STUDIES ON INFLUENCE OF SOWING DATES AND FRUIT LOAD ON SEED YIELD AND QUALITY OF CUCUMBER (*Cucumis sativus* L.)

Thesis

by

ANAMIKA WALIA
(H-2021-49-D)

submitted to

Dr. YASHWANT SINGH PARMAR UNIVERSITY OF HORTICULTURE & FORESTRY SOLAN (NAUNI) HP - 173 230 INDIA

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Dr. Kuldeep Singh Thakur
Major Advisor

Department of Vegetable Science
Dr. Yashwant Singh Parmar University of Horticulture & Forestry
(Nauni) Solan (HP) - 173 230 India

CERTIFICATE-I

This is to certify that the thesis titled, **"Studies on Influence of Sowing Dates and Fruit Load on Seed Yield and Quality of Cucumber (*Cucumis sativus* L.)"**, submitted in partial fulfilment of the requirements for the award of the degree of **Doctor of Philosophy Vegetable Science** in the discipline of **Horticultural Sciences** to Dr. Yashwant Singh Parmar University of Horticulture and Forestry, (Nauni) Solan (HP) - 173 230 is a bonafide research work carried out by **Ms. Anamika Walia (H-2021-49-D)** daughter of Sh. Manoj Kumar Walia under my supervision and that no part of this thesis has been submitted for any other degree or diploma.

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

Place: Nauni, Solan (HP)
Date: 19.04.25

(Dr. Kuldeep Singh Thakur)
Major Advisor

CERTIFICATE - II

This is to certify that the thesis titled, **"Studies on Influence of Sowing Dates and Fruit Load on Seed Yield and Quality of Cucumber (*Cucumis sativus* L.)"**, submitted by **Ms. Anamika Walia (H-2021-49-D)** daughter of Sh. Manoj Kumar Walia to the Dr. Yashwant Singh Parmar University of Horticulture and Forestry, (Nauni) Solan (HP) – 173 230, India in partial fulfilment of the requirements for the degree of **Doctor of Philosophy Vegetable Science** in the discipline of **Horticultural Sciences** has been approved by the Advisory Committee after an oral examination of the student in collaboration with an External Examiner.

11.04.25

Dr. Kuldeep Singh Thakur
Major Advisor

11/04/2025

Dr. Sanjeev Kumar
External Examiner

Members of Advisory Committee

1. **Dr. Ramesh Kumar Bhardwaj**
   Principal Scientist

11/04/25

2. **Dr. Rajender Sharma**
   Senior Scientist

11/04/25

3. **Dr. Meenu Gupta**
   Associate Professor

11/4/25

19.04.2025

Professor and Head
Department of Vegetable Science

Countersigned

Dean
College of Horticulture
Dr. Yashwant Singh Parmar University of Horticulture and Forestry
(Nauni) Solan (HP) – 173 230

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Place: Nauni, Solan
Date: **(Anamika Walia)**

CONTENTS

Chapter	Title	Page(s)
1.	INTRODUCTION	1-5
2.	REVIEW OF LITERATURE	6-27
3.	MATERIALS AND METHODS	28-42
4.	RESULTS AND DISCUSSION	43-185
5.	SUMMARY AND CONCLUSION	186-192
	LITERATURE CITED	193-202
	APPENDICES	i-xxxix
	ABSTRACT	203
	BRIEF BIO-DATA	-

LIST OF ABBREVIATIONS

ANOVA	:	Analysis of Variance
B:C	:	Benefit Cost Ratio
CD	:	Critical Difference
cm	:	Centimeter
CV	:	Coefficient of Variation
cv.	:	Cultivar
df	:	Degree of Freedom
dS	:	Deci Siemens
dw	:	Dry weight
e.g.	:	For example
EC	:	Electrical Conductivity
et al.	:	Co-workers
etc.	:	Et cetera
FAO	:	Food and Agriculture Organization
FYM	:	Farm Yard Manure
g	:	Gram
ha	:	Hectare
HP	:	Himachal Pradesh
i.e.	:	That is
IARI	:	The Indian Agricultural Research Institute
ICAR	:	The Indian Council of Agricultural Research
IIVR	:	The Indian Institute of Vegetable Research
K	:	Potassium
kg	:	Kilogram
L	:	Litre
m	:	Meter
m^2	:	Meter square
mg	:	Milligram
ml	:	Millilitre

mm	:	Millimeter
N	:	Nitrogen
NHB	:	National Horticulture Board
NS	:	Non-significant
P	:	Phosphorus
pH	:	Potential of Hydrogen
q	:	Quintal
RDF	:	Recommended Dose of Fertilizers
S	:	Siemens
SE	:	Standard Error
SS	:	Sum of Square
SV	:	Seedling vigour
t	:	tonne
TSP	:	Total Soluble Proteins
TSS	:	Total Soluble Sugars
USDA	:	The United States Department of Agriculture
viz.	:	*Videlicet*
YSP UHF	:	Dr. Yashwant Singh Parmar University of Horticulture and Forestry

LIST OF TABLES

Table	Title	Page(s)
MATERIALS AND METHODS		
3.1	Physico-chemical properties of the soil before planting	30
3.2	Details of treatment combinations	33
RESULTS AND DISCUSSION		
4.1.1	Effect of sowing dates and fruit load on vine length	45
4.1.2	Effect of sowing dates and fruit load on fruit length	48
4.1.3	Effect of sowing dates and fruit load on fruit breadth	52
4.1.4	Effect of sowing dates and fruit load on fruit weight	56
4.2.1	Effect of sowing dates and fruit load on total number of seeds per fruit	61
4.2.2	Effect of sowing dates and fruit load on seed yield per fruit	65
4.2.3	Effect of sowing dates and fruit load on seed yield per plant	68
4.2.4	Effect of sowing dates and fruit load on seed yield per plot	73
4.2.5	Effect of sowing dates and fruit load on seed yield per hectare	76
4.2.6	Effect of sowing dates and fruit load on seed yield index	80
4.2.7	Effect of sowing dates and fruit load on 1000 seed weight	84
4.2.8	Effect of sowing dates and fruit load on number of filled seeds	88
4.2.9	Effect of sowing dates and fruit load on number of unfilled seeds	92
4.2.10	Effect of sowing dates and fruit load on seed fresh weight	95
4.2.11	Effect of sowing dates and fruit load on seed dry weight	99
4.3.1	Effect of sowing dates and fruit load on seed germination	104
4.3.2	Effect of sowing dates and fruit load on speed of germination	107
4.3.3	Effect of sowing dates and fruit load on field emergence	112
4.3.4	Effect of sowing dates and fruit load on seedling length	115
4.3.5	Effect of sowing dates and fruit load on seedling dry weight	118
4.3.6	Effect of sowing dates and fruit load on seedling vigour index - I	122
4.3.7	Effect of sowing dates and fruit load on seedling vigour index - II	126
4.4.1	Effect of sowing dates and fruit load on electrical conductance from seed leachates	131
4.4.2	Effect of sowing dates and fruit load on total soluble sugars in seed leachates	135
4.4.3	Effect of sowing dates and fruit load on total soluble proteins in seed leachates	138

Table	Title	Page(s)
4.4.4	Effect of sowing dates and fruit load on total soluble sugars in seed	142
4.4.5	Effect of sowing dates and fruit load on total soluble proteins in seed	146
4.4.6	Effect of sowing dates and fruit load on total starch contents in seed	149
4.4.7	Effect of sowing dates and fruit load on oil content in seed	154
4.5.1	Effect of sowing dates and fruit load on soil pH	158
4.5.2	Effect of sowing dates and fruit load on soil EC	160
4.5.3	Effect of sowing dates and fruit load on organic carbon	162
4.5.4	Effect of sowing dates and fruit load on available N content in soil after termination of experiment	165
4.5.5	Effect of sowing dates and fruit load on available P content in soil after termination of experiment	168
4.5.6	Effect of sowing dates and fruit load on available K content in soil after termination of experiment	172
4.6.1	Effect of sowing dates and fruit load on incidence of fruit fly in cucumber	176
4.6.2	Effect of sowing dates and fruit load on incidence of powdery mildew in cucumber	179
4.6.3	Effect of sowing dates and fruit load on incidence of downy mildew in cucumber	181
4.7.1	Effect of sowing dates and fruit load on economics of the treatments	184

LIST OF FIGURES

Figure	Title	Page(s)
MATERIALS AND METHODS		
3.1	Graphical representation of monthly data pertaining to the temperature, rainfall and relative humidity during the cropping period (April - September 2022)	29
3.2	Graphical representation of monthly data pertaining to the temperature, rainfall and relative humidity during the cropping period (April - September 2023)	29
RESULTS AND DISCUSSION		**Between Page(s)**
4.1.1	Effect of sowing dates and fruit load on vine length	46-47
4.1.2	Effect of sowing dates and fruit load on fruit length	48-49
4.1.3	Effect of sowing dates and fruit load on fruit breadth	52-53
4.1.4	Effect of sowing dates and fruit load on fruit weight	56-57
4.1.5	Analytical visualization of plant and fruit character weightage using chord diagram	58-59
4.2.1	Effect of sowing dates and fruit load on total number of seeds per fruit	62-63
4.2.2	Effect of sowing dates and fruit load on seed yield per fruit	66-67
4.2.3	Effect of sowing dates and fruit load on seed yield per plant	68-69
4.2.4	Effect of sowing dates and fruit load on seed yield per plot	74-75
4.2.5	Effect of sowing dates and fruit load on seed yield per hectare	76-77
4.2.6	Effect of sowing dates and fruit load on seed yield index	80-81
4.2.7	Effect of sowing dates and fruit load on 1000 seed weight	84-85
4.2.8	Effect of sowing dates and fruit load on number of filled seeds	88-89
4.2.9	Effect of sowing dates and fruit load on number of unfilled seeds	92-93
4.2.10	Effect of sowing dates and fruit load on seed fresh weight	96-97
4.2.11	Effect of sowing dates and fruit load on seed dry weight	100-101
4.2.12	Analytical visualization of seed yield traits weightage using chord diagram	102-103
4.3.1	Effect of sowing dates and fruit load on seed germination	104-105
4.3.2	Effect of sowing dates and fruit load on speed of germination	108-109
4.3.3	Effect of sowing dates and fruit load on field emergence	112-113
4.3.4	Effect of sowing dates and fruit load on seedling length	116-117
4.3.5	Effect of sowing dates and fruit load on seedling dry weight	118-119
4.3.6	Effect of sowing dates and fruit load on seedling vigour index - I	122-123
4.3.7	Effect of sowing dates and fruit load on seedling vigour index - II	126-127
4.3.8	Analytical visualization of seed quality traits weightage using chord diagram	130-131

Table	Title	Between Page(s)
4.4.1	Effect of sowing dates and fruit load on electrical conductance from seed leachates	132-133
4.4.2	Effect of sowing dates and fruit load on total soluble sugars in seed leachates	136-137
4.4.3	Effect of sowing dates and fruit load on total soluble proteins in seed leachates	138-139
4.4.4	Effect of sowing dates and fruit load on total soluble sugars in seed	142-143
4.4.5	Effect of sowing dates and fruit load on total soluble proteins in seed	146-147
4.4.6	Effect of sowing dates and fruit load on total starch contents in seed	150-151
4.4.7	Effect of sowing dates and fruit load on oil content in seeds	154-155
4.4.8	Analytical visualization of seed physiological assays weightage using chord diagram	156-157
4.5.4	Effect of sowing dates and fruit load on available N content in soil after termination of experiment	166-167
4.5.5	Effect of sowing dates and fruit load on available P content in soil after termination of experiment	168-169
4.5.6	Effect of sowing dates and fruit load on available K content in soil after termination of experiment	172-173
4.7.1	Effect of sowing dates and fruit load on economics of the treatments	185-186

LIST OF PLATES

Plate	Title	Page(s)
INTRODUCTION		
1.1	Problems of quality seed production in cucumber	3
MATERIALS AND METHODS		**Between Page(s)**
3.1	Field layout for the experiment	33-34
3.2	General view of cucumber crop at Vegetable Research Farm, UHF, Nauni during year 2022 and 2023	42-43
3.3	Visual representation of different sowing dates utilized in the study	42-43
3.4	Visual representation of different fruit load utilized in the study	42-43
3.5	Illustration of the seed extraction process from fruits	42-43
RESULTS AND DISCUSSION		
4.1	Illustration of harvested fruits ready for seed extraction	185-186
4.2	Illustration of seed germination and seedling length in laboratory experiments	185-186

Chapter-1

INTRODUCTION

Cucumber, (*Cucumis sativus* L., chromosome number 2n=2x=14) is the second most extensively grown cucurbit in the family Cucurbitaceae. Cucurbitaceous vegetables represent the largest group within the vegetable kingdom, comprising approximately 130 genera and 900 species. Within this diverse group, the genus Cucumis boasts close to 40 species, with cucumber being the most significant among them. Cucumber is indigenous to India and presumably originated in the Himalayan foothills (Jia and Wang 2021). It has been grown in Western Asia for at least 3000 years. Cucumber is a perfect summer and *kharif* vegetable crop, grown all over the world for their nutritious, tender fruits, which are used as cooked vegetable, pickle, dessert fruit and salad ingredient (Gupta et al. 2021). Cucumber, a warm-season crop, thrives predominantly in tropical and subtropical regions. It is sensitive to even slight frost and demonstrates optimal growth within temperatures spanning from 18°C to 24°C.

Cucumber is a quintessential vegetable with significant economic worth due to its robust nutritional, pharmacological and health benefits. Cucumber fruit has more than 93 percent water, providing exceptional hydration and being extremely low in calories as a meal. According to USDA Food Data Central, cucumber provides 2.6 g of carbohydrates, 0.6 g of protein, 147 mg of potassium, 16 mg of calcium, 0.02 mg of thiamine, total dietary fibre of 0.5 g, 15 calories of energy, 0.2 mg of iron, 10 mg of vitamin C and 0.01 mg of niacin per 100 g of edible portion.

It also provides several health advantages, including blood pressure regulation, body weight management, cholesterol reduction, atherosclerosis prevention, bone health and antioxidant activity (Abbey et al. 2017). It is said to be the best fruit for those with jaundice and related conditions and it may also help avoid constipation. The presence of silica in cucumbers contributes to bolstering connective tissues, thereby aiding in alleviating joint pain. Recent investigations have shown that the presence of kaempferol in cucumber is a vital antidiabetic agent (Ibitoye et al. 2018). Cucumber peels and seeds, the most nutrient-dense parts, include phytonutrients, fibre and antioxidants that boost immunity, help in skin smoothening and crucial for eye care (Gupta et al. 2022). Additionally, cucumbers include

lignans, pinoresinol, lariciresinol and secoisolariciresinol, all of which can lower the risk of certain cancers and cardiovascular diseases (Pal et al. 2020). Ayurvedic remedies include cucumber seed oil, which aids brain development and bodily functioning (Robinson and Decker-Walter 1999). Cucumber is also widely used in cosmetics owing to its natural components and high-water content, making it a perfect skincare and ayurvedic ingredient.

In India, cucumber occupies an area of 1.31 lakh hectares with the production of 17.59 lakh MT with productivity of 13.42 MT/ha (Anonymous 2024). The top five states in India for cucumber production are West Bengal, Madhya Pradesh, Haryana, Karnataka and Uttar Pradesh. In 2020-21, India emerged as one of the largest exporters of cucumber and gherkins with a value of US$ 223 million (Anonymous 2022). Cucumbers hold substantial agricultural importance in Himachal Pradesh, particularly thriving in the low and mid hill zones. These regions provide ideal growing conditions that contribute to the successful cultivation of cucumbers, making them a crucial crop for local farmers.

In India, the average cucumber productivity is much lower than other countries. The population pressure and changing climate is causing a decline in per capita land resources (0.121 ha) in India, underscoring the need for higher production and productivity (Rank et al. 2024). The significant disparity in cucumber productivity can be traced back to several factors: the limited availability of high-yielding varieties, the absence of promising hybrids and a high incidence of pests and diseases (Kaddi et al. 2014). Additionally, the scarcity of quality seeds further exacerbates this gap, hindering optimal crop performance.

Cucumber is a fleshy fruited vegetable with seeds that retain a high moisture content throughout their growth. Since cucumbers have an indeterminate flowering habit, the fruits develop and reach physiological maturity at various periods during the growing season. For higher seed quality, fruits are allowed to grow beyond the edible stage before harvesting for seed production in this crop. Therefore, its seeds continue to grow and mature inside the flesh of its fruits until they are retrieved from the fruits. The seed is the primary component that influences the crop's quantitative and qualitative qualities. To boost the economic returns for seed farmers, it is crucial to focus on enhancing both the quantity and quality of seed production. High-quality cucumber seeds are in significant demand and meeting this need can lead to better market opportunities and increased profitability for farmers.

The seed quality is also important because it may prevent viviparous germination and pest fruit degradation in the cucumber field. Among the numerous factors impacting seed development, inadequate nutrition, source-sink restrictions and poor pollination stand out as key issues (Gupta et al. 2022). Furthermore, according to Trivedi and Gunasekaran (2013), the Indian minimum germination threshold for cucumber is just 60 percent, which is far below any international level of 90 percent. These combined constraints severely affect the overall productivity and quality of the seeds in cucumber.

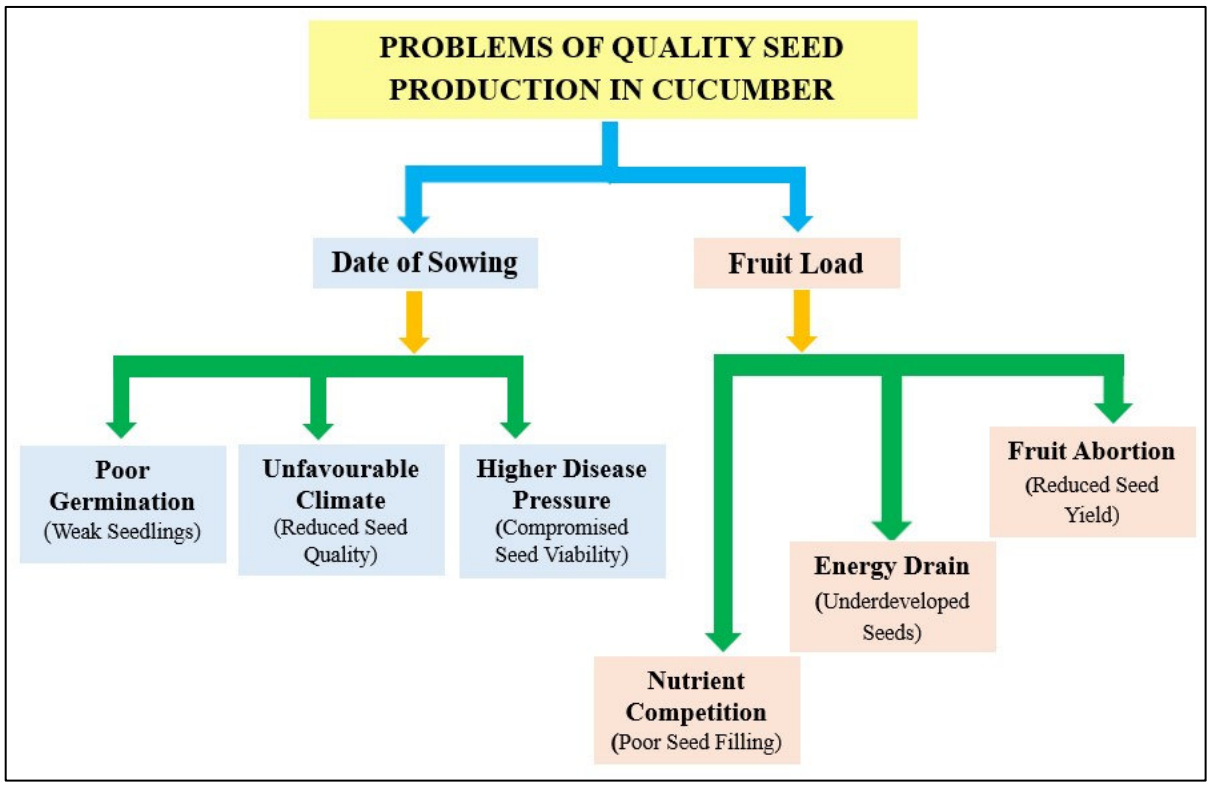


Plate 1.1. Problems of quality seed production in cucumber

Aside from the many issues with quality seed production in cucumber, the creation of a greater number of unfilled or under-developed seeds is the most severe issue (Gupta et al. 2021b). Underdeveloped or unfilled seeds in cucumbers can result from inadequate pollination and insufficient assimilate transfer for seed filling (Ram and Davri 2011). Cucumber pollination relies mainly on insect activity, while seed filling depends on the plant's photosynthetic activity and source-to-sink capability. The occurrence of morpho-physiological dormancy in cucumber seed is another significant issue that must be addressed (Patil 2018). A potential solution to improve cucumber seed quality and yield is to determine the optimal planting date and manage plant load through fruit regulation. Proper timing ensures the best growing conditions, while regulating the fruit load per plant allocates

resources efficiently, leading to healthier, more mature and filled seeds. To address this, it is essential to make comprehensive research available, particularly focusing on the timing of planting and fruit load management in cucumbers, to ensure good seed quality and yield.

The timing of sowing in agricultural crops, particularly in field conditions, significantly influences crop growth and subsequent yield outcomes (Aluko 2020). Research indicates that the timing of planting significantly impacts various growth factors, particularly temperature and moisture levels. Kaul et al. (2018) pointed out that untimely sowing could lead to a notable decrease in seed yield due to the crop's sensitivity to extreme temperatures. Also, at lower temperatures, pollinator activity is heightened, whereas it diminishes at higher temperatures. This decline in activity at elevated temperatures can adversely affect pollination rates and subsequently impact seed crop yield and quality. The timing of sowing is integral to enhancing seed production through the early utilization of rainfall, resulting in improved seed yield. Proper planting timing ensures adequate seed germination, timely emergence of seedlings and optimal root system development. Furthermore, it serves as a critical factor in pest and disease management, thus safeguarding seed quality.

Favourable climatic conditions, including temperature, alongside improved mineral nitrogen availability due to soil temperature, facilitate enhanced carbohydrate utilization by plants for protoplasm formation. Consequently, this metabolic shift results in increased cellular division and growth, thereby promoting overall plant development. Advanced planting, influenced by elevated atmospheric temperatures, accelerates the phenological cycle, which in turn results in inadequate seed setting and consequently reduced yield (Hussain et al. 2022). Hence, selecting an appropriate timing for sowing is crucial. It exposes crops to optimal climatic conditions necessary for their growth and development, ultimately contributing to increased agricultural productivity and farmer income (Tiwari et al. 2014).

Numerous researchers across various disciplines have identified a correlation between the number of fruits a plant produces and the quantity and quality of the seeds it produces (Narayan et al. 2009). If there are more fruits produced by each plant, the yield may be greater; but the quality of the seeds may suffer and vice versa. A larger number of fruits produced by each plant will also alter the transfer of assimilates, which may lead to a higher percentage of empty seeds. The number of fruits per plant, the number of seeds per fruit and

the weight of each individual seed determine the seed yield and quality in cucumber (Nerson 2008).

In cucurbits, only a small proportion of the numerous female flowers develop into mature fruits. Baniel et al. (2009) noted that cucurbit plants possess an inherent regulatory mechanism governing fruit production. This system inhibits the setting of younger ovaries while concurrently maintaining control over the fruit load through the growth of existing fruits. In cucumber seed production, fruits are retained on the plant until seed maturation, necessitating an accumulation of a greater amount of food compared to normal fruit development. Jing et al. (2000) showed the existence of initial dormancy, which was linked to intrinsic abscisic acid and specific germination inhibitors in developing cucumber seeds. While plethora of studies have documented the impacts of fruit retention on different seed and fruit parameters, there has yet to be a specific investigation targeting to study the effect of fruit load management on various seed quality and seed physiological assays.

Keeping in view of the above explained facts it was hypothesized to optimize the date of sowing and fruit load in the cucumber plant. Thus, in light of the information presented above, this study titled "**Studies on Influence of Sowing Dates and Fruit Load on Seed Yield and Quality of Cucumber (*Cucumis sativus* L.)"** was carried out to determine optimum date of sowing and fruit load management in the plant for the cucumber variety Solan Srijan with the following broad objectives:

OBJECTIVES:

i) To find out the appropriate date of sowing for seed yield and quality of cucumber
ii) To study the influence of fruit load on seed yield and quality of cucumber
iii) To decipher the economics of quality seed production in cucumber

Chapter-2

REVIEW OF LITERATURE

Cucumber (*Cucumis sativus* L.) is a significant crop in global agriculture, particularly valued for their refreshing taste and versatile use in the fresh market. A crucial factor in the successful cultivation of cucumbers is the availability of high-quality seeds, which directly influence crop yield and fruit quality (Cardoso et al. 2014). Despite the importance of seed quality, most research in cucumber cultivation has predominantly concentrated on fruit production, often overlooking the critical aspect of seed production. High-quality seeds ensure better germination rates, vigourous seedling growth and resistance to diseases, which are essential for achieving optimal yields (Smith et al. 2020). Furthermore, research indicates that seed vigour significantly affects plant establishment and can lead to improved resilience under suboptimal growing conditions (Jones and Clark 2018). Enhanced seed quality also contributes to uniform crop maturity and consistent fruit characteristics, boosting market value and profitability (Doe et al. 2017). Emphasizing seed quality can reduce the need for chemical inputs by producing more robust plants (Brown and Green 2019).

The timing of sowing and fruit load management are critical factors that significantly influence seed quality in cucumbers. Studies have shown that optimal sowing dates can improve seed filling and maturation, thereby enhancing seed quality attributes such as germination rate and seedling vigour (Smith et al. 2020). Additionally, managing the fruit load by selectively retaining a specific number of fruits per vine can improve seed size and weight, which are important indicators of seed quality (Jones and Clark 2018).

This chapter attempts to present a comprehensive review on the study titled **"Studies on Influence of Sowing Dates and Fruit Load on Seed Yield and Quality of Cucumber (*Cucumis sativus* L.)"** The published information pertaining to the development of high-quality cucumber seeds was limited, especially in terms of sowing dates and fruit load. Therefore, prior research on other crops, which provided insights to improve our understanding of cucumber seed production, was thoroughly evaluated and reviewed as under the following subheadings:

2.1 Effect of date of sowing on growth, yield and quality of seed

2.2 Effect of fruit load on growth, seed yield and quality

2.3 Economics of seed production

2.1 Effect of date of sowing on growth, yield and quality of seed

The timing of sowing has a significant impact on both cucumber yield and quality. A key factor in influencing seed quality, yield and germination is the date of planting, which may help minimize the detrimental effects of certain abiotic and biotic stresses on plants (Koca and Canavar 2014). Optimal sowing dates can enhance seed development by ensuring that the critical growth stages coincide with favorable environmental conditions, thereby improving seed vigour and overall plant performance (Pavlou et al. 2002). Additionally, appropriate sowing times can reduce the incidence of pest and disease attacks, further contributing to higher seed quality and yield. Various studies have shown that timely sowing can optimize soil moisture levels and temperature, promoting robust root systems and better nutrient uptake. Furthermore, studies indicate that delayed sowing can lead to reduced seed viability and lower overall productivity due to increased exposure to adverse weather conditions and pathogen pressure (Gou et al. 2022).

