*Original Research Article*

# Introduction of New Chickpea Variety JG-14 in DSSAT for a Sustainable Agricultural Development

## ABSTRACT

India is the largest consumer of pulses, but globally it is the second largest producer after China. Our nation can mitigate the gap between demand and supply by introducing new varieties along with modern technologies. Jawaharlal Nehru Krishi Viswavidyalaya, Jabalpur has released a short duration high yielding chickpea (*Cicer arietinum*) variety JG-14 in 2009. This variety is heat tolerant, moderately resistant to various pest and diseases. Any new variety may be cultivated in large scale after assessing its adaptability in varied situations and acceptability among the farmers. But it's extensively time consuming and expensive process. That's why various crop growth simulation models (CGSMs) like DSSAT are used to analyze the influence of all inputs without growing the crop on the specific land in real. The present study aims to calibrate genetic coefficient for new chickpea variety JG-14 in DSSAT. To fulfil this purpose, an experiment was conducted at District Seed Farm, Kalyani for three consecutive years, from 2018-19 to 2020-21. The derived genetic coefficient will be very handy for predicting performance of the crop under diverse environmental conditions and management practices. Promoting varieties like JG-14 trigger food cum nutritional security, self-resiliency, income enhancement, better policy making and step forward towards sustainable development goals.

*Keywords: Pulses, JG-14, Simulation, Crop growth simulation model (CGSM), DSSAT, Genetic coefficient.*

## 1. INTRODUCTION

India faces some challenges with the increasing demand of pulses because of explosively increasing population along with shrinking of total agricultural land in the present years. To alleviate this growing problem, in the year of 2009, Jawaharlal Nehru Krishi Viswavidyalaya (JNKV), Jabalpur has released a short duration chickpea (*Cicer arietinum*) variety JG-14, which has 100-105 days of growing period. The potential yield of this variety is 12-15 q/ha depending upon the environment, which is higher than the national average of 8.06 q/ha. Moreover, JG-14 chickpea variety is not only recommended as heat tolerant, but also moderately resistant to some major pest and diseases infestation like pod borer, wilt and dry root etc. (Indian Institute of Pulses Research, Kanpur).

Crop Growth Simulation Model (CGSM) mimics crop growth, to create a digital prototype with respect to phenological and yield attributes, changes in natural resources, climate change impact etc. Generally, these variables are function of soil, weather conditions and crop management systems. The Decision Support System for Agrotechnology Transfer or DSSAT was initiated by International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) project, supported by United States agency for international development to assist agronomic researches. Some primitive crop models like SOYGRO for soyabean (Wilkerson *et al.*, 1983), CERES-Wheat (Ritchie & Otter, 1985), CERES-Maize (Jones & Kiniry, 1986), PNUTGRO for peanut (Boote *et al*., 1986) etc., were already enjoying early success in the arena of crop simulation models. These were later incorporated in DSSAT. In the year of 2007, Suriharn *et al.* determined cultivar coefficients of seventeen peanut cultivars. Pande et al. (2012) explored the prospects and limitations of chickpea cultivation as a second crop in rainfed rice fallow land of India. Kumbhar and Singh

