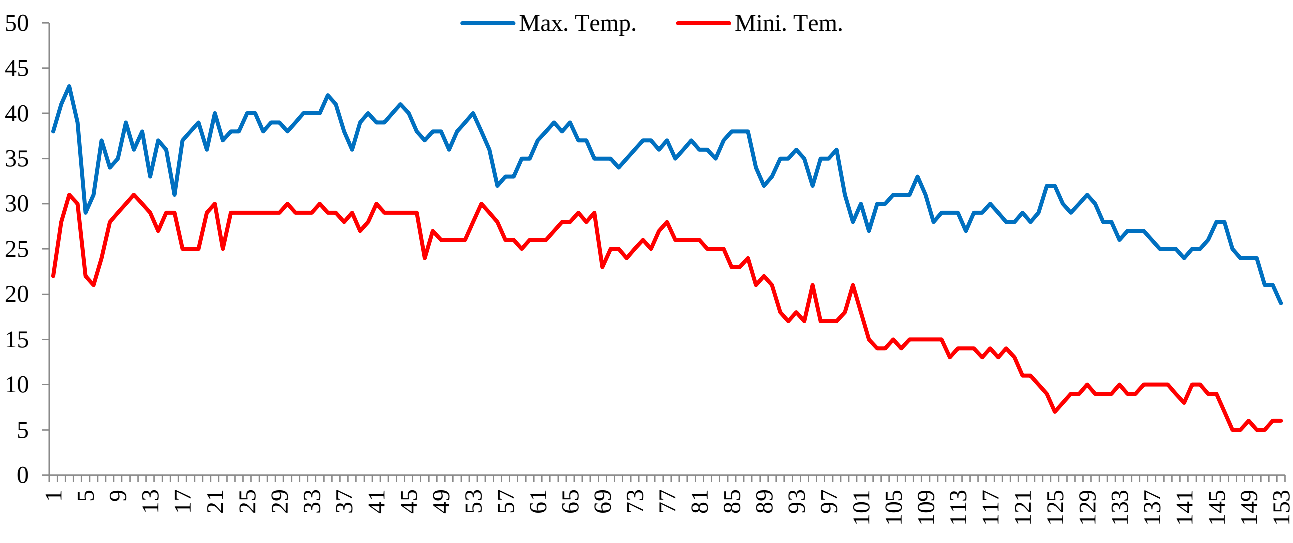

Fig. 2. Relative humidity and rainfall data during experimentation.

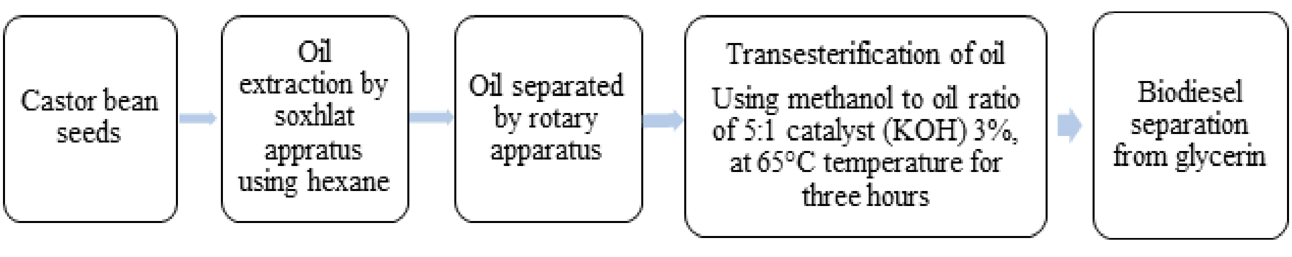

Fig. 3. Biodiesel synthesis procedure.

