RESPONSE OF *SUMMER* SOYBEAN CULTIVARS FOR SEED PRODUCTION UNDER DIFFERENT SOWING WINDOWS

by

Mr. Prem Shanker Gochar
(Reg. No.020/015)

A Thesis submitted to the
MAHATMA PHULE KRISHI VIDYAPEETH
RAHURI – 413 722, DIST. AHMEDNAGAR
MAHARASHTRA, INDIA

in partial fulfillment of the requirements for the degree

of

MASTER OF SCIENCE (AGRICULTURE)

in

AGRONOMY

DEPARTMENT OF AGRONOMY

POST GRADUATE INSTITUTE
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APPROVED BY

Dr. R.P. Andhale
(Chairman and Research Guide)

Dr. B.T. Sinare
(Committee Member)

Dr. R.S. Wagh
(Committee Member)

Dr. M.R. Patil
(Committee Member)

DEPARTMENT OF AGRONOMY

POST GRADUATE INSTITUTE
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2022

CANDIDATE'S DECLARATION

I hereby declare that this thesis or part
there of has not been submitted
by me or another person to any
other University or Institution
for a Degree or
Diploma

Place : MPKV, Rahuri

Date : / /2022 **(Prem Shanker Gochar)**

Dr. R.P. Andhale
Chairman and Research Guide
Associate Professor of Agronomy,
Mahatma Phule Krishi Vidyapeeth,
Rahuri – 413 722, Dist. Ahmednagar,
Maharashtra (India).

CERTIFICATE

This is to certify that the thesis entitled, **"RESPONSE OF *SUMMER* SOYBEAN CULTIVARS FOR SEED PRODUCTION UNDER DIFFERENT SOWING WINDOWS"** submitted to the Faculty of Agriculture, Mahatma Phule Krishi Vidyapeeth, Rahuri Dist. Ahmednagar (M.S.) in partial fulfillment of the requirement for the award of the degree of **MASTER OF SCIENCE (AGRICULTURE)** in **AGRONOMY,** embodies the results of a piece of *bona fide* research work carried out by **Mr. PREM SHANKER GOCHAR** under my guidance and supervision and that no part of the thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been duly acknowledged.

Place : MPKV, Rahuri (R.P. Andhale)
Date : / /2022 Research Guide

Dr. A.V. Solanke
Head,
Department of Agronomy
Mahatma Phule Krishi Vidyapeeth
Rahuri – 413 722, Dist. Ahmednagar
Maharashtra State, INDIA

CERTIFICATE

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Place : MPKV, Rahuri

Date : / /2022 (A.V. Solanke)

Dr. U.D. Chavan
Associate Dean
Post Graduate Institute
Mahatma Phule Krishi Vidyapeeth
Rahuri-413 722, Dist. Ahmednagar
Maharashtra State, INDIA

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Place : MPKV, Rahuri (U.D Chavan)

Date : / /2022

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Place : M.P.K.V., Rahuri.

Date : / / 2022 **(Prem Shanker Gochar)**

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LIST OF ABBREVIATIONS

@	:	At the rate of
%	:	Percentage
$^{-1}$	:	Per
Σ	:	Summation
µ	:	Micro
√	:	Square root
^{0}C	:	Degree celcius
B:C	:	Benefit cost ratio
CV	:	Co-efficient of variation
C.D.	:	Critical difference
cm	:	Centimeter
cv.	:	Cultivar
DAS	:	Days after sowing
dm^2	:	Decimeter square
dSm^{-1}	:	Deci Seimens per meter
E.C.	:	Electrical conductivity
et al.	:	etalli (And others)
etc.	:	et cetera (and so on)
Fig.	:	Figure
g	:	Gram
GDD	:	Growing degree days
ha	:	Hectare
ha^{-1}	:	Per hectare
hrs	:	Hours
i.e	:	id est (that is)
K	:	Potassium
K_2O	:	Potassium oxide
kg	:	Kilogram (s)
kg ha^{-1}	:	Kilogram per hectare
km hr^{-1}	:	Kilometer per hour
LAI	:	Leaf area index
m	:	Metre
M^2	:	Meter square
m^{-2}	:	Per meter square
mm	:	Millimeter (s)
Max	:	Maximum
mg	:	Milligram (s)

Min.	:	Minimum
MOP	:	Muriate of potash
MW	:	Meteorological week
N	:	Nitrogen
No.	:	Number
NS	:	Non-significant
OC	:	Organic carbon
P	:	Phosphorus
P_2O_5	:	Phosphorus penta oxide
ppm	:	Parts per million
pH	:	Pussance de hydrogen
PTU	:	Photo thermal unit
q	:	Quintal
RH	:	Relative Humidity
₹	:	Indian rupee
S	:	Sowing window (s)
S.E.m±	:	Standard Error of mean
SSP	:	Single Super Phosphate
t	:	Tonnes
V	:	Variety (s)
var.	:	Variety (s)
viz.,	:	Videlicent (Namely)

ABSTRACT

"RESPONSE OF SUMMER SOYBEAN CULTIVARS FOR SEED PRODUCTION UNDER DIFFERENT SOWING WINDOWS"

By

Mr. PREM SHANKER GOCHAR

A candidate for the degree
of
MASTER OF SCIENCE (AGRICULTURE)
in
AGRONOMY
2022

Research Guide	**:**	**Dr. R. P. Andhale**
Department	**:**	**Agronomy**

A field experiment entitled "Response of summer soybean cultivars for seed production under different sowing windows" was undertaken during *summer* season of the 2022 at PGI-farm, Post Graduate Institute, Mahatma Phule Krishi Vidyapeeth, Rahuri to assess the effect of different sowing windows and varietal performance on growth and yield of soybean in *summer* season.

The experiment was laid out in split plot design with three replications. The treatment comprised of four sowing windows *viz.,* S_1: 1st MW (01st Jan-07th Jan), S_2: 3rd MW (15th Jan- 21st Jan), S_3: 5th MW (29th Jan – 04th Feb), S_4: 7th MW (12th Feb – 18th Feb), and four varieties of soybean *viz.,* V_1: JS-9305, V_2: Phule Kimaya (KDS-753), V_3: Phule Sangam (KDS-726) and V_4: Phule Durva (KDS-992).

Among the sowing windows, sowing during 3rd MW recorded significantly higher growth attributes *viz.,* plant height (99.9 cm), plant spread (50.50 cm), number of functional leaves (30.56), number of primary branches plant^{-1} (8.27), leaf area plant^{-1} (48.51 dm^2), and dry matter production plant^{-1} (41.49 g) over the remaining sowing windows during *summer* 2022.

The number of days required to emergence, 50 % flowering and physiological maturity as well as at harvest were significantly higher in case of 1st MW sowing window (11.5, 75.6, 115 and 126.5 days, respectively) over rest of the sowing windows. The 7th MW sowing window took minimum days to emergence (7.4 days), 50 % flowering (55.5 days), physiological maturity (90.5 days) and harvest stage (101.8 days) during the period investigation.

The 3rd MW sowing window recorded significantly higher value of yield attributes *viz.,* number of pods plant^{-1} (84.33), number of seeds pod^{-1} (3.41), weight of pods plant^{-1} (34.53 g), weight of seeds plant^{-1} (14.02 g) and 100 seed weight (12.64 g) over remaining sowing windows. Grain yield (2633 kg ha^{-1}), halum yield (3091 kg ha^{-1}), biological yield (5725 kg ha^{-1}) and harvest index (46.1) and quality parameters like protein content (40.33 %) and Oil content (19.71 %), germination percentage (92.81 %), seed moisture content (9.75 %) and seed vigour index-I, II (2416 and 87.81) were recorded with higher in 3rd MW sowing window.

The maximum growing degree days value was recorded in 1st MW sowing window at emergence, physiological maturity and harvest stage (126.1, 1797.5, and 2068.1^{0}C days, respectively) and at 50% flowering highest GDD (982.1) recoded by 7th MW sown crop.

The highest values of soil available nitrogen (251 kg ha^{-1}), phosphorus (20.0 kg ha^{-1}) and potassium (370 kg ha^{-1}) content of soil after harvest of *summer* soybean was recorded under 7th MW sowing window.

The 3rd MW sowing window recorded higher gross monetary returns (3,68,713 ₹ ha^{-1}), net monetary returns (2,96,258 ₹ ha^{-1}) and B:C ratio (5.09) followed by 3rd and 5th MW sowing. The lowest gross monetary returns (3,01,151 ₹ ha^{-1}), net monetary returns (2,77,265 ₹ ha^{-1}) and B:C ratio (4.39) were recorded in 7th MW sowing window.

All the growth attributing characters increased progressively with advancement in the age of crop. The variety Phule Durva recorded significantly higher plant height (90.32 cm), plant spread (52.63 cm), number of functional leaves plant^{-1} (28.99), number of primary branches plant^{-1} (7.57), leaf area plant^{-1} (43.07 dm^2), and dry matter production plant^{-1} (35.70 g).

Abstract contd…. **Mr. Prem Shanker Gochar**

The number of days required to emergence, 50 % flowering, physiological maturity and harvest stage were significantly higher in case of Phule Durva (10.0, 68.2 104.5, and 118.7 days, respectively) over rest of the varieties under study.

Yield attributing characters *viz.,* number of pods plant^{-1} (82.49), number of seeds pod^{-1} (3.30), weight of pods plant^{-1} (33.43 g), weight of seeds plant $^{-1}$ (13.64 g) and 100 seed weight (12.93 g) were found significantly higher in Phule Durva than the other three varieties under study. The variety Phule Durva recorded significantly superior grain yield (2560 kg ha^{-1}), halum yield (3198 kg ha^{-1}) , biological yield (5758 kg ha^{-1}), quality parameters like protein content (40.01 %), oil content (19.13 %), and seed quality parameters *viz.,* germination percentage (92.28 %), seed moisture content (9.77 %) and seed vigour index-I, II (2407 and 87.52) over rest of the varieties under study.

The maximum growing degree days value was recorded in variety Phule Durva at emergence, 50 % flowering, physiological and harvest stage (110.8, 1019.8, 1829.0 and 2161.3^{0}C days, respectively).

The highest values for available nitrogen (245 kg ha^{-1}), phosphorus (19.2 kg ha^{-1}) and potassium (368 kg ha^{-1}) in soil after harvest of soybean was recorded with variety JS-9305.

The variety Phule Durva yielded higher gross monetary returns (3,58,446 ₹ ha^{-1}), net monetary returns (2,87,913 ₹ ha^{-1}) and B:C ratio (5.08) followed by JS-9305 over rest of the varieties.

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1. INTRODUCTION

Soybean (*Glycine max* L. Merrill) has become miracle crop of the 21st century and is often designated as 'Golden Bean', "Wonder crop" and 'Poor man's meat'. Soybean belongs to family Fabaceae (Leguminosae). It is the most important economic oilseed crop and recognized as the most popular pulse cum oilseed crop in the world (Mehetre *et al.,* 2022). The cultivated soybean (*Glycine max* L. Merrill) originated from its wild ancestor *Glycine ussuriensis*, which is presently known as *Glycine soja*. Soybean was migrated from China to neighboring countries with development of sea and land trade during 7th century (Dupare *et al.,* 2008). World soybean production is projected as 380.3 million tonnes during 2021-22 as compared to previous year (366.1 million tonnes). In 2021-22, India covered 121.76 lakh ha of area under soybean with 12.4 million tonne. Anon., (2022a) The important soybean growing states of the country are Madhya Pradesh, Maharashtra, Rajasthan, Karnataka and Telangana. In Maharashtra it is cultivated over an area of 46.1 lakh hectares with production and productivity of 54.22 lakh tonnes and 991 kg ha^{-1}during 2021-22, respectively Anon., (2022b).

Soybean is the number one oil seed crop in terms of oil production in the world. Soybean yields are two to three times higher than those of pulse crops, which are the major source of dietary protein. Soybean seed contains 40-45 per cent protein, 20-22 per cent oil, 20-26 per cent carbohydrate and high amount of Ca, P, vitamins and essential amino acid like lysine 5 per cent (Rahman *et al*., 2011). Soybean is the cheapest source of protein, therefore, it is called as "poor man's meat "and it is richest, cheapest and easiest source of best quality protein and fats and having multiple uses as food and industrial products, therefore, it is called as "wonder crop". Due to its capacity to fix atmospheric nitrogen in the soil to maintain the soil fertility and having beneficial effect on successive crop it is called as 'golden bean" or "Gold of soil". It is a triple beneficiary crop, a unique food, a valuable feed and an industrial raw material with considerable potential (Gurav *et al.,* 2022).

Soybean is generally sown in the beginning of monsoon and harvested at the end of October. It can be also grown from February -June. Most soybean cultivars respond to photoperiod as quantitative short-day plants. Soybean being a thermosensitive, short-day plant, non-monetary crop management practice such as sowing time has direct effect on production scenario right from its adoption to time of maturity (Kumar, 2005). Hodges and French (1985) reported that soybean has a juvenile stage after emergence when it is especially sensitive to temperature and insensitive to day length. Soybean cultivates well in warm and moist climate. Temperature of 26.5 to 30^0C is optimum for its good cultivation. Soil temperatures of 15.5^0C and above are favorable for rapid germination and vigorous vegetative growth. The minimum temperature for effective growth is about 10^0C. A lower temperature tends to delay the flowering. Temperature is the most crucial factor for achieving the optimum production, the temperature lower than 10^0C are not suitable for performance of soybean (Arshi *et al.,* 2010). Most of the varieties will flower and mature quickly if grown under condition where the day length is shorter than 14 hours as long as temperatures are favorable. Therefore, time of sowing may be a vital consideration in soybean. In northern India soybean is often planted from third week of June to first fortnight of July. Latest research results have shown that sowing soybean within the last week of June leads to maximum yield and after 7^{th} July causes reduction in seed yield up to 40 kg ha^{-1} day^{-1}.

The upper limit of soybean productivity depends on crop weather relation, which in turn depends on the time of sowing and seasonal variations. Amongst various agronomic manipulations, time of sowing plays an important role in influencing seed quality and yield of soybean. Time of sowing is one of the most important factors that govern crop phonological development, efficient conversion of biomass into economic yield. The anthesis, accumulation and translocation of photosynthates depend on building up of efficient photosynthetic infrastructure at pod filling stage. There must be favorable ʽsource - sink᾿ relationship in the plants for achieving higher productivity. Crop yield is mainly influenced by climatic conditions throughout the growing season. In recent past the productivity of soybean in India, had an average yield loss of 44 to 60 per cent due to weather abnormalities. The yield gaps can be reduced with better crop management, which include the sowing in proper window. Sowing windows influence soybean growth stages, due to variation in photoperiod (Han *et al*., 2006 and Kumudini *et al.,* 2007), air temperature (Chen and Wiatrak, 2010). Appropriate planting date causes optimal utilization of the climatic resources such as temperature, humidity, day length and also anthesis time adaptation with proper temperature (Hashemi, 2001).

Quality seed is a major factor in crop development and productivity. Seed quality, as measured by its viability and vigour worldwide, play a major role in crop establishment as well as the final crop yield. Seed deterioration leads to reductions in seed quality, performance and establishment (Donald and Humbblin, 1976). Despite the numerous constraints, soybean continues to make improvement in the world economy. Its poor storability remains a great challenge in soybean production worldwide. The germination and vigour potential of soybean is short lived as compared to other grain crops and it is often reduced prior to planting time (Nkang and Umoh., 1996).

Soybean is mostly grown in Maharashtra under rainfed condition. The adverse climatic condition especially temperature, rainfall, higher humidity, etc. cause crop to become more prone to insect and disease incidence that reduce the seed yield quality in *kharif* season. This unfavorable environmental condition not only causes the reduction in yield but also affect the germination per cent in *kharif* soybean production. Therefore, the production of seeds and availability of good seeds of soybean is a major challenge for farmers. To overcome this challenge, we need to produce good quality of soybean seed in *summer* for fulfilling the requirement of *kharif* soybean seeds. Therefore, it is necessary to determine an accurate date of sowing of different varieties in *summer* season to get maximum yield of *summer* soybean and increase availability of seeds for sowing in *kharif* season.

In *summer* season the soybean is less prone to attack of insect pest and disease**,** but may have some constraints for soybean production in *summer* season like, water availability, hot winds, weather, photoperiod, etc. Establishing the most appropriate sowing dates of different varieties for the production of quality seeds depends on number of factors, especially the genetic characters of the cultivars and the climatic conditions predominant in the region where they are planted. With this view the present experiment entitled "Response of *summer* soybean cultivars for seed production under different sowing windows" has been planned with following objectives: -

1. To study the effect of sowing time on growth and yield of *summer* soybean.
2. Yield performance of different soybean cultivars in *summer*.
3. Economic studies of soybean varieties under different sowing windows.

2. REVIEW OF LITERATURE

An experiment entitled "Response of *summer* soybean cultivars for seed production under different sowing windows", was conducted during the *summer* season of 2022 at Post Graduate farm, Post Graduate Institute, Mahatma Phule Krishi Vidyapeeth, Rahuri. Literature pertaining to soybean date of sowing and varieties is discussed under different sub heads.

2.1 Effect of sowing time on growth and yield of *summer* soybean.

Adjei and Splittstoesser (1994) reported that as planting date was delayed, total lipid was decreased but percent protein showed a negative correlation with the vegetative characteristics, seed yield and its components.

Gibson and Mullen (1996) reported that growth temperature influences the seed yield of soybean and showed that day/night temperatures of 30/20, 30/30, 35/20 and 35/30^{0}C were imposed during flowering and pod set (R1-R5), seed fill and maturation (R5-R8) resulted in reduced days to first flowering, days to 50 % flowering, days to maturity, seed formation and seed growth. They suggested that soybean seed yield reductions from high temperatures are primarily a response to day temperature and moderate to high night temperatures have a small effect on soybean seed yield components.

Arulnandhy (1998) reported that percentage of germination and emergence rate of harvested seed in sand and in field were highest with May sowing of the mother crop and were lowest with January and February sowing.

Chavan *et al.* (1998) concluded that, the crop sown on 31st January recorded higher values of all yield attributes *viz.,* number of branches plant^{-1}, pods plant^{-1}, 100-seed weight compared to earlier sown crop of 5th and 15th January and late sown crop of 15th February.

Halvankar *et al.* (2001) conducted a field experiment on response of soybean varieties to sowing date during *summer* season and reported that sowing of soybean on the 5th February recorded significantly the highest plant height than the 25th January and 15th February sowing at Pune.

Khalil *et al.* (2001) carried out a field experiment on soybean seed matured on different dates affect seed quality and reported that soybean seeds from January, February and March planted crop produced heavier seed while seeds from the July and August planted crops produced smaller seeds.

Kitano *et al.* (2006) studied the effect of higher temperature on seed yield of soybean by dividing effects on flowering and pod set. Higher air temperature from the pre-flowering stage to the flowering stage promoted vegetative growth, so that the pod setting ratio of the whole plant become higher but instead of an increase in the number of pods, the seed size become smaller.

Medida *et al.* (2006) conducted a field experiment to study the effect of influence of weather on thermal heat requirement for different phenophases on growth of soybean during *kharif* 2004 at CCS Haryana Agricultural University, Hisar. Results revealed that the different date of sowing had an effect on phonological stages. Growing degree-days consumed by the crop to reach physiological maturity was higher in early sown crop.

Rehman and Islam (2006) carried out a field experiment at Bangladesh Agriculture University, during the period from November 2003 to June 2004 to find out the effect of sowing date and variety on the yield and yield attributes of soybean. They reported that sowing between mid of December to mid-January showed significantly positive effect on yield of soybean due to highest number of pods plant^{-1} (55.58), number of seeds pod^{-1} (2), 100-seed weight (9.56 g), harvest index (50.12 %), seed yield (2210 kg ha^{-1}) and highest biological yield (4080 kg ha^{-1}).

Kumar *et al.* (2008) conducted an experiment during *kharif* season of 2004 on growth and yield response of soybean in relation to temperature, photoperiod and sunshine duration at Anand, Gujrat, India. It was concluded that early sown crop in *kharif* season on 16th June produced more dry matter and also resulted in higher seed yield (1871.3 kg ha^{-1}) and stover yield than the late sown crop as they accumulate more growing degree days (6157^{0}C day). The number of days taken for physiological maturity was 114, 106 and 78, when crop was sown on 16th June, 26th June and6th July, respectively.