(2013) mentioned the challenges faced during extraction of knowledge from raw data in Indian context. In their study, they recommended the application of advanced methods and techniques like decision support system for various agricultural practices. Srivastava *et al.* studied the impact of climate change on phenological and yield parameters of chickpea in CROPGRO-Chickpea (DSSAT v4.5) model in 2016. They conducted field experiments on two varieties of chickpea JG-315 and JG-11 for two consecutive years 2009-10 and 2010-11 in Madhya Pradesh. In 2017 D.D. Patil and H.R. Patel calculated genetic coefficient of a chickpea cultivar using DSSAT (v4.6) CROPGRO model with the experimental data for two rabi seasons 2014-15 and 2015-16 at Anand, Gujrat. Days to anthesis, days to first pod, days to physiological maturity, days to harvest maturity, seed yield and straw yield, these characters were validated for second year experiment. In the same year S. Kuri and H.S. Shivaramu (2017) calibrated genetic coefficients of two pigeon pea varieties for three different sowing dates. Field experiments were carried out during 2015-16 and 2016-17 at UAS, Bengaluru. Pandey *et al.* (2019) conducted an experiment for three different chickpea varieties *i.e.* Awarodhi, Pusa-362 and PG-186 to perform sensitivity analysis of various growth as well as yield attributes using DSSAT CGSM. Later in 2023, Hedayetullah mentioned the scope of chickpea in rice fallow of Indo-Gangetic alluvial regions of West Bengal as a second crop. Janghel and Puranik (2023) calibrated and validated CROPGRO model under DSSAT by using field data on three chickpea varieties. They conducted field trials for two consecutive rabi season during 2020-21 and 2021-22 at the Instructional farm of Indira Gandhi Krishi Vishwavidyalaya, Chhattisgarh. They considered 3 different dates of sowing and studied the phenological as well as yield attributes of chickpea. In the same year, Sharma *et al.* assessed the effect of genotypes and date of sowing on chickpea yield in DSSAT for three varieties HC1, HC5 and HC7. They have used four different dates of sowing *i.e.* 13$^{th}$ October, 1$^{st}$ November, 15$^{th}$ November and 2$^{nd}$ December respectively under their research. Ragul *et al.* (2023) evaluated spatial yield estimation for chickpea at Vidisha of Madhya Pradesh and Nagpur of Rajasthan using DSSAT CROPGRO module. Their model efficiently calibrated and validated chickpea yield at spatial level as the result showed high level of accuracy in terms of $R^2$, MAPE and d-stat value. The main objective of the present study is to generate the set of genetic coefficients of JG-14 chickpea, which is obviously new in DSSAT, by calibration and validation.

## 2. MATERIALS AND METHODS

Jones *et al.* (2003) re-designed the interface of DSSAT in easy integrable well-defined manner to facilitate more efficient incorporation of scientific advancements and described methodologies. They described the primary components and minimum data set (MDS) requirements for each module. The basis for the new DSSAT is a modular structure. It contains soil module, weather module and crop template module. The facility of plugged in or unplugged individual components along separate disciplinary lines helped to comparison of different components. Genetic or genotypic coefficient, also referred as genotype file in DSSAT, is variety-specific set of genotypic parameters, which plays a vital role in simulation process. It is indispensable to model the growth as well as development of any crop variety. Genetic coefficient is usually estimated based on some physiological and morphological characteristics of that particular genotype.

To accomplish the objective of the current study, field experiments (figure 1) on chickpea variety JG-14 were performed in District Seed Farm, Kalyani (22.987866° north, 88.424930° east and 11 meters altitude from mean sea level) of Bidhan Chandra Krishi Viswavidyalaya in collaboration with ICARDA (The International Center for Agriculture Research in the Dry Areas). The experiment was conducted for three consecutive years from 2018-19 to 2020-21 on two different dates of sowing. The following data were utilised in DSSAT to calculate the genetic coefficient of JG-14 chickpea:

Figure1: Field trials of JG-14 in District Seed Farm, Kalyani of Bidhan Chandra Krishi Viswavidyalaya

**Soil data:** The site belongs to new alluvial zone of lower Gangetic plain with a sandy clay loam texture and good drainage facility. Data related to basic soil properties like pH, bulk density, organic carbon content, available nitrogen, phosphorus and potash in different layers of the soil were collected.

**Climate data:** This farm is located near to the Tropic of cancer under sub-tropical humid climatic conditions with an average annual rainfall of 1460 mm. Maximum bright sunshine hours (BSSH) throughout the year is 10.5 hours and wind speed ranges from 0.5 km/hour to 7 km/hour. A minimum weather data set containing daily maximum and minimum temperature, solar radiation was created during the whole study period from the weather station under Bidhan Chandra Krishi Viswavidyalaya.