Data recorded: As per (Table 2) showed that the mean comparison for all studied traits as main effect had significant (*$p \leq 0.05$*) effect expect spikes per plant and 100 seed weight for castor varieties. However, the interactive responses of castor bean varieties with phosphorus regimes were also observed significant for all variables. Both cultivars selection and phosphorus fertilizer application significantly influenced the height of castor bean plants, which is a critical factor in determining yield. On the other hand, NIAB-Gold has the highest number of branches (4.6) in 60kg/ha phosphorus whereas, the DS-30 and NIAB-Gold showed the lowest number of branches (2.35) in 0 kg/ha phosphorus. Figs. 4 and 5 showed that the spike length has a significant variation among castor bean varieties and phosphorus treatments. The longest spike length (52.33 cm) was recorded in NIAB-Gold under 60 kg/ha phosphorus whereas DS-30 exhibited the shortest spike length (30.00 cm) under 0 kg kg/ha. NIAB-Gold has a greater number of spikes per plant (4.33) in 60 kg/ha phosphorus and the lowest number of spikes per plant was accumulated in DS-30 at 0 kg/ha. Moreover, the maximum number of capsules per plant (109.67) was gathered in NIAB-Gold at 60 kg/ha phosphorus whereas the minimum capsule per plant was taken in DS-30 under 0 kg/ha.