Ahmed *et al.* (2010) revealed that the highest number of pod plant^{-1} (39.85) and fertile pod plant^{-1} were observed with 16th December sowing while 7th November sowing showed the lowest number of pods.

Chen and wiatrak (2010) found that the high temperature at reproductive stage might have affected pollination, fertilization and consequently poor pod set resulting in lower number of pods plant^{-1}.

Ram *et al.* (2010) conducted an experiment at PAU Ludhiana, Punjab during *kharif* 2008 and 2009 to study the effect of time of sowing on the performance of soybean and reported that the highest plant height (77.7 cm), pods plant^{-1}(64), seeds pod^{-1} (2.4), 100-grain weight (10.0), oil content (20.52 %), protein content (43.24 %) and biological yield (5238 kg ha^{-1}) were found in June 5th sowing crop.

Rekha and Dhurua (2010) conducted a field experiment during *rabi* and *summer* seasons of 2004 and 2005 in vertisols at Agriculture Research Station, Adilabad Andhra Pradesh, to study the performance of soybean varieties JS-335, PK-1029 and MACS-450 with different sowing dates. They reported that JS-335 variety was performed better when sown on January 30th than other varieties.

Singh (2010) reported that, the sowing of soybean on 24th May recorded significantly highest plant height (89 cm), pod plant^{-1} (46), biological yield (6088 kg ha^{-1}) and 100-seed weight (9.7 g).

Khosla *et al.* (2011) carried out a field experiment at PAU, Ludhiana Punjab. They concluded that, the main season genotypes (May and June sowing) GY can be increased by increasing HI and enhancement of biomass production in early maturing-photo and thermo insensitive in February-March sowing could lead in yield improvement. Study also demonstrated that early maturing photo-thermo insensitive genotypes could be grown successfully during *spring/summer* (February to June).

Islami and Sugito (2012) explained that the number of days to maturity of soybean declined with each successive sowing date due to high temperature (35.6^{0}C) during vegetative development which might have shortened intervals between vegetative and reproductive growth stages.

Nabi *et al.* (2012) reported that, the effect of sowing date was significantly higher on traits including number of seeds pod^{-1}, number of pods plant^{-1}, grain yield, total dry matter, 1000-seed weight and harvest index in soybean.

Kandil *et al.* (2013) carried out a field experiment on influence of planting date on some genotypes of soybean growth, yield and seed quality at field crop research Institute, ARC, Egypt during *summer* 2010-11. Results revealed that, the genotype Giza 111 gave the highest seed yield (2462 kg ha^{-1}) and 100-seed weight (18.69 g), on 5th May sown crop.

Goyal *et al.* (2013) investigated the effect of environment on grain yield, its components and quality characters in soybean *(Glycine max* L. Merrill) at Department of Plant Breeding and Genetics, Punjab Agricultural University, Ludhiana during *spring* season and correlation analysis revealed that grain yield was positively correlated with plant height and number of pods plant^{-1} in all the three sowings except with plant height in late sowing. Oil content had highly negative significant correlation with protein content in *spring* sowing but showed no correlation in main and late sowings. Oil content showed negative correlation with 100-seed weight in *spring* sowing, but showed positive correlation in late sowing and no correlation in main sowing.

Rehman and Hossain (2013a) conducted a field experiment on effect of sowing date on germination and vigour of soybean (*Glycine max* (L.) Merrill) seeds at Agronomy Field, Agricultural University Bangladesh during *kharif* and *rabi* season and reported that the highest germination (97.83 %) and vigour index (43.9) were found in 4th November and 23rd September sown crop, respectively. Thus, it was concluded that soybean seed having high germination and vigour could be obtained by planting soybean during November to December and August to September.

Yari *et al.* (2013) investigated the yield and yield components of soybean cultivars as affected by planting date at Agricultural Research Station in Ilam province Iran during 2011-12 and results showed that the highest plant height (57.17 cm), number of pods plant^{-1} (38.12), seed yield (2544 kg ha^{-1}), biological yield (5538 kg ha^{-1}) were found in May 31st sowing crop.

Asim *et al.* (2014) reported that sowing dates significantly affected pods plant^{-1}, seeds pod^{-1}, seed weight and seed yield of soybean. Maximum pods plant^{-1}

(74.20), seeds pod^{-1} (2.1) and seed yield (1459 kg ha^{-1}) was recorded in April sown crop. However, May sown crop produce heaviest seed (11.5 g, 100-seeds wt.).

Rehman *et al.* (2014) studied the effect of planting time and cultivar on soybean performance in semi-arid Punjab during *spring* season. They reported that the highest plant height (96.23 cm), number of pods plant^{-1} (29.53), seed yield (1530.2 kg ha^{-1}) and biological yield (4430.5 kg ha^{-1}) were found in 28th January sown crop during *spring* season.

Singh *et al.* (2014) carried out a field experiment on influence of diverse environments on the growth and productivity of soybean genotypes in northern India at research farm of Punjab Agricultural University, Ludhiana during *kharif* 2012. They found that soybean crop sown on 5th June recorded significantly highest plant height (102.5 cm), number of pods plant^{-1} (78.9), seed index (14.06 g), straw yield (7471 kg ha^{-1}) and seed yield (2713 kg ha^{-1}), followed by 15th June sown crop.

Asewar *et al.* (2015) concluded that, the soybean crop sown on 25th MW recorded significantly highest seed yield (2297.4 kg ha^{-1}), number of pods plant^{-1} (29.88), number of seeds pod^{-1} (2.83), harvest index (38.11), biological yield (6027.4 kg ha^{-1}) and protein content (40.46 %), oil content (40.16 %).

Taware *et al.* (2015) carried out an experiment to find out the effect of different sowing dates on yield and its attributes in soybean during *kharif* season of 2009-11 in vertisol soil at Agharkar Research Institute, Pune M.S. It was observed that soybean crop sown during 15th June recorded significantly highest plant height (65.68 cm), number of pods plant^{-1} (73.5), branches plant^{-1} (4.23), seed index (14.76 g), harvest index (46.47 %), seed yield (3379 kg ha^{-1}), straw yield (3863 kg ha^{-1}) and oil content (18.73 %) followed by 30th June during *kharif* season.

Zao *et al.* (2015) chosen nine soybean varieties to carried out an experiment on the sowing date with nine soybean varieties under *summer* conditions of Yunnan. The results showed that with the delay of sowing date, the growth period of the tested varieties was shortened gradually and main days of blossom to physiological maturity were shortened. Plant and branch numbers decreased. Yield and its components, such as pod plant^{-1}, seed number plant^{-1} and 100-seed weight and yield, declined evidently and there was obvious difference among varieties.

Akter *et al.* (2016) conducted a field experiment at Agriculture Institute Osijek and reported that, the highest, plant height (59.18 cm), dry weight plant^{-1} (32.53 g), seed yield (2170 kg ha^{-1}) were found in early sowing (2nd January) than delayed sowing (1st February) which gave lowest yield (1640 kg ha^{-1}).

Jaybhay *et al.* (2016) investigated the response of soybean varieties to date of sowing, plant population and fertilizer dose during the *kharif* season of 2014 at experimental farm of Agharkar Research Institute, Pune. They observed that soybean crop sown on 20th June recorded highest plant height (55.68 cm), number of pods plant^{-1} (42.64), seed index (13.56 g) and seed yield (3143 kg ha^{-1}) followed by 5th July sowing crop.

Kundu *et al.* (2016) conducted a field experiment to find out the effect of sowing date on yield and seed quality of soybean during *rabi* season of 2013-14 at Sher-e-Bangla Agricultural University, Dhaka. The results revealed that, the maximum number of pods plant^{-1} (27.11), number of seeds pod^{-1} (1.91), 1000-seeds weight (86 g), seed yield (2244 kg ha^{-1}), harvest index (61.55), vigour index (21.03 %) and also maximum germination percentage (94.42 %), protein content (39.37 %) and oil content (25.94 %) were found when soybean was sown on 2nd December which accrued the maximum yield and good quality soybean seed.

Bagade *et al.* (2017) carried out a field experiment on impact of sowing windows on growth and yield components of soybean under changing climatic conditions at Pune during 2013-14. They observed that soybean crop sown during 25th MW recorded significantly highest plant height (55.55 cm), number of branches plant^{-1} (8.23), number of functional leaves plant^{-1} (14.31), leaf area plant^{-1} (9.29 dm^{-2}), dry matter accumulation plant^{-1} (17.66 g) followed by 27thMW sown crop.

Sheshama *et al.* (2017) **c**onducted a field experiment to find out the effect of sowing dates and varieties on growth, yield and N-uptake of soybean during early *rabi* season of 2014-15 on clay loam soil at Agriculture College Farm, Bapatala, AP. The results showed that, the soybean crop sown during early *rabi* on 15th September was found to be the optimum sowing time for getting higher yield (1269 kg ha^{-1}), plant height (52.9 cm), dry matter accumulation (3093 kg ha^{-1}), harvest index (38.8 %) and uptake of nitrogen in coastal AP.

Naidu *et al.* (2017) carried out an experiment during *rabi* 2015-16 to find out the effect of time of sowing and varieties on the performance of soybean at S.V Agricultural College, Tirupati A.P. It was observed that, the earlier sowing during 16th September availed the plants enough time for vegetative growth to get higher seed yield (1417.3 kg ha^{-1}), plant height (38.2 cm), dry matter production (4798.3 kg ha^{-1}), number of pods^{-1} (37.9), number of seed pod^{-1} (3.0), 100-seed weight (11.2 g), harvest index (30.8 %) of soybean. Irrespective of the time of sowing, JS-335 is an ideal soybean variety suitable for *rabi* season on sandy clay loam soils of Tirupati.

Nath *et al.* (2017) conducted an experiment to find out the effect of sowing dates and varieties on soybean performance in Vidarbha region of Maharashtra, India. They revealed that, the soybean crop sown up to 27th MW accumulated higher growing degree days (1640.5^{0}C day) and recorded significantly higher plant height (29.98 cm), leaf area plant^{-1}(836.42 cm^{2}), dry matter accumulation plant^{-1} (10.97 g), pods plant^{-1} (26.28), seed weight plant^{-1} (4.33 g), seeds pod^{-1} (2.58), 100-seed weight (8.32 g), seed yield (839 kg ha^{-1}), harvest index (30.26 %) and biological yield (2773 kg ha^{-1}).

Prabhakar *et al.* (2017) carried out a field experiment on seed yield and quality of soybean [*Glycine Max* (L.) Merrill] as influenced by cultivar and sowing date in vertisols of Andhra Pradesh during *kharif* season 2014-16. Results showed that, the variety JS-335 recorded significantly higher yield (1296 kg ha^{-1}) than JS-93-05 (690 kg ha^{-1}). Early sowings during July 2nd fortnight and August 1st fortnight recorded significantly at par yields (1087, 1101 kg ha^{-1} respectively) with good initial and aging germination percentage (81, 58.8 % respectively). Though September 1st fortnight sown crop recorded significantly lowest seed yield (860 kg ha^{-1}), the initial and aging germination percentage were highest (88.6, 66.0 %).

Shah *et al.* (2017) studied the yield and quality traits of soybean cultivars response to different planting windows at Agriculture Research Station Harichand, Charsadda, Pakistan. They observed that sowing of soybean on 21st March produced significantly highest plant height (97.23 cm), number of pods plant^{-1} (30.53), test weight (75.85 g), seed yield (1531.2 kg ha^{-1}) and biomass yield (4431.5 kg ha^{-1}).

Sulthana *et al.* (2017) conducted an experiment to study the influence of sowing dates on physiological quality of soybean during *kharif* 2013 at College of

Agriculture, Rajendranagar, Telangana. The results revealed that, the highest germination percentage (99 %), shoot length (18.13 cm), root length (18.56 cm), seedling dry weight (89.0 mg), seedling vigour index- I and II (3607 and 8.81, respectively) and field emergence (91 %) were recorded for crop sown in July 2ndweek and they noticed that sowing date significantly affected the seed quality parameters and seeds from early sowings (July 2nd week sowing) had the good seed quality.

Bhatia and Jumrani (2018) conducted a field experiment on combined effect of high temperature and water-deficit stress imposed at vegetative and reproductive stages on seed quality in soybean at ICAR-Indian Institute of Soybean Research, Indore. Results showed that, the highest average seed yield plant^{-1} (10.9 g) was observed at 30/22^{0}C, which was significantly reduced by 19, 42 and 64 per cent at 34/24, 38/24 and 42/28^{0}C, respectively and highest seed germination (77.1 %), seed vigour index-I (882.3), seed vigour index-II (109.8) was observed on 30/22^{0}C temperature.

Chavan *et al.* (2018) studied the heat unit requirement of soybean (*Glycine max*) varieties under varied weather conditions at Parbhani. The results revealed that, the highest seed yield (3021 kg ha^{-1}), straw yield (2639 kg ha^{-1}), biological yield (5660 kg ha^{-1}), growing degree day (1695^{0}C) were found on 27th MW sowing crop.

Deshmukh *et al.* (2018) investigated for analyzing the effect of different season and sowing dates on physical seed quality of soybean during *kharif, rabi* and *summer* season of 2015-16 at MPKV Rahuri. Results revealed that, the highest value for physical seed quality character in *kharif* were recorded in the crop sown on June 1st followed by 15th January in *summer* and 15th October in *rabi* season.

Jagtap *et al.* (2018) evaluated the soybean varieties in post-monsoon for growth and yield performance under varied weather conditions during 2017-18 at VNMKV, Parbhani. It was observed that during post-monsoon season early sowing of soybean on 38th MW resulted in higher growth, seed yield (1465.79 kg ha^{-1}), biological yield (3964.88 kg ha^{-1}) and harvest index (36.69 %) compared to late sown crop.

Kumar *et al.* (2018) conducted a field experiment to find out the effect of sowing dates and plant densities on productivity and nutrient uptake of soybean during *kharif* season of 2014 at Agriculture College, Mahanandi, AP. The results showed that, the soybean crop sown during *kharif* on 28th June was found to be the optimum sowing time for getting higher plant height (38.1 cm), dry matter production (3762 kg ha^{-1}), number of pods $plant^{-1}$ (44.7), number of seeds pod^{-1} (2.2), grain yield (1487 kg ha^{-1}), harvest index (39.1 %), test weight (9.9 g).

Nawale *et al.* (2018) carried out a field experiment on soybean followed by wheat cropping system under variable sowing windows and fertilizer levels at the Instructional Farm of Post Graduate Institute, Mahatma Phule Krishi Vidyapeeth, Rahuri during *Kharif* 2013-14 and reported that, the highest number of $pods^{-1}$ (69.33), pods weight $plant^{-1}$ (26.66 gm), seed weight $plant^{-1}$ (16.70 g), 100-seed weight (14.41 g), seed yield (2941 kg ha^{-1}), straw yield (3547 kg ha^{-1}), biological yield (6488 kg ha^{-1}), harvest index (45.39 %), protein content (42.65 %) and oil content (17.76) were found in 24th MW sowing crop.

Niaz *et al.* (2018) conducted a field experiment on effect of different sowing dates on growth, yield and quality of soybean cultivars at University of Agriculture, Faisalabad during *spring* season 2016. Results revealed that the significantly highest plant height (50.99 cm), number of pods $plant^{-1}$ (27), germination count (54 plant m^{-2}) and oil content (18.13 %) were recorded by 4th April sown crop.

Walke *et al.* (2018) reported that, the sowing of soybean during 4th MW recorded significantly higher seed yield (2295 kg ha^{-1}), halum yield (2704 kg ha^{-1}), higher gross monetary return (` 173494 $ha^{-1}$), net return (` 134410 ha^{-1}) and B:C ratio (4.43).

Dalvi (2019) carried out a field experiment in three seasons *viz. kharif, rabi and summer* at VNMKV, Parbhani to find the seed production feasibility in different seasons. The results revealed that the seed yield of soybean varieties was significantly higher in *kharif* season followed by *summer* as compared to *rabi* season.

Deshmukh *et al.* (2019) reported that, the lowest days required for maturity in *summer* were recorded in the crop sown on 15th February (84 days) followed by 1st October in *rabi* season (84 days) and July 15th in *kharif* season (100 days). Variety JS-335 required lowest days to maturity in *kharif* and *summer* season whereas Variety KS-103 took less days to maturity in *rabi* season.

Gathiye and Kushwaha (2019) carried out an experiment during 2016-17 to find out the productivity of diversified soybean-based cropping system in Malva plateau of M.P, India. They were concluded that soybean variety JS-9305 recorded highest number of pod^{-1} (47.50), number of seeds pod^{-1} (2.9), seed index (11.6 g) and seed yield (2199 kg ha^{-1}) during crop sown under different crop sequence in *kharif* season.

Kanade *et al*. (2019) conducted a study to evaluate the growth of soybean (*Glycine max* (L.) Merrill) influenced by canopy temperature and humidity under different sowing dates at Department of Agricultural Meteorology Farm, Centre of Advanced Faculty Training in Agricultural Meteorology (CAFT), College of Agriculture Pune during *kharif* seasons of 2013 and 2014. Results revealed that, among the four meteorological weeks 24th MW sown crop recorded highest plant height (62.64 cm) and number of branches plant^{-1} (9.11).

Kessler *et al.* (2020) conducted the study on soybean yield and crop stage response to planting date and cultivar maturity in Iowa, USA and showed that yield potential would be maximized by planting before 20th May and concluded that planting earlier in the spring was a better management practice than maturity selection to maximize yield and the R3-R7 period duration was critical in determining potential yield.

Lokesh *et al.* (2020) investigated the effect of planting windows for seed production of soybean in off season under Kaylan Karnataka region. They observed that soybean crop sown during 1st fortnight of November recorded significantly higher plant growth parameters as well as seed yield (1975 kg ha^{-1}) followed by 2nd fortnight of November during off season.

Nigade and Gajbhiye (2020) investigated that the performance of soybean varieties in response to varied sowing dates under the sub-montane climatic conditions of Maharashtra, India during *kharif* season 2015-17 at Zonal Agricultural Research Station, Kolhapur Maharashtra. Results revealed that the first sowing date on 23rd MW exhibited significantly highest number of pods plant^{-1} (40.04), 100-seed weight (19.74 g) and grain yield of soybean (2032 kg ha^{-1}).

Reddy (2020) conducted a study to evaluate the impact of climate change on soybean (*Glycine max* L.) production at Department of Horticulture, Agricultural College, Aswaraopet, Telangana and found that typical soybean yield decreases linearly by 181.77 kg ha^{-1} for each five days delay in sowing from the traditional date (25th June) within the central zone of India and therefore the delayed sowing also reduces the oil and protein content of soybean.

Oligini *et al.* (2021) investigated the effect of sowing date and maturity groups on the economic feasibility of soybean-maize double *summer* crop system at the Dois Vizinhos-Agriculture Research Station, Brazil during 2016-2018. They found that the highest grain yield (6205.54 kg ha^{-1}) and cost of cultivation (` 1652.78 ha^{-1}) were recorded on 1^{st} week of October sown crop.

Rajasekhar *et al.* (2021) conducted a field experiment to find out the effect of sowing dates and plant densities on growth and yield of soybean during *kharif* season of 2020 at Krishi Vigyan Kendra, Kurnool, AP. The results revealed that the significantly highest plant height (69.88 cm), plant dry weight (23.67 g), number of pods $plant^{-1}$ (30.73), number of seeds pod^{-1} (2.97), seed index (8.58 g), grain yield (2430 kg ha^{-1}) and harvest index (37.99) were recorded in the crop sown on 1^{st} fortnight of July.

2.2. Yield performance of different sowing cultivars in *summer*

Deokar *et al.* (2009) conducted field experiment to study the difference in growth and yield of soybean consisting of six genotypes *viz.,* JS-71-05, Kuber, Chaturbhuj, Indira Soya-9, JS-335 and MACS-124. The genotype MACS-124 showed maximum plant height (51.62 cm) among all other genotypes and recorded a greater number of leaves (82.88). Genotype Kuber recorded the highest dry weight $plant^{-1}$ (42.96 g) number of seed $plant^{-1}$ (216.2). While genotype JS-335 showed the highest harvest index (36.63 %).