**Crop production and management data:** Various crop production related details were noted as follows:
(i) New chickpea (*Cicer arietinum*) variety JG-14 was cultivated to fulfil the purpose of the study for three consecutive years and three replications performed in each year. Chickpea is a rabi or winter season crop.
(ii) The previous standing crop in this field was kharif paddy, which is generally grows in the rainy season.
(iii) Zero tillage *i.e.*, single tillage operation at 2-5 cm depth was performed in the field nearly one week earlier before sowing with the help of hand tine.
(iv) Two different dates of sowing were opted for the field trials. One date of sowing was on 5$^{th}$ November *i.e.*, early sowing condition and another is 20$^{th}$ November *i.e.*, late sowing condition.
(v) Only precipitation was the main source of soil moisture. No other types of irrigation was applied throughout the whole crop growing period.
(vi) 20:40:40 kg/ha of N-P-K was given at the time of land preparation as basal dose and 10:20:20 kg/ha of N-P-K was applied as 1$^{st}$ split dose at 20 days after sowing.
(vii) Four phenological data viz., dates of anthesis, 1$^{st}$ pod development, physiological maturity and harvest maturity of the crop were observed and noted carefully.
(viii) Leaf area index (LAI) and some yield attributing characters namely grain yield (kg/ha), grain number per m$^2$ and unit grain weight (mg) were also recorded at every 15 days of interval from date of sowing.

After arranging all these input data in proper format, model calibration and validation is carried out. Model calibration is an iterative process, *i.e.*, trial and error method. Calibration introduces adjustment of the model parameters in such a way that the simulated observations seem as accurate as the on-field observations. Two growing seasons were used for model calibration purpose, field data of 2018-19 and 2019-20. Adjustment of genetic coefficients for chickpea cultivar JG-14 was done in such a manner that the simulated results of crop phenology; growth attributes and yield be almost same as the observed field data. The model validation was executed based on comparison between the simulated results and the observed data in 2020-21. The model performance was evaluated through some statistical measures viz., $R^2$ value (coefficient of determination) and d-Stat value, provided by the DSSAT simulation model. $R^2$ or coefficient of determination is a measure of linearity between the observed and simulated values. This statistic is often found in various scientific literatures and defined as:

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(y_i - f_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2}$$

where, $y_i$ is the observed data, $f_i$ is the predicted data, $\bar{y}$ is the mean of all $y_i$ and n is the number of observations. If the calibrated genetic coefficient shows satisfactory results during validation, then only the new set of coefficients can be adopted for simulation or further projection of yield. Moreover, the model can predict various phenological and growth parameters based on predicted weather parameters and soil condition. It can also provide an idea related to soil nutrients, soil moisture status etc., which will assist the farmer to take needful strategies for the next season.

## 3.RESULTS AND DISCUSSION

Firstly, the soil data and weather data under the study period were incorporated in DSSAT crop growth simulation model using SBuild and WeatherMan modules respectively for District Seed Farm, Kalyani to create an environment for crop growth. Then all the relevant experimental details as well as management practices were taken in to create crop production data of JG-14 from 2018-19 to 2020-21 using XBuild tool. After that a preliminary set of genetic or genotypic coefficients was derived for this new variety using GenCalc and GLUE under DSSAT. In case of chickpea, this set contains 18 different coefficients based on various physiological, growth and yield attributing characters of the crop. An iterative process was followed thereafter to obtain the best performing, more specifically the final set of genotypic coefficients for chickpea variety JG-14 as summarised in table 1.