Under North Indian conditions, the impact of sowing dates on cucumber seed yield and quality has not been extensively studied. However, the existing reviews have been thoroughly discussed and are presented in detail below:

Helaly et al. (2023) carried out an experiment on a private research farm in Bani Mazar, Minia Governorate. The effects of planting dates (5th, 15th and 25th August) and six cucumber hybrids (Bahi, Mayadine, Hayel, El-Joker, Madin and Raider) on growth, flowering and yield were studied in 2020 and 2021. Hybrid Madin's main stem length increased significantly when planted on August 25th. On August 5th, the first planting date, the Mayadine hybrid flowering and harvesting began earlier than other hybrids. On August 25th, El-Joker Hybrid had the highest sex ratio. Mayadine, Hayel and El-Joker hybrids produced more fruits per plant and higher yield on August 25th. The third planting date, August 25th, yields high phosphorus, potassium and dry matter in the Hayel cucumber hybrid. Due to its higher yield and nutritional value in Minia Governorate, the Hayel hybrid was found suitable for open field growing on August 25th.

Maity et al. (2023) discussed in a review article that environmental factors, particularly sowing dates, significantly impact fruit and seed quality, with climate change playing a critical role. Temperature fluctuations and irregular rainfall, key aspects of climate change, affect seed production from early reproductive stages. Higher temperatures can

reduce seed set, increase pollen sterility and accelerate crop maturity, leading to lower yields, especially in tropical regions. Additionally, climate change alters seed biochemical composition, affecting fatty acid ratios, viability, dormancy and storability. It also shifts germination periods and promotes new seed-borne diseases, complicating production. Therefore, adjusting sowing dates and adopting climate-resilient agricultural practices are essential for maintaining high-quality seed production amidst changing climate conditions.

Akhoundnejad et al. (2022) conducted an experiment at the Agricultural Faculty research areas of Sirnak University, Turkey from May to August 2019. The experiment used three local melon cultivars: Sagsana, Ceriki and Destarki. This study examined planting dates of May 5, 20, 31 and June 15. Research suggested that planting melon on May 20th in Turkey's Şırnak area is optimal for achieving high nutritional yields. Melon yield was highest (3788 kg/decare) for the Destarki genotype, which possessed highest levels of potassium and calcium. The study found that Destarki and Sagsana melon genotypes may thrive in semi-arid Şırnak ecological conditions when planted on May 20th.

Sawale et al. (2022) conducted an experiment on the impact of sowing time and spacing on winter squash (*Cucurbita maxima* D.) cv. Arka Suryamukhi growth, yield and quality in South Gujarat during winter 2020-2021 and 2021-2022 at the Navsari Agricultural University, India. The experiment included four sowing times (P1: 1st fortnight of December, P2: 2nd fortnight of December, P3: 1st fortnight of January and P4: 2nd fortnight of January) and three spacings (S1: 2.0 m × 0.5 m, S2: 2.0 m × 0.75 m and S3: 2.0 m × 1.0 m) in a Split Plot Design with four replications. The results indicated that sowing in the first two weeks of December resulted in increased primary branch, vine length, node count, internodal length, early node appearance and days needed for first male and female flower appearance. Results indicated higher fruit yield (21.39 t ha^{-1}) when sown in the first fortnight of December. The interaction effect of sowing in the first fortnight of December with 2.0 m × 0.5 m spacing resulted in the highest fruit yield (24.41 t ha^{-1}).

A study on the impact of planting time and spacing on okra cv. Pusa Bhindi-5 on seed production and quality was conducted by Yadav et al. (2022) at the Research Farm, Division of Vegetable Science, IARI, New Delhi, during *kharif*-2017. The experiment had three planting dates (15th June, 30th June and 15th July) and three spacings (75 × 25 cm, 60 × 25 cm, 50 × 25 cm). The study used a Randomized Block Design with four replications and analyzed quantitative data using analysis of variance. Plant height and leaf count were

significantly affected by sowing timing and spacing at 30, 45 and 60 days post-sowing. Sowing timing greatly impacted days to first flowering (45.34), number of pods per plant (12.74), seed yield per plant (20.34 g), seed yield per hectare (1322 kg) and 1000 seed weight (47.26). A spacing of 50×25 cm was found suitable for sowing Pusa Bhindi-5 under Delhi conditions on June 15th for improved seed yield and quality.

Ali et al. (2021) conducted an experiment on the impact of planting dates on the growth, production and quality of muskmelon types at the Agriculture Research Institute Tarnab, Peshawar. The experiment utilized a Randomized Complete Block design with split plots. The seeds of three distinct varieties- Annanas, Honey Ball and Sweet King were planted on March 15th, March 30th and April 15th. Muskmelon variety “Annanas” recorded the best for maximum growth attributes. Early germination (5.8 days) and high germination percentage (87.8 %) were observed in muskmelons planted on April 15th. Muskmelons sown on March 30th exhibited the longest vine (177 cm), while those sown on March 15th exhibited early flowering (27.33 days), greater number of branches (6.8), more number of leaves (279.3), increased fruit weight (0.74 kg), maximum fruit thickness (3.15 cm) and fruit volume (1073.3 cm^3), greater number of fruits per vine (5.23) and per plot (20.9), an increased fruit weight per plot (16.1 kg) and a maximum yield ha^{-1} (53.6 tonnes). The muskmelon variety "Annanas" produced a higher yield and superior quality when planted on March 15th.

Borowska and Prusiński (2021) investigated the impact of three sowing dates on the growth, development and yield of four soybean cultivars under varying temperature and precipitation conditions. Early sowing yielded significantly higher soybean outputs, correlating with total precipitation in June and July, while later sowing correlated with August precipitation. The highest yields were achieved with sowing in late April to early May, with the mid-early Merlin cultivar showing the best seed and protein yield and protein content. Sowing date did not significantly affect the number or weight of seeds per pod or 1000-seed weight. Over the years, plant height, nodule weight, protein yield and leaf area index declined with significant correlations between seed yield and plant height and between seed number, seed weight per pod and 1000 seed weight.

A 3 × 2 factorial experiment was set up by Aluko (2020) with three replicates at the Teaching and Research Farm of Ekiti State University in Ado-Ekiti, Nigeria. The dates of planting were January, May and September and NPK (15:15:15) fertiliser was applied

@ 0 and 333 kg ha^{-1}. The experiment was set up in a Randomised Complete Block Design. Sowing dates had non-significant impact on growth, however, May planting resulted in more leaves per plant, larger leaf area and longer vines. Fertilised plants produced considerably more fruits (9.09 t ha^{-1}) compared to unfertilized plants (2.44 t ha^{-1}). Planting muskmelon in September resulted in more yield (11.29 t ha^{-1}), whereas planting in May resulted in a greater fruit weight (0.94 kg), but no significant difference was seen between sowing dates.

Tandoh et al. (2019) conducted field and laboratory experiments to assess the impact of planting dates on the physiological quality of two chilli pepper varieties. The field trial was a 2×3 factorial experiment with three replications in a Randomised Complete Block Design. Study factors included two chilli varieties (Shito Adope and Legon-18) and three planting dates (May 12th , June 13th and September 29th, 2015). A field study was conducted at the Crops Research Institute-Kwadaso Station in Kumasi, Ghana. Shito Adope variety planted in May produced the most fruits per plant and higher germination rates (89.9 %). September planting produced high seed yield parameters, including number of seeds per fruit (77.3), seed weight per fruit (0.40 g) and 1000 seed weight (5.00 g). Non-significant interactions between seed vigour treatments were found. The study found that genotype and environmental conditions interact to affect flowering and seed quality traits.

Behera et al. (2018) examined the impact of planting time and fertiliser dose on bitter gourd variety Pusa Rasdar in terms of growth, yield and quality in polyhouse and nethouse structures. The experiment was Factorial Randomised Block design with three replications. The treatments used four fertigation levels (15:7:16, 20:12:21, 25:17:26 and 30:22:31 kg NPK ha^{-1}) and three planting dates (15th August, 1st September and 15th September). In a nethouse, the 15th August sowing with 30:22:31 kg NPK ha^{-1} had the highest interaction effect on fruit number (11.47), fruit weight (235.26 g), yield per plant (2697.7 g) and yield per 1000 m^2 (107.91 q). Thus, growing bitter gourd variety Pusa Rasdar with 30:22:31 kg NPK ha^{-1} in an insect-proof nethouse on August 15th improved growth, yield and quality.

Undie (2018) in Southeastern Nigeria, examined planting dates and harvesting sequences for West African okra. Using a Randomized Complete Block Design with 3×4 factorial arrangements and three replicates, the experiment tested three planting dates (April 1st, June 30th and August 29th) and four harvesting sequences. Results indicated that growth, yield and fruit/seed production declined progressively from April to August. Fresh fruit yields were 1237.33 kg/ha (April 1st), 6147.44 kg/ha (June 30th) and 1377.03 kg/ha (August

29th), while seed yields were 624.92 kg/ha, 255.29 kg/ha and 63.31 kg/ha, respectively. The optimal combination was April 1st planting with harvesting every 2nd fruit, yielding the highest fresh fruit (18660.80 kg/ha) and seed yield (759.16 kg/ha).

The study was conducted by Mousa (2017) in Sidisalem district, Kafr El-Sheikh Governorate, Egypt, during the 2011 and 2012 summer plantation season. Watermelon seeds were planted at 15-day intervals on April 1st, April 15th, May 1st and May 15th. The results revealed that earliest sowing date increased watermelon seed yield. Seasonal mean weight of watermelon seeds from first and second planting dates was highest (6.670 and 7 kg/60m^2) (6.180 and 6.700 kg/60 m^2), respectively. Non-significant difference was found between the first and second planting dates. The study found that the first and second planting dates yielded more watermelon seeds than the delay planting date, likely due to favourable climatic conditions.

Longjam and Devi (2017) undertook an experiment at the Horticultural Experimental Field, College of Agriculture, Central Agricultural University, Imphal (Manipur) to standardize polyhouse cucumber planting timing. Three replications and eight treatments were used in a Randomized Block Design using two cucumber cultivars, Alamgir CT 280 and CT 380 and four planting dates (September, October, November and December). Vegetative characters, flowering, fruiting and yield were affected by planting time. Different planting times and varieties significantly affected cucumber development (@ 5% probability) in terms of main vine length, leaf count and leaf area. September planting produced the maximum main vine length (221.93 and 240.51 cm respectively), leaves per plant (21.21 and 21.92 respectively) and leaf area (393.26 cm^2 and 413.76 cm^2 respectively) for both varieties. In September planting with Alamgir CT 280, fruit set to maturity was 12.6 days shorter. Compared to other treatments, September planting with Alamgir CT 380 resulted in a superior yield (47.31 t/ha).

A field experiment was laid out by Nagendra et al. (2017) in the Department of Seed Science and Technology, College of Horticulture, Kerala Agricultural University, Vellanikkara, Thrissur to ascertain the ideal sowing timing for oriental pickling melon. Three replications of each treatment were conducted using a randomised block design. During the period of August 2016 to February 2017, the seeds were soaked for 24 hours and subsequently dispersed in the field on the first day of each month. August sowing yielded maximum fruit length (20.92 cm), fruit diameter (32.26 cm), fruit weight (1.15 kg) and fruit

yield per vine (2.99 kg). In November planting, least levels of fruit characteristics were noted. Time of planting had a major impact on the characteristics of seed yield. August planted crops revealed highest numbers of seeds per fruit (499.07), maximum seed yield per hectare (10.15 kg) as well as highest fresh (16.47 g) and dry weight (8.87 g). Sowing dates had non-significant effect on the weight of hundred seeds. There was a significant increase in vivipary in the December crop (6.25 %), which is detrimental for seed production.

Paul et al. (2016) conducted a trial at the Agronomy Division, Bangladesh Agricultural Research Institute, Joydebpur, Gazipur and Agricultural Research Station, Burirhat, Rangpur during the 2011-2012 *rabi* season. RCB design was used to evaluate six sowing dates (10th November, 20th November, 30th November, 10th December, 20th December and 30th December) with three replications. Date of sowing significantly affected garden pea seed yield per hectare. November 30th sowing produced the highest seed yield (3.66 t/ha at Joydebpur and 2.43 t/ha at Rangpur). The highest seed yield on November 30th might be due to the highest number of pods/plant, seeds/pod and 1000-seed weight. Different sowing dates also affected seed quality. The 30th November sowing at Joydebpur had the lowest moisture content (12.10 %), highest germination (97 %), maximum vigour index (2.52) and highest protein content (26.51 %). The results indicated that sowing garden pea seeds on November 30th offers the highest yield and quality seed production in Bangladesh.

The study conducted by Sharma and Kamboj (2015) examined the impact of planting time and spacing on bell pepper cv. Solan Bharpur seed yield and attributes at the Department of Vegetable Science, Dr. YSP UHF Nauni, Solan, during *kharif* 2011. The experiment used a randomized block design with 24 treatment combinations, including eight planting times (4th April, 11th April, 18th April, 25th April and 2nd May, 9th May, 16th May, 23rd May) and three spacing (60 × 45 cm, 45 × 45 cm and 45 × 30 cm). The experiment revealed considerable variations in maturity, quality, seed production and components based on planting time and spacing. $P_7 \times S_1$ (16th May, 60 × 45 cm) achieved the lowest days to maturity for fully ripe fruits (98.33), while $P_2 \times S_1$ (11th April, 60 × 45 cm) achieved the best results for seed number (196.58), seed weight (0.96 g), seed recovery (1.70 %), seed yield per plant (19.30 g), lowest fruit rot incidence, seed germination (95.38 %), seed vigour index I and II (436.80, 1265.52) and 1000-seed weight (4.88). Overall, the maximum seed output per plot (0.358 kg) and per ha (7.06 q) was produced by $P_2 \times S_3$ (11th April, 45 × 30 cm).

Jaiswal et al. (2015) conducted an experiment using a randomized complete block design with three replications to identify the optimal sowing date in cucumber at the Research Farm of the Indian Institute of Vegetable Research, Varanasi. In this study, 8 sowing dates were evaluated at 15 days interval *viz.* 15th January, 30th January, 14th February, 1st March, 16th March, 31st March, 15th April and 30th April. The sowing on March 1st resulted in the highest percentage of fruit set (46.05%), fruits per plant (3.15), fruit length (20.35 cm), fruit diameter (7.17 cm) and fruit weight (398.45 g). The lowest fruit set percentage and fruit weight were recorded with the April 30th sowing date, while minimum fruits per plant, shortest fruit length and smallest fruit diameter were observed with the January 15th sowing date. The maximum seed yield (57.64 kg/ha) and germination rates (70.31 %) were recorded with the March 1st sowing date, whereas the minimum seed yield (20.37 kg/ha) and germination rate (54.39 %) were recorded on April 30th sowing date.

Madhumathi and Sadarunnisa (2013) conducted an experiment which consisted of two parameters: transplanting dates and varieties at S.V. Agricultural College, ANGRAU, Tirupati. Two tomato varieties (Pusa Ruby and Pusa Early Dwarf) were planted across six transplanting dates: September 5th, September 15th, October 5th, October 15th, November 5th and November 15th. The experiment was replicated three times using a randomised block design with a factorial concept. The transplanting of tomato on October 15th resulted in increased fruit production (33.31), yield (1.25 kg), fruit size (length, diameter and volume), fruit weight (42.63 g), pulp content (54.01 %), ascorbic acid (20.81 mg/100 g pulp) and seeds per fruit (192.21) compared to other planting dates. Pusa Ruby planted on October 15th had the best fruit quality and seed characteristics among the treatment combinations.

Sonu et al. (2013) studied the effects of sowing time and plant geometry on okra seed quality in the rainy season of 2009 and 2010 at Seed Testing Laboratory of Gochar Mahavidyalaya, Saharanpur, Uttar Pradesh. Seed was collected from all twenty-four treatments that were subjected to laboratory testing. Laboratory experiment was Complete Randomised Design with three replications. Mean estimates of test weight (67.81 g), seedling length (27.96 cm) and seedling dry matter (1.21 g) for seed harvested from 24th June sowing were significantly better than other sowings. The 22nd July crop performed poorly in these parameters. The seed germination (87.46 %), seed viability (83.44 %), seed vigour index-I (2243.60) and seed vigour index-II (110.77) were better under Variety-1 (Parbhani Kranti).

A study by Oloyede and Adebooye (2013) was carried out at Obafemi Awolowo University's Teaching and Research Farm in Nigeria. The study used randomised complete block design with three replications and four planting dates: April 1st, April 15th, May 1st and May 15th. In a replicated experiment, April 1st and 15th crops yielded 53.56 and 49.93 tonnes ha^{-1}, outperforming all later crops. The results were due to lower rainfall, moderately higher temperatures and more sunshine. Fruit diameter, length and seed count did not vary by planting date. Seed weight per fruit was highest in the first (70.25 g) and second (71.99 g) planting dates but did not differ significantly. This experiment found that pumpkin yield was highest in April or during rainfall in the rainforest tropical region.

Bellad (2012) conducted a field experiment at the University of Agricultural Sciences, Dharwad, to evaluate the effects of four sowing dates (from the second week of November to the second week of February) on the growth, seed yield and quality of hybrid watermelon cv. Arka Jyothi. January sowing consistently produced the highest results: number of fruits per vine (6.25), fresh fruit yield per vine (6.68 kg), fresh fruit weight (32.78 kg), number of seeds per fruit (49.38), seed weight per fruit (4.62 g), seed recovery percentage (0.069 %), percentage of filled seeds (86.96 %), seed yield per vine (22.78 g) and seed yield per hectare (73.04 kg). In comparison, November sowing had lower growth and seed yield parameters, while February and December sowing yielded better results.

An investigation was conducted to study the impact of sowing date and plant population on the seed yield of *Cucurbita pepo* L. at the Islamic Azad University, Rasht, Iran by Sedaghathoor et al. (2012). The experimental treatments involved varying plant populations at three levels (0.6, 1.3 and 2.2 plants per m^2) as the main plot and different sowing dates at three levels (April 18th, April 29th and May 9th) as the sub-plot. Data was collected on seed yield per unit area, the number of seeds per fruit, fruits per plant, flowers per plant and auxiliary branches per plant. The plots with a sowing date of April 18 and a plant density of 2.2 plants per m^2 achieved the highest seed yield per unit area (1882.95 kg/ha). Therefore, the findings indicated that delaying the sowing date of pumpkin does not lead to any improvement in yield and yield components, regardless of the plant density.

The optimal planting timing and plant spacing for broccoli production were tested by Hossain et al. (2012) at Agricultural Research Station, Bangladesh Agricultural Research Institute, Thakurgaon, Bangladesh during *rabi* season, 2009-2010. The study involved three planting times (1st, 15th and 30th October) and three plant spacing (60 × 40 cm, 60 × 50 cm

and 60 × 60 cm). Yield and contributing characteristics were considerably affected by interventions. The maximum broccoli output was 21.39 t/ha on 1st October and the lowest was 13.6 t/ha on 30th October. Sowing on October 1st with 60 × 40 cm plant spacing had the best yield (22.5 t/ha), comparable to October 1st with 60 × 50 cm (21.9 t/ha), while 30th October with 60 × 60 cm yielded the lowest (12.8 t/ha).

Chattopadhyay et al. (2011) conducted field trials at the District Seed Farm, Bidhan Chandra Krishi Viswavidyalaya, West Bengal to determine optimal sowing times for okra, that result in higher yields, reduced YVMV incidence and high-quality seeds. The trials covered four years (2006-2009) with seven sowing times at fortnightly intervals (1st February, 16th February, 1st March, 16th March, 1st April and 16th April). Seed yield characteristics varied significantly with sowing dates. Seeds sown on February 16th produced the highest average yield (6.84 q/ha), followed by March 1st (6.18 q/ha) over time. Sowing seeds on February 16th or March 1st yielded the highest quality seeds (85.30 and 80.0% germination; 45.0 and 44.0 g test weight; 29.75 and 11.79 seed vigour index). Annual yield was negatively impacted by rainfall, which was the primary contributor.

Tomar et al. (2010) conducted an experiment during the spring-summer and *kharif* seasons to assess the impact of season, spacing and sowing time on the seed yield and quality of cucumber var. Pusa Uday at the Seed Production Unit field of IARI, New Delhi. The *kharif* crop matured 10 days earlier (40.79 days) than summer crop (50.67 days). Regardless of season, decreasing spacing to 1.25 m × 0.30 m resulted in enhanced seed output and fruit number. Compared to *kharif* season, the summer season had a lower germination percentage. However, summer crop had greater seed yield per fruit, 1000-seed weight, seed yield per hectare, seedling length, dry weight and seedling vigour index-I than *kharif* crop. Highest seed production (63.13 kg/ha) and superior germination (81.38 %) were obtained from the January 20th sowing throughout the spring-summer season. In the *kharif* season, planting on July 31st and August 7th yielded 41.58 kg and 39.37 kg of seeds per hectare and improved germination (93.31 % and 87.31 %), respectively.

A study conducted by Huang et al. (2010) at Vegetable Research Institute, Guangxi Academy of Agricultural Sciences, Nanning, China examined hybrid seed yield variation in bittergourd caused by environmental and cultural factors. From February 22nd to April 22nd, parental seeds were sown five times at 15-day intervals with 100 × 30 cm, 100 × 40 cm and 100 × 50 cm plant spacing. Higher plant density resulted in higher seed output than low

density. The maximum seed yield (551.42 g plot^{-1}) was obtained by planting seeds on March 23rd, 155.44% greater than the lowest yield (215.87 g plot^{-1}) on April 22nd. Similarly, the number of seeds per fruit and the weight of a single fruit varied. Fruit yield (r = 0.9428) and plant number per plot (r = 0.6072) were significantly related to seed yield per plot.

Yasari et al. (2009) evaluated the effects of sowing dates and source-sink limitations on soybean yield in Mazandaran, Iran, using a split plot design. They tested two sowing dates (22nd June and 6th July) and four soybean cultivars (BP, JK, 032 and 033), along with treatments involving the removal of leaves or flowers. The study found that earlier sowing (22nd June) resulted in a higher seed yield (58.62 g/m²) compared to the later date of 6th July (53.65 g/m²). Among the cultivars, BP had the highest yield (83.99 g/m²), attributed to more seeds per pod and pods per plant. The JK cultivar followed with a yield of 56.63 g/m². The highest yield (75.82 g/m²) was observed with no leaf or flower removal. Removing leaves from the lower canopy yielded 66.18 g/m², while flower removal resulted in 56.74 g/m², demonstrating the plant's ability to compensate for lost flowers.

2.2 Effect of fruit load on growth, seed yield and quality

Fruit load management is vital for optimizing seed yield and quality by balancing the number of fruits per plant, ensuring efficient resource allocation. Excessive fruit load can lead to variability in fruit size and quality, making consistent crop production challenging. Strategic practices such as pruning and thinning reduce competition among fruits for nutrients, water and light, allowing the remaining fruits to develop more uniformly and achieve higher quality. These practices also influence hormonal signalling and the metabolism of photosynthetic assimilates, which are crucial for optimal fruit development. Studies have consistently highlighted the importance of controlled fruit load in maximizing agricultural productivity by improving seed germination rates and overall seed yields.

The impact of fruit load management on cucumber seed yield and quality under North Indian conditions has not been extensively studied. However, existing reviews on this topic have been comprehensively examined and are detailed below:

Dilrukshi et al. (2024) investigated the relationship between fruit load per plant and seed quality in *Capsicum annuum* L. They found that as the number of fruits per plant increases, seed quality tends to decrease. The study categorized fruit loads from 8-9 fruits/plant to more than 18 fruits/plant and used a randomized complete block design with

ten replications. The treatment with 13-15 fruits/plant resulted in the highest seed quality, showing optimal values for dry weight of seeds per pod, seed number per pod, seed volume, dry weight of 1000 seeds, seed germination and viability percentages. Therefore, maintaining 13-15 fruits per plant in greenhouse conditions is recommended for high-quality seed production in *Capsicum annuum* L.

Patil et al. (2024) conducted a study at Anand Agriculture University, Anand, to investigate the impact of fruit retention on okra seed yield. They evaluated twelve treatment combinations across four levels of fruit retention: R_1 (10 fruits/plant), R_2 (15 fruits/plant), R_3 (20 fruits/plant) and R_4 (all fruits/plant). The R_2 treatment, which involved retaining 15 fruits per plant, achieved the highest values in several parameters: fruit weight (7.80 g), fruit length (17.77 cm), fruit girth (5.75 cm), number of seeds per fruit (47.01), 100-seed weight (6.893 g), germination rate (96.67 %), seedling root length (11.91 cm), shoot length (18.68 cm), total seedling length (30.58 cm), seedling fresh weight (4.810 g), seedling dry weight (0.1804 g), seedling vigour index-I (2955.96) and seedling vigour index-II (17.44).

The study conducted by Gupta et al. (2023) aimed to investigate the physio-biochemical changes associated with fruit load management and post-harvest ripening (PHR) in seed production of the bushy type summer squash cv. Kashi Subhangi. The research was carried out at the ICAR-Indian Institute of Vegetable Research, Varanasi, during the winter seasons of 2021-22 and 2022-23. Various treatments were applied, including different fruit loads (1, 2, 3, 4 and all fruits per plant) and PHR durations (0, 10, 20 and 30 days). The results indicated that retaining 2 fruits per plant and allowing PHR for 20-30 days resulted in superior seed quality (germination and vigour) and seed yield (total seed number per fruit and 100-seed weight). Limiting the number of fruits and extending the PHR period significantly enhanced seed yield and quality due to the targeted supply of assimilates and prolonged supply duration.

Vaghasiya et al. (2022) conducted a study on the effect of fruit position and fruit retention load on seed yield parameters in okra (*Abelmoschus esculentus* (L.) Moench) in summer 2018 at Junagadh Agricultural University, Gujarat. They examined three factors, including fruit retention load (H_1: fruits on different nodes for seed, H_2: all fruits retained). Maximum fruit length and seeds per fruit were from fruits on 1-3 nodes, followed by 1-8 and 4-8 nodes. Seeds from 1-3 nodes also resulted in the highest plant height and hundred seed

weight. Retaining all fruits yielded the highest seed yield per plant, followed by 1-8 and above 4^{th} nodes.

The effect of fruit load control on bushy summer squash cv. Kashi Subhangi seed production was investigated in a study by Gupta et al. (2022) at ICAR-IIVR, Varanasi, during two winter seasons. One and two fruits per plant had higher mean values for fruit weight (2.53 and 2.45 kg), length (47.5 and 45.7 cm), width (35.2 and 34.5 cm) and diameter (11.2 and 11.0 cm). Fruit growth and development in one or two fruits per plant increased mean seed attributes including total number of seeds (202 and 192), seed yield (38.9 and 34.6 g) and 100 seed weight (17.8 and 17.5 g). However, when all fruits were retained, the seed yield per plant was maximum (81.8 g). The mean data of two seasons showed that one fruit per plant had 86.5 % germination, equivalent to two (84.2 %), whereas all fruits retained per plant had 61.5 %. Treatments that kept one fruit per plant performed better, with seed vigour index-I (3183.2) and seed vigour index -II (70.9) matching two fruits per plant (SV-I 2955.4 and SV-II 68.2). Limiting seed number and allowing post-harvest ripening greatly increased seed output and quality due to tailored assimilate supply and extended supply duration.