Ruhul Amin *et al.* (2009) conducted a field experiment on three soybean varieties *viz.* Shohag, Bangladesh soybean-4 and BARI soybean-5 and observed that among the three varieties, BARI soybean-5 influenced plant to have maximum dry matter, number of leaves $plant^{-1}$, leaf area (cm), but, the maximum plant height was found the highest in Bangladesh soybean-4.

Ram *et al.* (2010) conducted an experiment at PAU Ludhiana Punjab during *kharif* 2008 and 2009 to study the effect of time of sowing on the performance of soybean. Results revealed that, the variety SL-744 gave the highest grain yield (2170.5 kg ha^{-1}) which was statistically at par with SL-790 (2026 kg ha^{-1}) but significantly higher than SL-525 (1782 kg ha^{-1}).

Naidu *et al.* (2017) carried out an experiment during *rabi* 2015-16 to find out the effect of time of sowing and varieties on the performance of soybean at S.V Agricultural College, Tirupati A.P. It was found that variety JS-335 recorded highest seed yield (1204.9 kg ha^{-1}) and lowest yield was recorded by JS-9305 (992.2 kg ha^{-1}).

Nath *et al.* (2017) conducted an experiment to find out the effect of sowing dates and varieties on soybean performance in Vidarbha region of Maharashtra, India. The results revealed that soybean variety TAMS 98-21 recorded significantly higher seed yield (734 kg ha^{-1}) over JS-9305 (653 kg ha^{-1}), however it was statistically at par with JS-335 (700 kg ha^{-1}).

Prabhakar *et al.* (2017) carried out a field experiment on seed yield and quality of soybean [*Glycine Max* (L.) Merrill] as influenced by cultivar and sowing date in vertisols of Andhra Pradesh during *kharif* season 2014-16. Results showed that, the variety JS-335 recorded significantly higher yield (1296 kg ha^{-1}) than JS-93-05 (690 kg ha^{-1}).

Sheshama *et al.* (2017) conducted a field experiment to find out the effect of sowing dates and varieties on growth, yield and N-uptake of soybean during early *rabi* season of 2014-15 on clay loam soil at Agriculture College farm, Bapatala, AP. The results revealed that the highest seed yield of soybean (1109 kg ha^{-1}) was recorded with JS-335 which was on at par with variety JS-9305 (1016 kg ha^{-1}).

Gathiye and Kushwaha (2019) carried out an experiment to find out the productivity of diversified soybean-based cropping system in Malva plateau of M.P India during *kharif, rabi and Zaid* seasons of 2015-16 and 2016-2017 at the research farm of KVK, Dhar, M.P. They found that soybean variety JS-9305 significantly recorded maximum yield (2108 to 2290 kg ha^{-1}) over the JS-9560 (1960 to 2078 kg ha^{-1}) during 2015-16 and 2016-17, respectively.

Dandge *et al.* (2020) carried out an experiment during *kharif* 2018-19 to find out the performance of varieties under different sowing dates in soybean at Reginal Research Center, Amravati. They concluded that, the soybean variety AMS-MB 5-8 recorded highest pods $plant^{-1}$(52), dry weight $plant^{-1}$ (6.86), seed index (10.26 g), seed yield (1904 kg ha^{-1}), straw yield (1688 kg ha^{-1}) and harvest index (44.81 %).

Khaire *et al.* (2020) carried out a field experiment on performance of soybean (*Glycine max* (L.) Merrill) varieties to different spacings on growth, yield characters and yield under mechanization at College of Agriculture, Pune, during *kharif* season 2018. It was observed that, among the two varieties of soybean Phule Kimaya (KDS- 753) and Phule Sangam (KDS-726), Phule Kimaya (KDS- 753) recorded the highest plant height (54.21 cm), plant spread (28.53 cm), number of branches plant^{-1} (8.88), dry matter plant^{-1} (22.04 g), number of pods plant^{-1} (95.60), number of seeds pod^{-1} (2.77), weight of pods plant^{-1} (25.26 g), seed yield (2371.73 kg ha^{-1}) and straw yield (2623.3 kg ha^{-1}) followed by Phule Sangam (KDS-726) during *kharif* season.

Lokesh *et al.* (2020) investigated the effect of planting windows for seed production of soybean in off season under Kaylan Karnataka region. The experiment comprised of eight sowing dates and two varieties. The results revealed that, among the eight sowing dates November 1st fortnight sowing resulted in highest seed yield with better seed quality of both cultivars (JS-335 and Dsb-21).

Nigade and Gajbhiya (2020) conducted an experiment during 2015-17 to find out the performance of soybean varieties in response to varied sowing dates under the sub-montane climatic conditions of Maharashtra, India. The results revealed that, the Phule Agrani recorded significantly highest number of pods plant^{-1} (39.59), 100-grain weight (21.74 g) and grain yield (1977 kg ha^{-1}).

Gunjal *et al.* (2021) conducted a field experiment on effect of land configuration methods and sulphur levels on growth attributing characters during different growth stages of soybean (*Glycine max L. Merrill*) at Post Graduate Research Farm, Agronomy Section, RCSM College of Agriculture, Kolhapur during *kharif* season 2019. They were found that the highest plant height (68.70 cm), plant spread (43.55 cm), number of branches plant^{-1} (5.98) and leaf area plant^{-1} (158 dm^{-2}) with the 3 ft ridge and furrow method during *kharif* season.

Kamble *et al.* (2021) conducted a field experiment at Agricultural Research Station, Kasbe Digraj, Sangli, Maharashtra, India during *kharif* season 2018-19 to study the effect of iron nutrition on growth, quality and yield of soybean (*Glycine max* L.) grown on problematic inceptisol. Results revealed that the variety Phule Sangam (KDS-726) recorded the highest plant height (86.33 cm), number of branches plant^{-1} (11), number of pods plant^{-1} (44), grain yield (2493 kg ha^{-1}), straw yield (3779 kg ha^{-1}), 100-seed weight (19.2 g), oil content (19.46 %) and protein content (32.44 %) with the soil application of $FeSO_4$ @ 20 kg ha^{-1} along with two foliar sprays of chelated Fe @ 0.2% at 30 and 50 days after sowing during *kharif* season.

Sarika *et al.* (2022) investigated the effect of fertilizer levels and foliar nutrition on growth and yield of soybean (*Glycine max* (L.) Merrill) at College of Agriculture, Pune during *kharif* 2019. Results revealed that the variety Phule Sangam (KDS-726) recorded the highest plant height (58.94 cm), number of branches plant^{-1} (6.67), leaf area plant^{-1} (29.10 dm^2), dry matter plant^{-1} (24.30 g), number of pods plant^{-1} (62.80), number of seeds pod^{-1} (2.46), seed weight plant^{-1} (29.87 g), seed and straw yield (2173 and 2963 kg ha^{-1}, respectively) with the application of 100 % GRDF during *Kharif* Season.

2.3 Economic studies of soybean varieties under different sowing windows

Ram *et al.* (2010) conducted an experiment at PAU Ludhiana Punjab during *kharif 2008* and 2009 to study the effect of time of sowing on the performance of soybean. It was observed that, the highest net return (` 27852 ha^{-1}) and B:C ratio (2.23) were recorded in June 5th sowing in 2008 and in June 15th sowing in 2009.

Singh *et al.* (2014) carried out a field experiment on influence of diverse environments on the growth and productivity of soybean genotypes in northern India at research farm of Punjab Agricultural University, Ludhiana during *kharif* 2012. It was found that soybean crop sown on 5th June recorded significantly highest gross monetary return (` 69465 ha$^{-1}$), net monetary return (` 50418 ha^{-1}) and B:C ratio (3.65) followed by 15th June sown crop and SL-958 genotype recorded highest gross monetary return (` 67523 ha$^{-1}$), net monetary return (` 48476 ha^{-1}) and B:C ratio (3.54).

Asewar *et al.* (2015) observed that, the soybean sown on 25th MW recorded significantly highest gross monetary return (` 61928 ha$^{-1}$), net monetary return (` 44210 ha^{-1}) and B:C ratio (2.49) over the other dates of sowing and MAUS-71 recorded highest gross monetary return (` 53706 ha$^{-1}$), net monetary return (` 35989 ha^{-1}) and B:C ratio (2.03) over MAUS-81.

Nigade and Gajbhiya (2020) conducted an experiment during 2015-17 to find out the performance of soybean varieties in response to varied sowing dates under the Sub-Montane climatic conditions of Maharashtra, India. Results revealed that, the soybean sown on 25thMW recorded significantly highest gross monetary returns (64289 ha^{-1}), net monetary returns (19857 ha^{-1}), B:C ratio (1.29) over the other dates of sowing and Phule Agrani recorded highest gross monetary returns (` 62267 $ha^{-1}$), net monetary returns (` 17895 ha^{-1}), B:C ratio (1.25) over the other varieties.

Rajasekhar *et al.* (2021) conducted a field experiment to find out the effect of sowing dates and plant densities on growth and yield of soybean during *kharif* season of 2020 at Krishi Vigyan Kendra, Kurnool, AP. It was found that, the soybean sown on 1st fortnight of July with 30 cm x 10 cm recorded significantly highest cost of cultivation (33885) gross monetary returns (103946), net returns (70060.8) and B:C Ratio (2.07).

Sarika *et al.* (2022) investigated the effect of fertilizer levels and foliar nutrition on growth and yield of soybean (*Glycine max* (L.) Merrill) at College of Agriculture, Pune during *kharif* 2019. They found that the higher gross monetary returns (` 83364 $ha^{-1}$), net monetary returns (` 40656 ha^{-1}) and benefit cost ratio (1.96) were obtained with the application of 100 % GRDF in Phule Sangam (KDS-726) which was more over the application of 75% GRDF (` 71649 ha^{-1}).

3. MATERIAL AND METHODS

The field experiment of the research study entitled, "Response of summer soybean cultivars for seed production under different sowing windows" was conducted at PGI Research Farm, Post Graduate Institute, Mahatma Phule Krishi Vidyapeeth, Rahuri during *summer* season of 2022 in order to accomplish the objectives of the study. The details of material used and methods employed during the course of investigation have been described in this chapter.

3.1 Details of Experimental Material

3.1.1 Location of the Experimental Site

The field experiment was carried out at PGI Research Farm, Post Graduate Institute, Mahatma Phule Krishi Vidyapeeth, Rahuri, during *summer*, 2022. The geographical location of the experimental site was $19^0$19' N latitude; $74^0$39' E longitude and 540 m altitude above the mean sea level (MSL).

3.1.2 Soil

The soil types are mainly controlled by topography and rock types (parent material). The topography of the experimental field was uniform and levelled. The soil of the experimental field was well drained having a depth of 120 cm. In order to study the chemical properties of soil, the soil samples from 0-30 cm depth at 10 different randomly selected locations were collected from the experimental area before laying out the experiment. These samples were mixed thoroughly to make it as a representative sample. This composite sample was analysed for chemical properties of soil and presented below (Table1) along with analytical methods used. The data in the table 1. reveals that soil of experimental site was clayey in texture, moderately saline in reaction (pH 7.6) and electrical conductivity was 0.30 dSm^{-1}. The soil was low in available nitrogen (230 kg ha^{-1}) and moderate phosphorous (18.2 kg ha^{-1}) and high in available potash (368 kg ha^{-1}) while medium in organic carbon content (0.51 %).

3.1.3 Climate and Weather

3.1.3.1 General

Rahuri is situated in Ahmednagar district which lies in central part of the state of Maharashtra. The climate of Rahuri is hot and dry, on whole extremely genial and is characterized by a hot summer and general dryness during major part of the year except during south-west monsoon season. Agroclimatically Rahuri comes under 'Scarcity' zone and average rainfall of this zone ranges from 400-600 mm. About 70-80 per cent of annual rainfall is received during south-west monsoon season (June to September). Erratic nature of the rainfall affects the moisture content in the soil and therefore this zone is commonly known as drought prone area. The average temperature ranges between 9^0C (during December) to 41^0C (during April and May). Major crops grown in this zone are Pearl millet, Soybean, Sorghum, Wheat, Sugarcane, Bengal gram and Safflower.

Table 1. Initial chemical properties of soil

S. N	Particulars	Results	Method adopted	Reference
A.	**Chemical composition**			
1.	Organic carbon (%)	0.51	Wet oxidation	Nelson and Sommer (1982)
2.	Available N (kg ha^{-1})	230	Alkaline permanganate with 0.32% $KMnO_4$	Subbiah and Asija (1956)
3.	Available P_2O_5 (kg ha^{-1})	18.2	Olsen method with 0.5 M $NaHCO_3$ (pH 8.5)	Watanabe and Olsen (1965)
4.	Available K_2O (kg ha^{-1})	368	Ammonium acetate extraction with NH_4OAc	Jackson (1973)
5.	Soil pH (1:2.5 soil water suspension)	7.6	Potentiometric	Jackson (1973)
6.	Electrical conductivity (dSm^{-1})	0.30	Conductometric	Jackson (1973)

3.1.3.2 Climatic condition during experimental period

The meteorological data presented in Table 2 indicated that the mean maximum and minimum temperature during the cropping period varied from 24.7^0C to 40.9^0C and 12.0^0C to 28.1^0C, respectively. The mean relative humidity-I and II were recorded between 45 to 91 per cent and 12 to 54 per cent, respectively. Regarding the bright sunshine hours, the maximum sunshine hours (10.2 hrs day^{-1}) were recorded during the 18^{th} meteorological week and the minimum (5.7 hrs day^{-1}) were observed in the 1st meteorological week and mean maximum and minimum wind speed 0.4 Km hr^{-1} and 6 Km hr^{-1}, respectively.

Table 2. Weekly Meteorological Data Recorded during the Experimental Period

Month and Year	MW No.	Dates	Mean Temp. (°C)		Relative humidity (%)		Daily Rainfall (mm)	Open Pan Evaporation (mm)	Wind speed (Km hr^{-1})	Bright sunshine hours
			Maximum	Minimum	RH-I	RH-II				
January 2022	1	01 to 07	28.3	15.0	91	42	0.0	4.1	0.4	5.7
	2	08 to 14	25.2	14.6	88	54	0.0	3.1	1.5	5.7
	3	15 to 21	26.7	14.0	89	44	0.0	3.1	0.5	6.9
	4	22 to 28	24.7	12.0	82	42	0.0	3.0	2.1	7.5
	5	29 to 04	28.7	12.1	82	24	0.0	3.8	0.8	10.0
February 2022	6	05 to 11	27.3	13.2	81	33	0.0	4.3	1.5	9.6
	7	12 to 18	29.2	14.4	80	30	0.0	4.0	0.7	9.5
	8	19 to 25	33.0	16.1	73	23	0.0	5.5	1.0	9.7
	9	26 to 04	33.1	18.1	55	21	0.0	5.7	0.6	9.0
March 2022	10	05 to 11	32.3	19.7	73	30	0.0	5.6	1.4	7.0
	11	12 to 18	35.7	21.1	59	18	0.3	6.8	2.0	9.0
	12	19 to 25	37.6	22.5	55	16	0.0	7.6	2.1	7.1
	13	26 to 01	38.2	22.3	55	14	0.0	8.8	1.8	9.0
April 2022	14	02 to 08	39.7	23.4	52	12	0.0	9.4	1.9	9.4
	15	09 to 15	38.9	24.5	59	17	0.0	8.9	2.2	8.6
	16	16 to 22	38.8	24.9	52	16	0.0	10.0	1.9	9.2
	17	23 to 29	39.4	27.5	45	17	0.0	10.1	2.0	8.7
May 2022	18	30 to 06	39.9	26.7	50	17	0.0	11.5	3.2	10.2
	19	07 to 13	40.9	28.1	50	21	0.0	12.1	3.6	7.0
	20	14 to 20	39.1	27.0	60	23	0.2	11.1	4.9	7.3
	21	21 to 27	37.5	27.0	61	25	0.0	9.9	5.9	8.4
	22	28 to 03	38.3	26.3	65	25	0.0	11.2	6.0	8.3
June 2022	23	04 to 10	38.1	26.0	65	31	1.2	10.0	3.8	6.5
	24	11 to 17	35.8	26.2	72	39	1.3	8.1	3.4	7.8
	25	18 to 24	33.4	24.9	80	52	13.8	6.8	3.5	6.1

3.1.4 Cropping History of Experimental Field

The cropping history of the experimental field prior to the commencement of the present study is presented in Table 3.

Table 3. Cropping history of experimental field

Year	Crops grown in previous year		
	Kharif	***Rabi***	***Summer***
2020-21	Maize	Wheat	Fallow
2021-22	Fallow	Fallow	Present investigation

As it is evident from the above Table 3, the present investigation was carried out on plot that is fallow during *kharif* and *rabi* seasons.

3.2 Methodology

3.2.1 Experimental Details

The experiment was laid out in split plot design with three replications and sixteen treatment combinations formed due to four sowing dates and four varieties. The details of the experiment are given below.

1. Name of crop : Soybean (*Glycine max.*)
2. Varieties : 1) JS-9305
   2) Phule Kimaya (KDS-753)
   3) Phule Sangam (KDS-726)
   4) Phule Durva (KDS-992)
3. Number of treatments : 16
4. Number of replications : 3
5. Number of plots : 48
6. Experimental Design : Split plot design
7. Plot size : a) Gross Plot : 3.60 m x 4.00 m = 14.4 m^2
   b) Net Plot : 2.70 m x 3.80 m = 10.26 m^2
8. Seed rate : 75 kg ha^{-1}
9. Spacing : 45 cm x 5 cm
10. Fertilizer dose : 50: 75: 45 (N: P_2O_5: K_2O in kg ha^{-1})
11. Season : *Summer,* 2022
12. Method of sowing : Line sowing

Table 4. Treatment details with symbols

SL No.	Treatment details	Symbols
A.	**Main plot: Sowing dates (S)**	
1.	1^{st} MW (1^{st} Jan – 7^{th} Jan)	S_1
2.	3^{rd} MW (15^{th} Jan – 21^{st} Jan)	S_2
3.	5^{th} MW (29^{th} Jan – 4^{th} Feb)	S_3
4.	7^{th} MW (12^{th} Feb – 18^{th} Feb)	S_4
B.	**Sub plot: Varieties (V)**	
1.	JS-9305	V_1
2.	Phule Kimaya (KDS-753)	V_2
3.	Phule Sangam (KDS-726)	V_3
4.	Phule Durva (KDS-992)	V_4

Table 5. Schedule of cultural operations carried out in experimental field during *summer* 2022

Sr. No.	Cultural operation	Frequ e-ncy	Date of operation			
			2021-22			
			1^{st}MW	3^{rd}MW	5^{th} MW	7^{th}MW
A.	**Preparatory tillage**					
1.	Ploughing	1	15-12-2021	15-12-2021	15-12-2021	15-12-2021
2.	Harrowing	1	22-12-2021	22-12-2021	22-12-2021	22-12-2021
3.	Collection of stubbles	1	25-12-2021	25-12-2021	25-12-2021	25-12-2021
5.	Field layout	1	28-12-2021	28-12-2021	28-12-2021	28-12-2021
B.	**Sowing operation**					
1.	Date of sowing	1	3-01-2022	17-01-2022	31-01-2022	14-02-2022
D	**Inter-culture operation**					
1.	Chemical weed control	2	4-01-2022 and 24-01-2022	18-01-2022 and 08-02-2022	01-02-2022 and 21-02-2022	15-02-2022 and 05-03-2022
E.	**Application of fertilizers and manure**					
1.	Basal dose of N as per treatment through Urea 50 kg,75 kg P_2O_5 through SSP and 45 kg K_2O through MOP per hectare, respectively.	1	3-01-2022	17-01-2022	31-01-2022	14-02-2022
2.	Vermicompost	1	28-12-2021	11-01-2022	22-01-2022	7-02-2022
F.	**Irrigations**		03-01-2022 24-01-2022 01-02-2022 07-03-2022 11-04-2022	17-01-2022 01-02-2022 07-03-2022 11-04-2022 05-05-2022	01-02-2022 07-03-2022 11-04-2022 05-05-2022	14-02-2022 07-03-2022 11-04-2022 05-05-2022
G.	**Harvesting**		04-05-2022	15-05-2022	22-05-2022	01-06-2022
H.	**Threshing and winnowing**		15-05-2022	30-05-2022	18-06-2022	18-06-2022

3.2.2 Plan of Layout

The experiment was laid out in split plot design and replicated thrice. The four sowing windows *viz,* 1^{st} MW, 3^{rd} MW, 5^{th} MW and 7^{th} MW sowing were taken in main plot and four sowing varieties *viz,* JS-9305, Phule Kimaya, Phule Sangam and Phule Durva were in sub plot. The treatment randomization was done as per the plan of layout shown in Fig 1.