Table 1: Estimated set of genotypic coefficients for chickpea variety JG-14:

| Sl. | Coefficient | Definition | Value |
|---|---|---|---|
| 1 | CSDL | Critical Short Day Length below which reproductive development progresses with daylength effect (for long day plants) (hour) | 9.348 |
| 2 | PPSEN | Slope of the relative response of development to photoperiod with time (negative for long day plants) (1/hour) | -0.143 |
| 3 | EM-FL | Time between plant emergence and flower appearance (R1) (photothermal days) | 38.24 |
| 4 | FL-SH | Time between first flower and first pod (R3) (photothermal days) | 13.65 |
| 5 | FL-SD | Time between first flower and first seed (R5) (photothermal days) | 15.00 |
| 6 | SD-PM | Time between first seed (R5) and physiological maturity (R7) (photothermal days) | 17.56 |
| 7 | FL-LF | Time between first flower (R1) and end of leaf expansion (photothermal days) | 34.00 |
| 8 | LFMAX | Maximum leaf photosynthesis rate at 30 C, 350 vpm $CO_2$, and high light (mg $CO_2$/$m^2$-s) | 0.925 |
| 9 | SLAVR | Specific leaf area of cultivar under standard growth conditions ($cm^2$/g) | 131 |
| 10 | SIZLF | Maximum size of full leaf (three leaflets) ($cm^2$) | 10.0 |
| 11 | XFRT | Maximum fraction of daily growth that is partitioned to seed + shell | 0.96 |
| 12 | WTPSD | Maximum weight per seed (g) | 0.185 |
| 13 | SFDUR | Seed filling duration for pod cohort at standard growth conditions (photothermal days) | 22.0 |
| 14 | SDPDV | Average seed per pod under standard growing conditions (#/pod) | 1.60 |
| 15 | PODUR | Time required for cultivar to reach final pod load under optimal conditions (photothermal days) | 19.0 |

| | | | |
|---|---|---|---|
| 16 | THRSH | The maximum ratio of (seed/(seed+shell)) at maturity. Causes seed to stop growing as their dry weights increase until shells are filled in a cohort. (Threshing percentage). | 78.0 |
| 17 | SDPRO | Fraction protein in seeds (g(protein)/g(seed)) | 0.216 |
| 18 | SDLIP | Fraction oil in seeds (g(oil)/g(seed)) | 0.048 |

After performing calibration, it's time to validate this set of genetic coefficients for both early sowing and late sowing condition data set of the final year *i.e.*, 2020-21. Model generated simulated values using this derived genetic coefficient were compared over the actual or observed on field data. Anthesis (DAS or days after sowing), 1st pod development (DAS), physiological maturity (DAS) and harvest maturity (DAS), these phenological attributes of JG-14 along with other yield attributing characteristics such as grain yield (kg/ha), grain number per $m^2$ and unit grain weight (mg) can be simulated further using the estimated genetic coefficients as referred to table 1.