The study, conducted at the ICAR-Indian Agricultural Research Institute, New Delhi, explores the impact of fruit load on seed quality in two cucumber varieties, Pusa Barkha and Pusa Uday, under open field and protected environments. The research conducted by Gupta et al. (2021a) investigated the effects of retaining one (T_1), two (T_2) or three (T_3) fruits per vine. Results indicated that retaining one fruit per vine significantly improved seed quality parameters such as germination (up to 92 %), seed vigour index I and II (1457.6 and 1836.7), total soluble sugars (6.8 mg/g), proteins (24.5 %), starch (29.4 %) and oil content (21.2 %), but resulted in the lowest seed yield (140 seeds per fruit). Retaining two fruits per vine achieved a balance, yielding better seed production (up to 300 seeds per fruit) with optimal quality. Conversely, three fruits per vine resulted in the lowest seed quality and yield, with germination as low as 78 percent and seed yield at 120 seeds per fruit. The study concluded that managing fruit load through controlled retention can effectively enhance both seed yield and quality, recommending two fruits per vine for the best overall outcomes.

Chandi et al. (2020) investigated the impact of training system and fruit load on bell pepper seed production and quality using cv. Solan Bharpur at the Department of Seed Science and Technology, Dr. YSP UHF Nauni, Solan (HP). Randomized Block Design (Factorial) was used in the open field and Randomized Complete Block Design in the lab for

the investigation. Different treatment combinations were employed using three training methods (no training -Tr_1, two stem training -Tr_2, four stem training -Tr_3) and four fruit loads (all fruits -FL_1, ten fruits -FL_2, twelve fruits -FL_3 and fourteen fruits -FL_4 per plant). The Tr_2FL_2 treatment (two stem training with ten fruits per plant) resulted in improved ripe fruit weight (66.65 g), length (6.56 cm), width (5.05 cm), number of seeds (187.77), 1000 seed weight (6.21 g), germination (96.50 %), speed of germination (15.95), seed vigour index-I (1448.30) and seed vigour index-II (284.77), as well as electrical conductivity (5.05 dSm^{-1}). To ensure high-quality bell pepper seed production in the mid-hills of Himachal Pradesh, the Tr_2FL_2 treatment combination was advised.

Bellad and Hiremath (2018) studied watermelon F_1 hybrid seed productivity and quality in the field and lab at the University of Agricultural Sciences, Karnataka. A randomized block design with two factors- four fruit load levels per vine (L_1: two fruits, L_2: three fruits, L_3: four fruits, L_4: all fruits) and five growth regulators were used in three replications. Different fruit loads caused significant differences in fruiting and seed output, regardless of growth regulators. As fruit load increased from L_1, fresh fruit weight and seed weight per fruit dropped. With two fruits per vine, seed weight (7.95 g), germination (82.60 %), vine length (13.76 cm), root length (9.57 cm), seedling dry weight (21.50 mg), seedling vigour index (1921) and field emergence (77.35 %) were higher. In contrast, all fruits per vine had significantly lower seed weight (5.51 g), germination (71.60 %), vine length (7.99 cm), root length (11.42 cm), dry weight (19.07 mg), seedling vigour index (1391) and field emergence (71.75 %) With two fruits per vine, the highest-quality seeds were thus produced, followed by three and four fruits.

Sharma et al. (2018) at the C.S. Azad University of Agriculture and Technology, Kanpur conducted a study to evaluate the effects of fruit positions and retention loads on okra seed yield and related traits. Using a Randomized Block Design (Factorial) with three replications, the study tested the okra variety Arka Anamika across 12 treatment combinations. The treatments included two fruit retention loads: R_1 (retention of fruits on different nodes for seed purposes and harvesting remaining fruits as vegetables) and R_2 (retaining all fruits). Additionally, six fruit positions were evaluated: P_1 (fruits on 1-3 nodes), P_2 (fruits on 4-6 nodes), P_3 (fruits on 7-9 nodes), P_4 (fruits on 10-12 nodes), P_5 (fruits on 13-15 nodes) and P_6 (fruits on all nodes). The results showed significant variations between the factors and their levels. The highest values for the number of fruits per plant, fruit length,

number of seeds per fruit and green fruit yield were observed in the R_1 treatment compared to R_2.

Sharma et al. (2017) conducted a factorial RBD experiment with three replications at the Experimental Farm, Department of Vegetable Science and Floriculture, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur, to determine the optimal stigma receptivity and fruit load for the tomato hybrid Palam Tomato Hybrid-1. There were nine treatment combinations with three pollination timings (8.00 am to 9.00 am, 9.00 am to 10:00 am and 10:00 am to 11:00 am) and three fruit loads (20, 25 and 30 per plant) in replications. The data showed that hybrid tomato seed production in polyhouses, pollinated between 9.00 and 10.00 am with 20 fruits per plant, resulted in higher fruit set (65.1 %), average fruit weight (64.2 g), 1000-seed weight (4.20 g), average seed weight per fruit (0.17 g), fruit yield per plant (1496.7 g), seed yield per plant (4.54 g) and seed quality parameters including germination (91.7 %) and seedling vigour index (1943).

Studies on fruit retention load and seed invigoration techniques in brinjal (*Solanum melongena* L.) were conducted by Bhanuje (2016) at a farmer's field in Belgaum district, Karnataka. The experiment, laid out in a randomized block design with seven treatments involving fruit load and green fruit pickings, was replicated thrice. Treatments T_7 (retaining all fruits for seed purpose) and T_1 (plucking the initial three fruits at the green stage for vegetable use and retaining the rest for seed) achieved the highest fruit yields (6959 kg/ha and 6613 kg/ha, respectively) and fruit girth (22.43 and 21.10 cm) as well as the highest number of seeds per fruit (2527 and 2482). T_7 also recorded the highest seed yield (369 kg/ha) and superior seed quality parameters, including test weight (4.61 g), germination (90.42 %), shoot length (5.88 cm), root length (8.05 cm), seedling dry weight (31.00 mg/10 seedlings) and seedling vigour index (1260). T_1 followed closely in seed quality metrics.

Chakma et al. (2016) conducted a field experiment at the Seed Technology Division, BARI, Gazipur, in 2013-2014 to determine the optimal number of fruits to retain on capsicum plants for quality seed production. Five treatments were tested: T_1 (control), T_2 (2 fruits), T_3 (4 fruits), T_4 (6 fruits) and T_5 (8 fruits). Results showed that fruit load significantly impacted yield and seed quality. The highest germination rate (90.67 %) was observed with T_4 (6 fruits), while other treatments had germination rates around 80 %. The maximum seed yield (194.9 kg) was achieved with T_5 (8 fruits). Thus, managing fruit load is crucial for optimizing both seed yield and quality.

Bhanuje and Raiker (2016) conducted an experiment at a farmer field in Chinchali village, Belgaum district, Karnataka, to examine the impact of fruit load and green fruit pickings on brinjal cv. Kudachi Local seed quality. The experiment had seven treatments with three replications in a randomized block design. The aggregated data showed that treatment T_7 (retaining all fruits for seed) improved seed quality measures. Significant changes in test weight, germination %, root and shoot length, vigour index and seedling dry weight were observed related to fruit load and green fruit pickings. The seed quality metrics were much greater in T_7 (retaining all fruits for seed purpose) (4.61 g, 90.42 %, 8.1 cm, 5.9 cm, 1260 and 31.00 mg, respectively). T_6 (plucking 18 green fruits for vegetable use and preserving the rest for seed) had considerably lower yields (3.20 g, 74.50 %, 4.9 cm, 4.3 cm, 687 and 15.80 mg).

At the Seed Production Unit at IARI, New Delhi, Tomar et al. (2015) conducted a field experiment in 2008 and 2009 to examine the impact of fruit retention and seed position on pumpkin cv. Pusa Hybrid-1 seed yield and quality. One fruit per vine (T_1) outperformed two fruits per vine (T_2) in fruit development and seed yield traits, including weight (4.46 kg), length (22.35 cm), width (20.53 cm), cavity size, filled seeds (473.50), total number of seeds (479.42), 100 seed weight (14.67 g) and seed yield (70.44 g). T_1 outperformed T_2 in seedling germination (94.27 %), total seedling length (32.76 cm), dry weight (51.01 mg), vigour index-I (3032.24) and vigour index-II (4721.10) and low moisture content. The central segment of the fruit had the maximum number of full seeds, total seeds, germination, seedling length, dry weight, vigour indices I and II and low moisture content. The recommendation is to keep one fruit per vine and remove seeds from the middle and stylar segments for high-quality pumpkin seed output in Pusa Hybrid-1.

Cebeci and Padem (2014) conducted an experiment on the "Yaren" cucumber variety, where parent lines were crossed, leaving 1 to 13 fruits on female plants to test seed quality and quantity. The study used complete randomized blocks with four replicates and five plants per replicate. Results showed that maximum fruit diameter (3.65 cm) and weight (731.0 g) occurred with 1 fruit per plant, while the smallest fruit diameter (2.30 cm), fruit length (18.63 cm) and fruit weight (300.33 g) were from plants with 12, 13 and 10 fruits, respectively. A negative correlation was found between fruit number and fruit size/weight, with significant differences at 5%. The highest seed yield was from plants with 11 fruits and the lowest from plants with 1 fruit. Seed weight ranged from 31.83 g to 38.80 g. No abnormal seedling

growth was observed, with the highest germination and seedling growth rates from 2 fruits per plant. Germination rates were highest (100 %) in plants with 1 to 5 fruits. The effects on germination, seedling growth and seedling vigour were significant ($p<0.05$).

Kromdijk et al. (2014) in a review paper concluded that fruit load management is crucial for producing high-yield and good quality seeds. It optimizes resource allocation by balancing the number of fruits per plant, which directly influences fruit size and composition. They have discussed that excessive fruit load can lead to variability in fruit characteristics, making it difficult to achieve consistent quality. By removing some flowers and young fruits early, competition among the remaining fruits is reduced, enhancing their growth and development. This practice also alters hormone signalling and adjusts the supply and metabolism of photosynthetic assimilates, resulting in better fruit quality.

Bellad (2012) evaluated the impact of fruit load on hybrid watermelon cv. Arka Jyothi. Retaining two fruits per vine achieved the highest fruit weight (7.42 kg), seed weight per fruit (4.40 g) and 100-seed weight (7.95 g), while retaining all fruits per vine resulted in lower values (6.29 kg, 3.08 g and 5.51 g, respectively). Germination, root length, shoot length, seedling vigour index, dry weight of seedlings and field emergence were also higher with two fruits per vine (82.60 %, 9.57 cm, 13.76 cm, 1929, 21.50 mg, 77.35 %) compared to all fruits retained per vine (71.60 %, 7.99 cm, 11.42 cm, 1391, 19.07 mg, 71.75 %). Three and four fruits per vine showed intermediate results.

The study by Huang et al. (2010) investigated the impact of number of fruits per plant on seed yield of bitter gourd. The research was conducted with different sowing dates and plant densities. It was found that plants with three to six fruits produced significantly higher seed yields compared to those with no limit on fruit set, except for the February 22nd sowing date. The highest seed yield was obtained with three fruits per plant, making this the optimal number for hybrid seed production. Generally, seed yield per plot was not affected by the number of fruits per plant, except on the April 7th sowing date. The study concludes that maintaining three fruits per plant yields the highest seed production, recommending this practice for optimal hybrid seed production in bitter gourd.

The influence of fruit number per plant on cucumber seed productivity and quality was investigated by Nerson (2008) in studies at the Department of Vegetable Crops, Agricultural Research Organization, Newe Ya'ar Studies Centre in northern Israel. Two trials

were conducted in a greenhouse in winter and in the field in summer. The number of fruits per plant did not affect fruit weight or seed output in either scenario. Fruit weight in the winter greenhouse trial ranged from 419 to 585 g, while seed output was 2.4 to 4.1 g per fruit. Summer field trial fruit weight ranged from 533 to 782 g and seed output was 3.4 to 7.4 g per fruit. These findings suggest that while environmental variables affected output, the number of fruits per plant had little effect on cucumber seed yield and quality.

The study conducted by Valantin-Morison et al. (2006) in Avignon, southern France, explored the effects of fruit load and seed content on the development and quality of cantaloupe melons. Researchers used plastic tunnels to grow two F_1 hybrids of "Charentais" cantaloupe, Talma and Galoubet. The experimental setup involved two treatments: one where all female flowers and young ovaries except one were removed to create a low fruit load and another where all fruits were allowed to develop naturally, creating a high fruit load. Pollination was carefully controlled to vary seed content within the fruits. The results indicated that fruit load did not influence the number of seeds per fruit, but higher fruit loads resulted in lighter individual seeds. Additionally, melons grown under high fruit load conditions exhibited reduced sweetness and a higher incidence of water-soaking, a physiological disorder, adversely affecting fruit quality.

Lytovchenko et al. (2004) emphasized the crucial role of fruit photosynthesis in tomato seed development, highlighting that proper fruit load management ensures adequate assimilate import, essential for high-quality seed production in tomato. Effective fruit load management, through strategic pruning and thinning, reduces competition among tomato fruits for resources, allowing for better growth and uniformity. This practice influences hormonal signaling and the metabolism of photosynthetic products, leading to improved fruit quality. Thus, controlled fruit load is vital for maintaining uniformity and achieving optimal fruit and seed production in tomato.

2.3 Economics of seed production

The economics of cucumber seed production are closely associated with the timing of sowing and fruit load management. Early sowing can capitalize on optimal growing conditions, potentially increasing yields, though it may elevate the risk of pest and disease infestations. In contrast, late sowing may mitigate such risks but could lead to reduced yields due to a shorter growing season. Effective management of fruit load ensures optimal

allocation of plant resources to a limited number of high-quality fruits, thereby enhancing seed quality and reducing production costs, ultimately maximizing economic returns.

The literature pertaining to economics of cucumber seed production, with a focus on sowing dates and fruit load management, is reviewed and summarized below:

The review article by Gupta et al. (2021b) delved into the impact of fruit load management on the economics of cucumber seed production. Their findings highlighted that allowing a higher number of fruits to mature on the mother plant results in a greater seed yield but with compromised quality. Conversely, managing the fruit load by limiting the number of fruits per vine enhances seed quality. The study underscored that retaining two fruits per vine achieves an optimal balance, producing higher seed yields without sacrificing quality. This management practice is crucial for achieving economic efficiency in cucumber seed production, addressing the balance between quantity and quality of seeds.

The experiment was conducted by Sahoo et al. (2021) during 2018-19 and 2019-20 at the Regional Research and Technology Transfer Station, Bhawanipatna, Kalahandi, Odisha. The field experiment used a split-plot design with twelve treatments, comprising two tomato hybrids (Arka Samrat and Arka Rakshak), in the main plots and six sowing dates in sub-plots, replicated thrice. Net returns from different sowing dates varied from Rs. 40,597 ha^{-1} to Rs. 272,947 ha^{-1}. The 30th September sowing date earned the highest net return (Rs. 272,947), followed by the 15th September (Rs. 209,797). Tomato hybrid Arka Rakshak recorded the highest B:C ratio of 2.0, compared to 1.9 in Arka Samrat. The 30th September sowing date recorded the maximum B:C ratio of 2.7, followed by 15th September with B:C ratio of 2.3.

Longjam and Devi (2017) conducted an experiment to standardize planting times for cucumber in a polyhouse during 2010-11 at the Horticultural Experimental Field, College of Agriculture, Central Agricultural University, Imphal, Manipur. The study, using a Randomised Block Design (Factorial) with three replications, evaluated four planting dates (September, October, November, December) and two cucumber varieties (Alamgir CT 280 and Alamgir CT 380). Results showed that Alamgir CT 380 planted in September yielded the highest in polyhouse conditions. However, the October planting had the highest cost-benefit ratio (1:2.24) due to better cucumber prices in October-November compared to November-December.

Bhanuje (2016) conducted field experiments at a farmer's field in Belagavi District, Karnataka, during *kharif* 2014-15 and 2015-16 in brinjal. The study involved seven treatments focusing on fruit load and green fruit pickings, replicated thrice in a randomized block design. The highest benefit-cost ratio of 2.68 was achieved with T_7 (retaining all fruits for seed purpose), followed by T_1 (plucking the initial three fruits at the green stage for vegetable use and retaining the rest for seed). Pooled data showed an additional income of Rs. 14,395 per hectare with T_1 over T_7. This extra income came from green fruits, as seed yield did not significantly decrease with the removal of three fruits for vegetable use.

Kumar et al. (2015) conducted an experiment during the *kharif* seasons of 2011 and 2012 at five randomly selected farmer's fields in Panchmahals district, Gujarat on okra. The treatments included three sequential sowing dates at 15-20 day intervals, starting from the 3rd week of June (T_1), 1st week of July (T_2) and 3rd week of July (T_3). Arranged in a randomized block design with five replications, the results showed maximum gross and net returns for T_1 (Rs. 116,265 and Rs. 86,980), followed by T_3 (Rs. 87,590 and Rs. 58,390) and T_2 (Rs. 75,895 and Rs. 45,778). The highest B:C ratio was recorded for T_1 (3.97), followed by T_3 (3.0) and T_2 (2.52). These variations are attributed to the fluctuating demand and supply of okra pods during early *kharif*, resulting in better prices due to higher demand and limited availability.

Jaiswal et al. (2015) conducted an experiment using a completely randomized block design with three replications to determine the optimal sowing date for cucumber seed yield during the winters of 2007 and 2008. Economic analysis revealed that the highest net return of Rs 17,059 and a B:C ratio of 2.44 were achieved with the March 1st sowing date. The lowest net return and B:C ratio was recorded for the January 15th sowing date.

Singh et al. (2015) conducted a study at the G. B. Pant University of Agriculture and Technology, Hill Campus, Tehri Garhwal, Uttarakhand during the spring-summer seasons of 2011 and 2012 to examine the effects of transplanting dates and mulching materials on summer squash (*Cucurbita pepo* L.) under rainfed conditions. The trial included black polyethylene, pine needles, FYM and dried leaves as mulches, with and without mulch (control) and three transplanting dates: 10th March, 25th March and 9th April, using a factorial randomized block design replicated thrice. Transplanting on 10th March yielded the best results in plant growth, total yield (61.35 t/ha), net return (Rs. 452,897/ha) and benefit-cost ratio (3.82). Among 15 treatment combinations, transplanting on 10th March with black

polyethylene achieved the highest yield (76.03 t/ha), net profit (Rs. 582,242/ha) and benefit-cost ratio (4.27).

Kabir et al. (2013) conducted an experiment at the Horticulture farm of Sher-e-Bangla Agricultural University, Dhaka, from November 2005 to April 2006, to evaluate the effects of sowing times and spacings on the growth and yield of carrot. The study assessed cucumber seed production economics with four sowing dates: November 28 (T_1), December 8 (T_2), December 18 (T_3) and December 28 (T_4) and three spacings: 20 cm×10 cm (S_1), 25 cm×15 cm (S_2) and 30 cm×20 cm (S_3). The highest production costs (TK 52,266) were for T_1S_1, T_2S_1, T_3S_1 and T_4S_1 treatments and the lowest (TK 47,709) for T_1S_3, T_2S_3, T_3S_3 and T_4S_3 treatments. The highest benefit-cost ratio was 2.95 for T_1S_1, while the lowest was -0.03 for T_4S_2.

Nandre and Sahane (2011) studied the effects of sowing dates and nutrient management on fenugreek seed production economics at the Department of Horticulture, Dr. Panjab Rao Deshmukh Krishi Vidyapeeth, Akola. Using a split-plot design with four replications and 24 treatment combinations, the study found that fenugreek seeds sown on November 1st (S_1) and supplied with 37.50 kg N + 18.75 kg P_2O_5 ha^{-1} + FYM @ 10 t ha^{-1} (F_5) yielded the highest gross monetary returns (₹ 52,211 and ₹ 66,104, respectively). The maximum net monetary returns (₹ 35,984 and ₹ 47,914, respectively) were achieved with November 1st (S_1) sown crop and supplied with 50 kg N + 25 kg P_2O_5 ha^{-1} (F_2). The highest cost-benefit ratio (5.59) was recorded for the S_1F_2 treatment combination.

Field trials conducted by Chattopadhyay et al. (2011) at the Bidhan Chandra Krishi Vishwavidyalaya, West Bengal, assessed the optimal sowing times for maximizing yield and seed quality of okra over four years. Seven sowing dates were tested: 1st February, 16th February, 1st March, 16th March, 1st April, 16th April and 1st May. Economic analysis indicated that sowing between 1st February and 2nd April was most profitable. The highest income per rupee investment (2.40) was achieved with sowing in the 2nd fortnight of February, followed by sowing on 1st March (1.90). Sowing in the 2nd fortnight of February was identified as the best practice for higher yields, lower YVMV disease incidence and superior seed quality in the Gangetic alluvium of eastern India.

Ravikumar et al. (2005) observed in their cucumber experiment that seed yield, seed quality and benefit-cost ratio were higher during the *kharif* season when adopting narrow spacing, no nipping and retaining four fruits per vine.

Jana (2005) studied the effects of various sowing dates (30th October, 15th November, 30th November, 15th December, 30th December, 15th January and 30th January) on French bean (*Phaseolus vulgaris*) performance in Terai, West Bengal, during the *rabi* seasons. The cv. Contender required fewer days to harvest (88.6) and had higher pods per plant (16.5), seed yield (25.4 g/plant and 2.32 t/ha) and 100-seed weight (39.18 g). Sowing on 15th November achieved the highest seeds per pod (5.2), seed yield (31.5 g/plant and 2.82 t/ha) and 100-seed weight (39.77 g). Thus, the cv. Contender sown on 15th November recorded the highest seed yield and cost-benefit ratio (1:3.80) in the Terai region of West Bengal.

Chapter-3

MATERIALS AND METHODS

The present research investigation titled **"Studies on Influence of Sowing Dates and Fruit Load on Seed Yield and Quality of Cucumber (*Cucumis sativus* L.)"** was carried out at the Experimental farm and Experimental laboratory of the Department of Vegetable Science, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh over the years 2022-2023 and 2023-2024. This chapter provides an overview of the experimental materials used, the methodologies adopted and the observations recorded during the course of investigations.

3.1 EXPERIMENTAL SITE

3.1.1 Location

The field experiments were carried out at the Experimental farm situated at Nauni, approximately 13 km from Solan city, at an elevation of 1270 meters above mean sea level, positioned between latitude 30°51'N and longitude 77°11'E. This area is classified within the mid-hill zone of Himachal Pradesh. The laboratory experiments were carried out at the Experimental laboratory of the Department of Vegetable Science, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh.

3.1.2 Climate

The area has a predominantly sub-temperate, semi-humid climate with cold winters. The hottest months are May and June, while December and January are the coldest. The farm, located in Himachal Pradesh's mid-hill zone, experiences a sub-temperate to sub-tropical climate with annual rainfall between 1000 and 1300 mm. The Meteorological data including temperature, rainfall and relative humidity, were recorded at the Meteorological Observatory of Department of Environmental Science, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, during the cropping periods from April to August in 2022 and 2023 and are presented in Figure 3.1 and Figure 3.2.

3.1.3 Soil characteristics

Prior to the layout of the experiment, soil samples were collected from five random locations at a depth of 0-15 cm within the experimental field. These samples were then

combined into a composite sample and analyzed for essential physical and chemical properties, with results presented in Table 3.1. Upon completion of the experiment, soil samples from each plot were collected and analyzed for available nutrients using standard methods.

Figure 3.1. Graphical representation of monthly data pertaining to the temperature, rainfall and relative humidity during the cropping period (April - September 2022)

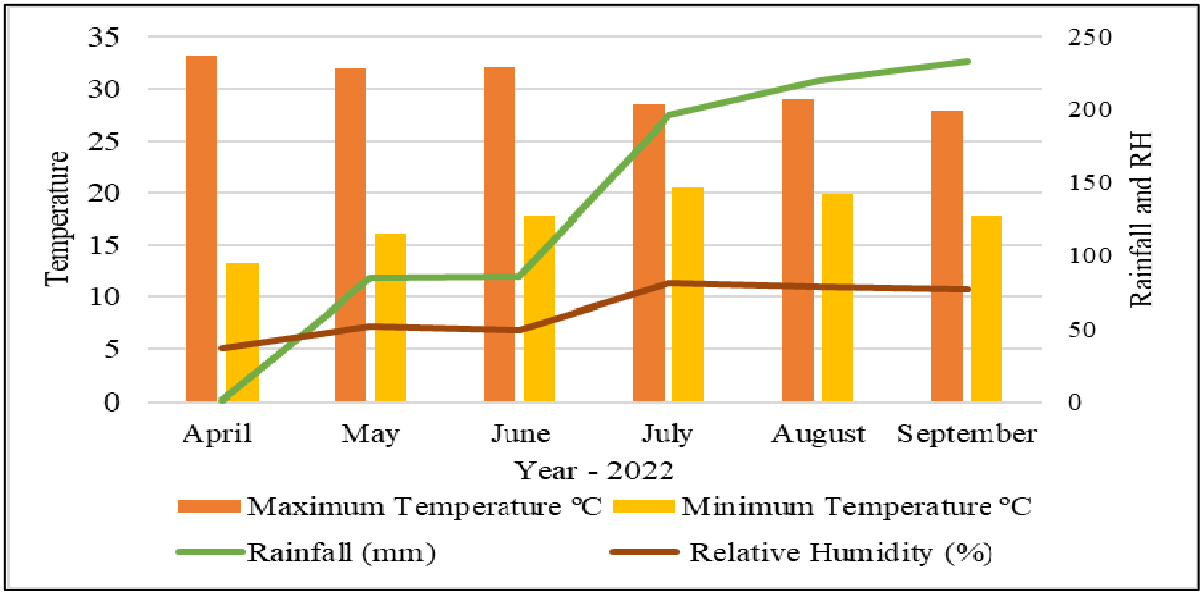
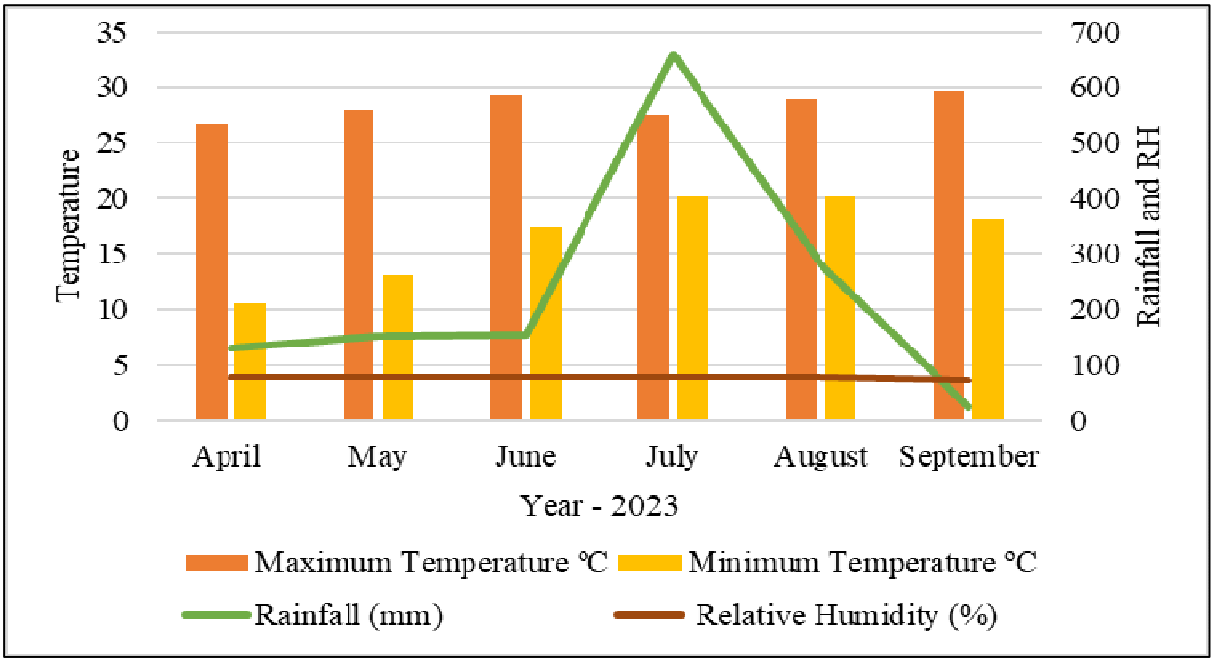


Figure 3.2. Graphical representation of monthly data pertaining to the temperature, rainfall and relative humidity during the cropping period (April - September 2023)



Source: Meteorological Observatory, Department of Environmental Science, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, HP- 173 230

Table 3.1: Physico-chemical properties of the soil before planting

Parameters	Values obtained (Year 2022-23)	Values obtained (Year 2023-24)	Methods used
Soil pH	7.32	7.35	Digital pH meter (Jackson 1973)
Soil EC (dSm^{-1})	0.24	0.27	Electrical conductivity meter (Jackson 1973)
Organic carbon (%)	1.32	1.41	Rapid titration method (Walkley and Black 1934)
Available N (kg/ha)	275.28	280.12	Alkaline potassium permanganate method (Subbiah and Asija 1956)
Available P (kg/ha)	55.30	60.95	Olsen's method (Olsen et al. 1954)
Available K (kg/ha)	380.15	391.12	Neutral normal ammonium acetate method (Merwin and Peech 1951)

3.2 EXPERIMENTAL MATERIALS

3.2.1 Source of seed

The seeds of the cucumber variety Solan Srijan were obtained from the Department of Vegetable Science, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh.