3.3 Cultural Operations

The detailed schedule of cultural operations carried out at appropriate stages of *summer* soybean cultivation during the course of experiment are mentioned in the Table 5.

3.3.1 Tillage Operations

Tillage operations *viz*., ploughing and harrowing was carried out to prepare the field for sowing of *summer* soybean crop.

3.3.2 Seeds and Sowing

The soybean seeds of JS-9305, Phule Kimaya (KDS-753), Phule Sangam (KDS-726) and Phule Durva (KDS-992) varieties were obtained from ARS, Kasbe Digraj, Sangali. Line sowing was done in rows spaced 45 cm apart by using seed rate of 75 kg ha^{-1}. The crop was sown on four different dates *viz*., 3^{rd} January, 17^{th} January, 31^{st} January and 14^{th} February 2022, respectively.

3.3.3 Fertilizer Application

The crop was uniformly fertilized with recommended dose of 50 kg N, 75 kg P_2O_5 and 45 kg K_2O ha^{-1}. Nitrogen, Phosphorus and Potassium were applied through urea (46 % N), SSP (16 % P_2O_5) and MOP (60 % K_2O), respectively. The full dose of nitrogen (50 kg ha^{-1}) and P_2O_5 (75 kg ha^{-1}) and K_2O (45 kg ha^{-1}) were applied as basal dose at sowing to all treatments.

3.3.4 Irrigation

Immediately after sowing first irrigation was given to ensure better germination of *summer* soybean and subsequent irrigations were applied as per the requirement of the crop during its growth period.

3.3.5 Chemical weed control

To keep the experimental plots weed free chemical weed control was done twice at Pre emergence and post emergence through herbicide.

3.3.6 Harvesting and Threshing

The experimental *summer* soybean crop sown on different sowing windows are harvested after attaining the proper stage of maturity. The observation plants were harvested carefully and then subsequently border and net plot were harvested manually with the help of sickle. The harvested produce of net plot was kept for sun drying. After sun drying, harvested produce of each plot was tied into bundles and tagged with luggage labels and weight of produce was recorded on electronic weighing balance. The harvested produce was threshed separately. Thereafter, treatment wise grain yield of all the three replications was recorded on electronic balance. The treatment-wise halum yield was calculated by deducting plot-wise grain yield from the respective biological yield noted at harvest in the field.

Table 6. Details of the biometric observations recorded

Sr. No.	Particulars	Frequ-ency	DAS	Number of plants for observation
A.	**Plant population**			
1.	Initial plant count	1	20 DAS	All plants from net plot
2.	Final plant count	1	At harvest	All plants from net plot
B.	**Biometric observation**			
1.	Plant height (cm)	4	30, 60, 90 DAS and at harvest	5 plants from net plot
2.	Plant spread plant^{-1}(cm)	4	30, 60, 90 DAS and at harvest	5 plants from net plot
3.	Number of primary branches plant^{-1}	4	30, 60, 90 DAS and at harvest	5 plants from net plot
4.	Number of functional leaves plant^{-1}	4	30, 60, 90 DAS and at harvest	5 plants from net plot
5.	Leaf area plant^{-1} (dm^2)	4	30, 60, 90 DAS and at harvest	5 plants from net plot
6.	Dry matter production plant^{-1}	4	30, 60, 90 DAS and at harvest	2 plants from net plot
7.	Critical growth stages	-	Respective growth stages	Net plot
C.	**Post-harvest studies**			
1.	Number of pods plant^{-1}	1	At harvest	5 plants from net plot
2.	Weight of pod plant^{-1}(g)	1	At harvest	5 plants from net plot
3.	Number of seed pod^{-1}	1	At harvest	5 plants from net plot
4.	Weight of seed plant^{-1}(g)	1	At harvest	5 plants from net plot
5.	100 seed weight (g)	1	At harvest	5 plants from net plot
D.	**Yield studies**			
1.	Grain yield (kg plot^{-1})	1	At harvest	Net plot
2.	halum yield (kg plot^{-1})	1	At harvest	Net plot
3.	Biological yield plot^{-1}	1	At harvest	Net plot
4.	Harvest index (%)	1	At harvest	-
E	**Seed quality studies**			
1.	Germination (%)	1	At harvest	-
2.	Moisture contains (%)	1	At harvest	-
3.	Seed vigour index	1	At harvest	-

Table 6 contd…

Sr. No.	Particulars	Frequ-ency	DAS	Number of plants for observation
F.	**Quality studies**			
1.	Protein content in seed (%)	1	At harvest	Net plot
2.	Oil content in seed (%)	1	At harvest	Net plot
G.	**Soil studies**			
1.	Initial soil pH, EC, OC, Available soil N, P, K	1	Initial	Composite sample
2.	Final soil pH, EC, OC, Available soil N, P, K	1	At harvest	Sample from each plot
H.	**Economics studies**			
1.	Cost of cultivation (₹ha^{-1})	1	-	
2.	Gross monetary returns (₹ha^{-1})	1	-	
3.	Net monetary returns (₹ha^{-1})	1	-	
4.	Benefit: Cost ratio	1	-	
I.	**Weather studies**			
1.	Growing degree days	-	As per critical growth stages	Net plot
J	**Statistical analysis**			

3.4 Biometric Observations

The details of biometric observations recorded during the experiment are mentioned in the Table 6.

3.4.1 Sampling Technique

In order to record the growth and yield observations, five plants were randomly selected from each net plot. The selected plants were tagged and labelled using paper tags wrapped inside a transparent polythene cover. All the growth and yield observations were recorded from these tagged plants.

3.4.2 Plant Count

The initial and final plant count were recorded at 20 DAS and at harvest, respectively from net plot and later converted into hectare basis.

3.5 Growth Studies

3.5.1 Plant Height (cm)

The plant height was measured from the base of the plant i.e., ground level to the tip of the fully opened upper leaf of the five randomly selected plants in each net plot at 30th, 60th, 90th DAS and at harvest.

3.5.2 Plant Spread (cm)

The plant spread was measured from five randomly selected plants in each net plot. Measured in North-South direction from the centre of the plant and recorded at 30^{th}, 60^{th}, 90^{th} DAS and at harvest.

3.5.3 Number of Primary Branches Plant^{-1}

The number of primary branches were recorded from five randomly selected plants in each net plot at 30^{th}, 60^{th}, 90^{th} DAS and at harvest.

3.5.4 Number of Functional Leaves Plant^{-1}

The number of functional leaves were counted from the five randomly selected plants in each net plot and recorded at 30^{th}, 60^{th}, 90^{th} DAS and at harvest.

3.5.5 Leaf area plant^{-1} (dm^2)

The leaflets were separated from each sampled plant which was uprooted for dry matter studies. The leaflets were graded into three categories *viz.* small, medium and big. The leaf numbers in each group were counted. The representative sample of each category was taken from its linear measurement of maximum length and breadth in cm. It was measured and recorded leaf area was worked by using following formula (Watson, 1952) for each grade and summation of leaf area for those grades was taken as leaf area per plant.

$$LA = L \times B \times K$$

Where,

LA = Leaf area in dm^2

L = Length of leaf in cm

B = Breadth of leaf in cm

K = Leaf area constant (0.786)

3.5.6 Dry Matter Production Plant^{-1} (g)

Dry matter production per plant was recorded by drawing a sample of two plants from randomly selected row in each net plot at 30^{th}, 60^{th} and 90^{th} day of crop growth and at harvest, respectively. At each observation, fresh plant samples were uprooted from each net plot. These samples were the first sun-dried and then in oven at about 60^0C till they exhibited constant weight. Then weight of these dried samples was recorded in grams to determine the dry matter per plant.

3.5.7 Days to Emergence

The number of days to emergence was recorded by observing plants from net plot at emergence stage.

3.5.8 Days to 50 % flowering

The number of days to 50 % flowering was recorded by observing plants from net plot at flowering stage.

3.5.9 Days to Physiological Maturity

The number of days taken by the *summer* soybean crop to attain maturity from the date of sowing was counted and reported as days to maturity. When the grains were hard and dry to feel, it was considered that the crop has reached the stage of physiological maturity.

3.6 Post Harvest Studies

The yield contributing characters were recorded at harvest from five tagged plants of each net plot and reported on per plant basis.

3.6.1 Number of Pods Plant^{-1}

The total number of pods plant^{-1} was counted at harvest from five observational plants and average number of pods plant^{-1} was calculated and used for further calculations.

3.6.2 Number of Seeds Pod^{-1}

The pods plucked from five observation plants were hand threshed separately. The number of seeds were counted and reported on mean basis.

3.6.3 Weight of Pods Plant^{-1}

The pod weight plant^{-1} was recorded by separating pods from the five observational plants from each plot and dried in sun for a week. The pod weight plant^{-1} was calculated on mean basis.

3.6.4 Weight of seeds plant^{-1}

The pods plucked from five observation plants were hand threshed separately. The seed weight plant^{-1} was calculated on mean basis.

3.6.5 100 seed weight (g)

One hundred seeds were randomly selected from each net plot and its weight was recorded.

3.7 Yield Studies

3.7.1 Grain Yield (kg ha^{-1})

The grain weight plot^{-1} was recorded after threshing all plants of each net plot. The grains were cleaned and weighed after threshing. The weight of grains recorded was converted to kg ha^{-1} by multiplying with hectare factor.

3.7.2 Halum Yield (kg ha^{-1})

The halum yield plot^{-1} was obtained by subtracting grain yield from biological yield (grain + halum) of the respective net plot. The halum yield per net plot was converted into per hectare yield by multiplying with hectare factor.

3.7.3 Biological yield (kg ha^{-1})

All the harvested plants along with pods from net plot were allowed for sun drying and then weight was recorded as biological yield plot^{-1}. The biological yield per net plot was converted into per hectare yield by multiplying with hectare factor.

3.7.4 Harvest index (%)

It is the per cent of economical yield to the total biological yield. Harvest index reflects the proportion of assimilate distribution between economical and total biomass (Donald and Hamblin, 1976).

It is computed by using following formula plot^{-1}

$$\text{Harvest index (\%)} = \frac{\text{Total grain yield/plot}}{\text{Total biological yield/plot}} \times 100$$

3.8 Quality studies

3.8.1 Protein Content in seed (%)

The seed samples from each net plot were collected and used for chemical analysis to determine the protein content. The dried samples of seeds were grind and passed through 20 mesh sieves and about 20 g was taken as representative sample. The sample was stored in plastic bag, properly labelled and used for estimation of protein. The nitrogen percentage in soybean seeds estimated by modified Kjeldahl’s method (Jakson, 1973). The protein content was calculated by multiplying the nitrogen percentage with factor 6.25 (Tai and Young, 1974).

3.8.2 Oil Content in seed (%)

Oil was estimated by using Soxhlet method (Soxhlet, 1879). The empty weight of the beaker along with four to five boiling stones was taken. Later three gram of ground seed sample was put on thimbles and put these thimbles with basket in to the beaker. The beaker was filled with 100 ml of 60-75 per cent petroleum ether and kept in soxtherm. The soxtherm is a computer-based programme and set the air pressure at five bars after turning on the tap water. The system was programmed for 3 h 25 min. After completion the beaker was kept in hot air oven for 30 min (103^0C or 105^0C). Later the beaker was kept immediately in desiccators for 30 min and took the weight of the beaker. The oil content was measured by using the following formula.

$$\text{Oil content (\%)} = \frac{\text{Final weight} - \text{Initial weight}}{\text{Weight of sample (g)}} \times 100$$

3.9 Physical seed quality studies

3.9.1 Germination (%)

Germination test was conducted in three replications of 100 seeds each by adopting between paper method as described by ISTA rules Anon., (2011c). The temperature of 25 ± 1^0C and RH of 95 per cent was maintained during the germination test. The number of normal seedlings were counted at the end of 8 days of germination and expressed in percentage.

$$\text{Germination (\%)} = \frac{\text{Number of normal seedlings}}{\text{Total number of seeds planted}} \times 100$$

3.9.2 Seed moisture

Five randomly selected plants from each replication of each plot were tagged before physiological maturity. The selected plants were cut off from ground level. Seeds from pod were removed and subjected to moisture determination following hot air oven method on wet weight basis (Singh and Gupta, 1982) as follows.

$$\text{Seed moisture (\%)} = \frac{W_1 - W_2}{W_1} \times 100$$

Where,

W_1 = Fresh weight of seed sample (g)

W_2 = Dry weight of seed sample (g)

3.9.3 Seed Vigour index

It is highly complex procedure. At the level of seed germinate, it involves speed and totally of germination, pushing power of the seedling, range of stress conditions under which germination occurs. Therefore, seed vigour from seed testing stand point is the sum total of all seed attributes favour stand establishment under varying field conditions. A vigour test is not a test for field response purpose. Vigour is usually defined as that condition of the active good health and robustness in seed which upon planting permits germination to proceed rapidly under a wide range of environmental or field conditions. It can be estimated by accelerated ageing and conductivity test. At the end of germination test, ten normal seedlings from each replication were selected for calculation of vigour index (Abdul- Baki and Anderson, 1973) and was calculated as under .

Seed vigour-I = Germination (%) x Mean seedling length (cm)

Seed vigour-II = Germination (%) x Mean seedling dry weight (g)

3.11 Weather studies

3.11.1 Growing Degree Days (GDD)

A growing degree day (GDD) or heat unit (HU) is the departure from the mean daily temperature above the threshold temperature of the crop. The threshold or base temperature is the temperature below which no growth of that particular crop takes place. This varies with crop, generally higher values for tropical crops and lower values for temperate crops. In the present investigation, the base temperature of soybean was taken as 10 ^{0}C. The growing degree day (GDD) or heat unit (HU) were computed at critical growth stages of the crop by using formula given by Nuttonson (1955) as under.

$$GDD = \sum_{i=1}^{n} \frac{T_{max.} + T_{min}}{2} - T\ base$$

Where,

$\sum_{i=1}^{n}$ = Period in days from sowing date till the last date of harvesting

GDD = Growing degree days

T_{max} = Daily maximum temperature of day i (^{0}C)

T_{min} = Daily minimum temperature of day i (^{0}C)

T_b = Base temperature

Growing degree days (GDD) thus determined was expressed as ^{0}C day.

3.11 Economics studies

3.11.1 Cost of cultivation (` ha^{-1})

The cost of cultivation (` ha $^{-1}$) of each treatment was worked out by considering the actual amount incurred for the purchase of required input amount spent on the labour charges and machinery power required for land preparation.

3.11.2 Gross monetary returns (` ha^{-1})

The per hectare gross monetary return (` ha^{-1}) was worked out by considering the seed and halum yields (kg ha^{-1}) of soybean from different treatments and prevailing market prices of the seed and halum.

3.11.3 Net monetary returns (` ha^{-1})

The net monetary returns (` ha^{-1}) of each treatment was worked out by subtracting the cost of cultivation from gross returns of the corresponding treatment. The formula used is given below.

Net monetary returns = Gross monetary returns – Cost of cultivation

3.11.4 Benefit: Cost ratio

The Benefit: Cost ratio was worked out by dividing the treatment wise gross monetary returns by the corresponding value of cost of cultivation.

$$BCR = \frac{\text{Gross monetary return (` ha}^{-1})}{\text{Cost of cultivation (` ha}^{-1})}$$

3.12 Statistical Analysis and Interpretation of Data

The statistical analysis of data is carried out by “Analysis of Variance” method (Panse and Sukhatme, 1967). When the treatment differences were significant standard error (S.E.±) and critical difference (C.D.) were calculated at 5 per cent probability level and when the treatment differences were not significant, only standard error was worked out. Tables and figures added where necessary.

4. RESULTS AND DISCUSSION

The present investigation entitled "Response of *summer* soybean cultivars for seed production under different sowing windows" was carried out during the *summer* season of the 2022 at PGI-Farm, Post Graduate Institute, Mahatma Phule Krishi Vidyapeeth, Rahuri. This chapter comprises of the results and data emanated from the present investigation which are summarized in data tables and graphical representation. An attempt has been made to give possible scientific explanation and supportive evidences based on the available literature.

4.1 Plant Count

Data pertaining to the initial and final plant count of *summer* soybean as influenced by various treatments during *summer* 2022 is presented in Table 7. The mean initial and final plant count recorded (ha^{-1}) was 411559 and 392201, respectively.

4.1.1 Effect of Sowing Windows

The initial and final plant count (ha^{-1}) did not differ significantly due to the different sowing windows.

4.1.2 Effect of Varieties

The influence of different varieties on initial and final plant count (ha^{-1}) was found non-significant during the field trial.

4.1.3 Effect of Interaction

The interaction effect between sowing windows and soybean varieties were found non-significant with respect to initial and final plant stand (ha^{-1}).

4.2 Growth Studies

The growth of *summer* soybean was determined in terms of biometric observations *viz*., plant height, plant spread, number of functional leaves $plant^{-1}$, number of primary branches $plant^{-1}$, critical growth stages, leaf area $plant^{-1}$, dry matter production $plant^{-1}$. Data of these growth attributing characters were recorded at regular interval of 30 days from sowing to harvest and presented here under subsequent heads.

Table 7. Mean initial and final plant count (ha^{-1}) of *summer* soybean as influenced by different treatments

Treatments	Initial (15 DAS)		Final (At harvest)	
	ha^{-1}	%	ha^{-1}	%
A. Main plot: Sowing windows (S)				
S_1 : 1st MW (1st Jan.-7th Jan.)	408391	91.8	390219	87.7
S_2 : 3rd MW (15th Jan.-21st Jan.)	411053	92.4	390625	87.8
S_3 : 5th MW (29th Jan.-04th Feb.)	412384	92.7	393576	88.5
S_4 : 7th MW (12th Feb.-18th Feb.)	414409	93.2	394386	88.7
S.Em. ±	5497		1185	
C.D. at 5%	NS		NS	
B. Sub plot: Varieties (V)				
V_1 : JS-9305	406076	91.3	388136	87.3
V_2 : Phule Kimaya	411747	92.6	390393	87.8
V_3 : Phule Sangam	413599	93.0	393923	88.6
V_4 : Phule Durva	414814	93.3	396354	89.1
S.Em. ±	5740		2203	
C.D. at 5%	NS		NS	
C. Interaction (S × V)				
S.Em. ±	11481		4406	
C.D. at 5%	NS		NS	
General Mean	411559		392201	

4.2.1 Plant Height (cm)

Plant height is a reliable indicator of plant growth over a period of time. Data regarding the progressive plant height of *summer* soybean at various stages of its growth is presented in Table 8 and graphically depicted in Fig 3-4. The scrutiny of the data reveals that the mean plant height was increased progressively with advancement in the age of crop.

4.2.1.1 Effect of sowing windows

The plant height was increased with advancement of the crop age and reached maximum at the 90 DAS (Table 8 and Fig. 3). It can be noted that sowing windows significantly influenced the periodical plant height of *summer* soybean. The maximum plant height was recorded in 7th MW sowing at 30 DAS (30.79 cm).

However, the maximum plant height at 60 DAS was recorded by 7th MW sowing (76.43 cm), which was at par with 5th and 3rd MW sowing (73.52 and 72.92 cm, respectively). Thereafter, maximum plant height was recorded in 3rd MW sowing at 90 DAS sowing (99.90 cm).