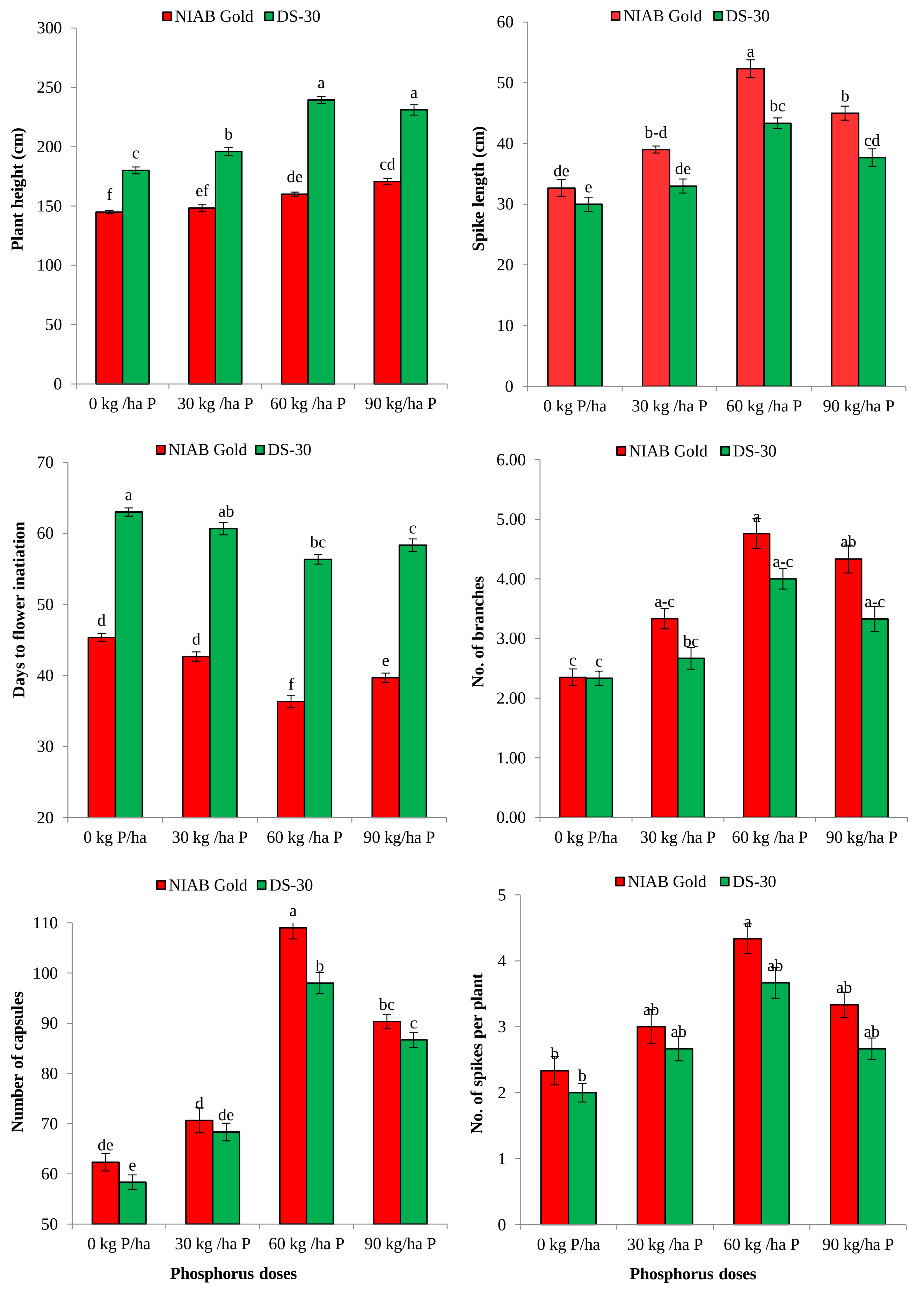

Fig. 4. Effect of differential phosphorus doses on castor bean varties for studied tratits and similar letters are statiscally inginficant at 5% probabolity using LSD test.