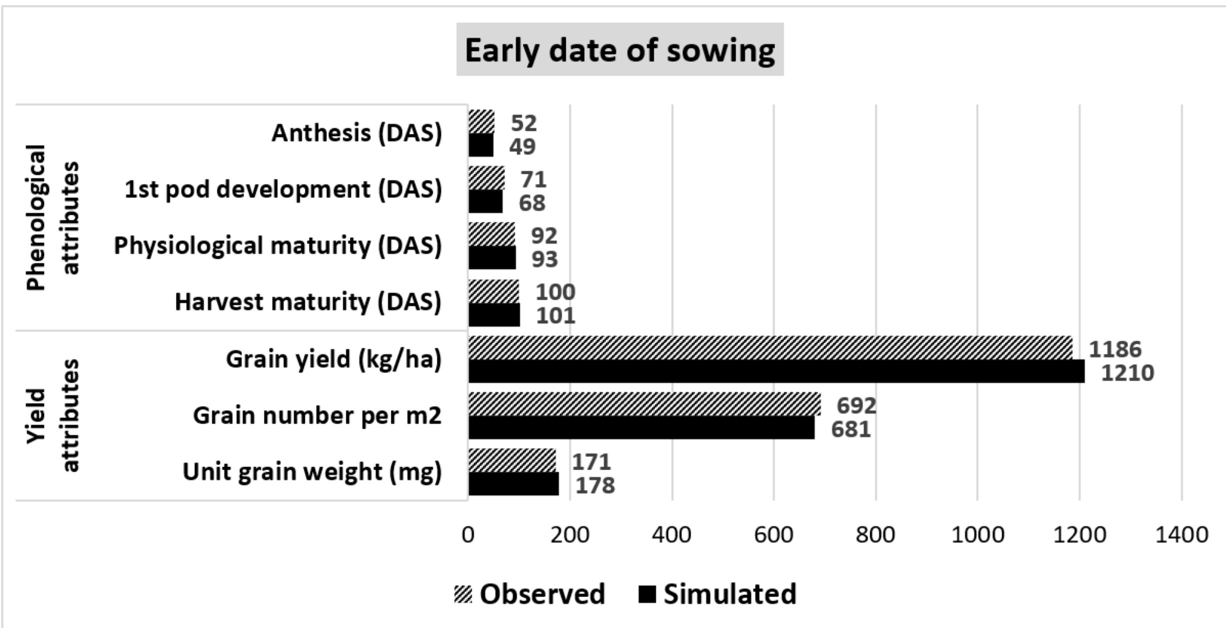


Figure 2: Validation of genetic coefficients for the early date of sowing data set

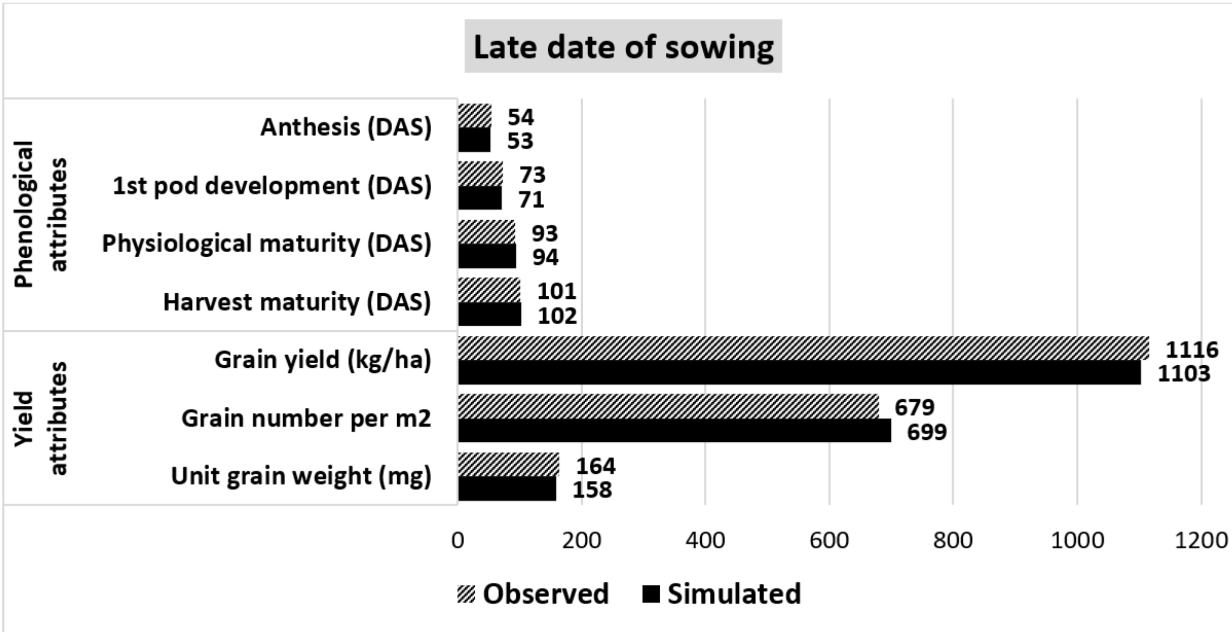


Figure 3: Validation of genetic coefficients for the late date of sowing data set