3.2.2 Description of variety

The cucumber variety Solan Srijan is a prolific fruit bearer that matures 55-60 days after planting. The fruits are cylindrical, crisp and green, measuring 18-22 cm in length and weighing 255-265 g each. Each plant typically produces 10-15 fruits, with an average yield of 200-225 quintals per hectare. This variety is well-suited for cultivation in Himachal Pradesh and other hilly regions.

3.2.3 Cultural practices

The standard cultural practices as recommended for raising a healthy crop of Cucumber as per the Package of Practices for Vegetable Crops, published by the Directorate of Extension Education, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh were followed (Anonymous 2020).

3.2.3.1 Preparation of field and sowing

The experimental field was thoroughly ploughed with a tractor and then planked 10 days before each sowing date. Stones, pebbles and residues from previous crops were

manually removed. The field was leveled, with adequate drainage provisions. During field preparation, well-decomposed farmyard manure (100 q/ha) was uniformly applied to all treatments. Beds of size 3.0 m × 1.5 m were prepared with channels of size 30 cm at both sides. The seeds of cucumber were directly sown on the beds at a spacing of 75 cm × 60 cm in both years.

3.2.3.2 Fertilizer application

Urea, superphosphate and potash were the source materials for supplying nutrients N, P_2O_5 and K_2O respectively. These nutrients were mixed based on the package of practices recommendation @100:50:60 kg/ha. Half dose of N and full dose of P_2O_5 and full dose of K_2O were applied as basal dose and remaining half dose of N was applied in two equal split doses at the time of vining and full blooming.

3.2.3.3 Irrigation

A light irrigation was applied after sowing while subsequent irrigations were scheduled every 3-4 days for the first 20 days. Afterwards, irrigation was provided every 8-10 days, depending on weather conditions and soil moisture levels.

3.2.3.4 Crop Management

All the intercultural operations were done thoroughly as per the package of practices recommendation. Pesticides and fungicides were used as needed to keep the crops free from pests and diseases. Rouging was done to remove off types and mosaic infected plants. The seed crops were kept weed-free through hand weeding throughout the growing period. Regular hoeing and earthing-up were done to raise a healthy crop of cucumber.

3.2.3.5 Trailing of vines and harvesting of seed crop

Vertical trailing with plastic coir and bamboo poles were practiced during the two years of investigation. Upon maturity of fruits for seed extraction, tagged fruits were harvested as per the treatment. The fruits were then cut open and the seeds were manually extracted, cleaned, washed and dried.

3.2.4 Chemicals and glassware

The glassware used in the experiment, including bottles, beakers, measuring cylinders, test tubes and flasks, were sourced from Borosil. All chemicals were procured from

Central Drug House (P) Ltd. and HiMedia and were of analytical grade. They were stored according to the manufacturer's instructions, either at room temperature or 4°C. Sterilized double-distilled water was used for preparing buffers and stock solutions.

3.3 METHODOLOGY

3.3.1 Experimental details

The experiment was carried out with the following details:

1.	**Crop**	:	Cucumber
2.	**Variety**	:	Solan Srijan
3.	**Design of Experiment**	:	Split Plot Design
4.	**Year of experiment**	:	2022-2023 and 2023-2024
5.	**Number of Replications**	:	03
6.	**Number of Treatments**	:	20
7.	**Plot size**	:	3.0 m × 1.5 m = 4.5 m^2
8.	**Plant spacing**	:	75 cm × 60 cm
9.	**Number of plants per plot**	:	10
10.	**Total number of plots**	:	60
11.	**Location**	:	Experimental Research Farm Department of Vegetable Science Dr. YSP UHF, Nauni, Solan (HP)

3.3.2 Treatment details

The details of the treatments used for the study are as under:

Based on two factors:

FACTOR- I: Sowing dates (number of levels = 4)

1. **D_1** = 15^{th} April
2. **D_2** = 30^{th} April
3. **D_3** = 15^{th} May
4. **D_4** = 30^{th} May

FACTOR- II: Fruit load / Number of fruits retained per plant (number of levels = 5)

1. **F_1** = 3 fruits per plant
2. **F_2** = 4 fruits per plant
3. **F_3** = 5 fruits per plant
4. **F_4** = 6 fruits per plant
5. **F_5** = Control (all fruits retained)

- Fruits were retained after the 6^{th} node on the plant.

3.3.3 Treatment combinations

The details of 20 treatment combinations used for the study are as under:

Table 3.2: Details of treatment combinations

S. No.	Treatment codes	Treatment combinations	Treatment details
1.	**T_1**	D_1F_1	15th April sowing date + 3 fruits per plant
2.	**T_2**	D_1F_2	15th April sowing date + 4 fruits per plant
3.	**T_3**	D_1F_3	15th April sowing date + 5 fruits per plant
4.	**T_4**	D_1F_4	15th April sowing date + 6 fruits per plant
5.	**T_5**	D_1F_5	15th April sowing date + all fruits retained (control)
6.	**T_6**	D_2F_1	30th April sowing date + 3 fruits per plant
7.	**T_7**	D_2F_2	30th April sowing date + 4 fruits per plant
8.	**T_8**	D_2F_3	30th April sowing date + 5 fruits per plant
9.	**T_9**	D_2F_4	30th April sowing date + 6 fruits per plant
10.	**T_{10}**	D_2F_5	30th April sowing date + all fruits retained (control)
11.	**T_{11}**	D_3F_1	15th May sowing date + 3 fruits per plant
12.	**T_{12}**	D_3F_2	15th May sowing date + 4 fruits per plant
13.	**T_{13}**	D_3F_3	15th May sowing date + 5 fruits per plant
14.	**T_{14}**	D_3F_4	15th May sowing date + 6 fruits per plant
15.	**T_{15}**	D_3F_5	15th May sowing date + all fruits retained (control)
16.	**T_{16}**	D_4F_1	30th May sowing date + 3 fruits per plant
17.	**T_{17}**	D_4F_2	30th May sowing date + 4 fruits per plant
18.	**T_{18}**	D_4F_3	30th May sowing date + 5 fruits per plant
19.	**T_{19}**	D_4F_4	30th May sowing date + 6 fruits per plant
20.	**T_{20}**	D_4F_5	30th May sowing date + all fruits retained (control)

3.4 OBSERVATIONS RECORDED

The observations were recorded for seed yield and quality of cucumber plants sown on 4 different sowing dates and subjected to 5 varying fruit load levels as under:

3.4.1 Plant and fruit characters

3.4.1.1 Vine length (cm)

The vine length of five randomly selected plants in a plot was measured from the ground level to the tip of vine at the time of harvesting of mature fruit and average was calculated.

3.4.1.2 Fruit length (cm)

The length of ten randomly selected fruits from each plot was measured with the help of scale and average fruit length was calculated.

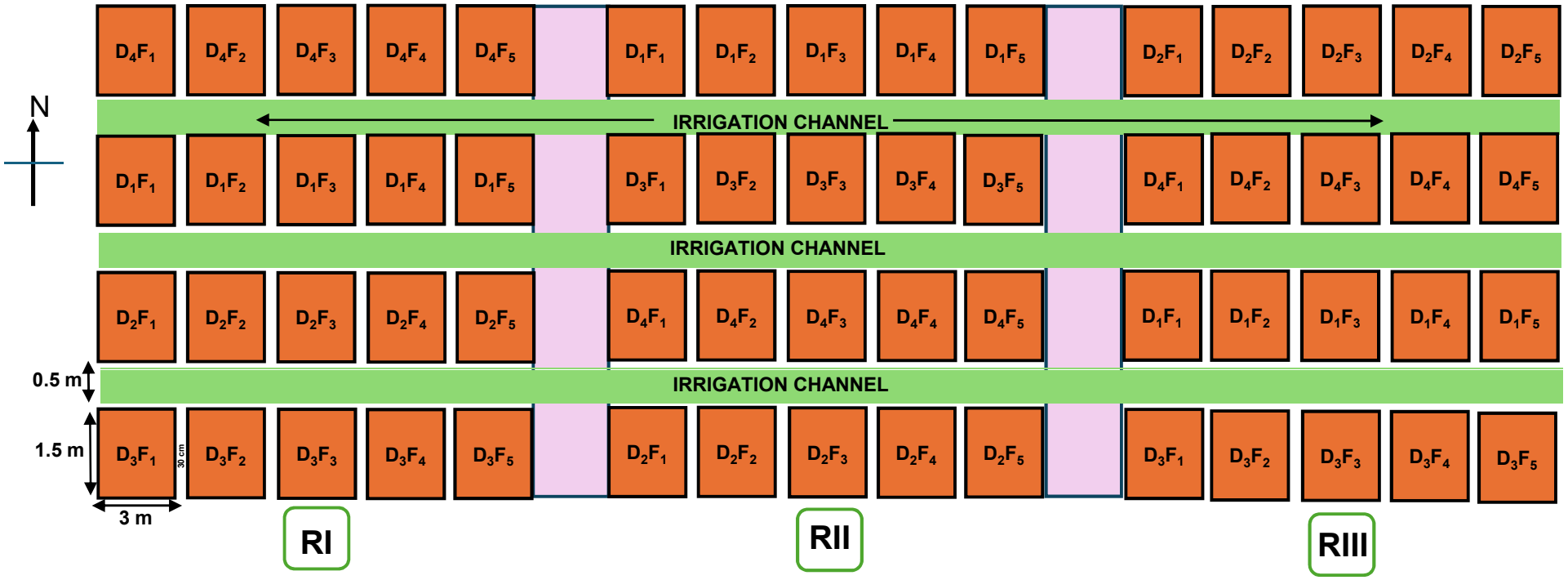


Plate 3.1: Field layout for the experiment

3.4.1.3 Fruit breadth (cm)

The fruits used to record the length were also used to measure the fruit width using a digital Vernier Caliper and the mean value was calculated.

3.4.1.4 Fruit weight (g)

Ten fruits were randomly selected from each plot and weighed using an electronic weighing balance. The average weight per fruit was then calculated.

3.4.2 Seed yield traits

3.4.2.1 Total number of seeds per fruit

The total number of seeds were counted from ten randomly selected fruits in each plot and the average value was calculated to determine the number of seeds per fruit for each treatment combination.

3.4.2.2 Seed yield per fruit (g)

From each plot, ten fruits were weighed randomly and the seeds were extracted, dried and then weighed. The seed yield from the ten fruits was determined by dividing the total seed weight by the total fruit weight. The seed yield per fruit for each treatment was then calculated by dividing the seed yield of the ten fruits by ten, with the result expressed in grams (g).

$$\text{Seed yield per fruit (g)} = \frac{\text{Weight of seed from fruits (g)}}{\text{Number of fruits}}$$

3.4.2.3 Seed yield per plant (g)

The seeds were harvested from each picking of five randomly selected plants in a plot, dried to 8 percent moisture content and weighed. The average seed yield per plant was then calculated.

3.4.2.4 Seed yield per plot (g)

The seed yield per plot (g) was worked out from seed yield per plant (g) as under:

Seed yield per plot = Seed yield per plant × Number of surviving plants per plot

3.4.2.5 Seed yield per hectare (kg)

The seed yield per hectare was calculated as follows:

$$\text{Seed yield per m}^2\text{ (g)} = \frac{\text{Seed yield per plot (g)}}{\text{Size of the plot}}$$

$$\text{Seed yield per hectare (kg)} = \frac{\text{Seed yield per m}^2\text{ (g)} \times 10000 \times 0.70}{1000}$$

While calculating the seed yield per hectare thirty percent area was considered as depreciation for construction of channels in the experimental field.

3.4.2.6 Seed yield index

The seed yield index for each treatment was calculated following the formula suggested by Nerson et al. (1994) as under:

$$\text{Seed yield index} = \frac{\text{Seed yield (g)}}{\text{Fruit weight (kg)}}$$

3.4.2.7 1000 seed weight (g)

Four random seed samples from each treatment were taken and 1000 seeds were counted, weighed and the average value was expressed in grams, following the procedure outlined by ISTA (Anonymous 2019).

3.4.2.8 Number of filled seeds

Hundred seeds were taken in three replications from each treatment and placed in a 250 ml beaker. Water was then poured into the beaker. After a few minutes, the seeds that sank were considered filled seeds. The seeds that remain floating were removed first and the number of filled seeds that sank were then counted.

3.4.2.9 Number of unfilled seeds

Hundred seeds were taken in three replications from each treatment and placed in a 250 ml beaker. Water was then poured into the beaker. After a few minutes, the seeds that float were considered unfilled seeds. The seeds that remain floating were removed carefully and counted.

3.4.2.10 Seed fresh and dry weight (g)

Hundred seeds were taken in three replications from each treatment. Their fresh weights were measured, then the seeds were dried in a hot air oven at 80 ± 2°C for 24 hours

and cooled at room temperature. The dried seeds were weighed using a digital weighing balance and the average weights were calculated and expressed in grams.

3.4.3 Seed quality traits

3.4.3.1 Seed germination (%)

Hundred seeds from all replications of each treatment were used for conducting the germination test as per ISTA (Anonymous 1985). This was carried out by using rolled paper method in the seed germinator at 25 ± 2 ºC and 85 per cent relative humidity. The number of normal seedlings were counted on eighth day (final count) of germination and expressed in percentage. Germination percentage was calculated by using the formula:

$$\text{Seed germination (\%)} = \frac{\text{Number of seeds germinated}}{\text{Total number of seeds placed for germination}} \times 100$$

3.4.3.2 Speed of germination

To determine the speed of germination, the number of seedlings that germinated was recorded daily from the first to eighth day. The speed of germination was then calculated following the method described by Maguire (1962).

$$\frac{\text{Number of seedlings emerged}}{1^{st} \text{ day of sowing}} + \ldots\ldots\ldots + \frac{\text{Number of seedlings emerged}}{\text{Day of last count } (8^{th})}$$

3.4.3.3 Field emergence (%)

A total of fifty seeds from each replication were randomly selected from each treatment and manually sown in protrays filled with potting mixture of cocopeat and vermicompost. The protrays were regularly watered to maintain optimal moisture levels for seedling emergence. The number of seedlings that emerged after eight days (final count) from sowing were recorded and expressed as the total field emergence (%).

$$\text{Field emergence (\%)} = \frac{\text{Number of seedlings emerged on final count}}{\text{Total number of seeds sown}} \times 100$$

3.4.3.4 Seedling length (cm)

The length of the seedlings was measured on the eighth day of the germination test. Ten normal seedlings were randomly selected from each replicate to determine the seedling length. The total seedling length was measured from the tip of the primary leaf to the tip of

the primary root using a scale and the average length was calculated and expressed in centimeters.

3.4.3.5 Seedling dry weight (mg)

The ten seedlings selected from each replicate for measuring seedling length were also used to determine seedling dry weight. These seedlings were placed in an oven at 103°C ± 2 for 24 hours. After drying, their weight was measured using an electronic weighing balance and the average weight was expressed in milligrams (mg).

3.4.3.6 Seedling vigour index - I

The seedling vigour index - I for each treatment was calculated using the formula proposed by Abdul-Baki and Anderson (1973) and expressed as a whole number.

$$\text{Seedling vigour index-I} = \text{Germination (\%)} \times \text{Seedling length (cm)}$$

3.4.3.7 Seedling vigour index – II

The seedling vigour index - I for each treatment was calculated using the formula proposed by Abdul-Baki and Anderson (1973) and expressed as a whole number.

$$\text{Seedling vigour index-II} = \text{Germination (\%)} \times \text{Seedling dry weight (mg)}$$

3.4.4 Seed physiological assay

3.4.4.1 Electrical conductance (µS $cm^{-1}g^{-1}$) from seed leachates

Fifty seeds, randomly selected from each replicate of all treatments, were weighed and soaked in 100 ml of double-distilled and sterilized water at 25°C for 24 hours. The electrical conductivity (EC) of the seed leachates was then measured using a digital conductivity meter and expressed in µS $cm^{-1}g^{-1}$, as described by Pandita and Nagarajan (2006). The EC was measured under laboratory ambient conditions and calculated using the following formula:

$$\text{EC } (\mu S\ cm^{-1}g^{-1}) = \frac{\text{Conductivity reading} - \text{Background reading}}{\text{Weight of seeds (g)}}$$

3.4.4.2 Total soluble sugars in seed leachates (mg g^{-1})

For each replicate of all treatments, 0.5 ml of seed leachate was taken in test tubes, to which 1 ml of 5% phenol was added, followed by 5 ml of concentrated sulfuric acid. The

reaction mixture was thoroughly mixed and allowed to cool at room temperature. The color intensity was measured at 490 nm using a spectrophotometer and the total soluble sugars were calculated using a standard curve and expressed as mg g^{-1} seed, as described by Dubois et al. (1956).

3.4.4.3 Total soluble proteins in seed leachates (mg g^{-1})

For each replicate of all treatments, 0.5 ml of seed leachate was placed in test tubes, followed by the addition of 5 ml of Bradford reagent. The mixture was agitated for 15 minutes and the absorbance was measured at 595 nm using a spectrophotometer. Total soluble proteins were then calculated using a Bovine Serum Albumin standard curve and expressed as mg g^{-1} seed (Bradford 1976).

3.4.4.4 Total soluble sugars in seed (mg g^{-1}_{dw})

Total soluble sugars were measured using the phenol-sulfuric acid method described by Dubois et al. (1956). 100 mg of crushed seed sample was placed in a test tube and 5 ml of 2.5N HCl was added. The mixture was then hydrolyzed by boiling in a water bath for 3 hours. After cooling to room temperature, the solution was neutralized with solid sodium carbonate until the effervescence stopped. The volume was then adjusted to 100 ml and the mixture was centrifuged to collect the supernatant. This supernatant was used to create a standard curve, with a series of concentrations (0.2, 0.4, 0.6, 0.8, 1.0 ml). Working samples of 0.1 and 0.2 ml were pipetted into test tubes and diluted to 1 ml. Then, 1 ml of phenol and 5 ml of sulfuric acid were added to each tube and the tubes were placed in a water bath at 25-30°C for 20 minutes. The orange-yellow color that developed was measured at 490 nm using a spectrophotometer. Total soluble sugars were calculated using the standard curve and expressed as mg g^{-1} dry weight (dw) in the seed.

3.4.4.5 Total soluble proteins in seed (mg g^{-1}_{dw})

The total soluble proteins in the seed were measured using the Bradford reagent method (Bradford 1976). A sample of 100 mg of seeds was homogenized in potassium phosphate buffer (1:5 w/v, pH 7.0). The homogenate was then centrifuged at 10,000 × g for 30 minutes at 0°C and the supernatant was collected. In the next step, 5 ml of Bradford reagent was added to test tubes, followed by 10 µl of the crude extract. The mixture was agitated for 15 minutes and the absorbance was measured at 595 nm using a

spectrophotometer. The total soluble proteins were calculated using a Bovine Serum Albumin (BSA) standard curve and expressed as mg g^{-1} dry weight (dw) in the seed.

3.4.4.6 Total starch contents in seed (mg g^{-1}_{dw})

Starch content in developing seeds was determined using the Anthrone method (Hodge and Hofreiter 1962). A 100 mg seed sample was homogenized in hot 80 % ethanol to remove sugars. The residue was collected after centrifugation and re-washed with hot 20 % ethanol until no colour developed with the anthrone reagent. After drying the residue in a water bath, 5 ml of double-distilled water and 6.5 ml of 52 % perchloric acid were added and the mixture was kept at 0°C for 20 minutes. The extract was collected after centrifugation and the extraction process was repeated with fresh perchloric acid. The extracts were pooled and the volume was adjusted to 100 ml with 52 % perchloric acid. To 0.2 ml of the extract, 0.8 ml of double-distilled water and 4 ml of anthrone reagent were added. The reaction mixture was heated for 8 minutes in a boiling water bath and then cooled rapidly. The colour intensity was measured at 630 nm using a spectrophotometer. D-glucose was used as a standard and the starch content was expressed as mg g^{-1} dry weight (dw) in the seed.

3.4.4.7 Oil content in seeds (%)

Seed oil extraction was carried out using the method described by the Association of Official Agricultural Chemists (AOAC 1970). A Soxhlet extractor was employed to extract the oil from the seeds using diethyl ether as the solvent. A 5 g sample of ground seed was placed in the extractor unit and subjected to the solvent's boiling point for 8-10 hours. Following extraction, the sample was dried in an oven at 105°C for 3 hours and then re-weighed to determine the oil content.

$$\text{Oil content (\%)} = \frac{\text{Weight of sample before extraction} - \text{Weight of sample after extraction}}{\text{Total number of seeds sown}} \times 100$$

3.4.5 Soil analysis

Soil samples were collected from a depth of 0-15 cm in all experimental plots separately after the crop harvest. The samples were air-dried, crushed, passed through a 2 mm sieve and stored in cloth bags for subsequent soil analysis.

3.4.5.1 Soil pH

The pH was measured in a 1:2.5 soil-to-water suspension using a glass electrode digital pH meter, as described by Jackson (1973).

3.4.5.2 Soil EC (dSm^{-1})

The electrical conductivity of the soil was measured in a 1:2 soil-to-water suspension using a glass electrode digital EC meter, following the method described by Jackson (1973).

3.4.5.3 Organic carbon (%)

The amount of organic carbon in the sample was determined using the Walkley-Black chromic acid wet oxidation method (Walkley and Black 1934).

3.4.5.4 Available N, P and K content in soil before planting and after termination of experiment (kg/ha)

Available N, P and K content of soil before sowing were determined using different methods and the details have been shown in Table 3.1. After completion of the experiment, the soil samples from each plot were collected and analyzed again for available nutrients using standard methods. The available N was determined by alkaline potassium permanganate method (Subbiah and Asija 1956). The available P was determined by stannous chloride reduced molybdate method in HCL system (Olsen et al. 1954). The available K was extracted by normal neutral ammonium acetate method (Mervin and Peech 1951).

3.4.6 Incidence (%) of economically important insect-pest / diseases of cucumber

3.4.6.1 Incidence of fruit fly (%) in cucumber

The total number of fruits per plant and fruits infested with fruit fly were counted from the randomly selected plants to work out the incidence of fruit fly as per the following formula:

$$\text{Incidence of fruit fly (\%)} = \frac{\text{Number of fruit fly infested fruits}}{\text{Total number of fruits}} \times 100$$

3.4.6.2 Incidence of powdery mildew (%) in cucumber

The number of plants affected by incidence of powdery mildew were counted and the per cent disease incidence was worked out as per following formula:

$$\text{Incidence of powdery mildew (\%)} = \frac{\text{Number of infested plants}}{\text{Total number of plants}} \times 100$$

3.4.6.3 Incidence of downy mildew (%) in cucumber

The number of plants affected by incidence of downy mildew were counted and the per cent disease incidence was worked out as per following formula:

$$\text{Incidence of downy mildew (\%)} = \frac{\text{Number of infested plants}}{\text{Total number of plants}} \times 100$$

3.4.7 Economics of the treatments

The economics of treatments is the most important consideration of making any recommendation to the farmer for its adoption. The cost of cultivation was worked out for calculating economics of cucumber seed production under individual treatments. Gross return was calculated by multiplying the seed yield per hectare (kg) with the sale rate of seeds (₹). Net return was calculated by subtracting the total cost of cultivation from gross return. The resultant of net return divided by total cost of cultivation gave benefit: cost ratio (Sharma et al. 2008).

3.5 STATISTICAL ANALYSIS

Analysis of variance for the experiment was done as per the model suggested by Panse and Sukhatme (1978). The data recorded was analysed using Microsoft Excel 2021, OPSTAT package, WASP 2.0 and 'R' statistical package software's as per design of the experiment for working out the following values:

Source of variation	Degree of freedom	Sum of squares	Mean sum of squares
Replication (r)	r-1	Sr	$\frac{Sr}{(r-1)} = Mr$
Treatment (t)	t-1	St	$\frac{St}{(t-1)} = Mt$
Error (e)	(r-1) (t-1)	Se	$\frac{Se}{(r-1)(t-1)} = Me$

Where,

r = Number of replications

t = Number of treatments

Sr = Sum of squares due to replications

St = Sum of squares due to treatments

Se = Sum of squares due to error

Mr = Mean sum of squares due to replications

Mt = Mean sum of squares due to treatments

Me = Mean sum of squares due to error

The replication and treatment mean sum of square was tested against mean sum of squares due to error by 'F' test with (r-1), (r-1) (t-1) and (t-1), (r-1) (t-1) degree of freedom at P = 0.05. The calculated F- values were compared with tabulated F- value. Where F-test was found significant, critical difference was calculated to find out the superiority of one treatment over the other.