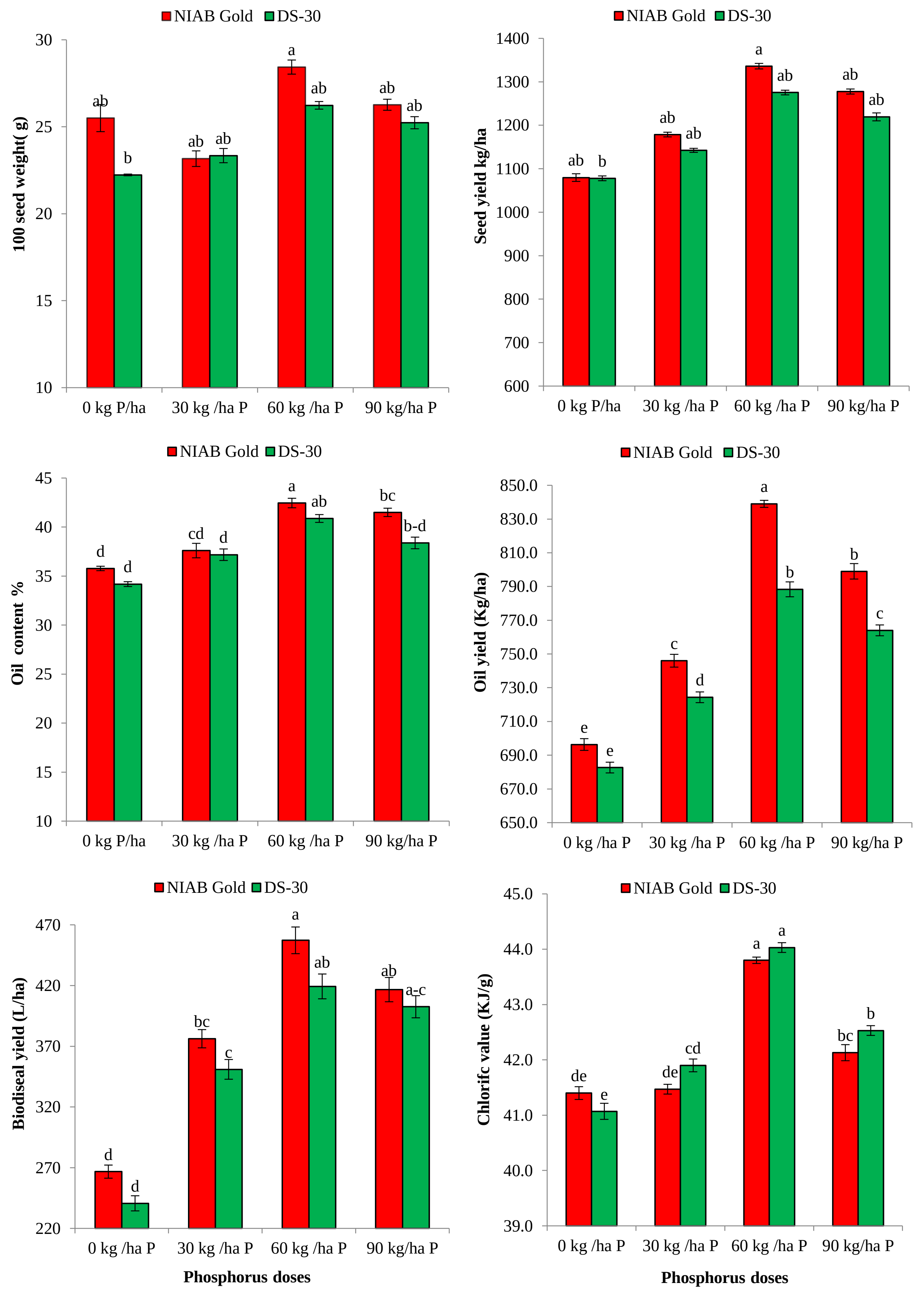

Fig. 5. Effect of differential phosphorus doses on castor bean varties for studied tratits and similar letters are statiscally inginficant at 5% probabolity using LSD test.

Table 2. Mean comparison of main effects of phosphorus doses and castor bean varieties of traits i.e. plant height (PH) Table for phonological, agronomic and oil bearing of castor bean varieties under varying phosphorus regimes.

Treatments	Parameters											
	PH	SL	NB	DF	NC	SPP	100 SW	SY	OC	OY	BDY	CL
0 kg/ha	162.5±2.0^{c}	31.33±1.3^{c}	2.3±0.1^{c}	54.2±0.6^{a}	60.3±1.6^{d}	2.2±0.17^{b}	23.9±0.4^{b}	1078.8±7.1^{d}	36.1±0.2^{c}	689.5±3.3^{d}	253.7±5.8^{c}	41.2±0.1^{d}
30 kg/ha	172.2±2.9^{b}	36.00±0.9^{d}	3.0±0.2^{bc}	51.7±0.8^{b}	69.5±2.1^{c}	2.8±0.22^{b}	23.3±0.4^{b}	1160.5±4.9^{c}	37.0±0.7^{c}	735.2±3.5^{c}	363.6±7.8^{b}	41.7±0.1^{c}
60 kg/ha	200.8±2.3^{a}	47.83±1.2^{a}	4.4±02^{a}	46.3±0.7^{d}	103.5±2.1^{a}	4.0±0.22^{a}	27.3±0.3^{a}	1305.7±5.8^{a}	41.7±0.4^{a}	813.7±3.2^{a}	438.3±10.6^{a}	43.9±0.1^{a}
90 kg/ha	199.7±3.3^{a}	41.33±1.3^{b}	3.8±0.2^{ab}	49.0±0.8^{c}	88.5±1.5^{b}	3.0±0.17^{ab}	25.8±0.3^{ab}	1248.5±7.5^{b}	38.9±0.5^{b}	781.5±3.8^{b}	409.5±9.5 a	42.3±0.1^{b}
LSD @ 5%	**2.69**	**4.19**	**0.99**	**1.58**	**6.08**	**1.03**	**3.25**	**19.65**	**1.57**	**11.02**	**35.37**	**0.31**
NIAB-Gold	211.6±1.98^{a}	42.3±1.1^{a}	3.7±0.2^{a}	41.0±0.7^{b}	83.1±2^{a}	3.25±0.22	25.84±0.5	1218.0±6.5^{a}	38.53±0.5^{a}	770.1±3.5^{a}	379.2±8.5 a	42.2±0.1^{b}
DS-30	156.0±3.35^{b}	36.0±1.2^{b}	3.1±0.2^{b}	59.6±0.8^{a}	77.8±1.7^{b}	2.75±0.18	24.26±0.3	1178.8±6.2^{b}	38.05±0.4^{b}	739.8±3.4^{b}	353.4±8.4 b	42.4±0.1^{a}
LSD @ 5%	**4.38**	**2.19**	**0.51**	**0.82**	**3.17**	**Ns**	**Ns**	**10.25**	**0.18**	**5.75**	**18.45**	**1.47**
Interaction	*	**	*	*	**	*	**	*	*	*	**	**

Here, PH= Plant height, SL= Spike length, NB= Number of branches, DF= Days to flower initiation, NC= Number of capsules, SPP= Spike per plant, 100S W= Hundred seed weight, SY= Seed yield, OC= Oil content %, OY= Oil yield, BDY= Biodiesel yield and CL= Calorific content

Table 3. Correlation analysis of growth, yield and oil traits.