It is clear from figure 2 and figure 3 that the simulated values are very close to the observed data for both the sowing conditions. Harvest maturity of early sown crop occurs after 101 days in the simulated model against observed 100 days in 2020-21 and in case of late sowing condition, simulated model shows 102 days against 101 days observed harvest maturity. The set of genetic coefficients also can simulate the yield attributes like grain yield, grain number per $m^2$ and unit grain weight. Grain yield for early date of sowing is simulated as 1210 kg/ha, while the observed grain yield is 1186 kg/ha. On the other hand, this model shows 1103 kg/ha simulated grain yield for late sowing condition against 1116 kg/ha observed in 2020-21. There are negligible amount of deviations between the observed data and simulated results for other two yield attributes *i.e.*, grain number per $m^2$ and unit grain weight in both the sowing conditions. Moreover, some model statistics like $R^2$ value and d-Stat value under DSSAT were presented in table 2 for further comprehensible justification.

Table 2: Various model statistics in DSSAT for all phenological and yield attributes under study:

| **Parameters** | **$R^2$ Value** | **d-Stat value** |
|---|---|---|
| **Phenological attributes** | | |
| Anthesis (DAS) | 0.179 | 0.429 |
| $1^{st}$ pod development (DAS) | 0.104 | 0.406 |
| Physiological maturity (DAS) | 0.206 | 0.447 |
| Harvest maturity (DAS) | 0.522 | 0.522 |
| **Yield attributes** | | |
| Grain yield (kg/ha) | 0.668 | 0.788 |
| Grain number per $m^2$ | 0.192 | 0.524 |
| Unit grain weight (mg) | 0.507 | 0.720 |

$R^2$ value of harvest maturity (DAS), grain yield (kg/ha) and unit grain weight (mg) were recorded as 0.522, 0.668 and 0.507, which are sufficiently good for accepting the set of genetic coefficients. The d-Stat value closer to 1 for any character denotes better performance for that attribute specifically. From the table it can also be observed that all the three yield attributing characters along with phenological parameter harvest maturity have satisfactory d-Stat values to adopt the genotypic coefficient of the new chickpea variety JG-14.

The generated genotypic coefficient can be used for futuristic prediction of crop phenology and yield attributes as the model performs well throughout the validation process. It will be very useful to identify potential JG-14 producing areas all over India without cultivating the crop on field in advance. It will save time by providing valuable insights to government and many non-government policy-making organisations to ensure agricultural resilience and sustainable development not only in India, but also throughout any part of this world.

## 4. CONCLUSION

This study successfully calibrated and validated a set of genotypic coefficients for the chickpea variety JG-14 using the DSSAT crop growth simulation model. By integrating soil and weather data along with detailed management practices from 2018-19 to 2020-21, a comprehensive set was developed. The final set of 18 coefficients accurately captured key phenological and yield attributes, with validation showing strong alignment between simulated and observed data across both early and late sowing conditions.

The derived set of genetic coefficients also can determine the best strategies that should be followed in different location depending upon a wide range of management practices and environmental conditions. Better combination of management practices for any area can be easily identified in advance. Moreover, this coefficient will also develop a sense regarding long term climate change impact like changes in temperature, precipitation pattern, incoming solar radiation, day length, $CO_2$ concentration in the atmosphere etc. The effect of these climatic variables can be increased or decreased to observe their influence on production of JG-14 chickpea variety in varied agro-climatic regions under “Environmental modification” module. This research establishes a robust framework for enhancing chickpea production at both national and global levels.

## DISCLAMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declares that NO generative AI technologies such as large Language Models (ChatGPT, COPILOT, etc) and text-to-image generation have been used during writing or editing of this manuscript.

## DATA AVAILABILITY STATEMENT

On reasonable request, the corresponding author will provide data supporting the study’s results. The raw data, cannot be made public for reasons of confidentiality and privacy. However, researchers who satisfy the requirement for access to confidential data can be given access to aggregated and anonymized data.

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