The standard errors and critical differences were calculated as follows:

SE (m) ± = $\sqrt{Me/r}$

SE (d) ± = $\sqrt{2Me/r}$

$CD_{(0.05)}$ = S.E. (d) × $t_{(0.05)}$ (r-1) (t-1) df

SE (m) ± = Standard error of mean

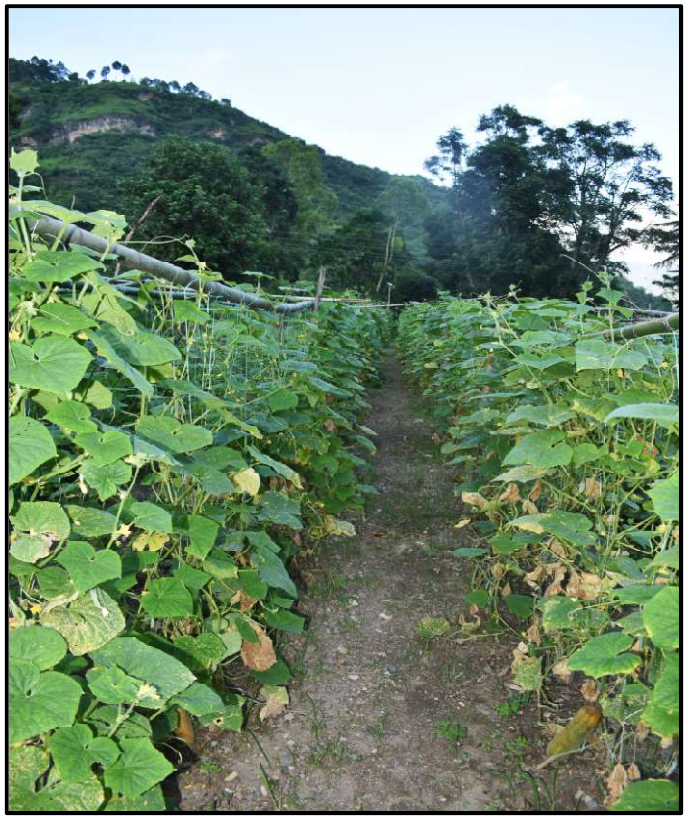
SE (d) ± = Standard error of difference

$CD_{(0.05)}$ = Critical difference at 5 per cent level of significance

The graphs were created using Microsoft Excel 2021 (graph tool) and 'R' statistical package. The chord diagrams for various plant and fruit characters, seed yield and quality traits and seed physiological assays were created using OriginPro software (OriginLab Corporation).



2022-2023



2023-2024

Plate 3.2: General view of cucumber crop at Vegetable Research Farm, UHF, Nauni during the year 2022 and 2023



D_1-15th April



D_2-30th April



D_3-15th May



D_4-30th May

Plate 3.3: Visual representation of different sowing dates utilized in the study



3 fruits per plant



4 fruits per plant



5 fruits per plant



6 fruits per plant



All fruits per plant (control)

Plate 3.4: Visual representation of different fruit load utilized in the study



Plate 3.5: Illustration of the seed extraction process from fruits

Chapter-4

RESULTS AND DISCUSSION

In cucumber cultivation, the date of sowing and fruit load management are critical agronomic practices that significantly influence seed production. These factors determine the environmental conditions experienced during key stages of seed development and the efficient allocation of resources for seed maturation. Despite their crucial role, these factors have been comparatively overlooked in favour of studies focusing on seed yield and quality. The present study titled **"Studies on Influence of Sowing Dates and Fruit Load on Seed Yield and Quality of Cucumber (*Cucumis sativus* L.)"** comprehensively examined the effects of date of sowings and fruit load management, highlighting their importance in improving seed production practices. The results underscore the need for precise management of these factors to achieve consistent and high-quality seed yield in cucumber.

The data pertaining to various parameters under study were subjected to statistical analysis and the significance of the results was rigorously evaluated. This chapter provides a comprehensive presentation and discussion of the findings related to plant and fruit characteristics, seed yield and quality traits, physiological assays, soil parameters, disease and pest incidence and the economics performance of the crop. The results were interpreted with detailed reasoning and supported by evidence to elucidate the cause-and-effect relationships among the different treatments. Furthermore, the implications of these findings are discussed in the context of existing literature to provide a broader perspective. The results have been systematically organized and discussed under the following sub-headings:

4.1 Plant and fruit characters
4.2 Seed yield traits
4.3 Seed quality traits
4.4 Seed physiological assays
4.5 Soil analysis
4.6 Incidence (%) of economically important insect-pest /diseases of cucumber
4.7 Economics of the treatments

4.1 Plant and fruit characters

4.1.1 Vine length (cm)

Vine length is a vital determinant of cucumber growth, influencing both overall plant development and seed production. It has been established that vine elongation enhances the plant's photosynthetic capacity by increasing the surface area available for light capture, thereby facilitating greater energy production for growth and fruit development (Wu et al. 2022). Longer vines contribute to higher sink strength, supporting the development of more fruits, which serve as primary sinks for photosynthates. In the context of seed production, vine length plays a vital role by promoting the growth of more fruit-bearing nodes, thereby enhancing seed yield. Thus, vine length directly impacts the plant's ability to produce high-quality seeds, making it a crucial factor in optimizing cucumber seed production.

A perusal of the data of two consecutive years 2022-2023 and 2023-2024, revealed that there were significant differences among the treatments for the vine length (Table 4.1.1 and Figure 4.1.1).

During the first year 2022-2023, the effect of sowing dates and fruit load were significant whereas their interaction effect was non-significant for vine length (cm). Regarding the effect of sowing dates, results showed that maximum vine length (278.11 cm) was recorded when sowing was done on 30th April (D_2) whereas, the minimum vine length (177.40 cm) was recorded when sowing was done on 30th May (D_4). Regarding the effect of fruit load, maximum vine length (251.01 cm) was recorded when 3 fruits per plant (F_1) were retained whereas, the minimum vine length (228.98 cm) was recorded when all fruits per plant (F_5) were retained. The data pertaining to the interaction effect of sowing dates and fruit load indicated a non-significant effect and the values ranged from 295.39 cm - 165.33 cm.

During the second year 2023-2024, the effect of sowing dates and fruit load were significant whereas their interaction effect was also non-significant for vine length (cm). Regarding the effect of sowing dates, results showed that maximum vine length (293.13 cm) was recorded when sowing was done on 30th April (D_2) whereas, the minimum vine length (172.83 cm) was recorded when sowing was done on 30th May (D_4). Regarding the effect of fruit load, maximum vine length (245.90 cm) was recorded when 3 fruits per plant (F_1) were retained whereas, the minimum vine length (217.37 cm) was recorded when all fruits per plant (F_5) were retained. The data pertaining to the interaction effect of sowing dates and fruit load also indicated a non-significant effect and the values ranged from 307.95 cm - 162.19 cm.

Table 4.1.1: Effect of sowing dates and fruit load on vine length

Vine length (cm)						
Y_1 (2022-2023)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	266.59	265.27	258.31	255.83	254.33	**260.07**
D_2	295.39	281.66	273.61	271.22	268.67	**278.11**
D_3	248.40	244.35	241.20	236.10	227.60	**239.53**
D_4	193.66	180.66	175.66	171.66	165.33	**177.40**
Mean	**251.01**	**242.99**	**237.19**	**233.70**	**228.98**	**238.77**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	2.52			8.92		
F	1.20			3.54		
D×F	5.64			NS		
Y_2 (2023-2024)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	276.34	270.13	267.18	255.62	239.69	**261.79**
D_2	307.95	298.29	297.20	282.45	279.76	**293.13**
D_3	214.73	207.82	196.92	195.11	187.84	**200.48**
D_4	184.57	176.69	172.33	168.40	162.19	**172.83**
Mean	**245.90**	**238.23**	**233.41**	**225.39**	**217.37**	**232.05**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	2.33			8.22		
F	1.70			4.92		
D×F	5.21			NS		
Pooled						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	271.47	267.70	262.74	255.73	247.01	**260.93**
D_2	301.67	289.98	285.40	276.83	274.22	**285.62**
D_3	231.56	226.09	219.06	215.60	207.72	**220.01**
D_4	189.12	178.67	173.99	170.03	163.76	**175.11**
Mean	**248.45**	**240.61**	**235.30**	**229.55**	**223.18**	**235.41**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	1.71			5.19		
F	1.04			2.96		
D×F	2.09			NS		
Y	1.21			3.67		
Y×D	2.42			7.35		
Y×F	2.09			NS		
Y×D×F	2.96			8.38		

***D =** Sowing dates; D_1= 15th April; D_2 = 30th April; D_3 = 15th May; D_4 = 30th May
***F =** Fruit load; F_1 = 3 fruits; F_2 = 4 fruits; F_3 = 5 fruits; F_4 = 6 fruits; F_5 = all fruits retained (control)
***Y =** Year; Y_1 = 2022-2023; Y_2 = 2023-2024

The pooled data for both the years revealed that the effect of sowing dates and fruit load were significant whereas their interaction effect was also non-significant for vine length (cm). Regarding the effect of sowing dates, results showed that maximum vine length (285.62 cm) was recorded when sowing was done on 30th April (D_2) whereas, the minimum vine length (175.11 cm) was recorded when sowing was done on 30th May (D_4). Regarding the effect of fruit load, maximum vine length (248.45 cm) was recorded when 3 fruits per plant (F_1) were retained whereas, the minimum vine length (223.18 cm) was recorded when all fruits per plant (F_5) were retained. The pooled analysis of the interaction between sowing dates and fruit load also indicated that the effect was statistically non-significant and the values ranged from 301.67 cm - 163.76 cm.

Amongst both the years, maximum vine length (238.77 cm) was recorded in the first year 2022-2023 as compared to vine length (232.05 cm) in second year 2023-2024. Interaction between year and date of sowings (Y × D) also showed significant effect and the maximum vine length (293.13 cm) was recorded in the second year 2023-2024 when sowing was done on 30th April (Y_2D_2). Similarly, the minimum vine length (172.83 cm) was also recorded in the second year 2023-2024 when sowing was done on 30th May (Y_2D_4). The interaction between years and fruit load (Y × F) showed non-significant effect. The interaction between years, date of sowings and fruit load (Y × D × F) resulted in significant effect and the maximum vine length (307.95) was recorded in the second year 2023-2024 when sowing was done on 30th April and 3 fruits per plant were retained ($Y_2D_2F_1$) whereas minimum vine length (162.19 cm) was recorded in the second year 2023-2024 when sowing was done on 30th May and all fruits per plant were retained ($Y_2D_4F_5$).

The results from the years 2022-2023 and 2023-2024, alongside pooled analysis, reveal that sowing dates and fruit load significantly impacted vine length in cucumbers, while their interaction remained non-significant, indicating independent effects.

The longest vines were recorded when sowing was done on 30th April (D_2), attributed to optimal environmental conditions like temperature and photoperiod enhancing vegetative growth. Similar findings were reported by Behera et al. (2018); Longjam and Devi (2017); and Sharma and Kamboj (2015), who noted that early sowing maximizes vegetative development due to reduced environmental stress. Shorter vine length was recorded with late sowing of 30th May (D_4) which aligns with findings from Oloyede and Adebooye (2013),

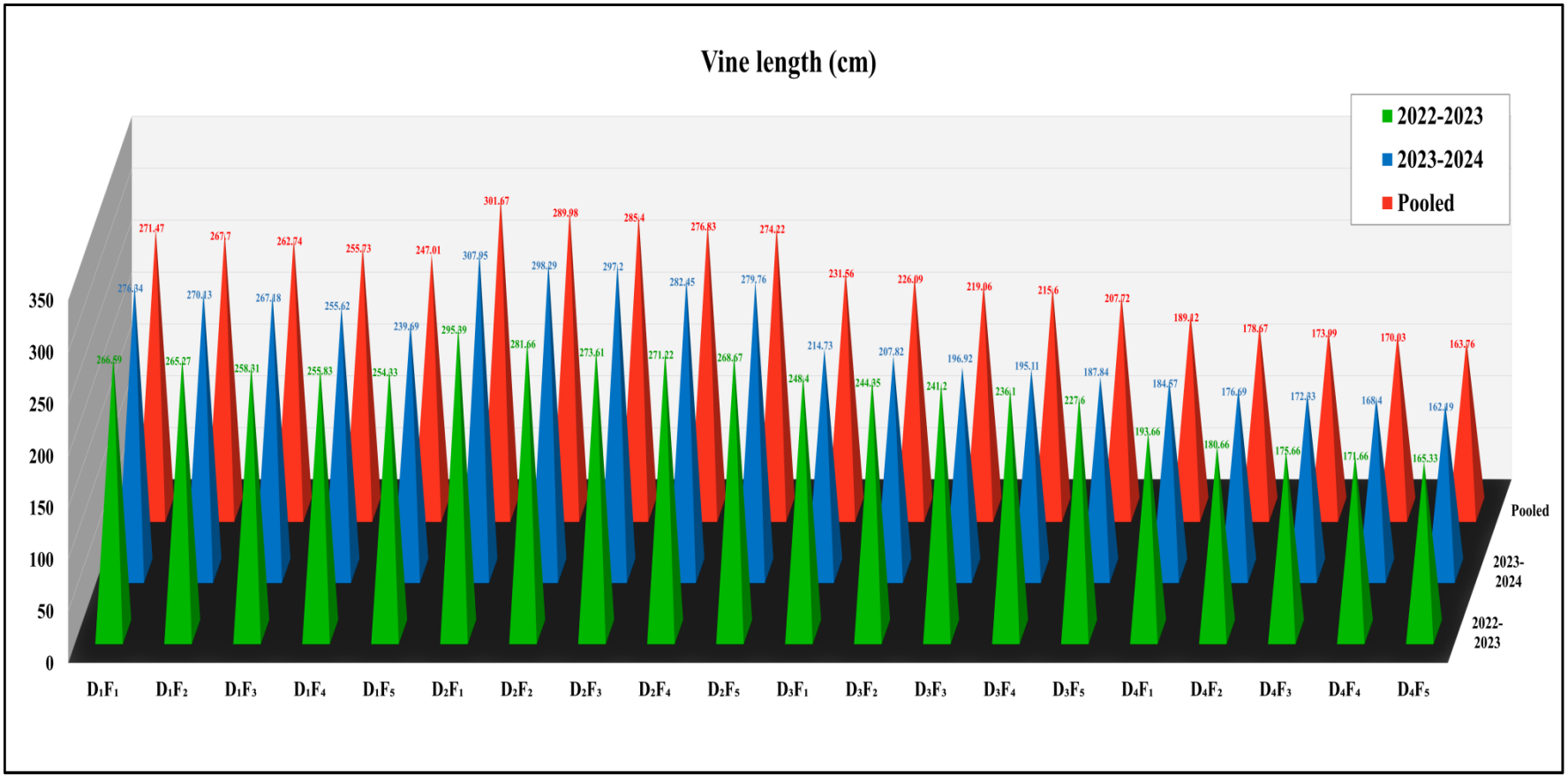


Figure 4.1.1: Effect of sowing dates and fruit load on vine length

who observed that heat stress and water scarcity inhibit vine elongation due to inhibition of cell elongation and overall plant growth in late-sown crop of pumpkin.

Reduced fruit retention with 3 fruits per plant (F_1) promoted longer vine length, supporting the source-sink theory, where lower fruit load increases photosynthate availability for vegetative growth (Gupta et al. 2021a). In contrast, Bellad (2012) found that when all fruits per vine are retained (F_5) it limits vine elongation as plants prioritize reproductive sinks over vegetative tissues resulting in reduced vine length.

From the perusal of data, yearly differences were observed, with the first year 2022-2023 recording slightly longer vines than the second year 2023-2024. This could be attributed to variations in climatic conditions, such as rainfall patterns, temperature fluctuations and other abiotic stresses, which may have influenced vine growth dynamics. Additionally, the significant interaction between year, sowing dates and fruit load highlights the complexity of these relationships. The highest vine length recorded in the $Y_2D_2F_1$ combination underscores the importance of aligning optimal sowing dates and fruit load management with prevailing climatic conditions to maximize vine length and consequently, seed yield and quality.

4.1.2 Fruit length (cm)

Fruit length is a crucial agronomic parameter in cucumber cultivation, significantly impacting both marketable yield and seed production. Extended fruit length enhances the capacity for ovule development, thereby increasing the number of seeds per fruit and contributing to superior seed quality (Zhang et al. 2021). The elongation of fruit promotes efficient nutrient translocation, ensuring optimal seed filling and maturation. Furthermore, the measurement of fruit length serves as an indicator of the plant's physiological response to environmental conditions, reinforcing its importance in agronomic practices aimed at maximizing seed yield and quality.

The data collected from the two consecutive years 2022-2023 and 2023-2024, along with pooled analysis, shows significant differences in fruit length across the treatments (Table 4.1.2 and Figure 4.1.2).

During the first year 2022-2023, the effect of sowing dates and fruit load and their interaction was significant for fruit length (cm). The maximum fruit length (26.99 cm) was recorded when sowing was done on 30th April (D_2), while the minimum fruit length

Table 4.1.2: Effect of sowing dates and fruit load on fruit length

Fruit length (cm)						
Y_1 (2022-2023)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	24.60	24.21	23.91	23.67	23.49	**23.98**
D_2	29.04	27.79	26.91	26.03	25.19	**26.99**
D_3	23.11	22.07	21.98	21.71	21.53	**22.08**
D_4	21.08	20.43	19.36	18.50	16.53	**19.18**
Mean	**24.46**	**23.62**	**23.04**	**22.48**	**21.69**	**23.05**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.09			0.34		
F	0.12			0.35		
D×F	0.22			0.73		
Y_2 (2023-2024)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	26.27	25.23	24.99	24.18	24.00	**24.93**
D_2	30.32	28.59	27.88	27.27	26.60	**28.13**
D_3	23.77	23.21	23.04	22.52	22.32	**22.97**
D_4	22.04	21.46	20.67	20.31	19.52	**20.80**
Mean	**25.60**	**24.62**	**24.14**	**23.57**	**23.11**	**24.20**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.35			1.25		
F	0.20			0.58		
D×F	0.79			NS		
Pooled						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	25.44	24.72	24.45	23.93	23.75	**24.46**
D_2	29.68	28.19	27.39	26.65	25.89	**27.56**
D_3	23.44	22.64	22.51	22.12	21.93	**22.53**
D_4	21.56	20.94	20.01	19.40	18.03	**19.99**
Mean	**25.03**	**24.12**	**23.59**	**23.02**	**22.40**	**23.63**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.23			0.69		
F	0.11			0.33		
D×F	0.66			0.66		
Y	0.49			0.49		
Y×D	0.32			NS		
Y×F	0.16			NS		
Y×D×F	0.33			NS		

***D =** Sowing dates; D_1= 15th April; D_2 = 30th April; D_3 = 15th May; D_4 = 30th May
***F =** Fruit load; F_1 = 3 fruits; F_2 = 4 fruits; F_3 = 5 fruits; F_4 = 6 fruits; F_5 = all fruits retained (control)
***Y =** Year; Y_1 = 2022-2023; Y_2 = 2023-2024

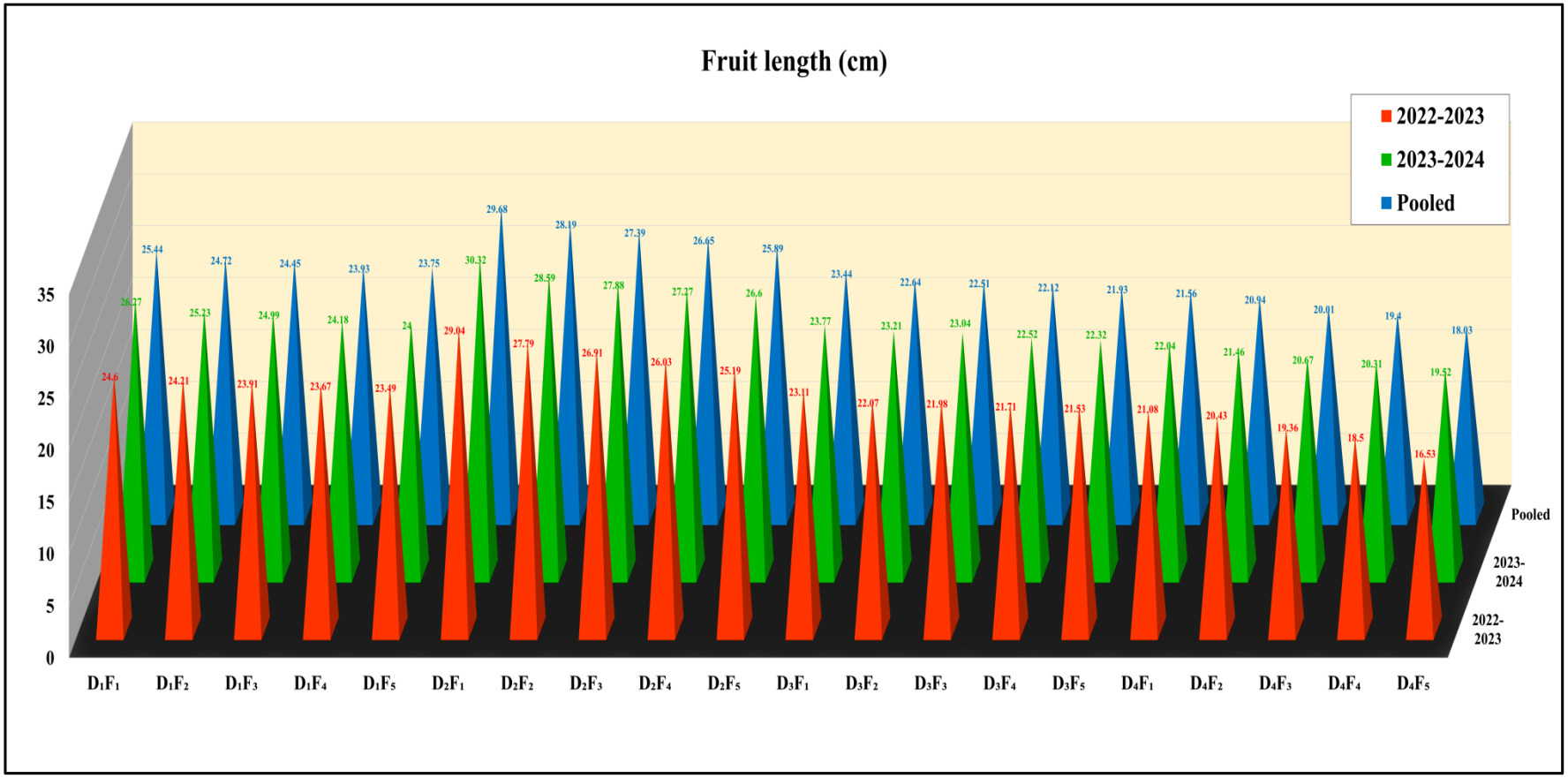


Figure 4.1.2: Effect of sowing dates and fruit load on fruit length

(19.18 cm) was observed when sowing was done on 30th May (D_4). Regarding the effect of fruit load treatments, the maximum fruit length (24.46 cm) was observed when 3 fruits per plant were retained (F_1), while the minimum fruit length (21.69 cm) was recorded when all fruits per plant were retained (F_5). The interaction of sowing dates and fruit load showed that when sowing was done on 30th April and 3 fruits per plant were retained (D_2F_1) it resulted in the maximum fruit length (29.04 cm), whereas when sowing was done on 30th May and all fruits per plant were retained (D_4F_5) it resulted in the minimum fruit length (16.53 cm).

In the second year 2023-2024, the effects of sowing dates and fruit load remained significant, but their interaction showed non-significant effect on fruit length. The maximum fruit length (28.13 cm) was observed when sowing was done on 30th April (D_2), while the minimum fruit length (20.80 cm) was observed when sowing was done on 30th May (D_4).

Among the fruit load treatments, the maximum fruit length (25.60 cm) was observed when 3 fruits per plant were retained (F_1) while the minimum fruit length (23.11 cm) was observed when all fruits per plant were retained (F_5). The interaction between sowing dates and fruit load revealed non-significant effect and the values ranged from 30.32 cm - 19.52 cm.

For the pooled analysis across both years, significant effects were observed for sowing dates and fruit load and their interaction. The maximum fruit length (27.56 cm) was recorded when sowing was done on 30th April (D_2), while the minimum (19.99 cm) was observed when sowing was done on 30th May (D_4). For fruit load treatments, the maximum fruit length (25.03 cm) was observed when 3 fruits per plant were retained (F_1), while the minimum fruit length (22.40 cm) was recorded when all fruits per plant were retained (F_5). The interaction of sowing dates and fruit load showed that when sowing was done on 30th April and 3 fruits per plant were retained (D_2F_1), it resulted in the maximum fruit length (29.68 cm), while the minimum fruit length (18.03 cm) was observed when sowing was done on 30th May and all fruits per plant were retained (D_4F_5).

Among both the years, the maximum fruit length (24.20 cm) was recorded in the second year 2023-2024, as compared to the first year 2022-2023, which recorded less fruit length (23.05 cm). The interaction between both years and sowing dates (Y × D) and years and fruit load (Y × F) showed non-significant effects on fruit length. Similarly, the

interaction between years, sowing dates and fruit load (Y × D × F) also showed non-significant effects.

The results from the years 2022-2023 and 2023-2024 demonstrate that both sowing dates and fruit load management significantly affect fruit length in cucumber. The consistently significant effect of sowing dates highlights the importance of optimal planting time in maximizing fruit growth and seed development. The sowing date 30th April (D_2) consistently produced the longest fruits across both years, likely due to favourable environmental conditions such as optimal temperature and light availability, which are crucial for promoting vegetative and reproductive growth. In contrast, the sowing on 30th May (D_4) resulted in the shortest fruits, suggesting that late sowing may expose plants to heat stress or limited water availability, which can inhibit fruit elongation. Similar findings were also reported by Ali et al. (2021); Behera et al. (2018); Longjam and Devi (2017) and Nagendra et al. (2017).

Fruit load management further demonstrates the critical balance between source-sink relationships. The longest fruits were consistently observed when 3 fruits per plant (F_1) were retained, indicating that reducing fruit load allows for more efficient allocation of photosynthates to fewer fruits, promoting elongation. Conversely, when all fruits per plant (F_5) were retained, it produced the shortest fruits, as the increased number of developing fruits intensifies competition for assimilates, thereby limiting individual fruit growth. These findings align with established theories on assimilate partitioning and resource competition, supporting research by Gupta et al. (2022); Chandi et al. (2020) and Tomar et al. (2015), that highlights the impact of fruit load on seed production and quality.

The interaction between sowing dates and fruit load was significant in the first year 2022-2023, suggesting that environmental conditions in that year amplified the combined influence of these factors. The D_2F_1 combination consistently produced the longest fruits across both years, indicating that optimal sowing dates paired with reduced fruit load synergistically enhance fruit length. This trend is further validated by the pooled data, which highlights the consistent effectiveness of sowing dates and fruit load management across different seasons.