	PH	SL	SPP	NB	DF	NC	OC	SY	BDY	CV	HSW
SL	-0.006										
SPP	0.057	0.969**									
NB	0.077	0.990**	0.950**								
DF	0.661	-0.652	-0.610	-0.628							
NC	0.317	0.938**	0.926**	0.949**	-0.444						
OC	0.180	0.956**	0.943**	0.968**	-0.576	0.955**					
SY	0.252	0.958**	0.936**	0.981**	-0.503	0.977**	0.979**				
BDY	0.294	0.886**	0.886**	0.908**	-0.453	0.915**	0.938**	0.958**			
CV	0.499	0.7863**	0.854**	0.785*	-0.197	0.922**	0.829**	0.849**	0.797*		
HSW	0.034	0.845**	0.811**	0.806**	-0.626	0.863**	0.840**	0.792*	0.693*	0.782*	
OY	0.164	0.976**	0.949**	0.987**	-0.577	0.971**	0.982**	0.994**	0.955**	0.827**	0.824**

PH= Plant height, SL= Spike length, NB= Number of branches, DF= Days to flower initiation, SPP= Spike per plant, 100S W= Hundred seed weight, SY= Seed yield, OC= Oil content %, OY= Oil yield, BD= Biodiesel yield and CL= Calorific content

However, phenological variable like days to flower inanition was the highest days (63.0) in DS-30 at 0 kg/ha that is recorded with statistically similar trend of NIAB-Gold at 30 kg/ha phosphorous whereas, the least days for flowering was observed in NIAB-Gold at 60 kg/ha phosphorus. The highest 100 seed weight (28.43g) was recorded in NIAB-Gold at 60kg/ha that was statistically recorded at par findings of remaining all treatments whereas, the least (22.23g) 100 seed weight was obtained from DS-300 variety when exposed to 0kg/ha phosphorus. The interaction between phosphorus and different varieties were found statistically significant with respect to the total seed yield of castor bean. The maximum seed yield (1336.0 kg/ha) was calculated in NIAB-Gold at 60 kg/ha, but the lowest seed yield (1078.0 kg/ha) was calculated in DS-30 at 0 kg/ha phosphorus application.

The interaction between phosphorus doses and variety was found significant regarding oil yield. The highest oil yield (839.00 kg/ha) was taken in NIAB-Gold at 60kg/ha phosphorus whereas, the minimum oil yield (682.7 Kg/ha) was recorded in DS-30 at 0 kg/ha phosphorus application. The maximum oil content percentage (42.45%) was extracted from NIAB-Gold at 60 kg/ha phosphorus while the NIAB-Gold and DS-30 at 30kg/ha had showed the identical oil content (37.60%). The minimum oil content percentage (34.18%) was measured in NIAB-Gold at 0 kg/ha which is statistically similar to DS-30 at 0 kg/ha.

The highest biodiesel yield (457.2 L/ha) was recorded in NIAB-Gold at 60kg/ha. The minimum biodiesel yield (240.6 L/ha) was calculated in DS-30 at 0kg/ha phosphorus which is statistically similar to NIAB-Gold at 0 kg/ha. Similarly, the data regarding calorific value was responded significantly. The maximum calorific value (43.8 KJ/g) was recorded in NIAB-Gold at 60 kg/ha that is statistically at par with DS-30 at 60 kg/ha; however, the lowest calorific value (41.1) was recorded in Ds-30 at 0 kg/ha phosphorus. Along with this the interaction between different doses of phosphorus fertilizer and verities was found significant for biodiesel yield.