Table 8. Mean periodical plant height (cm) of *summer* soybean as influenced by different treatments

Treatments	Plant height (cm)			
	30 DAS	**60 DAS**	**90 DAS**	**At harvest**
A. Main plot: Sowing windows (S)				
S_1 : 1st MW (1st Jan.-7th Jan.)	19.80	60.92	85.22	85.22
S_2 : 3rd MW (15th Jan.-21st Jan.)	24.80	72.92	99.90	99.90
S_3 : 5th MW (29th Jan.-04th Feb.)	25.25	73.52	79.78	79.78
S_4 : 7th MW (12th Feb.-18th Feb.)	30.79	76.43	78.12	78.12
S.Em. ±	0.9	3.0	3.5	3.5
C.D. at 5%	3.1	10.5	12.1	12.1
B. Sub plot: Varieties (V)				
V_1 : JS-9305	23.49	67.30	79.28	79.28
V_2 : Phule Kimaya	24.28	69.02	84.27	84.27
V_3 : Phule Sangam	25.94	72.60	89.15	89.15
V_4 : Phule Durva	26.92	74.87	90.32	90.32
S.Em. ±	0.8	1.9	2.5	2.5
C.D. at 5%	2.4	5.7	7.4	7.4
C. Interaction (S × V)				
S.Em. ±	1.6	3.9	5.1	5.1
C.D. at 5%	NS	NS	NS	NS
CV %	11.6	9.6	10.3	10.3
General Mean	25.16	70.95	85.76	85.76

The plant height in the second sowing (3rd MW) was significantly superior as compared to delayed sowing and early sowing due to favourable weather condition. The favourable weather condition, proper availability of moisture and nutrients and enhanced photosynthetic rate resulted in taller plants. The plant height was decreased in 1st MW sowing due to low temperature resulting into stunted growth of the soybean. Plant height decreased with deferral in sowing because of quick changes in photoperiod, which accelerated the development towards reproductive stage thus, shortening the period of vegetative growth.

The rate of increase in plant height was slow upto 30 days in 1st,2nd, 3rd sowing and accelerated increased in plant height was noticed in 7th MW sowing up to 60 DAS but there after highest plant height was attained by 3rd MW sowing at 90 DSA and at harvest among all sowing windows due to favorable weather condition. But it increased at greater pace between 30 to 60 days due to active vegetative growth of the plant indicating the grand growth period of soybean. Sheshama *et al.* (2017), Shah *et al.* (2017) and Niaz *et al.* (2018) also reported the similar results.

4.2.1.2 Effect of varieties

Among all the soybean varieties, periodical data on plant height of *summer* soybean showed significant difference at all the stages of the crop growth (Table 8 and Fig 4). The maximum plant height was attained at harvest in all varieties. The variety Phule Durva recorded significantly superior plant height at 30,60, 90 DAS and at harvest (26.92, 74.87, 90.32 and 90.32 cm, respectively), which was at par with Phule Sangam at 60, 90 DAS and at harvest while at 30 DAS, sowing Phule Sangam and Phule Kimaya recorded similar plant height as that of Phule Durva.

The above result revealed the fact that the variety Phule Durva adapted very well to the soil and agro-climatic conditions of Rahuri region thus, maximizing its growth and development potential. Data also indicated that different varieties recorded varying plant height at all stages which may be due to their genetic character affecting nutrient absorbing capacity, photosynthetic ability and metabolic activity. Thus, it influenced the plant height and other yield attributing characters. These results are in agreement with the findings of Ahmed *et al.* (2010) and Kamble *et al.* (2021).

4.2.1.3 Effect of interaction

The periodical interaction effect on plant height of *summer* soybean due to different treatment combinations was found non-significant.

4.2.2 Plant spread (cm)

Data pertaining to the mean plant spread of *summer* soybean as influenced periodically by the various treatments are presented in Table 9 and graphically depicted in Fig. 5-6. The plant spread of *summer* soybean was progressively increased with advancement in the age of crop during the experimentation. The increment in plant spread was maximum at 90 DAS. The mean maximum plant spread of *summer* soybean (47.81 cm) was obtained at 90 DAS.

4.2.2.1 Effect of sowing windows

The plant spread was increased with advancement of the crop age and reached maximum at 90 DAS (Table 9 and Fig 5). The maximum plant spread was recorded in 7th MW sowing at 30 and 60 DAS (25.59, 45.03 cm, respectively) and at par with 5th sowing at 30 DAS (21.54 cm). while at 60 DAS 5th and 3rd MW (44.12 and 43.55 cm, respectively) sowing were at par with 7th MW sowing. Thereafter maximum plant spread was recorded in 3rdMW sowing at 90 DAS and at harvest (50.50 and 30.02 cm, respectively).

The effect of sowing windows on plant spread was differed significantly during all the crop growth stages. The plant spread increased progressively up to 90 DAS in all sowing windows. Thereafter highest plant spread was attained by 3rdMW sowing due to longer growing period and favourable environmental condition at 90 DAS and lowest in 7th MW sowing due to shorter growth period respectively. The plant spread was slow during primary growth stages of *summer* soybean due to low temperature effect during 1st, 3rd and 5th MW sowing respectively. Similar results were also reported by Khaire *et al.* (2020).

4.2.2.2 Effect of varieties

Among all the soybean varieties, the periodical data on plant spread of *summer* soybean showed significant difference at all the stages of the crop growth (Table 9 and Fig. 6). The maximum plant spread was attained at 90 DAS in all varieties. The variety Phule Durva recorded significantly superior plant spread at 30, 60, 90 DAS and at harvest (22.18, 46.08, 52.63 and 31.57 cm, respectively) and at par with Phule Sangam or Phule Kimaya at 30 DAS (21.68 and 20.22 cm, respectively) and 60 DAS (44.83 and 44.08 cm, respectively). However, at 90 DAS and at harvest variety Phule Sangam (49.98 and 29.42 cm, respectively) was at par with Phule Durva. This might be due to the varietal characteristics and genotypic variation of varieties affecting plant spread. Similar results were also quoted by Khaire *et al.* (2020) and Gunjal *et al.* (2021).

Table 9. Mean periodical plant spread (cm) of *summer* soybean as influenced by different treatments

Treatments	**Plant spread (cm)**			
	30 DAS	**60 DAS**	**90 DAS**	**At harvest**
A. Main plot: Sowing windows (S)				
S_1 : 1st MW (1st Jan.-7th Jan.)	16.07	40.96	49.15	28.14
S_2 : 3rd MW (15th Jan.-21st Jan.)	19.96	43.55	50.50	30.02
S_3 : 5th MW (29th Jan.-04th Feb.)	21.54	44.12	46.26	26.13
S_4 : 7th MW (12th Feb.-18th Feb.)	25.59	45.03	45.33	24.68
S.Em. ±	1.6	0.5	1.0	0.4
C.D. at 5%	5.5	1.9	3.7	1.6
B. Sub plot: Varieties (V)				
V_1 : JS-9305	19.08	38.67	40.93	20.68
V_2 : Phule Kimaya	20.22	44.08	47.69	27.31
V_3 : Phule Sangam	21.68	44.83	49.98	29.42
V_4 : Phule Durva	22.18	46.08	52.63	31.57
S.Em. ±	0.6	1.3	1.3	0.8
C.D. at 5%	2.0	3.9	3.8	2.4
C. Interaction (S × V)				
S.Em. ±	1.3	2.7	2.6	1.6
C.D. at 5%	NS	NS	NS	NS
CV %	11.5	10.8	9.5	10.4
General Mean	20.79	43.41	47.81	27.24

4.2.2.3 Effect of interaction

The periodical interaction effect on plant spread of *summer* soybean due to different treatment combinations was found non-significant.

4.2.3 Number of functional leaves plant^{-1}

The data pertaining to number of functional leaves plant^{-1} as influenced periodically by different treatments are presented in Table 10 and graphically depicted in Fig 7-8. The number of functional leaves plant^{-1} increased with the advancement of the age of the crop and maximum number of leaves were produced at 90 DAS. Further the crop entered the leaf senescence stage and number of functional leaves declined up to harvest under all the treatment combinations.

4.2.3.1 Effect of sowing windows

The values of number of functional leaves plant^{-1} were statistically significant at all the growth stages of *summer* soybean crop due to the effect of sowing windows (Table 10).The significantly higher number of functional leaves plant^{-1} was recorded in 7th MW sowing at 30 and 60 DAS (4.88 and 22.55 cm, respectively) which was at par with 5th MW (3.58) sowing at 30 DAS. However, the 5th (21.68) and 3rd MW (20.28) sowing recorded at par values with 7th MW sowing at 60 DAS. Thereafter higher number of functional leaves plant^{-1} was recorded in 3rdMW sowing at 90 DAS and at harvest (30.56 and 14.39 cm, respectively) which was at par with 1st MW (28.78) sowing. The maximum number of functional leaves plant^{-1} at harvest was significantly recorded by 3rd MW (14.39) sowing.

The variation in number of functional leaves plant^{-1} among different sowing windows is attributed to changing climatic conditions during crop growth period. The increase in temperature increases the number of functional leaves plant^{-1} when the sowing is delayed beyond 1st MW sowing upto 60 DAS. Thereafter, highest number of functional leaves plant^{-1} was attained by 3rdMW sowing at 90 DAS and at harvest due to favourable temperature and longer growing period. Temperature is the main environmental factor determining leaf appearance and initiation rates in the C3 crop like soybean. At increased temperature, the number of node initiation rate was reduced. These results are found to be consistent with the findings of Tenorio (2016) and Bagade *et al.* (2017).

4.2.3.2 Effect of varieties

The perusal of the data in the Table 10indicated that number of functional leaves plant^{-1} did vary significantly between four soybean varieties *viz*., JS-9305, Phule Kimaya, Phule Sangam, Phule Durva at all the stages of crop growth. The highest number of functional leaves plant^{-1} was observed in Phule Durva at 30, 60, 90 DAS and at harvest (3.91, 22.03, 28.99 and 13.68, respectively). However, at 60, 90 DAS and at harvest Phule Sangam (21.29, 28.01 and 13.21, respectively) and Phule Kimaya (20.72, 27.05 and 13.15, respectively) both the varieties were at par with Phule Durva.

Table 10. Number of functional leaves plant^{-1} of *summer* soybean as influenced periodically by different treatments

Treatments	Number of functional leaves plant^{-1}			
	30 DAS	**60 DAS**	**90 DAS**	**At harvest**
A. Main plot: Sowing windows (S)				
S_1 : 1st MW (1st Jan.-7th Jan.)	3.00	18.38	28.78	12.75
S_2 : 3rd MW (15th Jan.-21st Jan.)	3.18	20.28	30.56	14.39
S_3 : 5th MW (29th Jan.-04th Feb.)	3.58	21.68	26.21	12.65
S_4 : 7th MW (12th Feb.-18th Feb.)	4.88	22.55	24.13	11.42
S.Em. ±	0.1	0.7	0.9	0.3
C.D. at 5%	0.3	2.6	3.4	1.2
B. Sub plot: Varieties (V)				
V_1 : JS-9305	3.48	18.85	25.63	11.18
V_2 : Phule Kimaya	3.56	20.72	27.05	13.15
V_3 : Phule Sangam	3.68	21.29	28.01	13.21
V_4 : Phule Durva	3.91	22.03	28.99	13.68
S.Em. ±	0.1	0.6	0.8	0.4
C.D. at 5%	0.2	1.8	2.3	1.2
C. Interaction (S × V)				
S.Em. ±	0.2	1.2	1.6	0.8
C.D. at 5%	NS	NS	NS	NS
CV %	9.6	10.4	10.3	11.3
General Mean	3.66	20.72	27.42	12.80

It was observed that least number of functional leaves was recorded in all the varieties at 30 DAS (3.48, 3.56, 3.68 and 3.91 respectively) and at harvest (11.18, 13.15, 13.21 and 13.68 respectively). This might be due to low temperature and unfavourable environmental condition at early stage of the soybean crop and at harvest the predominating senescence phenomenon as the crop approached physiological maturity stage might have reduced the number of functional leaves. Similar results were documented by Ruhul Amin *et al.* (2009) and Deokar *et al*. (2009).

4.2.3.3 Effect of interaction

The periodical interaction effect on number of functional leaves plant $^{-1}$ of *summer* soybean due to different treatment combinations was found non-significant

4.2.4 Number of primary branches plant^{-1}

The data regarding the mean number of primary branches as influenced periodically by different treatments are presented in Table 11 and graphically depicted in Fig. 9-10. The mean maximum number of branches plant^{-1} (7.21) was observed at 90 DAS.

4.2.4.1 Effect of sowing windows

The statistical data in the Table 11 show's that all the four sowing windows significantly influenced the number of primary branches plant^{-1}. The significantly highest number of primary branches plant^{-1} was recorded in 7th MW sowing at 60 DAS (5.82). The significantly highest number of primary branches plant^{-1} was recorded in *summer* sowing of soybean during 3rdMW sowing at 90 DAS (8.27).

The number of primary branches plant^{-1} increased with the advancement of age of the crop. The increase in temperature increases the number of primary branches plant^{-1} when the sowing is delayed beyond 1st MW sowing upto 60 DAS. Thereafter highest number of primary branches plant^{-1} was recorded by 3rd MW sowing at 90 DAS due to favourable weather and nourishment of the crop as well as longer growing period compare to 5th and 7th MW sowings. Better growth and development of *summer* soybean sown at 3rd MW might be due to the congenial climatic conditions prevailed throughout the growing period. Similar results were also revealed by Bagade *et al.* (2017) and Kanade *et al*. (2019).

Table 11. Number of primary branches plant^{-1} of *summer* soybean as influenced periodically by different treatments

Treatments	Number of primary branches plant^{-1}		
	60 DAS	**90 DAS**	**At harvest**
A. Main plot: Sowing windows (S)			
S_1 : 1st MW (1st Jan.-7th Jan.)	4.71	7.13	7.13
S_2 : 3rd MW (15th Jan.-21st Jan.)	4.96	8.27	8.27
S_3 : 5th MW (29th Jan.-04th Feb.)	5.22	7.09	7.09
S_4 : 7th MW (12th Feb.-18th Feb.)	5.82	6.34	6.34
S.Em. ±	0.19	0.29	0.29
C.D. at 5%	0.68	1.01	1.01
B. Sub plot: Varieties (V)			
V_1 : JS-9305	5.21	7.27	7.27
V_2 : Phule Kimaya	5.09	6.93	6.93
V_3 : Phule Sangam	5.12	7.08	7.08
V_4 : Phule Durva	5.28	7.57	7.57
S.Em. ±	0.18	0.25	0.25
C.D. at 5%	NS	NS	NS
C. Interaction (S × V)			
S.Em. ±	0.36	0.5	0.5
C.D. at 5%	NS	NS	NS
CV %	12.0	12.1	12.1
General Mean	5.18	7.21	7.21

4.2.4.2 Effect of varieties

The number of primary branches plant^{-1} varied significantly at different growth stages due to four soybean varieties (Table 11 and Fig. 10). Among the varieties, Phule Durva recorded significantly higher number of primary branches plant^{-1} during *summer* season at 60, 90 DAS and at harvest (5.28, 7.57 and 7.57, respectively). Such a reduction in number of primary branches plant^{-1} is mainly attributed to the respective varietal characteristic's performance during *summer* and genotypic variations of varieties affecting branching pattern. Similar results were also reported by Kanade *et al.* (2019), Kamble *et al.* (2021) and Gunjal *et al.* (2021).

4.2.4.3 Effect of interaction

The periodical interaction effect on number of primary branches plant^{-1} of *summer* soybean due to different treatment combinations was found non-significant.

4.2.5 Critical growth stages (DAS)

The number of days required to emergence, 50 % flowering and physiological maturity as well as harvest are significantly influenced by varieties, sowing windows and relevant data is tabulated (Table 12) and delineated graphically in figure 11-12. The days to emergence, 50 % flowering and physiological maturity as well as harvest were 9.4, 65.6 102.1 and 113.6 days respectively, during *summer* 2022.

4.2.5.1 Effect of sowing windows

A perusal of data revealed that in case of sowing windows, days to achieve emergence, 50 % flowering and physiological maturity as well as at harvest were significantly affected as the sowing of *summer* soybean was delayed from 1st MW to 7th MW. The data presented in Table 12 shows that the 1st MW sown crop took significantly a greater number of days (11.5, 75.6, 115 and 126.5 days, respectively) to reach emergence, 50 % flowering stage and physiological maturity as well as harvest, respectively.

It is clear from the above findings that different sowing windows had profound effect on number of days taken to reach emergence, 50 % flowering and physiological maturity as well as harvest. Late sown crop took lesser number of days to attain emergence, 50 % flowering, physiological maturity and harvest as compared to early sown crop. This is because when crop was sown late, its period from emergence to harvest gets shortened considerably as it experiences the temperature which is significantly higher than optimum for flowering. Therefore, the late sown crop was forced to flower and mature early where as early sown crop experienced minimum temperature during the growth phases which resulted in delayed phenological growth stages. Similar results were also reported by Gibson and Mullen (1996), Ram *et al.* (2010) and Reddy (2020).

Table 12. Days required to attain critical growth stages (DAS) of *summer* soybean as influenced periodically by different treatments

Treatments	Critical growth stages (DAS)			
	Emergence (VE)	50 % flowering	Physiological maturity	At harvest
A. Main plot: Sowing windows (S)				
S_1 : 1st MW (1st Jan.-7th Jan.)	11.5	75.6	115.0	126.5
S_2 : 3rd MW (15th Jan.-21st Jan.)	9.8	69.0	105.2	116.9
S_3 : 5th MW (29th Jan.-04th Feb.)	9.0	62.4	97.7	109.2
S_4 : 7th MW (12th Feb.-18th Feb.)	7.4	55.5	90.5	101.8
S.Em. ±	0.2	0.5	1.0	0.7
C.D. at 5%	0.7	1.8	3.6	2.5
B. Sub plot: Varieties (V)				
V_1 : JS-9305	8.5	59.5	95.7	100.3
V_2 : Phule Kimaya	9.5	67.0	104.0	117.4
V_3 : Phule Sangam	9.6	67.8	104.2	118.0
V_4 : Phule Durva	10.0	68.2	104.5	118.7
S.Em. ±	0.2	0.8	0.8	0.6
C.D. at 5%	0.8	2.4	2.4	1.7
C. Interaction (S × V)				
S.Em. ±	0.5	1.6	1.6	1.2
C.D. at 5%	NS	NS	NS	NS
General Mean	9.4	65.6	102.1	113.6

4.2.5.2 Effect of varieties

The soybean varieties significantly influenced the days to emergence, 50 % flowering and days to physiological maturity as well as harvest. The variety Phule Durva took significantly more days (10.0, 68.2, 104.5 and 118.7 days, respectively) to reach emergence, 50 % flowering, physiological maturity and harvest stage respectively. This was at par with Phule Sangam (9.6, 67.8, 104.2 and 118 days, respectively) and Phule Kimaya (9.5, 67.0, 104 and 117.4 days, respectively).Whereas, it was observed that lowest number of days to attain emergence, 50 % flowering and physiological maturity stage as well as harvest stage (8.5, 59.5, 95.7 and 100.3 days, respectively) were taken by variety JS-9305, because it is a short duration variety and its complete the life cycle within 90 to 95 days. The variety JS-9305 took minimum number of days to harvesting (100.3 days) during the field trial. Therefore, it was noted that the time to achieve maturity was reduced by around 18 days with JS-9305 variety. The results are in accordance with the earlier findings by Kitano *et al.* (2006) and Ram *et al.* (2010).

4.2.5.3 Effect of interaction

The interaction effect between soybean varieties and sowing dates in respect of emergence, 50 % flowering and physiological maturity as well as harvest stage was found non-significant.

4.2.6 Leaf area plant^{-1} (dm^{2})

Leaf area is an important factor influencing the interception of solar radiation, photosynthesis and ultimately the total biomass production. The data pertaining leaf area plant^{-1} for *summer* soybean recorded at periodic intervals during the field trial have been presented in Table 13 and illustrated graphically in Fig 13-14. There was a noticeable increase in the leaf area with advancement in the age of the crop and maximum mean leaf area was recorded at 90 DAS (40.26) during *summer* 2022. Thereafter, a declining trend in the values of leaf area plant^{-1}was observed up to harvesting due to increased leaf aging and senescence in all the four varieties and sowing windows.

4.2.6.1 Effect of sowing windows

The values of leaf area plant^{-1} (dm^{2}) were statistically significant at all the growth stages of *summer* soybean crop due to four sowing windows (Table 13). The significantly higher leaf area plant^{-1} at 30 and 60 DAS (2.54 and 31.50, respectively) was recorded with sowing of *summer* soybean during 7th MW sowing. However, the 5th MW and 3rd MW (28.11 and 27.43, respectively) sowings were at par with 7th MW sowing at 60 DAS. The significantly higher leaf area plant^{-1} at 90 DAS and at harvest (48.51 and 22.05, respectively) was recorded with sowing of *summer* soybean during 3rd MW sowing. Whereas at harvest 3rd MW sowing was found superior and at par with 1st MW (20.07) sowing. Leaf area plant^{-1} values decreased gradually after 90 DAS in all the sowing windows under study.