Yearly variations in fruit length, with slightly longer fruits in the second year 2023-2024, reflects more favourable climatic conditions during that year, such as improved rainfall

patterns or temperature moderation. The non-significant interaction between years, sowing dates and fruit load demonstrates the consistency of sowing dates and fruit load management across varying environmental conditions, emphasizing their significance in cucumber seed production.

4.1.3 Fruit breadth (cm)

Fruit breadth plays a crucial role in cucumber cultivation, significantly affecting both marketable yield and seed production. A wider fruit breadth allows for the development of larger seed cavities, increasing the potential for well-formed, high-quality seeds (Zhang et al. 2021). This broader dimension also facilitates effective nutrient allocation within the fruit, ensuring proper seed growth and maturation. Moreover, fruit breadth acts as an important indicator of the plant's adaptability to environmental factors, making it a key consideration in agronomic strategies focused on enhancing seed yield and overall fruit quality.

The data collected from the two consecutive years 2022-2023 and 2023-2024, along with pooled analysis, indicates significant differences in fruit breadth across the treatments (Table 4.1.3 and Figure 4.1.3).

During the first year 2022-2023, the effects of sowing dates and fruit load were significant for fruit breadth, while their interaction was also significant. The maximum fruit breadth (5.14 cm) was recorded when sowing was done on 30th April (D_2), whereas the minimum fruit breadth (4.37 cm) was observed when sowing was done on 30th May (D_4). Regarding fruit load treatments, when 3 fruits per plant (F_1) were retained, maximum fruit breadth (4.95 cm) was observed, while the minimum fruit breadth (4.60 cm) was observed when all fruits per plant (F_5) were retained. The interaction of sowing dates and fruit load showed the maximum fruit breadth (5.61 cm) when sowing was done on 30th April and 3 fruits per plant were retained (D_2F_1) and the minimum fruit breadth (4.11 cm) was recorded when sowing was done on 30th May and all fruits per plant were retained (D_4F_5).

In the second year 2023-2024, both sowing dates and fruit load had significant effects on fruit breadth, while their interaction was also significant. The maximum fruit breadth (5.54 cm) was recorded when sowing was done on 30th April (D_2) and the minimum fruit breadth (4.59 cm) was recorded when sowing was done on 30th May (D_4). Among fruit load treatments, when 3 fruits per plant (F_1) were retained the maximum fruit breadth (5.22 cm) was observed, while the minimum (4.86 cm) was observed when all fruits per plant (F_5)

Table 4.1.3: Effect of sowing dates and fruit load on fruit breadth

Fruit breadth (cm)						
Y_1 (2022-2023)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	4.89	4.87	4.83	4.80	4.77	**4.83**
D_2	5.61	5.16	5.06	4.96	4.93	**5.14**
D_3	4.74	4.74	4.71	4.62	4.61	**4.68**
D_4	4.58	4.54	4.33	4.32	4.11	**4.37**
Mean	**4.95**	**4.82**	**4.73**	**4.67**	**4.60**	**4.75**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.04			0.14		
F	0.02			0.08		
D×F	0.09			0.17		
Y_2 (2023-2024)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	5.27	5.19	5.12	5.09	5.02	**5.14**
D_2	5.90	5.67	5.44	5.39	5.31	**5.54**
D_3	4.99	4.97	4.91	4.90	4.81	**4.92**
D_4	4.75	4.71	4.63	4.55	4.31	**4.59**
Mean	**5.22**	**5.14**	**5.03**	**4.98**	**4.86**	**5.04**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.03			0.10		
F	0.02			0.06		
D×F	0.06			0.13		
Pooled						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	5.08	5.03	4.98	4.94	4.90	**4.98**
D_2	5.75	5.41	5.25	5.18	5.12	**5.34**
D_3	4.86	4.86	4.81	4.76	4.71	**4.80**
D_4	4.66	4.62	4.48	4.43	4.21	**4.48**
Mean	**5.09**	**4.98**	**4.88**	**4.83**	**4.73**	**4.90**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.02			0.08		
F	0.01			0.05		
D×F	0.03			0.09		
Y	0.01			0.05		
Y×D	0.03			NS		
Y×F	0.02			NS		
Y×D×F	0.05			NS		

***D =** Sowing dates; D_1= 15th April; D_2 = 30th April; D_3 = 15th May; D_4 = 30th May
***F =** Fruit load; F_1 = 3 fruits; F_2 = 4 fruits; F_3 = 5 fruits; F_4 = 6 fruits; F_5 = all fruits retained (control)
***Y =** Year; Y_1 = 2022-2023; Y_2 = 2023-2024

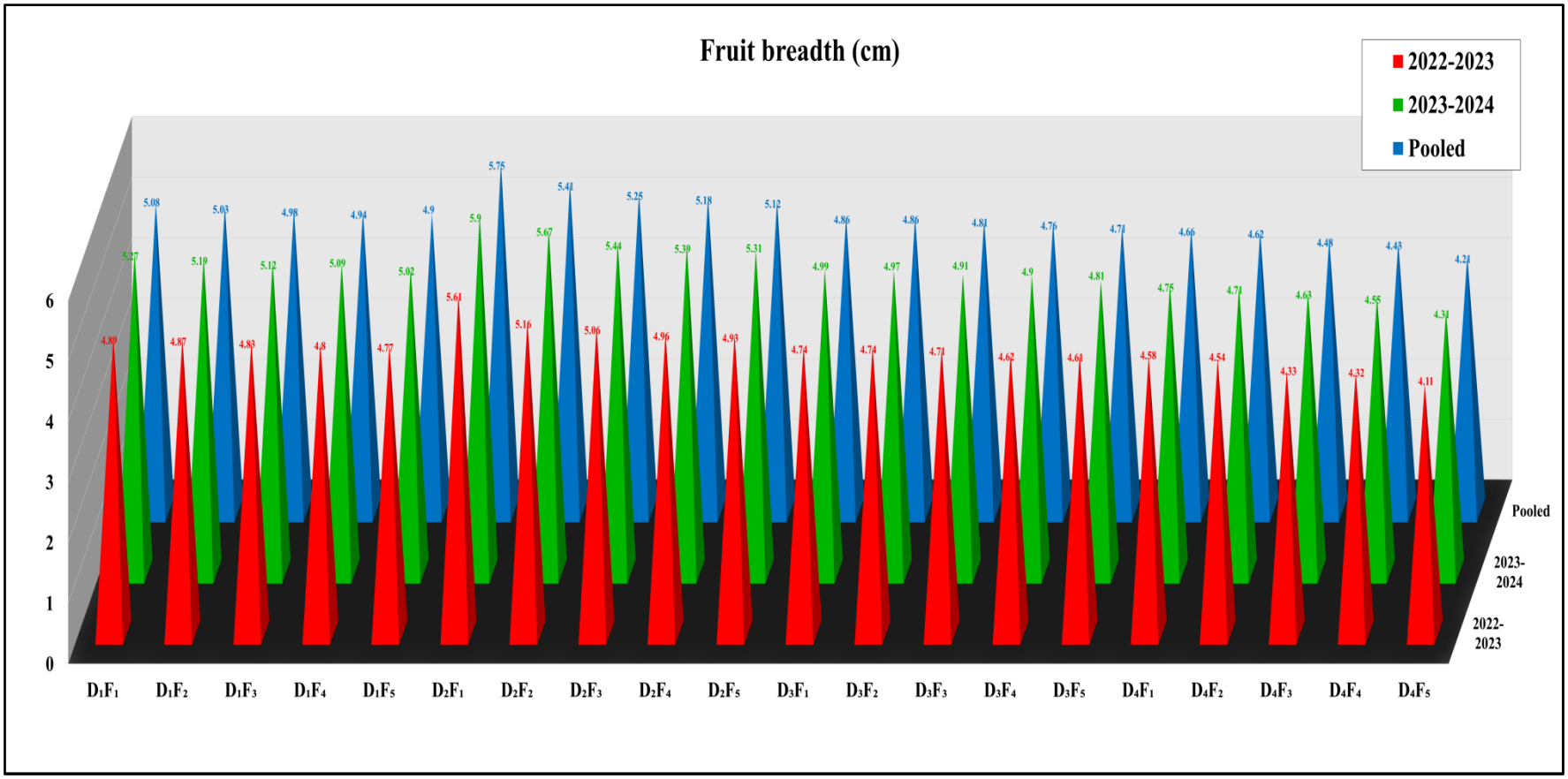


Figure 4.1.3: Effect of sowing dates and fruit load on fruit breadth

were retained. The interaction of sowing dates and fruit load resulted in the maximum fruit breadth (5.90 cm) when sowing was done on 30th April and 3 fruits per plant were retained (D_2F_1) and the minimum (4.31 cm) when sowing was done on 30th May and all fruits per plant were retained (D_4F_5).

The pooled data from both years showed significant effects of sowing dates and fruit load, while their interaction was also significant. The maximum fruit breadth (5.34 cm) was recorded when sowing was done on 30th April (D_2) and the minimum (4.48 cm) when sowing was done on 30th May (D_4). Among the fruit load treatments, when 3 fruits per plant (F_1) were retained, it recorded the maximum fruit breadth (5.09 cm), while it recorded the minimum fruit breadth (4.73 cm) when all fruits per plant (F_5) were retained. The interaction of sowing dates and fruit load indicated the maximum fruit breadth (5.75 cm) when sowing was done on 30th April and 3 fruits per plant were retained (D_2F_1) and the lowest fruit breadth (4.21 cm) when sowing was done on 30th May and all fruits per plant were retained (D_4F_5).

Between the two years, the maximum fruit breadth (5.04 cm) was recorded in in the second year 2023-2024, compared to 4.75 cm in the first year 2022-2023. The interaction between both years and sowing dates (Y × D) and years and fruit load (Y × F) showed non-significant effects on fruit breadth. Similarly, the interaction between years, sowing dates and fruit load (Y × D × F) also showed non-significant effects.

The results from the 2022-2023 and 2023-2024 growing seasons clearly show that both sowing dates and fruit load management have a significant impact on fruit breadth in cucumber. Sowing on 30th April (D_2) consistently resulted in the maximum fruit breadth across both years, likely due to favourable environmental conditions such as moderate temperatures and sufficient light, which support fruit development. In contrast, late sowing on 30th May (D_4) led to the minimum fruit breadth, suggesting that delayed sowing may expose plants to stressors like heat or water scarcity, limiting fruit expansion. This supports findings from previous studies by Ali et al. (2021), Behera et al. (2018) and Nagendra et al. (2017), which emphasize the importance of choosing the right sowing time for maximum yield and quality.

Fruit load management also played a crucial role. The retention of 3 fruits per plant (F_1) consistently produced the maximum fruit breadth, as fewer fruits allowed for better resource allocation, promoting larger fruit growth. On the other hand, when all fruits per

plant were retained (F_5) it resulted in the minimum fruit breadth, as higher fruit load increased competition for nutrients, limiting individual fruit development. These results align with existing research on resource partitioning and its impact on crop quality (Gupta et al. 2022; Chandi et al. 2020).

The significant interaction between sowing dates and fruit load in the first year 2022-2023 further emphasizes how these factors combined to enhance fruit breadth. The D_2F_1 combination consistently produced fruits with maximum fruit breadth, highlighting the synergy between early sowing and reduced fruit load. The pooled data reinforced the consistent influence of these practices across years, underlining their importance in cucumber seed production.

The slight increase in fruit breadth (cm) in the second year 2023-2024 compared to the first year 2022-2023 may be linked to more favourable climatic conditions, such as better rainfall and moderate temperatures. However, the non-significant interaction between years, sowing dates and fruit load shows the stability of these agronomic practices, even under changing conditions. This consistency underscores the vital role of early sowing and managing fruit load for maximizing fruit breadth, which ultimately enhances both growth and quality in cucumber seed production.

4.1.4 Fruit weight (g)

Fruit weight is a fundamental parameter in cucumber cultivation, with a significant influence on both marketable yield and seed production. Higher fruit weight is often associated with enhanced resource allocation, leading to the development of larger seed cavities and a greater number of well-formed, viable seeds, ultimately improving seed yield and quality (Gupta et al. 2022). The weight of the fruit is indicative of the plant's photosynthetic efficiency and the translocation of assimilates, which are critical for seed filling and maturation (Zhang et al. 2021). Additionally, fruit weight is a reliable physiological indicator of the plant's response to environmental factors such as temperature, light and water availability, which are crucial for optimal seed development.

The data from the two consecutive years 2022-2023 and 2023-2024, along with pooled analysis, indicate substantial differences in fruit weight across the various treatments as presented in Table 4.1.4 and Figure 4.1.4.

During the first year 2022-2023, the effects of sowing dates, fruit load and their interaction were significant for fruit weight (g). The maximum fruit weight (636.61 g) was recorded when sowing was done on 30th April (D_2). while the minimum fruit weight (368.98 g) was observed when sowing was done on 30th May (D_4). Regarding the effect of fruit load treatments, the highest fruit weight (554.73 g) was recorded when 3 fruits per plant (F_1) were retained while the lowest fruit weight (465.98 g) was observed when all fruits per plant (F_5) were retained. The interaction between sowing dates and fruit load showed that when sowing was done on 30th April and 3 fruits per plant were retained (D_2F_1), it produced the maximum fruit weight (677.16 g) which was at par with sowing on 30th April and 4 fruits per plant retained (D_2F_2), whereas when sowing was done on 30th May and all fruits per plant were retained (D_4F_5) it resulted in the minimum fruit weight (281.66 g).

Similarly in the second year 2023-2024, the effects of sowing dates, fruit load and their interaction were significant for fruit weight (g). The maximum fruit weight (651.73 g) was recorded when sowing was done on 30th April (D_2), while the minimum fruit weight (301.02 g) was observed when sowing was done on 30th May (D_4). Among fruit load treatments, the highest fruit weight (531.23 g) was recorded when 3 fruits per plant (F_1) were retained, whereas when all fruits per plant (F_5) were retained, it recorded the lowest fruit weight (434.93 g). The interaction between sowing dates and fruit load showed that when sowing was done on 30th April and 3 fruits per plant were retained (D_2F_1), it resulted in the maximum fruit weight (683.22 g) which was at par with sowing on 30th April and 4 fruits per plant retained (D_2F_2), whereas when sowing was done on 30th May and all fruits per plant were retained (D_4F_5) it resulted in the minimum fruit weight (230.89 g).

The pooled data for both years revealed significant effects of sowing dates and fruit load on fruit weight, while their interaction remained significant. The maximum fruit weight (644.17 g) was recorded when sowing was done on 30th April (D_2), while the minimum (335.00 g) was observed when sowing was done on 30th May (D_4). Regarding fruit load treatments, when 3 fruits per plant (F_1) were retained, it recorded the highest fruit weight (542.98 g), while it recorded the lowest (450.46 g) when all fruits per plant (F_5) were retained. The interaction between sowing dates and fruit load revealed that when sowing was done on 30th April and 3 fruits per plant were retained (D_2F_1), it again resulted in the maximum fruit weight (680.19 g), whereas when sowing was done on 30th May and all fruits per plant were retained (D_4F_5) it resulted in the minimum fruit weight (256.28 g).

Table 4.1.4: Effect of sowing dates and fruit load on fruit weight

Fruit weight (g)						
Y_1 (2022-2023)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	591.15	575.59	551.36	545.66	528.98	**558.55**
D_2	677.16	660.33	638.53	611.96	595.06	**636.61**
D_3	505.31	480.72	475.08	461.38	458.23	**476.14**
D_4	445.29	418.68	368.56	330.73	281.66	**368.98**
Mean	**554.73**	**533.83**	**508.38**	**487.43**	**465.98**	**510.07**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	8.94			31.54		
F	4.72			13.66		
D×F	19.99			30.49		
Y_2 (2023-2024)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	604.50	564.88	521.49	514.62	506.48	**542.39**
D_2	683.22	663.36	653.10	634.53	624.47	**651.73**
D_3	484.57	462.26	430.71	407.51	377.88	**432.59**
D_4	352.62	344.83	308.15	268.62	230.89	**301.02**
Mean	**531.23**	**508.83**	**478.36**	**456.32**	**434.93**	**481.93**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	11.03			38.93		
F	4.04			11.71		
D×F	24.68			27.00		
Pooled						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	597.83	570.23	536.43	530.14	517.73	**550.47**
D_2	680.19	661.84	645.82	623.24	609.76	**644.17**
D_3	494.94	471.49	452.90	434.44	418.05	**454.36**
D_4	398.95	381.75	338.35	299.67	256.28	**335.00**
Mean	**542.98**	**521.33**	**493.37**	**471.87**	**450.46**	**496.00**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	6.81			20.65		
F	3.10			8.78		
D×F	6.21			17.57		
Y	4.81			14.60		
Y×D	9.63			29.21		
Y×F	4.39			NS		
Y×D×F	8.79			24.85		

***D =** Sowing dates; D_1= 15th April; D_2 = 30th April; D_3 = 15th May; D_4 = 30th May
***F =** Fruit load; F_1 = 3 fruits; F_2 = 4 fruits; F_3 = 5 fruits; F_4 = 6 fruits; F_5 = all fruits retained (control)
***Y =** Year; Y_1 = 2022-2023; Y_2 = 2023-2024

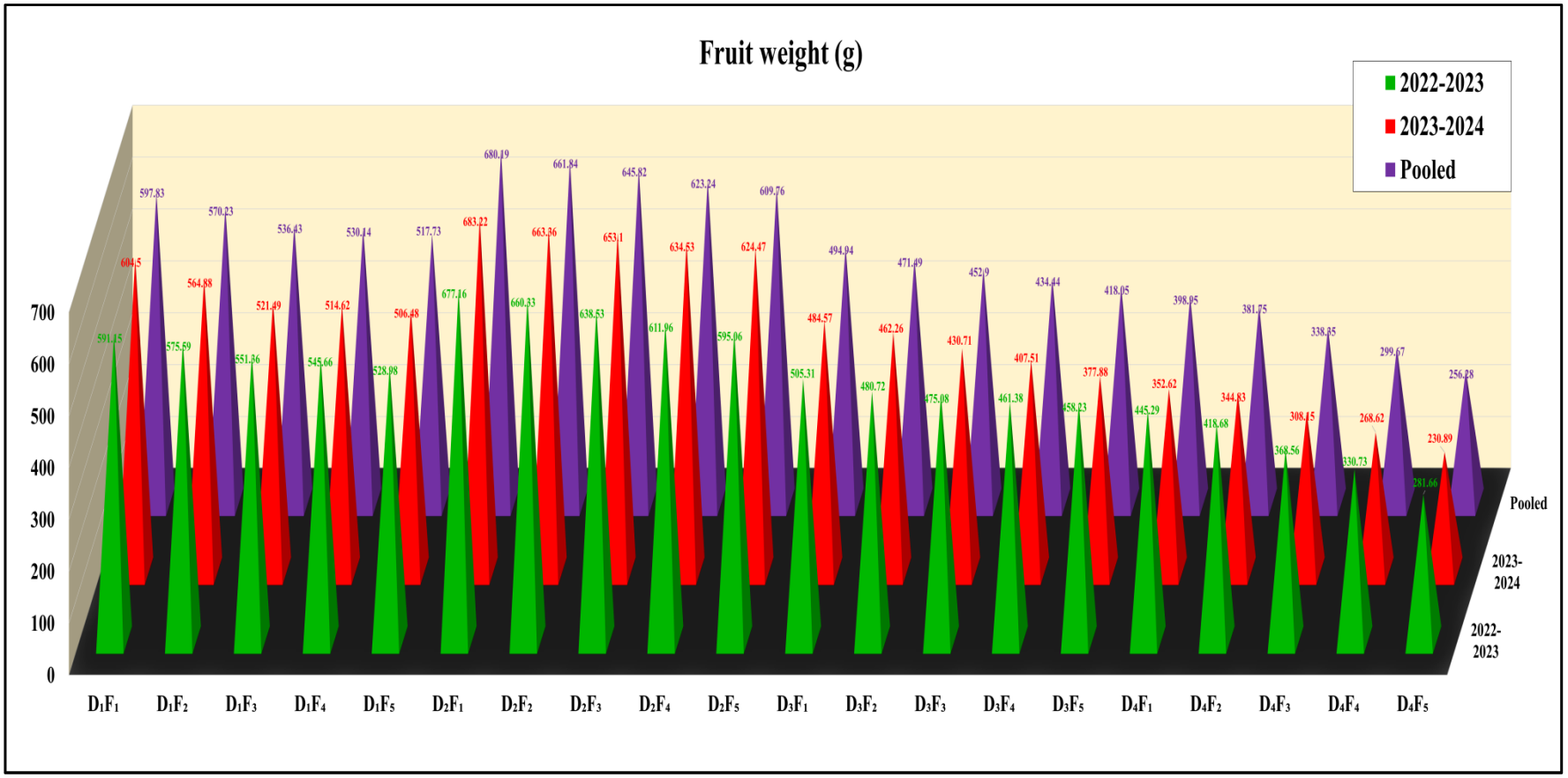


Figure 4.1.4: Effect of sowing dates and fruit load on fruit weight

Between the two years, the maximum fruit weight (510.07 g) was recorded in the first year 2022-2023 compared to lower fruit weight (481.93 g) in the second year 2023-2024. The interaction between years and sowing dates (Y × D) showed significant effects, with the maximum fruit weight (651.73 g) recorded in the second year 2023-2024 when sowing was done on 30th April (Y_2D_2) and the minimum fruit weight (301.02 g) was also recorded in the second year 2023-2024 when sowing was done on 30th May (Y_2D_4). The interaction between years and fruit load (Y × F) was non-significant.

The three-way interaction between years, sowing dates and fruit load (Y × D × F) showed significant effects, with the maximum fruit weight (683.22 g) recorded in the second year 2023-2024 when sowing was on 30th April and 3 fruits per plant were retained ($Y_2D_2F_1$) and the minimum fruit weight (230.89 g) was observed in the second year when sowing was done on 30th May and all fruits per plant were retained ($Y_2D_4F_5$).

The findings from the years 2022-2023 and 2023-2024 underscore the significant impact of sowing dates and fruit load management on cucumber fruit weight. The sowing done on 30th April (D_2) consistently produced the highest fruit weight across both years, highlighting the advantage of early planting. Favourable conditions during early sowing, such as moderate temperatures and adequate light, are likely to enhance photosynthesis and nutrient translocation, promoting greater fruit development. In contrast, the sowing done on 30th May (D_4) consistently yielded the lowest fruit weight, suggesting that late planting may expose plants to environmental stressors like heat and water scarcity, which hinder fruit growth. This aligns with research by Ali et al. (2021); Behera et al. (2018), Nagendra et al. (2017) and Jaiswal et al. (2015) which emphasized sowing time as a critical factor in crop productivity.

Fruit load also played a crucial role, with the retention of 3 fruits per plant (F_1) resulting in the highest fruit weight across both years. This can be attributed to reduced competition for resources, allowing individual fruits to develop fully. Conversely, the retention of all fruits per plant (F_5) recorded the lowest fruit weight, reflecting how increased fruit numbers intensify competition for nutrients and photosynthates, limiting growth. These outcomes support previous studies on the resource allocation theory, which indicate that lower fruit load enhance fruit size and weight (Patil et al. 2024; Gupta et al. 2022 and Chandi et al. 2020).

The significant interaction between sowing dates and fruit load further highlights how these factors work together. The D_2F_1 consistently achieved the highest fruit weight, demonstrating that optimal sowing and reduced fruit load synergize to maximize growth potential. In contrast, D_4F_5 consistently resulted in the lowest fruit weight, reinforcing the negative effects of delayed sowing and high fruit load on resource distribution.

The pooled analysis supports these findings, showing that both sowing dates and fruit load significantly influence fruit weight across different environmental conditions. While slight variations were observed between the years, the consistently significant effect of the D_2F_1 combination in both years highlights its robustness as a strategy for enhancing growth. Moreover, the significant three-way interaction between year, sowing dates and fruit load indicates that while environmental conditions may vary between years, the combined effect of these factors remains consistent in influencing fruit weight.

This highlights the importance of integrating the sowing dates and fruit load management to ensure stable and enhanced yields, contributing to both growth and improved seed production and quality in cucumber cultivation.

Chord Diagram for plant and fruit characters

The chord diagram depicted in Figure 4.1.5 visually represents the inter-relationships between the parameters measured in the study, namely vine length, fruit length, fruit breadth and fruit weight across different 20 treatment combinations. The outer segments of the diagram correspond to the treatments and parameters, while the chords inside illustrate the interactions between them. The diagram reveals significant variations in the response of each parameter to the treatments and highlights their interdependence.

The results demonstrate that vine length, a critical vegetative growth parameter, exhibits a strong positive association with fruit weight, indicating that treatments promoting longer vines tend to support higher fruit weights. This suggests that vine vigour plays an essential role in enhancing reproductive traits by ensuring better nutrient translocation and assimilation. Similarly, fruit length and fruit breadth are closely linked, reflecting the influence of treatments on fruit morphology and their potential implications for plant and fruit characters. The treatments in the D_2 (sowing on 30th April) group consistently show superior performance for both plant and fruit characters, highlighting their efficacy in promoting balanced growth.

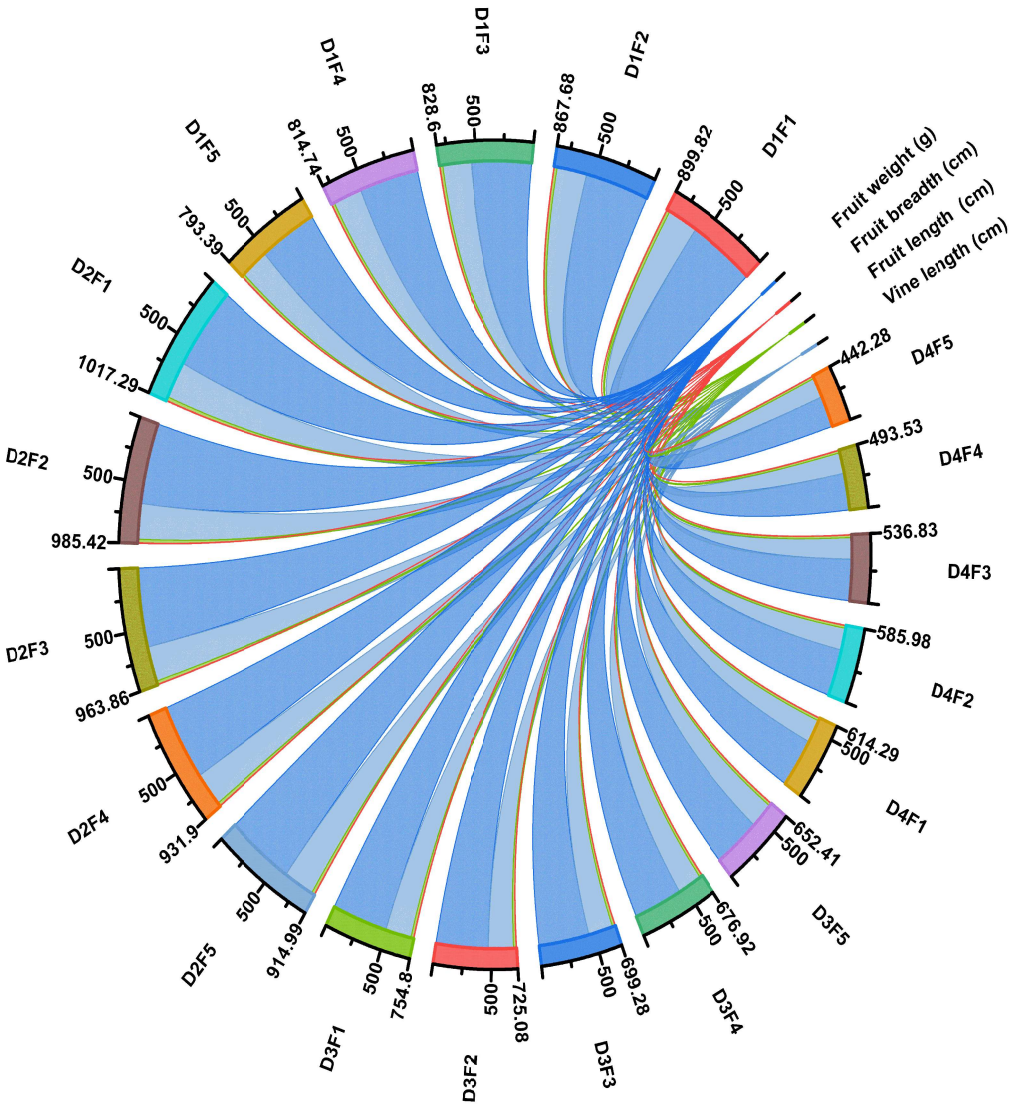


Figure 4.1.5: Analytical visualization of plant and fruit character weightage using chord diagram

Furthermore, the diagram underscores the multifaceted interplay between parameters, with specific treatments enhancing multiple traits simultaneously. For example, certain treatments result in higher vine length, which in turn contribute to increased fruit weight and improved fruit length and fruit breadth. This indicates that optimizing vegetative growth in terms of fruit load management is key to achieving better reproductive outcomes. The chord diagram also helps identify treatments that may show trade-offs between parameters, offering insights into the differential impact of fruit load management practices.