Correlation analysis

The Pearson's correlation analysis was used to ascertain the possible relationship/s among different doses of phosphorus of both castor bean cultivars. (Table 3) showed that the correlation between the number of spikes per plant and spike length was found highly significant (R^2=0.969) thus showing that more spike length had a greater number of spikes. The correlation between days to flower inanition to spike length, spike per plant and number of branches were found negative correlations consequently a greater number of days for flowering had inverse relationship with motioned traits. The correlation between oil content percentage with respect to other parameters like spike length, spike per plant, number of branches and number of capsules were found highly significant (R^2= 0.956, 0.943, 0.968 and 0.955 respectively) showing that correlated traits had significantly contributed to oil % age. However, seed yield was significantly increased due to more spike length, spike per plant, number of branches, number of capsules and oil content. A positive correlation was found between oil yield and spike length, spike per plant, number of branches, number of capsules, oil content, seed yield, biodiesel yield, calorific value. It showed that oil yield was substantially increased with increasing of aforementioned traits.

Discussion

The application of phosphorus nutrient influenced the yield and related attributes in both castor bean cultivars. In the current study, the application of phosphorus result in increased plant height, number of branches and capsules per plants. The current findings are similar to the results of (Vanaha *et al*., 2008) who explained that yield is directly proportional to number of branches and number of capsules per plant. Moreover, the highest spike length recorded in our study was also in line with the results of Jamil *et al*., 2008 and Srinivas *et al*., 2005 who concluded that nitrogen and phosphorus application increase the spike length and capsules per plants.

However, the seed yield is directly related to higher capsules per plants and 100 grain weight. The seed yield increased by the adding of mineral nutrition that was also reported by Pacheco *et al*., (2008) Neto *et al*., (2009); Hadvani *et al*., (2010) in castor bean. The higher seed yield in castor bean cultivars may be attributed due to more mobilization of phosphorus nutrients in soil for root uptake which resulted less shrinkage of proper plant metabolism in the plant body and higher proliferation of cell functioning to produce grain yield.

Moreover, the phosphorus fertilizer enhanced the seed yield of castor bean because of the release of more concentration of phosphatases, phytase and organic acids (Tarafdar & Gharu, 2006; Chen *et al*., 2006). Nonetheless, phosphorus uses can enhanced the growth and diminishing the time until harvest. The higher value of castor seed yield was the result of higher value of different growth and yield contributing characters. These findings are following the result of (Singh *et al*., (2013); Yadav & Yadav (2015) and lower yield was recorded without application of phosphorus fertilizer.

Castor bean seed yield, hundred seed weight and oil content % was increased due to more occurrence of phosphorus in soil. This is in line with earlier finding that phosphorus applications accelerated the growth of the hyperaccumulator and boosted the shoot yield of spinach (Dheri *et al*., 2007; Chen *et al.,* 2012). Additionally, prior research has shown that the addition of KH_2Po_4 increased the production of biomass (Bolan *et al*., 2003). Our experiment showed significant results regarding oil content percentage. Our finding of oil content % was the same as reported by Tomar *et al*., (2004) who reported that inoculation and phosphorus application increased oil contents of soybean. Similar research finding has been reported by (Singh *et al*., 2013; Vaghasia *et al*., 2017).

Conclusion and Recommendations

The present study was concluded that NIAB-Gold caster bean variety showed excellent performance against 60 kg phosphorus application while DS-30 castor bean variety showed least performance against different concentration of phosphorus. It is recommended that for better oil yield, biodiesels production at 60 kg phosphorus application is ideal in NIAB-Gold castor bean variety.

References

Adekanbi, M.L., B.T. Ibukun and E. Steve. 2021. The potential of biodiesel in mitigating the energy crisis in Sub-Saharan Africa energy sectors. Sustinere: *J. Environ. Sustain.*, 5(2): 79-89.

Ahmad, M, A.Y. Elnaggar, L.K. Teong, S. Sultana, M. Zafar, M. Munir, E.E. Zussein and S.Z. Abidin. 2022. Sustainable and eco-friendly synthesis of biodiesel from novel and non-edible seed oil of *Monotheca buxifolia* using green nano-catalyst of calcium oxide. *Energy Conver. Manag*., 1(13): 100142.

Anonymous. 2012. F. Database Internet. Food and Agriculture Organization of the United Nations). Disponible en: http://faostat. fao. org. 2008.