Table 13. Leaf area plant^{-1} (dm^2) of *summer* soybean as influenced periodically by different treatments

Treatments	Leaf area plant^{-1} (dm^2)			
	30 DAS	**60 DAS**	**90 DAS**	**At harvest**
A. Main plot: Sowing windows (S)				
S_1 : 1st MW (1st Jan.-7th Jan.)	1.22	21.44	41.88	20.07
S_2 : 3rd MW (15th Jan.-21st Jan.)	1.46	27.43	48.51	22.05
S_3 : 5th MW (29th Jan.-04th Feb.)	1.82	28.11	37.78	18.09
S_4 : 7th MW (12th Feb.-18th Feb.)	2.54	31.50	32.86	16.00
S.Em. ±	0.06	1.2	0.5	0.7
C.D. at 5%	0.2	4.4	1.7	2.7
B. Sub plot: Varieties (V)				
V_1 : JS-9305	1.57	23.99	35.40	16.80
V_2 : Phule Kimaya	1.70	26.97	40.39	19.11
V_3 : Phule Sangam	1.83	27.43	42.17	19.86
V_4 : Phule Durva	1.92	30.08	43.07	20.44
S.Em. ±	0.06	0.7	1.3	0.5
C.D. at 5%	0.1	2.2	3.8	1.7
C. Interaction (S × V)				
S.Em. ±	0.1	1.5	2.6	1.1
C.D. at 5%	NS	NS	NS	NS
CV %	12.7	10.0	11.4	10.5
General Mean	1.76	27.12	40.26	19.05

The crop sown early in 3rd MW sowing might have exposed to better climatic condition particularly APAR, RH which resulted in higher photosynthesis rate and higher availability of photosynthates at vegetative and reproductive phase enables plants for promotion of cell division and expansion of leaves consequently increasing the leaf area. Similar result was reported by Nath *et al.* (2017).

4.2.6.2 Effect of varieties

The data reported in the Table 13 indicated that the leaf area plant^{-1}varied significantly within varieties *viz*., JS-9305, Phule Kimaya, Phule Sangam, Phule Durva at all the stages of crop growth. Phule Durva recorded highest leaf area plant^{-1} at 30, 60, 90 DAS and at harvest (1.92, 30.08, 43.07 and 20.44 dm^2, respectively)which was at par with Phule Sangam (1.83) followed by Phule Kimaya (1.70) at 30 DAS. Whereas, at 60 DAS higher leaf area plant^{-1}was attained by Phule Durva (30.08). However, at 90 DAS and at harvest Phule Sangam (42.17 and 19.86, respectively) and Phule Kimaya (40.39 and 19.11, respectively) both varieties were at par with Phule Durva. Therefore, it supports the fact that, the grand growth period was witnessed between 30 to 60 DAS. This might be due to varietal performance to growing period and a greater number of functional leaves and profound growth of the plants. The results are in the close line with those reported earlier by Ruhul Amin *et al.* (2009) and Kamble *et al.* (2021).

4.2.6.3 Effect of interaction

The periodical interaction effect on leaf area plant^{-1} of *summer* soybean due to different treatment combinations was found non-significant.

4.2.7 Dry matter production plant^{-1} (g)

The dry matter production plant^{-1} (g) is the prime index reflecting growth and metabolic efficiency of plants and the data presented in Table 14 and graphical illustrations (Fig. 15-16) regarding total dry matter production plant^{-1} by soybean crop during *summer* 2022 also followed the similar trend as was found in case of plant height and number of functional leaves plant^{-1}, only with the difference that the dry matter production plant^{-1} continued to increase throughout the crop growing period up to the 90 DAS. The rate of increase was rapid during flowering and reproductive period.

4.2.7.1 Effect of sowing windows

The analysis of data pertaining to dry matter production plant^{-1} (g) showed that it was significantly influenced by four sowing windows at all the growth stages (Table 14). Evidently, 7th MW sowing accumulated significantly higher dry matter plant^{-1} at 30 and 60 DAS (1.97 and 17.39 g, respectively) than rest of the sowing. Thereafter significantly highest dry matter production plant^{-1} (g) was recorded in 3rdMW sowing at 90 DAS and (41.49 g).

However, at harvest 1st MW recorded the dry matter (32.68 g) which was at par with 3rd MW sowing. In all the sowing windows, dry matter production plant^{-1} (g) increased with the ontogeny of the crop.

Table 14. Dry matter production plant^{-1} (g) of *summer* soybean as influenced periodically by different treatments

Treatments	Dry matter production plant^{-1} (g)			
	30 DAS	**60 DAS**	**90 DAS**	**At harvest**
A. Main plot: Sowing windows (S)				
S_1 : 1st MW (1st Jan.-7th Jan.)	1.11	7.12	37.03	32.68
S_2 : 3rd MW (15th Jan.-21st Jan.)	1.25	10.80	41.49	35.02
S_3 : 5th MW (29th Jan.-04th Feb.)	1.36	14.77	32.85	27.17
S_4 : 7th MW (12th Feb.-18th Feb.)	1.97	17.39	22.19	17.36
S.Em. ±	0.05	0.5	1.0	0.9
C.D. at 5%	0.1	1.8	3.7	3.3
B. Sub plot: Varieties (V)				
V_1 : JS-9305	1.22	10.97	30.87	24.58
V_2 : Phule Kimaya	1.41	12.06	33.02	28.16
V_3 : Phule Sangam	1.48	12.54	33.96	29.16
V_4 : Phule Durva	1.59	14.52	35.70	30.33
S.Em. ±	0.04	0.3	1.0	0.8
C.D. at 5%	0.1	1.1	2.9	2.4
C. Interaction (S × V)				
S.Em. ±	0.08	0.7	2.0	1.7
C.D. at 5%	NS	NS	NS	NS
CV %	10.1	10.6	10.4	10.5
General Mean	1.42	12.52	33.39	28.06

It is noticed from Table 14 that, dry matter production plant^{-1} (g) increased with deferral in sowing window *i.e.*, the values of dry matter plant^{-1} (g) showed increasing trend with delayed sowings (S_1 to S_4) upto 60 DAS, thereafter trend was changed to the opposite direction (S_4 to S_2) at 90 DAS and at harvest due to unfavourable environment condition. The sowing of 7th MW accumulated lowest dry matter compared to other sowing windows at 90 DAS and at harvest. This was mainly due to less favourable weather conditions, shorter crop growing period, reduced plant height and leaf area. The late sown soybean crop was exposed to higher heat stress which forced it to mature earlier shortening the growing period. Therefore, vegetative growth and dry matter production were less in extended sowing windows. Similar results were also reported by Nabi *et al.* (2012), Bagade *et al.* (2017) and Nath *et al.* (2017).

4.2.7.2 Effect of varieties

The dry matter production plant^{-1} (g) differed significantly due to varieties at all the stages of crop growth (Table 14). The close scrutiny of the data revealed that dry matter production plant^{-1} (g) gradually increased with crop age and attained maximum at the 90DAS. Among the varieties, significantly highest dry matter production plant^{-1} (g) was observed in Phule Durva at 30, 60, 90 DAS and at harvest (1.59, 14.52, 35.70 and 30.33 g, respectively). However, at 90 DAS and at harvest Phule Sangam (33.96 and 33.02 g respectively) and Phule Kimaya (29.46 and 28.16 g respectively) both the varieties were at par with Phule Durva.

The variety Phule Durva achieved higher values in leaf area with increased plant height and number of functional leaves as well as superiority of yield components which were mainly responsible for this increased dry matter production compared to rest of the varieties. This is the consequence of better adaptation of the variety Phule Durva to the present agro-climatic condition of Rahuri region. Similar findings were noted earlier by Deokar *et al.* (2009), Ruhul Amin *et al.* (2009), Khaire *et al.* (2020) and Sarika *et al.* (2022).

4.2.7.3 Effect of interaction

The periodical interaction effect on dry matter production plant^{-1} (g) of *summer* soybean due to different treatment combinations was found non-significant.

4.3 Yield Attributing Characters

A significant variation in growth and development of *summer* soybean led to a noticeable difference in yield attributes of soybean varieties *viz.,* number of pods plant^{-1}, number of seeds pod^{-1}, weight of pods plant^{-1}, weight of seeds plant^{-1}, 100-seed weight. A comparison of these yield attributing characters showed a marked significant variation due to sowing windows and varieties. The data pertaining to yield attributing characters of *summer* soybean were recorded at harvest and have been discussed here under the following heads:

4.3.1 Number of pods plant^{-1}

The number of pods plant^{-1}is one of the key determinants of grain yield. The observed data on number of pods plant^{-1}as influenced by sowing windows and varieties are presented in Table 15 and graphically demonstrated in Fig. 17-18. The mean maximum number of pods plant^{-1} was observed 75.74.

4.3.1.1 Effect of sowing windows

The data related to number of pods plant^{-1} as influenced by sowing windows are presented in the Table 15. The difference in values of number of pods plant^{-1} in different sowing was statistically significant. The crop sown on 3rd MW sowing produced significantly a greater number of pods plant^{-1} (84.33) than rest of the sowing.

The results exhibited a decreasing trend with respect to number of pods plant^{-1} as the sowing was delayed from 3rd MW to 7th MW. Significantly a greater number of pods plant^{-1} was registered in early sown crop (3rd MW) as sufficient time period was available for vegetative growth of the crop, resulting in better yield attributes. Whereas, the increase in temperature in case of late sown crop reduced the duration of vegetative growth which resulted in lower number of pods plant^{-1}. The high temperature at reproductive stage might have affected pollination, fertilization and consequently poor pod set resulting in lower number of pods plant^{-1}. These results are completely aligned with those reported by Halvankar *et al.* (2001), Chen and Wiatrak, (2010), Asim *et al.* (2014), Singh *et al.* (2014) and Taware *et al.* (2015).

4.3.1.2 Effect of varieties

A significant difference was found in number of pods plant^{-1} due to varieties and the data is presented in Table 15. The variety Phule Durva produced maximum number of pods plant^{-1}(82.49) which was at par with JS-9305 (78.35). This might be due to a greater number of branches plant^{-1}, plant height, plant spread, number of branchesplant^{-1}, leaf areaplant^{-1}, dry matter productionplant^{-1} and the genetic makeup of the variety. Similar results were also reported by Ahmed *et al*. (2010), Khaire *et al.* (2020) and Kamble *et al.* (2021).

4.3.1.3 Effect of interaction

The periodical interaction effect on number of pods plant^{-1} of *summer* soybean due to different treatment combinations was found non-significant.

Table 15. Yield attributing characters of *summer* soybean as influenced periodically by different treatments

Treatments	Number of pods plant^{-1}	Number of seeds pod^{-1}	Weight of pods plant^{-1}(g)	Weight of seeds plant^{-1} (g)	100-seed Weight (g)
A. Main plot: Sowing windows (S)					
S_1 : 1st MW (1st Jan.-7th Jan.)	79.35	3.14	32.17	12.32	11.59
S_2 : 3rd MW (15th Jan.-21st Jan.)	84.33	3.41	34.53	14.02	12.64
S_3 : 5th MW (29th Jan.-04th Feb.)	76.13	2.97	29.53	12.07	11.47
S_4 : 7th MW (12th Feb.-18th Feb.)	63.13	2.90	28.90	11.81	11.09
S.Em. ±	1.2	0.06	1.0	0.3	0.2
C.D. at 5%	4.3	0.2	3.7	1.2	0.7
B. Sub plot: Varieties (V)					
V_1 : JS-9305	78.83	3.13	30.91	12.34	11.35
V_2 : Phule Kimaya	65.74	2.92	29.25	11.51	10.32
V_3 : Phule Sangam	75.88	3.07	31.55	12.72	12.18
V_4 : Phule Durva	82.49	3.30	33.43	13.64	12.93
S.Em. ±	2.2	0.09	0.9	0.3	0.3
C.D. at 5%	6.4	0.2	2.7	1.0	0.9
C. Interaction (S × V)					
S.Em. ±	4.4	0.1	1.8	0.7	0.6
C.D. at 5%	NS	NS	NS	NS	NS
CV %	10.1	10.1	10.2	10.1	10.1
General Mean	75.74	3.10	31.28	12.55	11.69

4.3.2 Number of seeds pod^{-1}

The potential grain yield is directly influenced by number of seeds pod^{-1}. The significant difference was found in number of seeds pod^{-1} due to sowing windows and varieties. The data is presented in Table 15 and graphically depicted in Fig 17-18. The mean number of seeds pod^{-1} recorded during the trial was 3.10.

4.3.2.1 Effect of sowing windows

The observed data on number of seeds pod^{-1}was significantly influenced by sowing windows which is presented in Table 15. The sowing of soybean at 3rd MW sowing produced maximum number of seeds pod^{-1} (3.41) which was significantly superior over rest of sowings. A gradual decline in number of seeds pod^{-1} was noticed when sowing is delayed beyond 3rd MW sowing.

The higher number of seeds pod^{-1} obtained in 3rd MW sown crop over delayed sowings was due to availability of optimum environmental conditions like favourable temperature regime for growth and development of crop. This resulted in enhanced synthesis and translocation of photosynthates to the yield attributes. In case of delayed sowing, soybean crop was exposed to higher temperature than optimum which reduced the vegetative and grain development period leading to less production of photosynthates. Thus, the rise in temperature during delayed sowing might have reduced the pod fillings resulting into less number of seeds pod^{-1}. Asim *et al*. (2014), Asewar *et al.* (2015), Naidu *et al.* (2017), Kumar *et al.* (2018) and Rajasekhar *et al.* (2021) also recorded the similar observations.

4.3.2.2 Effect of varieties

The number of seeds pod^{-1} differed significantly due to varieties (Table 15). The data revealed that Phule Durva recorded significantly higher number of seeds pod^{-1} (3.30) than rest of the varieties. This was at par with JS-9305 (3.13). The differences in number of seeds pod^{-1} among varieties might be attributed to their varietal characteristics and genetic makeup which influenced the pod development and pod filling. These findings are strongly supported by those of Ahmed *et al.* (2010)**,** Deokar *et al.* (2009), Khaire *et al.* (2020) and Sarika *et al.* (2022).

4.3.2.3 Effect of interaction

The periodical interaction effect on number of seeds pod^{-1} of *summer* soybean due to different treatment combinations was found non-significant.

4.3.3 Weight of pods plant^{-1} (g)

The grain weight of pods plant^{-1}ofsoybean crop as influenced by varieties and sowing windows is enumerated in Table 15. The observed mean weight of pods plant^{-1} was 31.28 g during the year of experiment.

4.3.3.1 Effect of sowing windows

The weight of pods plant^{-1} (g) was significantly affected due to different sowing windows (Table 15). The significantly higher weight of pods plant^{-1} (34.53 g) was registered with crop sown during 3rd MW which was at par with 1st MW (32.17 g).

The minimum weight of pods plant^{-1}was recorded in 7th MW sowing (28.90 g). A decreasing trend was observed in values of weight of pods plant^{-1}with delayed sowings.

In case of delayed sowings, the soybean crop was exposed to temperature higher than the optimum leading to reduction in yield attributing characters like number of pods plant^{-1} and number of seeds pod^{-1} etc. This in turn, also reduced weight of pods plant^{-1} (g). Zao *et al.* (2015) and Khaire *et al.* (2020) also found the similar results.

4.3.3.2 Effect of varieties

Data on weight of pods plant^{-1} (g) of *summer* soybean is presented in Table 15. It is apparent from the data that weight of pods plant^{-1} was significantly influenced by the varieties. Among the varieties, Phule Durva recorded highest weight of pods plant^{-1} to the tune of (33.43 g) which was significantly at par with Phule Sangam (31.55 g) and JS-9305 (30.91 g). The yield attributes of the crop are not only controlled by the environment where it is grown but also by the inherent genetic makeup of the plant which influences the pod development and seed formation. Thus, weight of pods plant^{-1} (g) varied among the varieties. Similar results were also obtained by Zao *et al.* (2015) and Khaire *et al.* (2020).

4.3.3.3 Effect of interaction

The periodical interaction effect on weight of pods plant^{-1} (g) of soybean due to different treatment combinations was found non-significant.

4.3.4 Weight of seeds plant^{-1} (g)

The weight of seeds plant^{-1} (g)is one of the key determinants of grain yield. The observed data on weight of seeds plant^{-1}as influenced by varieties and sowing windows are presented in Table 15 and graphically demonstrated in Fig. 17-18. The mean maximum weight of seeds plant^{-1} (12.55 g) was observed during experiment.

4.3.4.1 Effect of sowing windows

The data related to weight of seeds plant^{-1} (g) as influenced by sowing windows are presented in the Table 15. The difference in values of weight of seeds plant^{-1} (g) in different sowing windows was statistically significant. The crop sown on 3rd MW sowing produced significantly greater weight of seeds plant^{-1} (14.02, g) than rest of the sowings. The least weight of seeds plant^{-1}was observed in 7th MW sowing (11.81). Similar results were also reported by Zao *et al.* (2015).

4.3.4.2 Effect of varieties

A significant difference was found in weight of seeds plant^{-1}due to varieties and the data is presented in Table 15. The variety Phule Durva produced highest weight of seeds plant^{-1} (13.64, g). This was significantly at par with Phule Sangam (12.72, g). Similar results were also reported by Zao *et al.* (2015).

4.3.4.3 Effect of interaction

The periodical interaction effect on weight of seeds plant^{-1}(g) of soybean due to different treatment combinations was found non-significant

4.3.5 100-seeds weight (g)

The weight of 100-seeds (g) is an important yield attribute, which determines the yield contribution and quality appearance of individual seeds. Data with regard to weight of 100-seeds (g) presented in Table 15and shown graphically in Fig 17-18 clearly states that it was significantly affected by the sowing windows and varieties. The mean value of weight of 100-seeds recorded at harvest was 11.69 g.

4.3.5.1 Effect of sowing windows

The 100-seeds weight varied significantly with respect to different sowing windows. The data presented in Table 15 revealed that the weight of 100-seeds in 3rdMW sowing (12.64 g) was significantly higher than rest of the sowings at harvest. The lowest 100-seeds weight at harvest was recorded in 7th MW sowing (11.09 g). It could be seen that significantly lowest 100-seeds weight was recorded with delayed sown soybean crop.

The final seed weight can be expressed as a function of rate and duration of seed filling. Also, temperature is the most important environmental factor affecting the 100-seed weight. In late sown crop the high-temperature stress leads to shorter growing period and less production of photosynthates. The size of the endosperm is also decreased with reduced starch deposition. Therefore, delayed sowings affected both duration and rate of seed filling ultimately reducing 100-seed weight (g) of *summer* soybean. Similar results were also reported by Asim *et al.* (2014), Ram *et al*. (2010), Yari *et al*. (2013) and Naidu *et al.* (2017).

4.3.5.2 Effect of sowing varieties

The soybean varieties had a significant effect on weight of 100-seeds (g) as enumerated in the Table 15. It could be observed that variety Phule Durva recorded significantly higher weight of 100-seeds (12.93 g) which was at par with Phule Sangam (12.18 g). The Phule Durva showed superior weight of 100-seeds results which prove to be a good choice under present conditions.

The differential performance with respect to weight of 100-seeds is associated with genetic differences among the varieties. However, other factors including adverse growing environment like temperature extremes are equally responsible for reduction in 100-seed weight. These observations were supported by Halvankar *et al.* (2001), Deokar *et al.* (2009) and Kamble *et al.* (2021).

4.3.4.3 Effect of interaction

The periodical interaction effect on 100-seeds weight (g) of soybean due to different treatment combinations was found non-significant.

4.4 Yield studies

The yield of any crop species depends upon the source-sink relationship. It is the cumulative function of various growth parameters and yield attributing characters *viz.*, number of pods plant^{-1}, number of seeds pods^{-1}, weight of pods plant^{-1}, weight of seeds plant^{-1}and weight of 100-seeds.

A considerable variation in growth and yield attributing characters of *summer* soybean due to varieties and sowing windows led to pronounced variations in the grain yield, halum yield, biological yield and harvest index as shown in Table 16 and Fig 19-20. The mean grain yield, halum yield, biological yield and harvest index during *summer* season 2022 was 2392, 2939, 5331 kg ha^{-1} and 44.92 per cent, respectively.