Overall, the visualization highlights the intricate relationships between the parameters under study, emphasizing the importance of optimization in sowing dates and fruit load.

4.2 Seed yield traits

4.2.1 Total number of seeds per fruit

The total number of seeds per fruit directly reflects the reproductive efficiency and genetic potential of the crop. It is a key determinant of seed yield and plays a pivotal role in assessing the quality and marketability of the produce. The number of seeds per fruit is influenced by various factors, including environmental conditions, pollination efficiency, nutrient availability and cultural practices such as sowing dates and fruit load management (Gupta et al. 2022). Optimal seed development depends on efficient nutrient translocation and hormonal signaling within the fruit, which are regulated by these factors. Additionally, the total number of seeds per fruit serves as a reliable indicator of the plant's physiological and metabolic health, offering insights into its adaptability to environmental and agronomic conditions.

The data collected from the two consecutive years 2022-2023 and 2023-2024, along with pooled analysis, indicates significant differences in total number of seeds per fruit across the treatments (Table 4.2.1 and Figure 4.2.1).

During the first year 2022-2023, the effects of sowing dates, fruit load and their interaction were significant for the total number of seeds per fruit. The maximum number of seeds per fruit (412.73) was recorded when sowing was done on 30th April (D_2), while the minimum number of seeds (346.00) was observed when sowing was done on 30th May (D_4). Regarding fruit load treatments, the maximum total number of seeds per fruit (387.41) was recorded when 3 fruits per plant (F_1) were retained, whereas the lowest number of seeds

(368.50) was observed when all fruits per plant (F_5) were retained. The interaction between sowing dates and fruit load revealed that the maximum number of seeds per fruit (424.33) were produced when sowing was done on 30th April and 3 fruits per plant were retained (D_2F_1) which was at par with sowing on 30th April and 4 fruits per plant retained (D_2F_2), while the minimum number of seeds per fruit (335.00) were recorded when sowing was done on 30th May and all fruits per plant were retained (D_4F_5).

Similarly, in the second year 2023-2024, the effects of sowing dates, fruit load and their interaction were significant for the total number of seeds per fruit. The highest number of seeds (444.00) were recorded with sowing on 30th April (D_2), while the lowest (348.33) was observed with sowing on 30th May (D_4). Among fruit load treatments, the maximum seeds per fruit (407.50) were recorded when 3 fruits per plant (F_1) were retained, whereas the minimum (377.66) was recorded when all fruits per plant (F_5) were retained. The interaction between sowing dates and fruit load revealed that when sowing was done on 30th April and 3 fruits per plant were retained (D_2F_1), it produced the maximum total number of seeds per fruit (465.33), while the minimum number of seeds per fruit (331.00) was recorded when sowing was done on 30th May and all fruits per plant were retained (D_4F_5).

The pooled data for both years showed significant effects of sowing dates and fruit load on the total number of seeds per fruit, with their interaction remaining significant. The maximum number of seeds per fruit (428.36) was recorded when sowing was done on 30th April (D_2), while the minimum (347.16) was observed with sowing on 30th May (D_4). Regarding fruit load treatments, the highest number of seeds per fruit (397.45) was recorded when 3 fruits per plant (F_1) were retained, while the lowest (373.08) was recorded when all fruits per plant were retained (F_5). The interaction between sowing dates and fruit load showed that the highest number of seeds per fruit (444.83) were recorded when sowing was done on 30th April and 3 fruits per plant were retained (D_2F_1), while the minimum number of seeds per fruit (333.00) were recorded when sowing was done on 30th May and all fruits per plant were retained (D_4F_5).

Between the two years, the maximum total number of seeds per fruit (392.74) were recorded in the second year 2023-2024, compared to minimum number of seeds per fruit (378.13) in the first year 2022-2023. The interaction between years and sowing dates (Y × D) showed significant effects, with the maximum number of seeds per fruit (444.00) recorded in the second year 2023-2024 with sowing on 30th April (Y_2D_2), while the minimum (346.00)

Table 4.2.1: Effect of sowing dates and fruit load on total number of seeds per fruit

Total number of seeds per fruit						
Y_1 (2022-2023)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	398.00	390.00	386.66	382.33	376.00	**386.60**
D_2	424.33	421.33	413.00	404.00	401.00	**412.73**
D_3	372.00	369.00	368.00	365.00	362.00	**367.20**
D_4	355.33	349.00	347.33	343.33	335.00	**346.00**
Mean	**387.41**	**382.33**	**378.75**	**373.66**	**368.50**	**378.13**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	1.42			5.03		
F	1.05			3.04		
D×F	3.19			6.57		
Y_2 (2023-2024)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	417.00	408.66	400.66	393.66	388.33	**401.66**
D_2	465.33	454.33	448.00	430.00	422.33	**444.00**
D_3	384.66	382.00	376.00	373.33	369.00	**377.00**
D_4	363.00	358.66	347.33	341.66	331.00	**348.33**
Mean	**407.50**	**400.91**	**393.00**	**384.66**	**377.66**	**392.74**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	3.43			12.12		
F	1.45			4.20		
D×F	7.68			9.58		
Pooled						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	407.50	399.33	393.66	388.00	382.16	**394.13**
D_2	444.83	437.83	430.50	417.00	411.66	**428.36**
D_3	378.33	375.50	372.00	369.16	365.50	**372.10**
D_4	359.16	353.83	347.33	342.50	333.00	**347.16**
Mean	**397.45**	**391.62**	**385.87**	**379.16**	**373.08**	**385.43**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	1.85			5.63		
F	0.89			2.53		
D×F	1.79			5.07		
Y	1.31			3.98		
Y×D	2.62			7.90		
Y×F	1.26			3.58		
Y×D×F	2.53			NS		

***D =** Sowing dates; D_1= 15th April; D_2 = 30th April; D_3 = 15th May; D_4 = 30th May
***F =** Fruit load; F_1 = 3 fruits; F_2 = 4 fruits; F_3 = 5 fruits; F_4 = 6 fruits; F_5 = all fruits retained (control)
***Y =** Year; Y_1 = 2022-2023; Y_2 = 2023-2024

was recorded in the first year 2022-2023 with sowing on 30th May (Y_1D_4). The interaction between years and fruit load (Y × F) was also significant with the maximum number of seeds per fruit (407.50) recorded in the second year 2023-2024 when 3 fruits per plant were retained (Y_2F_1), while the minimum number of seeds per fruit (368.50) were recorded in first year 2022-2023 when all fruits per plant were retained (Y_1F_5). The three-way interaction between years, sowing dates and fruit load (Y × D × F) showed non-significant effects.

The findings from the years 2022-2023 and 2023-2024 underscore the significant impact of sowing dates and fruit load management on total number of seeds per fruit in cucumber. The consistently higher total number of seeds per fruit associated with the sowing date of 30th April (D_2) highlights the advantage of optimal sowing time. Early sowing likely coincides with favourable environmental conditions, such as moderate temperatures and adequate light availability, which are crucial for pollination, fertilization and seed development.

Conversely, the significantly lower seed counts recorded for the sowing date of 30th May (D_4) suggest that delayed planting exposes the plants to heat stress or reduced soil moisture, which may impair reproductive processes and limit nutrient availability for seed formation. The increase in temperature during late sowing reduces fertility by way of pollen mortality or stigma dryness (Tomar et al. 2010). Similar trends have been reported by Tandoh et al. (2019); Nagendra et al. (2017); Paul et al. (2016) and Sharma and Kamboj (2015), reinforcing the pivotal role of sowing dates in influencing seed yield and quality.

The impact of fruit load management on seed production was also notable. The highest total number of seed per fruit was observed when 3 fruits per plant (F_1) were retained, likely due to reduced competition among fruits for assimilates and other resources, which ensures adequate supply for ovule fertilization and seed filling. In contrast, when all fruits per plant (F_5) were retained, it recorded the lowest number of seeds per fruit, which can be attributed to the intensified resource competition, resulting in suboptimal seed development. These results align with the resource competition theory, which suggests that fewer fruits per plant allow for enhanced resource allocation, promoting superior seed development (Dilrukshi et al. 2024; Patil et al. 2024; Gupta et al. 2023; Vaghasiya et al. 2022 and Gupta et al. 2022).

The interaction between sowing dates and fruit load further underscores their combined effect on seed production. The D_2F_1 combination consistently produced the highest

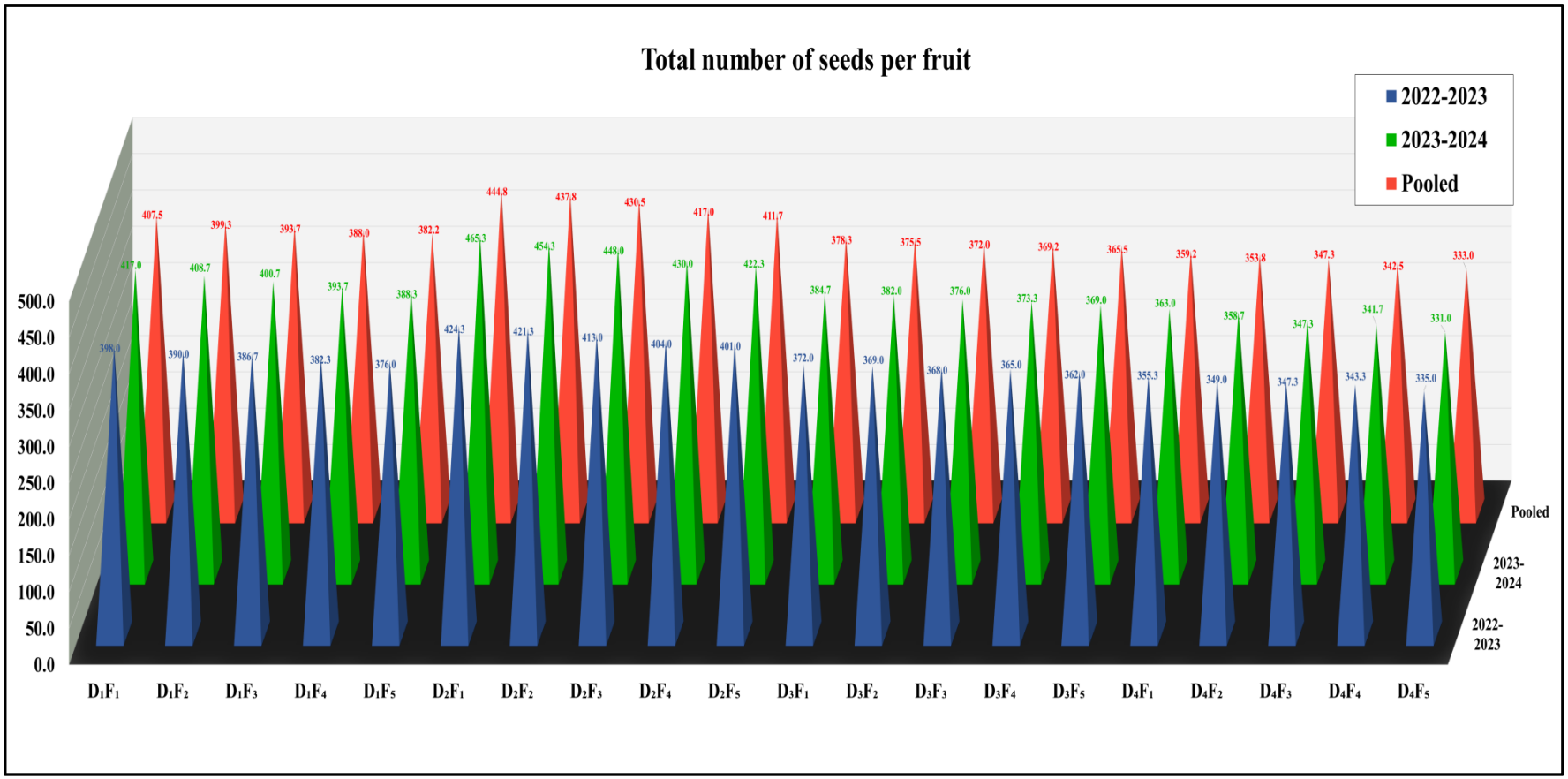


Figure 4.2.1: Effect of sowing dates and fruit load on total number of seeds per fruit

total number of seeds per fruit across both years and the pooled data, demonstrating the synergistic benefits of optimal planting time and reduced fruit load. In contrast, the D_4F_5 combination consistently resulted in the lowest seed counts, reinforcing the negative impacts of delayed sowing and excessive fruit load on seed yield of cucumber.

Yearly variations in total number of seeds per fruit, with higher values recorded in second year 2023-2024 as compared to first year 2022-2023, likely reflects differences in environmental conditions such as rainfall distribution or temperature fluctuations. The non-significant three-way interaction (Y × D × F) indicates that the combined effects of year, sowing dates and fruit load do not exhibit significant variation, suggesting that the primary factors influencing total number of seeds per fruit remain stable across different years.

As per the results, the early sowing combined with reduced fruit load not only enhances the total number of seeds per fruit but also ensures consistent performance across varying environmental conditions, making it an essential practice for improving seed yield and quality in cucumbers.

4.2.2 Seed yield per fruit (g)

Seed yield per fruit is a key parameter in seed production that reflects the number of seeds extracted from a single fruit. It is an essential metric for assessing the productivity of fruit-bearing crops, particularly in commercial seed production systems. This metric serves as an important indicator of reproductive success and resource allocation within the plant. It directly impacts the economics of seed production, where higher seed yields per fruit can reduce production costs while ensuring adequate seed quality.

The data collected from the two consecutive years 2022-2023 and 2023-2024, along with pooled analysis, indicates significant differences in seed yield per fruit (g) across the treatments (Table 4.2.2 and Figure 4.2.2).

During the first year 2022-2023, the effects of sowing dates, fruit load and their interaction were significant for the seed yield per fruit (g). The highest seed yield per fruit (9.50 g) was recorded when sowing was done on 30th April (D_2), while the lowest seed yield per fruit (7.08 g) was observed when sowing was done on 30th May (D_4). Regarding fruit load treatments, the highest seed yield per fruit (8.66 g) was recorded when 3 fruits per plant (F_1) were retained, whereas the lowest number of seeds (7.67 g) was observed when all fruits per plant (F_5) were retained. The interaction between sowing dates and fruit load revealed that the

highest seed yield per fruit (10.09 g) was obtained when sowing was done on 30th April and 3 fruits per plant were retained (D_2F_1) which was at par with sowing on 30th April and 4 fruits per plant retained (D_2F_2) and sowing on 30th April and 5 fruits per plant retained (D_2F_3), while the lowest seed yield per fruit (6.76 g) was recorded when sowing was done on 30th May and all fruits per plant were retained (D_4F_5).

In the second year 2023-2024, the effects of sowing dates, fruit load and their interaction were significant for the seed yield per fruit (g). The highest seed yield per fruit (11.46 g) was recorded when sowing was done on 30th April (D_2), while the lowest seed yield per fruit (8.53 g) was observed when sowing was done on 30th May (D_4). Regarding fruit load treatments, the highest seed yield per fruit (10.69 g) was recorded when 3 fruits per plant (F_1) were retained, whereas the lowest seed yield per fruit (7.00 g) was observed when all fruits per plant (F_5) were retained. The interaction between sowing dates and fruit load revealed that the highest seed yield per fruit (12.76 g) was recorded when sowing was done on 30th April and 3 fruits per plant were retained (D_2F_1) which was at par with sowing on 30th April and 4 fruits per plant retained (D_2F_2), while the lowest seed yield per fruit (8.02 g) was recorded when sowing was done on 30th May and all fruits per plant were retained (D_4F_5).

The pooled data for both years showed significant effects of sowing dates and fruit load on the seed yield per fruit (g), with their interaction remaining significant. The highest seed yield per fruit (10.48 g) was recorded when sowing was done on 30th April (D_2), while the lowest seed yield per fruit (7.81 g) was observed with sowing on 30th May (D_4). Regarding fruit load treatments, the highest seed yield per fruit (9.68 g) was recorded when 3 fruits per plant (F_1) were retained, while the lowest seed yield per fruit (8.34 g) was recorded when all fruits per plant were retained (F_5). The interaction between sowing dates and fruit load showed that the highest seed yield per fruit (11.42 g) was recorded when sowing was done on 30th April and 3 fruits per plant were retained (D_2F_1), while the lowest seed yield per fruit (7.39 g) was recorded when sowing was done on 30th May and all fruits per plant were retained (D_4F_5).

Between the two years, the higher seed yield per fruit (9.94 g) was recorded in the second year 2023-2024, compared to first year 2022-2023 with lower seed yield per fruit (8.22 g) . The interaction between years and sowing dates (Y × D) showed significant effects, with the highest seed yield per fruit (11.46 g) recorded in the second year 2023-2024 with sowing on 30th April (Y_2D_2), while the lowest (7.08 g) was recorded in the first year 2022-

Table 4.2.2: Effect of sowing dates and fruit load on seed yield per fruit

Seed yield per fruit (g)						
Y_1 (2022-2023)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	8.65	8.44	8.23	8.00	7.92	**8.26**
D_2	10.09	9.92	9.71	9.39	8.41	**9.50**
D_3	8.54	7.84	8.00	8.30	7.60	**8.06**
D_4	7.39	7.21	7.10	6.96	6.76	**7.08**
Mean	**8.66**	**8.35**	**8.26**	**8.18**	**7.67**	**8.22**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.06			0.22		
F	0.07			0.20		
D×F	0.14			0.42		
Y_2 (2023-2024)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	11.18	10.86	10.61	9.55	9.43	**10.32**
D_2	12.76	12.40	12.20	10.57	9.39	**11.46**
D_3	9.82	9.69	9.41	9.32	9.16	**9.48**
D_4	8.99	8.82	8.50	8.31	8.02	**8.53**
Mean	**10.69**	**10.44**	**10.18**	**9.44**	**9.00**	**9.94**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.10			0.35		
F	0.03			0.11		
D×F	0.12			0.40		
Pooled						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	9.91	9.65	9.42	8.81	8.67	**9.29**
D_2	11.42	11.16	10.95	9.98	8.90	**10.48**
D_3	9.18	8.77	8.71	8.81	8.38	**8.77**
D_4	8.19	8.02	7.80	7.63	7.39	**7.81**
Mean	**9.68**	**9.40**	**9.22**	**8.81**	**8.34**	**9.08**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.05			0.17		
F	0.04			0.11		
D×F	0.08			0.22		
Y	0.04			0.12		
Y×D	0.08			0.24		
Y×F	0.05			0.15		
Y×D×F	0.11			0.31		

***D =** Sowing dates; D_1= 15th April; D_2 = 30th April; D_3 = 15th May; D_4 = 30th May
***F =** Fruit load; F_1 = 3 fruits; F_2 = 4 fruits; F_3 = 5 fruits; F_4 = 6 fruits; F_5 = all fruits retained (control)
***Y =** Year; Y_1 = 2022-2023; Y_2 = 2023-2024

2023 with sowing on 30th May (Y_1D_4). The interaction between years and fruit load (Y × F) was also significant with the highest seed yield per fruit (10.69 g) recorded in the second year 2023-2024 when 3 fruits per plant were retained (Y_2F_1), while the lowest seed yield per fruit (7.67 g) was recorded in first year 2022-2023 when all fruits per plant were retained (Y_1F_5).

The three-way interaction between years, sowing dates and fruit load (Y × D × F) also showed significant effects, with the highest seed yield per fruit (12.76 g) recorded in the second year 2023-2024 with sowing on 30th April and 3 fruits per plant retained ($Y_2D_2F_1$), while the lowest seed yield per fruit (6.76 g) was recorded in the first year 2022-2023 with sowing on 30th May and all fruits per plant retained ($Y_1D_4F_5$).

The study demonstrated significant influences of sowing dates and fruit load on seed yield per fruit, with interaction between these factors also proving statistically significant. The sowing on 30th April (D_2) consistently produced the highest seed yield per fruit in both years, suggesting that the sowing date provided optimal environmental conditions such as moderate temperatures and sufficient daylight hours. These conditions likely enhanced photosynthetic efficiency and nutrient partitioning toward reproductive organs, thereby improving seed development. Large seed size, which increased the seed yield per fruit, observed in the early sowing treatment, is associated with more vigourous seedlings, which provides an early advantage in light interception and resource assimilation. Conversely, delayed sowing on May 30th (D_4) exposed plants to higher temperatures during critical growth stages, resulting in reduced seed yield per fruit due to heat-induced stress on reproductive processes (Tandoh et al. 2019; Nagendra et al. (2017); Jaiswal et al. 2015; Tomar et al. 2010 and Huang et al. 2010). Conversely, few studies have shown that while seed yield per fruit generally increases with fruit weight, there are diminishing returns beyond a certain point.

Fruit load significantly impacted seed yield per fruit, with 3 fruits retained per plant (F_1) recorded the highest values. This can be attributed to reduced competition among developing fruits for assimilates, ensuring adequate resource allocation to fewer fruits. Retaining all fruits per plant (F_5) diluted the plant's nutrient supply among numerous fruits, leading to compromised seed development and lower seed yield per fruit. These findings align with those of Gupta et al. (2022); Tomar et al. (2015), Chakma et al. (2016); Nerson (2008) who observed that lower fruit load enhance seed production by optimizing nutrient distribution.

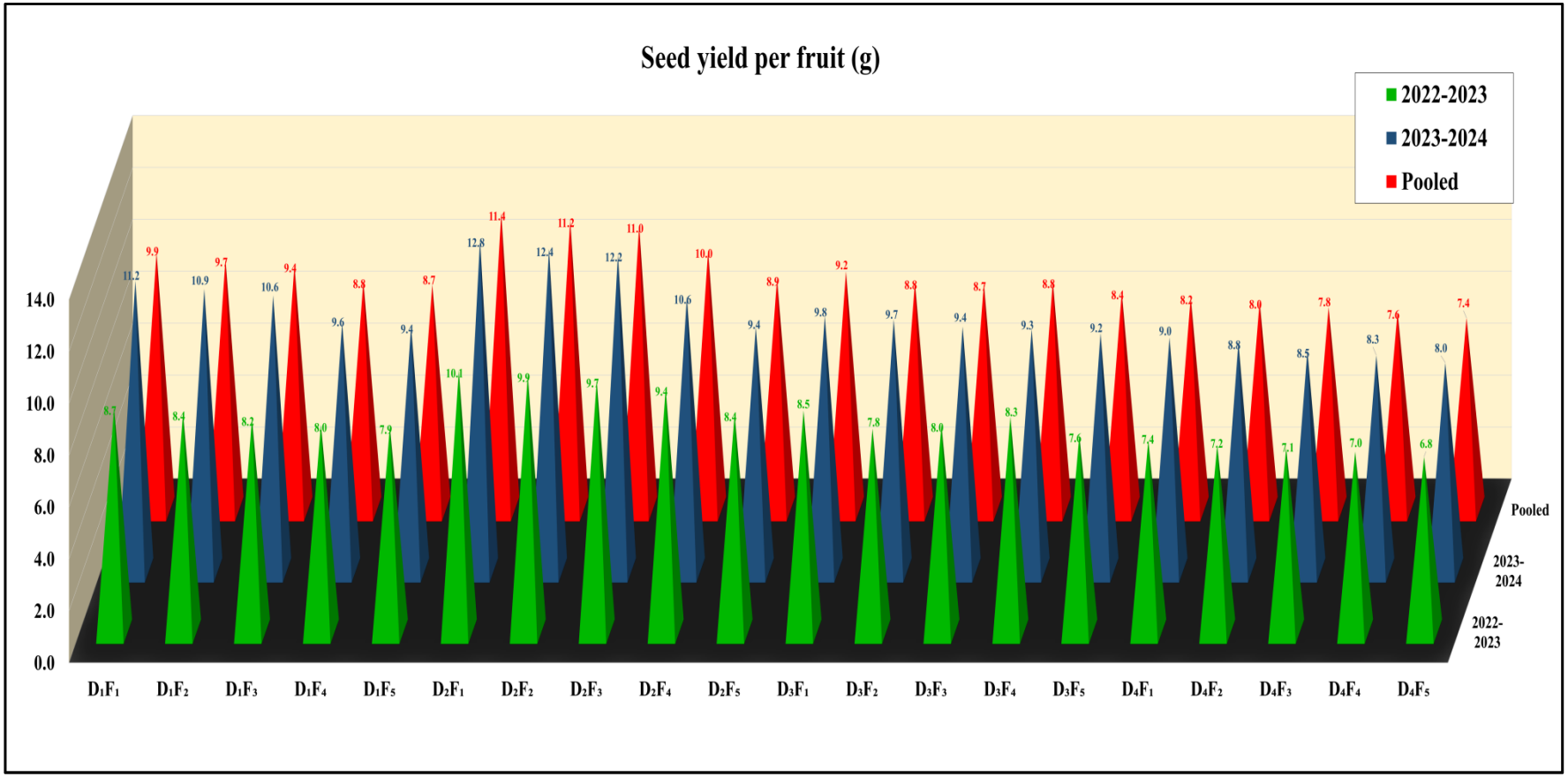


Figure 4.2.2: Effect of sowing dates and fruit load on seed yield per fruit

The interaction between sowing dates and fruit load highlighted the synergy between optimal planting times and reduced fruit load. The maximum seed yield per fruit was recorded with 30th April sowing and 3 fruits per plant (D_2F_1), reinforcing the importance of integrating favourable environmental conditions with controlled fruit retention for maximizing seed yield per fruit. Similar results have been reported in studies on cucurbits and other crops, where strategic manipulation of cultural practices like appropriate sowing dates and fruit load management improved reproductive efficiency (Pandey et al. 2019).