Anonymous. 2018. Castor. Available: http://www.parc.gov.pk/index.php/en/csi/137-narc/crop-sciences-institue/732-castor [Accessed 12/18/2018].

Bolan, N.S., D.C. Adriano, P. Duraisamy, A. Mani and K. Arulmozhiselvan. 2003. Immobilization and phyto availability of cadmium in variable charge soils. Effect of phosphate addition. *Plant Soil*, 250: 83-94.

Carvalho, M., F. Torres, V. Ferreire, J. Silva, J. Martin and E. Torres. 2020. Effect of diethyl ether inroduction in emission and performance of a diesel engine fueled with biodiesel-ethanol blends. *Energies*., 13: 3787.

Chen, Y.P., P.D. Rekha, A.B. Arun, F.T. Shen, W.A. and C.C. Young. 2006. Phosphate solubilizing bacteria from subtropical soil and their tricalcium phosphate solubilizing abilities. *Appl. Soil Ecol*., 34(1): 33-41.

Chen, R., E. Blagodatskaya, M. Senbaryram, S, Blagodastsky, O. Myachina and K. Dittert. 2012. Decomposition of biogas residues in soil and their effect on microbial growth kinetics and enzyme activities. *Biomass Bioenergy*, 45: 221-229.

Cheema, N.M., U. Farooq, G. Shabbir, M.K. Shah and M. Musa. 2013. Prospects of castor bean cultivation in rainfed tract of Pakistan. *Pak. J. Bot*., 45(1): 219-240.

Dheri, G.S., M.S. Brar and S.S. Malhi. 2007. Influence of phosphorus application on growth and cadmium uptake of spinach in two cadmium uptakes in two contaminated soils. *J. Plant Nutr. Soil Sci*., 170: 495-499.

Englund, O., I. Dimitriou, V.H. Dale, K.L. Kline, B. MolaYudego, F. Murphy, B. English, J. Mcgrath, G. Busch, M.C. Negri and M. Brown. 2020. Multifunctional perennial production systems for bioenergy: performance and progress. Wiley Interdisciplinary Reviews: *Energy Environ.*, 9(5): 375.

Gupta, A.K. M.A. Rather, A.K. Jha, A. Shashank, S. Singhal, M. Sharma, U. Pathak, D. Sharma, A. Mastinu. 2020. A. *Artocarpus lakoocha* Roxb. and *Artocarpus heterophyllus* Lam. Flowers: New Sources of Bioactive Compounds. *Plants*, 9: 1329.

Hadvani, N.G., K.V. Jadavd and G.J. Hadvani. 2010. Responses of castor (*Ricinus communis* L.) to nitrogen and potassium levels on growth, yields attributes and yields under irrigation condition. *Adv. Plant Sci*., 23(1): 165-167.

Jamil, M., S.S. Hussain, M.A. Qureshi, S.M. Mehdi and M.Q. Nawaz. 2017. Impact of sowing techniques and nitrogen fertilization on castor bean yield in salt affected soils. *J. Anim. Plant Sci.*, 127(2).

Javed, T., M.I. Awan, S. Sadaf, A. Mukhtar, X. Wang and S. Fiaz. 2021. Bio-diesel production of sunflower through sulphar management in a semi-arid subtropical environment. *Environ. Sci. Pol. Res*., 29: 13268-13278.

Kumar, A. and S. Sharma. 2011. Potential non-edible oil resources as biodiesel feedstock: an Indian perspective. Renew. *Sustain. Energy Rev.*, 15(4): 1791-800.

Malhotra, H., S. Sharma and R. Pandey. 2018. Phosphorus nutrition: plant growth in response tdeficiency and excess. In Plant nutrients and abiotic stress tolerance. pp. 171-190. Springer, Singapore.

Mitran,T., R.S. Meena, R. Lal, J. Layek, S. Kumar and R. Datta. 2018. Role of soil phosphorus on legume production. In Legumes for soil health and sustainable management pp. 487-510. Springer, Singapore.