4.4.1 Grain Yield (Kg ha^{-1})

It is noticed from the previous section (4.3) that, grain yield of *summer* soybean is a resultant effect of various yield attributing characters like number of pods plant^{-1}, number of seeds pods^{-1}, weight of pods plant^{-1}, weight of seeds plant^{-1}and weight of 100-seeds. The amalgamation of their cumulative effect over grain yield shows that the grain yield was significantly influenced with respect to sowing windows and varieties. The data pertaining to grain yield as influenced by different treatments is presented in the Table 16.

Table 16. Grain yield, halum yield, biological yield and harvest index of *summer* soybean as influenced by different treatments

Treatments	Grain yield (kg ha^{-1})	Increase in grain yield (%)	Halum yield (kg ha^{-1})	Biological yield (kg ha^{-1})	Harvest index (%)
A. Main plot: Sowing windows (S)					
S_1 : 1st MW (1st Jan.-7th Jan.)	2498	16.1	2986	5484	45.6
S_2 : 3rd MW (15th Jan.-21st Jan.)	2633	22.4	3091	5725	46.1
S_3 : 5th MW (29th Jan.-04th Feb.)	2288	6.3	2914	5202	44.0
S_4 : 7th MW (12th Feb.-18th Feb.)	2151	…	2764	4915	43.7
S.Em. ±	91		60	136	0.7
C.D. at 5%	317		208	472	NS
B. Sub plot: Varieties (V)					
V_1 : JS-9305	2418	6.4	2634	5053	47.7
V_2 : Phule Kimaya	2272	….	2957	5229	43.6
V_3 : Phule Sangam	2320	2.1	2966	5286	43.8
V_4 : Phule Durva	2560	12.6	3198	5758	44.4
S.Em. ±	70		115	141	1.0
C.D. at 5%	204		337	412	3.1
C. Interaction (S × V)					
S.Em. ±	140	-	231	282	2.1
C.D. at 5%	NS	-	NS	NS	NS
CV %	10.1	-	13.6	9.1	8.2
General Mean	2392	-	2939	5331	44.92

4.4.1.1 Effect of sowing windows

The marked difference in grain yield of *summer* soybean crop was observed due to sowing windows (Table 16). The significantly higher grain yield (2633 kg ha^{-1}) was observed under 3rd MW sowing which was at par with 1st MW (2498 kg ha^{-1}). Statistically the lowest value of yield was recorded with 7th MW sowing (2151 kg ha^{-1}). Delayed sowing adversely affected the yield of *summer* soybean crop.

Among the four sowing windows percent highest yield increment was observed in 3rd MW sowing (22.4 %) followed by 1st and 5th MW sowing based on 7thMW sowing.

The reason behind significantly higher grain yield values in 3rd MW sowing might be due to availability of optimum environmental conditions for growth and development of crop (Table 16) which could have enhanced accumulation of photosynthates from source to sink. Lowest grain yield of *summer* soybean crop in 7th MW sowing may be result of the least time taken to maturity as compared to other sowing. High temperature during reproductive period of crop growth under delayed sowing reduced the plant height, number of functional leaves plant^{-1}, leaf area plant^{-1}and dry matter production plant^{-1}. It also shortened the duration of each developmental phase and enhanced the maturity. Moreover, the yield attributes like number of pods plant^{-1}, number of seeds pods^{-1}, weight of pods plant^{-1}, weight of seeds plant^{-1} and weight of 100-seeds were reduced under delayed sowings and hence, reduced the grain yield. Due to high temperature stress during flowering might have induced flower drop, resulting into lower yield as compared to early sowings. The findings are in conformity with those of Kandil *et al.* (2013), Yari *et al.* (2013), Asim *et al.* (2014), Singh *et al.* (2014), Kundu *et al.* (2016), Nawale *et al.* (2018) and Rajasekhar *et al.* (2021).

4.4.1.2 Effect of varieties

A perusal of data in Table 16 revealed that grain yield differed significantly due to soybean cultivars. Amongst the cultivars tested Phule Durva gave significantly highest grain yield (2560 kg ha^{-1}) which was at par with JS-9305 (2418 kg ha^{-1}). The cultivar Phule Kimaya (2272 kg ha^{-1}) produced significantly lowest grain yield as compared to aforesaid varieties.

Among the four cultivars under study, the highest percent yield increment was observed in Phule Durva (12.6 %) followed by JS-9305 (6.4 %) and Phule Sangam (2.1 %) based on the yields of Phule Kimaya.

The difference in the grain yield among the varieties might have occurred due to significant variation observed in their growth and yield attributing characters. These characters are by and large governed by respective genetic make-ups and yielding ability of varieties under a given set of environments. These results are in accordance with Halvankar *et al*. (2001), Zao *et al.* (2015), Nigade *et al.* (2020) Kamble *et al.* (2021) and Sarika *et al.* (2022)

4.4.1.3 Effect of interaction

The periodical interaction effect on grain yield of *summer* soybean due to different treatment combinations was found non-significant.

4.4.2 Halum Yield (Kg ha^{-1})

The halum yield is reflected by growth parameters like plant height, number of branches plant^{-1}, number of functional leaves plant^{-1}, leaf area plant^{-1} and dry matter production plant^{-1}. Data relevant to halum yield was influenced significantly by varieties and sowing windows which is presented in Table 16 and graphically depicted through Fig. 19-20. The mean halum yield of soybean during *summer* 2022 was 2939 kg ha^{-1}.

4.4.2.1 Effect of sowing windows

The sowing windows significantly influenced the halum yield during *summer* 2022. Among four sowing windows, the significantly higher halum yield was obtained in 3rd MW sowing (3091 kg ha^{-1}) which was at par with 1st MW (2986 Kg ha^{-1}) and 5th MW (2914 Kg ha^{-1}) sown crop . Crop sown on 7th MW sowing recorded significantly lower halum yield (2764 kg ha^{-1}). It can be inferred that delay in sowing decreased the halum yield.

The higher halum yields in 3rd MW sown crop might be due to the reason that 3rd MW sown crop received optimum environmental conditions conducive for proper crop growth and got more time for attaining better plant height, leaf area plant^{-1} and dry matter production plant^{-1}. However, under delayed sowings, temperature was elevated between anthesis and physiological maturity which led to forced maturity and shortened crop duration. It was a probable reason for reduced plant height, number of leaves plant^{-1}, leaf area plant^{-1}, dry matter production plant^{-1} and in turn less halum yield under late sown conditions. Similar findings were also documented by Zao *et al*. (2015) Ram *et al.* (2010), Taware *et al.* (2015), Chavan *et al.* (2018), Nawale *et al.* (2018) and Dandge *et al.* (2020).

4.4.2.2 Effect of varieties

The halum yield of *summer* soybean was influenced significantly due to soybean varieties (Table 16). The halum yield was significantly higher in variety Phule Durva (3198 kg ha^{-1}) which was at par with Phule Sangam (2966 Kg ha^{-1}) and Phule

Kimaya (2957 Kg ha^{-1}) varieties. The variety JS-9305 recorded significantly lowest halum yield (2634 kg ha^{-1}).

In general, it is always essential for a variety to produce sufficient dry matter during vegetative phase to achieve higher halum yield. The higher halum yield in Phule Durva could be attributed to greater genetic potential with efficient utilization of radiation leading to production of maximum number of functional leaves plant^{-1}, leaf area plant^{-1}, number of branches plant^{-1} and dry matter production plant^{-1}. The above results are in harmony with those of Ram *et al.* (2010), Zao *et al.* (2015), Khaire *et al.* (2020), Kamble *et al.* (2021) and Sarika *et al.* (2022).

4.4.2.3 Effect of interaction

The periodical interaction effect on halum yield of *summer* soybean due to different treatment combinations was found non-significant.

4.4.3 Biological yield (Kg ha^{-1})

The biological yield is reflected by both growth and yield parameters like plant height, number of branches plant^{-1}, number of functional leaves plant^{-1}, leaf area plant^{-1} dry matter production plant^{-1}, number of pods plant^{-1}, number of seeds pod^{-1}, weight of pods plant^{-1}, weight of seeds plant^{-1} and 100-seed weight. Data relevant to biological yield as influenced significantly by varieties and sowing windows are presented in Table 16and graphically depicted through Fig. 19-20. The mean biological yield of soybean during *summer* 2022 was 5331 kg ha^{-1}.

4.4.3.1 Effect of sowing windows

The sowing windows significantly influenced the biological yield during *summer* 2022. Among four sowing windows, the significantly higher biological yield was obtained in 3rd MW sowing (5725 kg ha^{-1}) which was at par with1st MW (5484 kg ha^{-1}). Crop sown on 7th MW sowing recorded significantly lower biological yield (4915 kg ha^{-1}). It can be inferred that delay in sowing decreased the biological yield. Similar results were also reported by Zao *et al.* (2015) Ram *et al.* (2010), Singh *et al.* (2010), Yari *et al.* (2013), Asewar *et al.* (2015), Jagtap *et al.* (2018) and Nawale *et al.* (2018).

4.4.3.2 Effect of varieties

The biological yield of *summer* soybean was influenced significantly due to soybean varieties (Table 16). The biological yield was significantly higher in variety

Phule Durva (5758 kg ha^{-1}) and was significantly superior over rest of the cultivars. These results are in accordance with Halvankar *et al.* (2001**)**, Rehman and Islam (2006), Ram *et al.* (2010), Zao *et al.* (2015).

4.4.3.3 Effect of interaction

The periodical interaction effect on biological yield of *summer* soybean due to different treatment combinations was found non-significant.

4.4.4 Harvest index

4.4.4.1 Effect of sowing windows

The harvest index was found non-significant among the sowing windows(Table 16). However, higher harvest index noted in under 3^{rd}MW sowing (46.1 %). The lowest value of harvest index was recorded with 7^{th} MW sowing (43.7 %). Delayed sowing adversely affected the harvest index of *summer* soybean crop. Similar findings were also documented by Asewar *et al.* (2015), Taware *et al.* (2015), Sheshama *et al.* (2017), Nawale *et al.* (2018) and Rajasekhar *et al.* (2021).

4.4.4.2 Effect of varieties

A perusal of data in Table 16 revealed that harvest index differed significantly due to soybean varieties. Amongst the varieties tested JS-9305 recorded significantly highest harvest index (47.7 %). The variety Phule Kimaya (43.6 %) produced significantly lowest harvest index as compared to aforesaid varieties. The variety JS-9305 produced significantly lower halum yield and higher grain yield compare to other varieties and the inherent character of short duration of JS-9305 might have resulted into higher harvest index. Similar results were also reported by Taware *et al.* (2015) and Dandge *et al.* (2020).

4.4.4.3 Effect of interaction

The periodical interaction effect on harvest index of *summer* soybean due to different treatment combinations was found non-significant.

4.5 Quality studies

4.5.1 Protein content in seed (%)

The data regarding the protein content in seed (%) as influenced by different treatments are presented in Table 17. The mean protein content 39.04 per cent was recorded after harvest.

Table 17. Protein and oil content (%) in seed of *summer* soybean as influenced by different treatments

Treatments	Protein content (%)	Oil content (%)
A. Main plot: Sowing windows (S)		
S_1 : 1st MW (1st Jan.-7th Jan.)	39.05	18.92
S_2 : 3rd MW (15th Jan.-21st Jan.)	40.33	19.71
S_3 : 5th MW (29th Jan.-04th Feb.)	38.42	18.64
S_4 : 7th MW (12th Feb.-18th Feb.)	38.37	18.10
S.Em. ±	0.5	0.3
C.D. at 5 %	NS	NS
B. Sub plot: Varieties (V)		
V_1 : JS-9305	38.06	18.53
V_2 : Phule Kimaya	39.04	18.81
V_3 : Phule Sangam	39.06	18.90
V_4 : Phule Durva	40.01	19.13
S.Em. ±	1.1	0.5
C.D. at 5 %	NS	NS
C. Interaction (S × V)		
S.Em. ±	2.3	1.1
C.D. at 5%	NS	NS
CV %	10.2	10.5
General Mean	39.04	18.84

4.5.1.1 Effect of sowing windows

The protein content (%) was found non-significant among the sowing windows. However, the maximum protein percent was noted in 3rdMW sowing (40.33 %). The percent protein in seed is partly a function of accumulation of nitrogen in seeds wherein the increase in nitrogen uptake during early sowing of *summer* soybean is due to efficient translocation of photosynthates that might have increased the protein content. Similar results were also reported by Ram *et al.* (2010), Asewar *et al.* (2015), Kundu *et al.* (2016) and Nawale *et al.* (2018).

4.5.1.2 Effect of varieties

The protein content (%) was found non-significant among the varieties. However, the maximum protein percent was noticed in variety Phule Durva (40.01 %) followed by Phule Sangam (39.06 %) and Phule Kimaya (39.04 %) respectively. Phule Durva had high protein content which might be due to genetic behaviour of the variety. Similar results were also reported by Halvankar *et al.* (2001) and Nawale *et al.* (2018).

4.5.1.3 Effect of interaction

The periodical interaction effect on protein content (%) of *summer* soybean due to different treatment combinations was found non-significant.

4.5.2 Oil content in seed (%)

The data regarding the oil content (%) in seed of *summer* soybean as influenced by different treatments are presented in Table 17. The mean oil content 18.84 per cent was recorded after harvest.

4.5.2.1 Effect of sowing windows

The oil content (%) was found non-significant among the sowing windows. However, the maximum oil percent was noted in 3rd MW sown crop (19.71 %). Similar results were also reported by Ram *et al.* (2010), Asewar *et al.* (2015), Taware *et al.* (2015) and Niaz *et al.* (2018).

4.5.2.2 Effect of varieties

The oil content (%) was found non-significant among the varieties. However, the maximum oil (%) was noticed in variety Phule Durva (19.13 %). Phule Durva had high oil content which might be due to genetic behaviour of the variety. Similar results were also reported by Halvankar *et al.* (2001), Kamble *et al.* (2021).

4.5.2.3 Effect of interaction

The periodical interaction effect on oil content of *summer* soybean due to different treatment combinations was found non-significant.

4.6 Physical seed quality studies

The data regarding the seed germination (%), seed moisture content (%), seed vigour index-I and seed vigour index-II of *summer* soybean as influenced by different treatments are presented in Table 18 and graphically depicted in Fig. 11. The mean seed germination (%), seed moisture content (%), seed vigour index-I and seed vigour index-II was (91.87, 9.66 %, 2375 and 86.55, respectively).

Table 18. Physical seed quality studies of *summer* soybean as influenced by different treatments

Treatments	Germination (%)	Seed moisture content (%)	Seed vigour index-I	Seed vigour index-II
A. Main plot: Sowing windows (S)				
S_1 : 1st MW (1st Jan.-7th Jan.)	91.75	9.71	2390	86.40
S_2 : 3rd MW (15th Jan.-21st Jan.)	92.81	9.75	2416	87.81
S_3 : 5th MW (29th Jan.-04th Feb.)	91.30	9.66	2365	86.21
S_4 : 7th MW (12th Feb.-18th Feb.)	90.57	9.52	2331	85.78
S.Em. ±	0.68	0.13	50	1.8
C.D. at 5%	NS	NS	NS	NS
B. Sub plot: Varieties (V)				
V_1 : JS-9305	90.94	9.71	2372	86.37
V_2 : Phule Kimaya	91.37	9.59	2359	86.08
V_3 : Phule Sangam	91.84	9.56	2363	86.23
V_4 : Phule Durva	92.28	9.77	2407	87.52
S.Em. ±	2.2	0.26	65	2.4
C.D. at 5%	NS	NS	NS	NS
C. Interaction (S × V)				
S.Em. ±	4.5	0.52	130	4.9
C.D. at 5%	NS	NS	NS	NS
CV %	8.5	9.4	9.5	9.9
General Mean	91.87	9.66	2375	86.55

4.6.1 Effect of sowing windows

The seed germination (%), seed moisture (%), seed vigour index-I and seed vigour index-II of *summer* soybean was found non-significant among the sowing windows. The highest seed germination (%), seed moisture (%), seed vigour index-I and seed vigour index-II (92.81 %, 9.75 %, 2416 and 87.81, respectively) was recorded with sowing of *summer* soybean during 3rd MW sowing. This might be due to steady accumulation growing Degree Days (GDDs), in early sowings. Similar results were also reported by Rahman *et al.* (2013), Kundu *et al.* (2016), Prabhakar *et al.* (2017), Sulthana *et al.* (2017), Bhatia *et al*. (2018).

4.6.2 Effect of varieties

The seed germination (%), seed moisture (%), seed vigour index-I and seed vigour index-II of *summer* soybean was found non-significant among the varieties. The variety Phule Durva registered highest seed germination (%), seed moisture (%), seed vigour index-I and seed vigour index-II (92.28 %, 9.77 %, 2407 and 87.52, respectively). Similar results were also reported by Sulthana *et al.* (2017), Bhatia *et al*. (2018).

4.6.3 Effect of interaction

The periodical interaction effect on seed germination (%), seed moisture (%), seed vigour index-I and seed vigour index-II of *summer* soybean due to different treatment combinations was found non-significant.

4.7 Micrometeorological Observations

4.7.1 Growing Degree Days (GDD) / Heat Units

Growing degree days (heat unit) is an important agro meteorological index that is proposed to explain the relationship between growth duration and mean air temperature. A growing degree day (GDD) or a heat unit is the departure of mean daily temperature over the base temperature. The thermal environment and response of *summer* soybean crop can be characterized based on the GDD. The total accumulated growing degree days (GDD) required by the *summer* soybean crop to attain various phenophases varied with varieties and sowing windows.

The data presented in the Table 19 revealed that the GDD requirement at critical growth stages of *summer* soybean was strongly influenced by the sowing windows and varieties. The cumulative GDD at critical growth stages was highest in 1^{st} MW sowing to attain emergence, physiological maturity and harvest stage (126.1, 1797.5 and 2068.1^{0}C days, respectively) and at 50% flowering highest GDD (982.1 ^{0}C days) attain by 7^{th} MW sown crop.

The GDD requirement at critical growth stages was influenced significantly due to soybean varieties (Table 19). The cumulative GDD at critical growth stages was highest in Phule Durva to attain emergence, 50% flowering, physiological maturity and harvest stage (110.8, 1019.8, 1829.0 and 2161.3 ^{0}C days, respectively) followed by Phule Sangam (106.6, 1011.2, 1823.3 and 2144.4 ^{0}C days, respectively) and Phule Kimaya (104.9, 994.8, 1820.4 and 2131.3^{0}C days, respectively).

Table 19. Cumulative growing degree days (heat units) at critical growth stages as influenced by different treatments

Treatments	**Growing Degree Day's**			
	Emergence (VE)	**50% Flowering**	**Physiological maturity**	**At harvest**
A. Main plot: Sowing windows (S)				
S_1 : 1st MW (1st Jan.-7th Jan.)	126.1	959.0	1797.5	2068.1
S_2 : 3rd MW (15th Jan.-21st Jan.)	98.2	955.5	1747.5	2022.7
S_3 : 5th MW (29th Jan.-04th Feb.)	96.4	976.7	1771.1	2038.1
S_4 : 7th MW (12th Feb.-18th Feb.)	98.0	982.1	1781.3	2040.2
B. Sub plot: Varieties (V)				
V_1 : JS-9305	96.6	847.3	1624.6	1732.0
V_2 : Phule Kimaya	104.9	994.8	1820.4	2131.3
V_3 : Phule Sangam	106.6	1011.2	1823.3	2144.4
V_4 : Phule Durva	110.8	1019.8	1829.3	2161.3
General Mean	104.7	968.3	1774	2042.3

It is known fact that every crop needs a specific amount of GDD to enter its reproductive phase from vegetative phase. Earlier sown crop took higher number of days to reach different growth stages which may be attributed to prevailing cool temperatures during early stages of the crop growth.Early sowing resulted in absorbing sufficient GDD in relatively more time. Therefore, early sown crop had consumed maximum GDD at all phenological stages as compared to the rest of sowing.

In case of delayed sown conditions, the crop experienced the much higher temperature causing reduction in number of days taken to attain any phenological stage. This resulted in the lower consumption of heat units under delayed sowing condition. The differential behaviour of varieties with respect to days required to reach various phenophases and GDD requirement could be solely ascribed to their genetic makeup.

These results are in conformity with Medida *et al*. (2006), Kumar *et al.* (2008 a), Nath *et al.* (2017), Chavan *et al.* (2018) and Kessler *et al.* (2020).

4.8 Soil study

The data in respect of pH, EC (dSm^2), OC (%) and available N, P, K, (kg ha^{-1}) content in soil as influenced by different treatment are presented in Table 20.

Table 20. pH, EC (dSm^{-2}), OC(%), and available N, P, K (kg ha^{-1}) content in the soil after harvest of *summer* soybean as influenced by different treatments

Treatments	pH (1:2.5 Soil : water suspension)	OC (%)	EC (dSm^2)	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})
A. Main plot: Sowing windows (S)						
S_1 : 1st MW (1st Jan.-7th Jan.)	7.8	0.46	0.33	240	16.8	358
S_2 : 3rd MW (15th Jan.-21st Jan.)	7.7	0.46	0.32	236	16.7	349
S_3 : 5th MW (29th Jan.-04th Feb.)	7.7	0.48	0.32	244	19.1	367
S_4 : 7th MW (12th Feb.-18th Feb.)	7.6	0.49	0.31	251	20.0	370
S.Em. ±	0.1	0.01	0.01	7.4	0.8	5.3
C.D. at 5%	NS	NS	NS	NS	NS	NS
B. Sub plot: Varieties (V)						
V_1 : JS-9305	7.7	0.48	0.31	245	19.2	368
V_2 : Phule Kimaya	7.7	0.47	0.32	242	17.8	362
V_3 : Phule Sangam	7.7	0.48	0.33	242	18.0	357
V_4 : Phule Durva	7.6	0.47	0.33	241	17.5	356
S.Em. ±	0.1	0.01	0.01	5.9	0.6	8.6
C.D. at 5%	NS	NS	NS	NS	NS	NS
C. Interaction (S × V)						
S.Em. ±	0.3	0.02	0.02	11.9	1.3	17.3
C.D. at 5%	NS	NS	NS	NS	NS	NS
CV %	8.7	8.8	10.8	8.5	12.6	8.3
General Mean	7.7	0.47	0.32	243	18.1	361
Initial value	7.6	0.51	0.30	230	18.2	368

4.8.1 Effect of sowing windows

The pH, EC (dSm^2), OC (%) and available residual N, P, K, (kg ha^{-1}) content in soil did not differ significantly due to sowing windows. The highest N, P and K in soil were found in 7th MW sowing (251, 20.0 and 370 respectively) due to delayed sowing resulting into short life cycle of crop and poor uptake of nutrients. Similar results were also reported by Sheshama *et al.* (2017).

4.8.2 Effect of varieties

The pH, EC (dSm^2), OC (%) and available residual N, P, K, (kg ha^{-1}) content in soil were non-significant due to varieties. Among all the soybean varieties highest N, P, and K in soil were found in JS-9305 (245, 19.2, 368, respectively).

4.8.3 Effect of interaction

The pH, EC (dSm^2), OC (%) and available residual N, P, K, (kg ha^{-1}) content in soil of *summer* soybean due to different treatment combinations was found non-significant.

4.9 Economic studies

The data regarding the economics as influenced by different treatments are presented in Table 21**.** The mean values of economic evaluation of *summer* soybean in terms of cost of cultivation, gross and net monetary returns and B:C ratio are 70,533 (₹ ha^{-1}), 3,34,996 (₹ ha^{-1}), 2,64,463 (₹ ha^{-1}) and 4.74, respectively.

4.9.1 Effect of sowing windows

The cost of cultivation (₹ ha^{-1}), gross monetary return (₹ ha^{-1}) and net monetary return (₹ ha^{-1}) as well as B:C ratio differed numerically with respect to different sowing windows. The data presented in Table 21 revealed that the gross monetary return (₹ ha^{-1}) and net monetary return (₹ ha^{-1}) as well as B:C ratio in 3rd MW sowing (3,68,713 ₹ ha^{-1}, 2,96,258 ₹ ha^{-1} and 5.09, respectively) was numerically higher than rest of the sowing after harvest. It could be seen that; numerically lowest gross monetary return (₹ ha^{-1}), net monetary return (₹ ha^{-1}) and B:C ratio were recorded with late sown *summer* soybean crop. Similar results were also reported by Singh *et al.* (2014), Asewar *et al.* (2015), Walke *et al.* (2018), Oligini *et al.* (2021) and Rajasekhar *et al.* (2021).

Table 21. Cost of cultivation, gross and net monetary return (` ha^{-1}) and B:C Ratio of *summer* soybean as influenced by different treatments

Treatments	Cost of Cultivation (` ha^{-1})	Gross monetary return (` ha^{-1})	Net monetary return (` ha^{-1})	B:C Ratio
A. Main plot: Sowing windows (S)				
S_1 : 1st MW (1st Jan.-7th Jan.)	72455	349720	277265	4.83
S_2 : 3rd MW (15th Jan.-21st Jan.)	72455	368713	296258	5.09
S_3 : 5th MW (29th Jan.-04th Feb.)	68611	320401	251790	4.67
S_4 : 7th MW (12th Feb.-18th Feb.)	68611	301151	232540	4.39
B. Sub plot: Varieties (V)				
V_1 : JS-9305	70533	338566	268033	4.79
V_2 : Phule Kimaya	70533	318091	247558	4.50
V_3 : Phule Sangam	70533	324881	254348	4.60
V_4 : Phule Durva	70533	358446	287913	5.08
General Mean	70533	334996	264463	4.74
Price rate of TFL seed – 140 ₹ kg^{-1}				

4.9.2 Effect of varieties

A substantial difference was found in gross monetary return (` $ha^{-1}$), net monetary return (` ha^{-1}) and B:C ratio due to varieties and the data is presented in Table 21. The variety Phule Durva recorded highest gross monetary return (` $ha^{-1}$) and net monetary return (` ha^{-1}) as well as B:C ratio (3,58,446 ₹ ha^{-1}, 2,87,913 ₹ ha^{-1} and 5.08 respectively). Similar results were also reported by Kumar *et al.* (2005) and Singh *et al.* (2010), Sarika *et al.* (2022).

5. SUMMARY AND CONCLUSIONS

A field experiment entitled "Response of *Summer* Soybean Cultivars for Seed Production under Different Sowing Windows" was carried out during the *summer* season of the 2022 at Post Graduate Farm, PGI, Mahatma Phule Krishi Vidyapeeth, Rahuri. The investigation was carried out to assess the effect of different sowing windows and varietal performance on growth and yield of *summer* soybean. The soil of the experimental field was clayey in texture, moderately alkaline in reaction (pH 7.6), low in available nitrogen (230 kg ha^{-1}) and moderate phosphorous (18.2 kg ha^{-1}) and high in available potassium content (368 kg ha^{-1}).

The experiment was laid out in split plot design consisting of four sowing windows *viz.,* S_1: 1st MW (01st Jan-07th Jan), S_2: 3rd MW (15th Jan- 21st Jan), S_3: 5th MW (29th Jan – 04th Feb), S_4: 7th MW (12th Feb – 18th Feb), as first factor and four varieties of soybean *viz.,* V_1: JS-9305, V_2: Phule Kimaya (KDS-753), V_3: Phule Sangam (KDS-726) and V_4: Phule Durva (KDS-992) as second factor and was replicated thrice. The observations of growth attributes, yield attributes, grain yield, halum yield and meteorological parameters were recorded. The brief and precise summary of findings emerged and conclusion arrived through the present investigation are described in the following text.

5.1 Summary

5.1.1 Performance of sowing windows

Among all the sowing windows, 3rd MW sowing recorded significantly higher value of growth attributes *viz.,* plant height (99.90 cm), plant spread (50.50 cm), number of functional leaves (30.56), number of primary branches $plant^{-1}$ (8.27), leaf area $plant^{-1}$(48.51 dm^2) and dry matter production $plant^{-1}$ (41.49 g) during *summer* 2022. This was followed by 1st MW and 5th MW sowings. The sowing during 7th MW recorded lowest value of growth attributes *viz.,* plant height (78.12 cm), plant spread (45.33 cm), number of functional leaves (24.13), number of primary branches $plant^{-1}$ (6.34), leaf area $plant^{-1}$ (32.86 dm^2) and dry matter production $plant^{-1}$ (22.19 g). The number of days required to emergence, 50 % flowering, physiological maturity and harvest stage were significantly higher in case of 1st MW sowing (11.5, 75.6,115 and 126.5 days, respectively) over 3rd MW (9.8, 69.0, 105.2 and 116.9 days, respectively) and 5th MW sowings (9.0, 62.4, 97.7 and 109.2 days, respectively). The 7th MW sowing took minimum days to emergence (7.4 days), 50 % flowering (55.5 days) and physiological maturity (90.5 days) as well as at harvest (101.8 days) during the year of investigation.

The 3rd MW sowing recorded significantly higher values of yield attributes *viz.,* number of pods plant^{-1} (84.33), number of seeds pod^{-1} (3.41), weight of pods plant $^{-1}$ (34.53 g), weight of seeds plant^{-1} (14.02 g) and 100 seed weight (12.64 g) during *summer* 2022. This was followed by 1st MW and 5th MW sowings. Whereas, 7th MW sowing recorded lowest value of yield attributes *viz.,* number of pods plant^{-1} (63.13), number of seeds pod^{-1} (2.90), weight of pods plant $^{-1}$ (28.90 g), weight of seeds plant $^{-1}$ (11.81 g) and 100 seed weight (11.09 g).

Grain yield (2633 kg ha^{-1}), halum yield (3091 kg ha^{-1}) and biological yield (5725 kg ha^{-1}) as well as harvest index (46.1) was higher in 3rd MW sowing followed by 1st MW (2498, 2986, 5484 kg ha^{-1} and 45.6 %, respectively) and 5th MW sowing (2288, 2914, 5202 kg ha^{-1} and 44.0 %, respectively). The lower grain yield (2151 kg ha^{-1}), halum yield (2764 kg ha^{-1}) and biological yield (4915 kg ha^{-1}) as well as harvest index (43.7 %) was recorded in 7th MW sowings.

The data pertaining to effect of different sowing windows on protein (%), oil (%), germination (%), seed moisture content and seed vigour-I, II was found to be non-significant and was not affected due to different sowings under study. However, the highest protein content (40.33 %), oil content (19.71 %), germination (92.81 %), seed moisture content (9.75 %) and seed vigour index-I, II (2416 and 87.81) was obtained under 3rd MW sowing.

The highest values for available nitrogen (251 kg ha^{-1}), phosphorus (20.0 kg ha^{-1}) and potassium (370 kg ha^{-1}) content of soil after harvest of *summer* soybean was recorded under 7th MW sowing.

The 3rd MW sowing recorded higher gross monetary returns (3,68,713 ₹ ha^{-1}), net monetary returns (2,96,258 ₹ ha^{-1}) and B:C ratio (5.09) followed by 1st and 5th MW sowing.

5.1.2 Performance of varieties

The advancement in growth of *summer* soybean was determined in terms of growth attributes *viz*., plant height, plant spread, number of functional leaves, number of primary branches plant^{-1}, leaf area plant^{-1}, dry matter production plant^{-1}, days to emergence, 50 % flowering, physiological maturity and harvest stage. All the growth contributing characters increased progressively with advancement in the age of crop.

Amongst all the soybean varieties, Phule Durva recorded significantly higher plant height (90.32 cm) followed by Phule Sangam (89.15 cm) and Phule Kimaya (84.27 cm). It was observed that variety JS-9305 (79.28 cm) recorded significantly lowest plant height among all the varieties at 90 DAS. Similarly, plant spread (52.63 cm), number of functional leaves plant^{-1} (28.99), leaf area plant^{-1}(43.07 dm^{2}) and dry matter production plant^{-1} (35.70 g), were found significantly higher in cultivar Phule Durva followed by Phule Sangam, Phule Kimay and JS-9305 (respectively).

The number of primary branches plant^{-1}(7.57) was highest in Phule Durva followed by JS-9305 (7.27), Phule Sangam (7.08) and Phule Kimaya (6.93), respectively.

The number of days required to emergence, 50 % flowering, physiological maturity and harvest stage were significantly higher in case of variety Phule Durva (10.0, 68.2, 104.5 and 118.7 days, respectively) over Phule Sangam (9.6, 67.8, 104.2 and 118 days, respectively) and Phule Kimaya (9.5, 67.0, 104 and 117.4 days, respectively). The variety JS-9305 took minimum days to emergence (8.5), 50 % flowering (59.5 days), physiological maturity (95.7 days) and harvest stage (100.3 days) during the field trial.

The data on yield attributing characters clearly showed that the variety Phule Durva recorded significantly higher number of pods plant^{-1} (82.49), number of seeds pod^{-1} (3.30), followed by JS-9305 (V_1) (78.83 and 3.13, respectively) and the variety Phule Durva recorded highest weight of pods plant^{-1} (33.43 g), weight of seeds plant^{-1} (13.64 g) and 100 seed weight (12.93 g) followed by Phule Sangam and JS-9305. On the other hand, variety Phule Kimaya registered lowest number of pods plant^{-1} (65.74), number of seeds pod^{-1} (2.92), weight of pods plant^{-1} (29.25 g), weight of seeds plant^{-1} (11.51 g) and 100 seed weight (10.32 g).

The variety Phule Durva recorded significantly superior grain yield (2560 kg ha^{-1}) it was at par with JS-9305(2418 kg ha^{-1}) and followed by Phule Sangam (2320 kg ha^{-1}) and Phule Kimaya (2272 kg ha^{-1}) respectively. The halum yield and biological yield was higher in Phule Durva (3198 and 5758 kg ha^{-1} respectively) followed by Phule Sangam (2966 and 5286 kg ha^{-1} respectively), Phule Kimaya (2957 and 5229 kg ha^{-1}, respectively) and JS-9305 (2634 and 5053 kg ha^{-1} respectively). The variety JS-9305 recorded significantly highest harvest index (47.7 %) followed by Phule Durva (44.4 %) and Phule Sangam (43.6 %), respectively. The lowest harvest index was recorded in variety Phule Kimaya (43.6 %).

The data pertaining to the effect of different varieties on protein (%), oil (%), germination (%), seed moisture content and seed vigour-I, II of *summer* soybean was found to be non-significant and was not affected due to different varieties under study. However, the highest protein content (40.01 %), oil content (19.13 %), germination (92.28 %), seed moisture content (9.77 %) and seed vigour index-I, II (2407 and 87.52) was recorded in Phule Durva.

The highest values for available nitrogen (245 kg ha^{-1}), phosphorus (19.2 kg ha^{-1}) and potassium (368 kg ha^{-1}), in soil after harvest was recorded with variety JS-9305.

The variety Phule Durva accrued higher gross monetary returns (3,58,446 ₹ ha^{-1}), net monetary returns (2,87,913 ₹ ha^{-1}) and B:C ratio (5.08).

5.1.3 Performance of interaction

The interaction effect between sowing windows and soybean varieties were found non-significant with respect to growth attributes, yield attributes, yield studies, quality studies and soil studies.

5.2 Agro-meteorological indices

With regard to agro-meteorological indices, GDD was used to quantify the thermal response on soybean crop. GDD or heat unit requirement values decreased with the subsequent delay in sowing. The cumulative GDD to attain emergence, physiological maturity and harvest stage (126.1, 1797.5 and 2068.1^{0}C days, respectively) was highest under 1st MW sowing and at 50% flowering highest GDD (982.1) attain by 7th MW sowing. The cumulative GDD at critical growth stages was highest in Phule Durva to attain emergence, 50 % flowering, physiological maturity and harvest stage (110.8, 1019.8, 1829.0 and 2161.3^{0}C days, respectively).

5.3 Conclusions

Based on the findings of this investigation, the following conclusions are drawn:

1. The study revealed that among the sowing windows *summer* soybean crop sown on 17th January (3rd MW) was found to be superior with respect to growth and yield attributes as well as yield.
2. Based on the study, it can be adjudged that the soybean variety Phule Durva (KDS-992) was most promising variety with respect to growth and yield attributes, as well as yield.
3. The highest net monetary return and B:C ratio was obtained by 17thJanuary (3rd MW) sown crop. Amongst all the soybean varieties, Phule Durva (KDS-992) obtained significantly higher gross and net monetary returns as well as B:C ratio.

Thus, from economic point of view, it can be advised that *summer* soybean sown between 15th January -21st January is beneficial for achieving higher seed production, productivity and profitability and among all the soybean varieties Phule Durva (KDS-992) is superior.

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7. APPENDICES

Appendix-I : Details of prices used for economic evaluation

Sr. No.	Particulars	Unit	Rate ₹
1.	**Tillage**		
a.	Ploughing	ha^{-1}	5000
b.	Cultivator	ha^{-1}	2000
c.	Rotavator	ha^{-1}	4500
d.	Labour charges	day^{-1}	337
2.	**Seed, Seed treatment and Sowing**		
a.	Soybean seed cost	kg^{-1}	140
b.	Seed treatment-: Azotobacter	kg^{-1}	160
c.	Sowing charges	ha^{-1}	4960
3.	**Fertilizers and Manure's**		
a.	Urea	kg^{-1}	5.6
b.	SSP	kg^{-1}	15
c.	MOP	kg^{-1}	34
d.	Vermicompost	kg^{-1}	10.5
4.	**Insecticide and pesticides**		
a.	Emamectin Benzoate 5% SG	kg^{-1}	2600
b.	Thiamethoxam (12.6%) + Lamdacyhalothrin (9.5%) ZC (Alika)	lit^{-1}	3375
c.	Bavistin 50% WP	kg^{-1}	1900
d.	Carbendazim 12 % + Mancozeb 63 % WP (SAAF- Fungicide)	kg^{-1}	700
5.	**Herbicides and application charge**		
a.	Pendimethalin 30 Ec	lit^{-1}	520
b.	Imazethapyr 10 SL	lit^{-1}	1587
6.	**Irrigation charge**	ha^{-1}	750
7.	**Harvesting charges (Combine harvester machine)**	ha^{-1}	6200
8.	**Main product**		
	Market rate of soybean seeds	kg^{-1}	140
9.	**Land revenue**	$Year^{-1}$	750

Appendix-II : Sowing window wise cost of cultivation

Sr. No.	Particulars	S_1	S_2	S_3	S_4
1.	**Tillage**				
a.	Ploughing	5000	5000	5000	5000
b.	Cultivator	2000	2000	2000	2000
c.	Rotavator	4500	4500	4500	4500
d.	Total labor cost	6066	6066	4044	4044
2.	**Seed, Seed treatment and Sowing**				
a.	Soybean seed cost	10500	10500	10500	10500
b.	Seed treatment-: Rhizobium	200	200	200	200
c.	Sowing charge (machine)	4960	4960	4960	4960
3.	**Fertilizers and Manure's**				
a.	Urea	616	616	616	616
b.	SSP	7031	7031	7031	7031
c.	MOP	2448	2448	2448	2448
d.	Vermicompost	6300	6300	6300	6300
4.	**Insecticide and fungicides**	790	790	790	790
5.	**Application charges of insecticide and pesticide**	2500	2500	2000	2000
6.	**Herbicides and application charge**	674	674	674	674
a.	Pendimethalin 30 Ec	520	520	520	520
b.	Imazethapyr 10 SL	1589	1589	1589	1589
7.	**Irrigation charges**	5435	5435	4348	4348
8.	**Harvesting charge (Combine harvester machine)**	6200	6200	6200	6200
9.	**Cost A (Working capital)**	67329	67329	63720	63720
10.	**Land revenue**	750	750	750	750
11.	**Interest on capital**	4376	4376	4141	4141
12.	**Cost B (9+10+11)**	72455	72455	68611	68611

8. VITAE

PREM SHANKER GOCHAR

MASTER OF SCIENCE (AGRICULTURE)
IN
AGRONOMY
2022

Title of thesis		:	"Response of *summer* soybean cultivars for seed production under different sowing windows"
Major field		:	Agronomy
Biographical information			
Personal	**Date of Birth**	:	10-04-1999
	Place of Birth	:	Balkasa
	Father's Name	:	Mr. Birdi Lal
	Mother's Name	:	Mrs. Kiskanda Bai
Educational	**Bachelor Degree Obtained**	:	SCRS Govt. College, Sawai Madhopur (Raj.)
	Class	:	First
	Name of University	:	Agriculture University Kota (Rajasthan) India
Address		:	V.P. Balkasa, The. - K. Patan, Dist.- Bundi (Rajasthan), Pincode : 323301
	Email- id	:	Prem100499@gmail.com
	Contact Number	:	7891690693