Muanruksa, P., P. Dujjanutat and P. Kaewkannetra. 2020. Entrapping immoblization of lipase on bio composite hydrogel toward for biodiesel production from waste frying acid oil. *Catalysts*, 10: 834.

Neto, M.A., J.A. Távora, L.A. Crisóstomo and L.M. Diniz. 2009. NPK fertilization and sowing time for castor plant. I-Production and yield components. *Revista Ciência Agronômica*., 40(4): 578.

Pacheco, D.D., N.P. Gonçalves, H.M. Saturnino and P.D. Antunes. 2008. Produção e disponibilidade de nutrientes para mamoneira (*Ricinus communis* L.) adubada com NPK. *Revista de Biologia e ciências da Terra*, 8(1): 153-160.

Reza Yousefi, A., S. Rashidi, P. Moradi and A. Mastinu. 2020. Germination and seedling growth responses of *Zygophyllum fabago*, *Salsola kali* L. and *Atriplex canescens* to peg-induced drought stress. *Environ*., 7: 107.

Shrirame, H.Y., N.L. Panwar and B.R. Bamniya. 2011. Bio diesel from castor oil-a green energy option Low Carbon Economy. 2(1): 1-6.

Silva, N.D., M.R. Maciel and C.B. Batistella. 2006. Optimization of biodiesel production from castor oil. In: *Twenty-Seventh Symposium on Biotechnology for Fuels and Chemicals*, pp. 405-414.

Singh, I., R.S. Chawra, M.S. Rathore and J.C. Tarafdar. 2013. Response of biophos to castor at varying phosphorus levels under irrigated conditions. *Green Farm*., 4(1): 37-39.

Singh, A., S. Singh and V. Singla. 2019. Performance and emission analysis of a CI engine using ethanol and its blends with jojoba biodiesel and diesel as a fuel. In: *Advances in Interdisciplinary Engineering*. pp. 229-239. Springer, Singapore.

Srinivas, M., S.H. Mohammad and A. Sairam. 2005. Yield components and yield of castor (*Ricinus communis* L.) as influenced by different planting geometries and row proportions of intercropped groundnut or pearl millet. *Crop Rese. Hisar*., 30(3): 349.

Tarafdar, J.C. and A. Gharu. 2006. Mobilization of organic and poorly soluble phosphates by *Chaetomium globosum*. *Appl. Soil Ecol*., 32: 273-283.

Vaghasia, P.M., R.L. Davariya and R.N. Daki. 2017. Effect of Bio-Phos (*Chaetomium globosum*) on castor (*Ricinus communis* L.) yield at different levels of phosphorus under Irrigated Conditions. *Int. J. Curr. Microbiol. App. Sci*., 6(9): 1974-1978.

Vanaja, M., M. Jyothi, P. Ratnakumar, P.R. Vagheera, P.R. Reddy, N.J. Lakshmi, S.K. Yadav, M. Maheshwari and B. Venkateswarlu. 2008. Growth and yield responses of castor bean (*Ricinus communis* L.) to two enhanced CO2. *Plant Soil Environ.*, 54(1): 38-46.

Velioglu, S.D., H.T. Temiz, E. Ercioglu, H.M. Velioglu, A. Topcu and I.H. Boyaci. 2017. Use of Raman spectroscopy for determining erucic acid content in canola oil. *Food Chem*., 221: 87-90.

Yadav, J.S. and S.S. Yadav. 2015. Effect of bio-phos (*Chaetomium globosum*) on castor at varying levels of phosphorus application under irrigated conditions. In: National seminar on Strategic interventions to enhance oilseeds production in India, Indian Society of Oilseeds Research, Hyderabad, Feb. 19- 21, 2015. Extended Summary pp. 183-185.

Yusuf, A.K., P.A. Mamza, A.S. Ahmed and U. Agunwa. 2015. Extraction and characterization of castor seed oil from wild *Ricinus communis* Linn. *Int. J. Sci. Environ. Technol*., 4(5): 1392-1404.

Zahan, K.A. and M. Kanumber. 2018. Biodiesel production from palm oil, its by-products, and mill effluent: A review. *Energies*, 11(8): 2132.

(Received for publication 22 February 2023)