Inter-annual variations revealed higher seed yields per fruit in second year 2023-2024 compared to first year 2022-2023. This difference could be due to more favourable weather conditions during the second year, which may have enhanced crop growth and seed development. Significant three-way interaction (Y × D × F) further emphasizes the necessity of a holistic approach combining sowing date, fruit load and annual climatic variations to optimize seed production.

4.2.3 Seed yield per plant (g)

Seed yield per plant is a crucial determinant of overall productivity in seed crops, influenced by various agronomic and physiological factors. The number of fruits retained per plant significantly impacts the plant's ability to allocate resources like nutrients, water and photosynthates. Retaining an optimal number of fruits per plant ensures that resources are efficiently utilized, leading to the production of larger and more viable seeds, which contribute to a higher seed yield per plant. When fruit load is excessive, competition among fruits for limited resources increases, often resulting in smaller fruits with reduced seed yield and compromised seed quality. Conversely, retaining too few fruits may underutilize the plant's potential, lowering overall seed production per plant. Thus, striking a balance in fruit load is essential to optimize seed yield without compromising the physiological health of the plant.

The data collected over two consecutive years, 2022-2023 and 2023-2024, along with the pooled analysis, revealed significant variations in seed yield per plant (g) across the treatments, as presented in Table 4.2.3 and illustrated in Figure 4.2.3.

During the first year 2022-2023, the effects of sowing dates, fruit load and their interaction were significant for the seed yield per plant (g). The highest seed yield per plant (43.38 g) was recorded when sowing was done on 30th April (D_2), while the lowest seed yield

Table 4.2.3: Effect of sowing dates and fruit load on seed yield per plant

Seed yield per plant (g)						
Y_1 (2022-2023)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	25.95	33.78	41.15	48.43	34.30	**36.72**
D_2	30.26	39.70	48.55	56.33	42.06	**43.38**
D_3	25.64	31.39	40.02	49.80	38.01	**36.97**
D_4	22.16	28.85	35.53	41.73	33.80	**32.41**
Mean	**26.00**	**33.43**	**41.31**	**49.07**	**37.04**	**37.37**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.26			0.94		
F	0.46			1.34		
D×F	0.87			2.58		
Y_2 (2023-2024)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	33.54	43.45	53.06	57.31	40.77	**45.63**
D_2	38.29	49.61	61.03	63.44	46.95	**51.86**
D_3	29.47	38.79	47.06	55.95	45.82	**43.42**
D_4	26.96	35.32	42.53	49.87	40.14	**38.96**
Mean	**32.07**	**41.79**	**50.92**	**56.64**	**43.42**	**44.96**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.53			1.89		
F	0.33			0.96		
D×F	0.80			2.55		
Pooled						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	29.75	38.62	47.11	52.87	37.53	**41.17**
D_2	34.27	44.65	54.79	59.89	44.50	**47.62**
D_3	27.55	35.09	43.54	52.87	41.92	**40.19**
D_4	24.56	32.08	39.03	45.80	36.97	**35.69**
Mean	**29.03**	**37.61**	**46.11**	**52.86**	**40.23**	**41.16**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.28			0.85		
F	0.27			0.81		
D×F	0.57			1.61		
Y	0.19			0.06		
Y×D	0.39			1.20		
Y×F	0.40			1.14		
Y×D×F	0.81			2.29		

***D =** Sowing dates; D_1= 15th April; D_2 = 30th April; D_3 = 15th May; D_4 = 30th May
***F =** Fruit load; F_1 = 3 fruits; F_2 = 4 fruits; F_3 = 5 fruits; F_4 = 6 fruits; F_5 = all fruits retained (control)
***Y =** Year; Y_1 = 2022-2023; Y_2 = 2023-2024

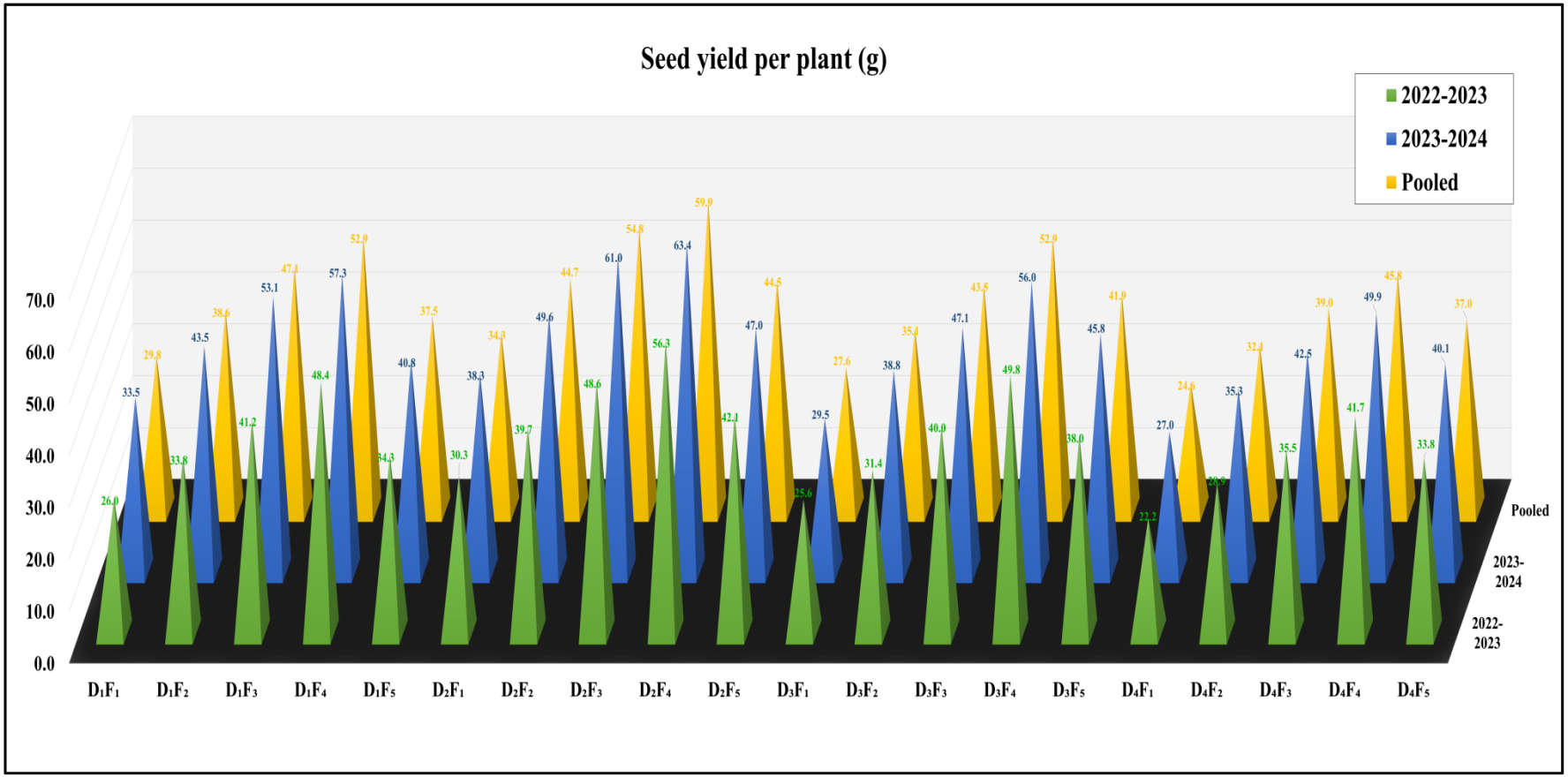


Figure 4.2.3: Effect of sowing dates and fruit load on seed yield per plant

per plant (32.41 g) was observed when sowing was done on 30th May (D_4). Regarding fruit load treatments, the highest seed yield per plant (49.07 g) was recorded when 6 fruits per plant (F_4) were retained, whereas the lowest seed yield per plant (26.00 g) was observed when 3 fruits per plant (F_1) were retained. The interaction between sowing dates and fruit load revealed that the highest seed yield per plant (56.33 g) was obtained when sowing was done on 30th April and 6 fruits per plant were retained (D_2F_4) while the lowest seed yield per plant (22.16 g) was recorded when sowing was done on 30th May and 3 fruits per plant were retained (D_4F_1).

In the second year 2023-2024, the effects of sowing dates, fruit load and their interaction were significant for the seed yield per plant (g). The highest seed yield per plant (51.86 g) was recorded when sowing was done on 30th April (D_2), while the lowest seed yield per plant (38.96 g) was observed when sowing was done on 30th May (D_4). Regarding fruit load treatments, the highest seed yield per plant (56.64 g) was recorded when 6 fruits per plant (F_4) were retained, whereas the lowest seed yield per plant (32.07 g) was observed when 3 fruits per plant (F_1) were retained. The interaction between sowing dates and fruit load revealed that the highest seed yield per plant (63.44 g) was obtained when sowing was done on 30th April and 6 fruits per plant were retained (D_2F_4) which was at par with sowing on 30th April and 5 fruits per plant retained (D_2F_3), while the lowest seed yield per plant (26.96 g) was recorded when sowing was done on 30th May and 3 fruits per plant were retained (D_4F_1).

The pooled data for both years showed significant effects of sowing dates and fruit load on the seed yield per plant (g), with their interaction remaining significant. The highest seed yield per plant (47.62 g) was recorded when sowing was done on 30th April (D_2), while the lowest seed yield per plant (35.69 g) was observed with sowing on 30th May (D_4). Regarding fruit load treatments, the highest seed yield per plant (52.86 g) was recorded when 6 fruits per plant (F_4) were retained, while the lowest seed yield per plant (29.03 g) was recorded when 3 fruits per plant were retained (F_1). The interaction between sowing dates and fruit load showed that the highest seed yield per plant (59.89 g) was recorded when sowing was done on 30th April and 6 fruits per plant were retained (D_2F_4), while the lowest seed yield per plant (24.56 g) was recorded when sowing was done on 30th May and 3 fruits per plant were retained (D_4F_1).

Between the two years, the higher seed yield per plant (44.96 g) was recorded in the second year 2023-2024, compared to first year 2022-2023 with lower seed yield per plant (37.37 g). The interaction between years and sowing dates (Y × D) showed significant effects, with the highest seed yield per plant (51.86 g) recorded in the second year 2023-2024 with sowing on 30th April (Y_2D_2), while the lowest (32.41 g) was recorded in the first year 2022-2023 with sowing on 30th May (Y_1D_4). The interaction between years and fruit load (Y × F) was also significant with the highest seed yield per plant (56.64 g) recorded in the second year 2023-2024 when 6 fruits per plant were retained (Y_2F_4), while the lowest seed yield per plant (26.00 g) was recorded in first year 2022-2023 when 3 fruits per plant were retained (Y_1F_1).

The three-way interaction between years, sowing dates and fruit load (Y × D × F) also showed significant effects, with the highest seed yield per plant (63.44 g) recorded in the second year 2023-2024 with sowing on 30th April and 6 fruits per plant retained ($Y_2D_2F_4$), while the lowest seed yield per plant (22.16 g) was recorded in the first year 2022-2023 with sowing on 30th May and 3 fruits per plant retained ($Y_1D_4F_1$).

The results demonstrated that sowing dates, fruit load and their interaction significantly influence the seed yield per plant. The highest seed yield per plant was consistently observed when sowing was done on 30th April (D_2), suggesting that optimal environmental conditions during critical growth phases can enhance reproductive performance in crops. Early sowing (D_2) likely benefited from favourable temperature and light conditions, which are known to improve pollination, seed set and nutrient partitioning. Similar results have been reported by Yadav et al. (2022) and Sharma and Kamboj (2015) for higher seed yield per plant due to earlier sowing of crops. In contrast, late sowing on 30th May (D_4) significantly reduced seed yield, particularly when fruit load was limited to 3 fruits per plant (F_1). This reduction may be attributed to shortened growth periods, reduced photosynthetic activity and suboptimal environmental conditions.

Interestingly, retaining 6 fruits per plant (F_4) resulted in higher seed yield across all sowing dates. While reduced fruit retention of 3 fruits per plant (F_1) enhanced seed quality per fruit, the reduced number of fruits limits the total seed yield per plant. This trade-off between fruit load and seed yield highlights the need for balanced crop management strategies tailored to specific growing conditions. The results obtained in the current study

align with the previous studies done by Gupta et al. (2022) and Vaghasiya et al. (2022) who have reported that retaining more fruits per plant resulted in higher seed yield per plant.

The year-wise variation in seed yield further underscores the influence of inter-annual climatic variability. The second year (2023-2024) consistently outperformed the first year (2022-2023), indicating that climatic conditions in the latter year were more conducive for cucumber seed production. This observation aligns with studies suggesting that variations in temperature, humidity and solar radiation can significantly impact crop performance.

The significant three-way interaction between years, sowing dates and fruit load (Y × D × F) reaffirms the complex interplay of genetic, environmental and management factors. The highest seed yield per plant was achieved in the second year 2023-2024 with early sowing on 30th April and retention of 6 fruits per plant ($Y_2D_2F_4$), highlighting the synergistic effect of favourable environmental conditions and optimal fruit load management practices.

4.2.4 Seed yield per plot (g)

Seed yield per plot serves as a vital indicator in assessing the productivity and efficiency of seed production practices. It is derived from the seed yield per plant multiplied by the number of surviving plants within a given plot. This formula underscores the dual importance of maximizing individual plant productivity and ensuring high plant survival rates throughout the growing season.

The data collected over two consecutive years, 2022-2023 and 2023-2024, along with the pooled analysis, revealed significant variations in seed yield per plot (g) across the treatments, as presented in Table 4.2.4 and illustrated in Figure 4.2.4.

During the first year 2022-2023, the effects of sowing dates, fruit load and their interaction were significant for the seed yield per plot (g). The highest seed yield per plot (216.91 g) was recorded when sowing was done on 30th April (D_2), while the lowest seed yield per plot (162.09 g) was observed when sowing was done on 30th May (D_4). Regarding fruit load treatments, the highest seed yield per plot (245.39 g) was recorded when 6 fruits per plant (F_4) were retained, whereas the lowest seed yield per plot (130.03 g) were observed when 3 fruits per plant (F_1) were retained. The interaction between sowing dates and fruit load revealed that the highest seed yield per plot (281.67 g) was obtained when sowing was

done on 30th April and 6 fruits per plant were retained (D_2F_4) while the lowest seed yield per plot (110.84 g) was recorded when sowing was done on 30th May and 3 fruits per plant were retained (D_4F_1).

In the second year 2023-2024, the effects of sowing dates, fruit load and their interaction were significant for the seed yield per plot (g). The highest seed yield per plot (259.33 g) was recorded when sowing was done on 30th April (D_2), while the lowest seed yield per plot (194.83 g) was observed when sowing was done on 30th May (D_4). Regarding fruit load treatments, the highest seed yield per plot (283.23 g) was recorded when 6 fruits per plant (F_4) were retained, whereas the lowest seed yield per plot (160.35 g) were observed when 3 fruits per plant (F_1) were retained. The interaction between sowing dates and fruit load revealed that the highest seed yield per plot (317.21 g) was obtained when sowing was done on 30th April and 6 fruits per plant were retained (D_2F_4) which was at par with sowing on 30th April and 5 fruits per plant retained (D_2F_3), while the lowest seed yield per plot (134.83 g) was recorded when sowing was done on 30th May and 3 fruits per plant were retained (D_4F_1).

The pooled data for both years showed significant effects of sowing dates and fruit load on the seed yield per plot (g), with their interaction remaining significant. The highest seed yield per plot (238.12 g) was recorded when sowing was done on 30th April (D_2), while the lowest seed yield per plot (178.46 g) was observed with sowing on 30th May (D_4).

Regarding fruit load treatments, the highest seed yield per plot (264.31 g) was recorded when 6 fruits per plant (F_4) were retained, while the lowest seed yield per plot (145.19 g) was recorded when 3 fruits per plot were retained (F_1). The interaction between sowing dates and fruit load showed that the highest seed yield per plot (299.44 g) was recorded when sowing was done on 30th April and 6 fruits per plant were retained (D_2F_4), while the lowest seed yield per plot (122.83 g) was recorded when sowing was done on 30th May and 3 fruits per plant were retained (D_4F_1).

Between the two years, the higher seed yield per plot (224.85 g) was recorded in the second year 2023-2024, compared to first year 2022-2023 with lower seed yield per plot (186.87 g). The interaction between years and sowing dates (Y × D) showed significant effects, with the highest seed yield per plot (259.33 g) recorded in the second year 2023-2024 with sowing on 30th April (Y_2D_2), while the lowest (162.09 g) was recorded in the first year

Table 4.2.4: Effect of sowing dates and fruit load on seed yield per plot

Seed yield per plot (g)						
Y_1 (2022-2023)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	129.77	168.92	205.76	242.17	171.49	**183.62**
D_2	151.31	198.50	242.74	281.67	210.30	**216.91**
D_3	128.21	156.93	200.09	249.04	190.09	**184.87**
D_4	110.84	144.29	177.65	208.67	169.01	**162.09**
Mean	**130.03**	**167.16**	**206.56**	**245.39**	**185.22**	**186.87**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	1.34			4.74		
F	2.32			6.72		
D×F	4.37			12.91		
Y_2 (2023-2024)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	167.73	217.27	265.34	286.58	203.88	**228.16**
D_2	191.46	248.05	305.15	317.21	234.77	**259.33**
D_3	147.38	193.96	235.29	279.75	229.11	**217.10**
D_4	134.83	176.58	212.68	249.37	200.70	**194.83**
Mean	**160.35**	**208.96**	**254.62**	**283.23**	**217.11**	**224.85**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	2.68			9.47		
F	1.67			4.84		
D×F	4.02			12.77		
Pooled						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	148.75	193.09	235.55	264.38	187.68	**205.89**
D_2	171.39	223.28	273.95	299.44	222.54	**238.12**
D_3	137.79	175.45	217.69	264.39	209.60	**200.98**
D_4	122.83	160.43	195.17	229.02	184.85	**178.46**
Mean	**145.19**	**188.06**	**230.59**	**264.31**	**201.17**	**205.86**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	1.40			4.24		
F	1.43			4.04		
D×F	2.86			8.09		
Y	0.99			3.00		
Y×D	1.98			6.00		
Y×F	2.02			5.72		
Y×D×F	4.05			11.44		

***D =** Sowing dates; D_1= 15th April; D_2 = 30th April; D_3 = 15th May; D_4 = 30th May
***F =** Fruit load; F_1 = 3 fruits; F_2 = 4 fruits; F_3 = 5 fruits; F_4 = 6 fruits; F_5 = all fruits retained (control)
***Y =** Year; Y_1 = 2022-2023; Y_2 = 2023-2024

2022-2023 with sowing on 30th May (Y_1D_4). The interaction between years and fruit load (Y × F) was also significant with the highest seed yield per plot (283.23 g) recorded in the second year 2023-2024 when 6 fruits per plant were retained (Y_2F_4), while the lowest seed yield per plot (130.03 g) was recorded in first year 2022-2023 when 3 fruits per plant were retained (Y_1F_1).

The three-way interaction between years, sowing dates and fruit load (Y × D × F) also showed significant effects, with the highest seed yield per plot (317.21 g) recorded in the second year 2023-2024 with sowing on 30th April and 6 fruits per plant retained ($Y_2D_2F_4$), while the lowest seed yield per plot (110.84 g) was recorded in the first year 2022-2023 with sowing on 30th May and 3 fruits per plant retained ($Y_1D_4F_1$).

The results from 2022-2023 and 2023-2024, combined with pooled data, revealed significant effects of sowing dates, fruit load and their interaction on seed yield per plot. Early sowing on 30th April (D_2) consistently achieved the highest seed yields, likely due to optimal environmental conditions, including temperature and photoperiod, that favour reproductive development and seed filling.

The data demonstrated that increasing fruit load per plant significantly enhances seed yield per plot, as retaining more fruits optimizes resource utilization and increases the overall seed output (Gupta et al. 2022). However, this increase in quantity comes at the cost of seed quality. A higher fruit load can lead to resource competition among developing seeds, potentially affecting parameters such as seed size, weight and vigour. Conversely, lower fruit load, though yielding fewer seeds, are associated with better seed quality due to reduced intra-plant competition and a more efficient allocation of assimilates to individual fruits.

The interaction between sowing dates and fruit load revealed that early sowing on 30th April combined with a high fruit load of 6 fruits per plant consistently observed the highest seed yield . This synergy highlights the importance of aligning cultural practices with environmental conditions to maximize productivity. However, the quality of seeds under this combination may need careful assessment, as the trade-off between yield and quality becomes evident when more fruits are retained.

Year-to-year variations were evident, with significantly higher yields recorded in the second year 2023-2024 compared to first year 2022-2023, underscoring the role of climatic

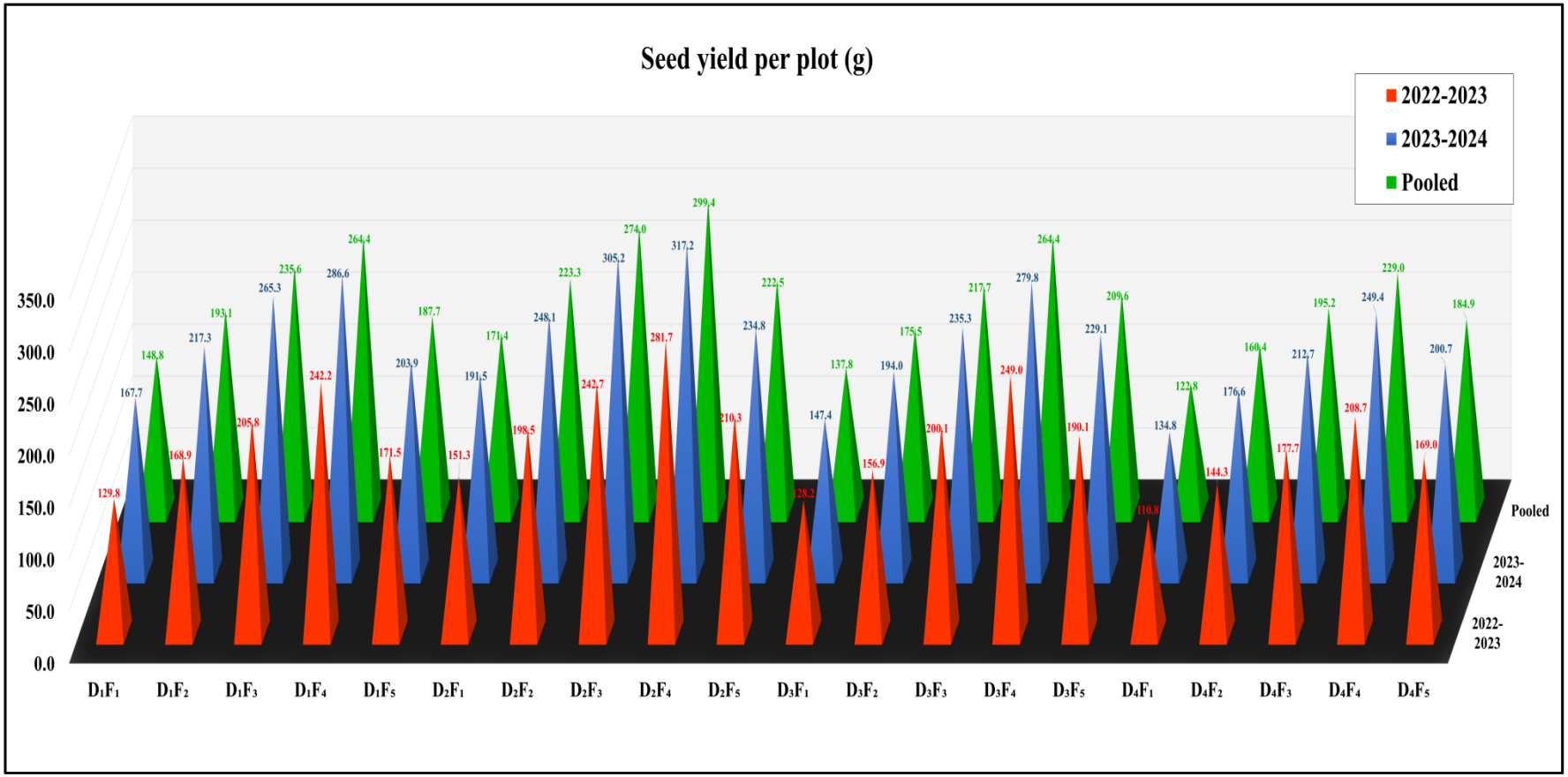


Figure 4.2.4: Effect of sowing dates and fruit load on seed yield per plot

differences in influencing productivity. The interaction among years, sowing dates and fruit load revealed a consistent trend of early sowing combined with a high fruit load in 2023-2024 achieved the maximum seed yield per plot, while delayed sowing with a low fruit load in 2022-2023 resulted in the minimum seed yield per plot.

4.2.5 Seed yield per hectare (kg)

Seed yield per hectare (kg) is the most critical parameter for evaluating the economic viability of crop production systems and is a primary basis for providing actionable recommendations to farmers. High seed yield per hectare (kg) ensures better resource use efficiency, higher profitability and improved economic returns for farmers, making it a key indicator for assessing crop management strategies.

The observations collected over two consecutive years, 2022-2023 and 2023-2024, along with pooled data analysis, highlight significant differences in seed yield per hectare (kg) across the various treatments. These findings, presented in Table 4.2.5 and depicted in Figure 4.2.5, emphasize the critical impact of sowing dates, fruit load and their interaction in optimizing seed yield potential.

During the first year 2022-2023, the effects of sowing dates, fruit load and their interaction were significant for the seed yield per hectare (kg). The highest seed yield per hectare (337.42 kg) was recorded when sowing was done on 30th April (D_2), while the lowest seed yield per hectare (252.15 kg) was observed when sowing was done on 30th May (D_4). Regarding fruit load treatments, the highest seed yield per hectare (381.72 kg) was recorded when 6 fruits per plant (F_4) were retained, whereas the lowest seed yield per hectare (202.28 kg) was observed when 3 fruits per plant (F_1) were retained. The interaction between sowing dates and fruit load revealed that the highest seed yield per hectare (438.16 kg) was obtained when sowing was done on 30th April and 6 fruits per plant were retained (D_2F_4) while the lowest seed yield per hectare (172.42 kg) was recorded when sowing was done on 30th May and 3 fruits per plant were retained (D_4F_1).

In the second year 2023-2024, the effects of sowing dates, fruit load and their interaction were significant for the seed yield per hectare (kg). The highest seed yield per hectare (403.41 kg) was recorded when sowing was done on 30th April (D_2), while the lowest seed yield per hectare (303.08 kg) was observed when sowing was done on 30th May (D_4).

Table 4.2.5: Effect of sowing dates and fruit load on seed yield per hectare

Seed yield per hectare (kg)						
Y_1 (2022-2023)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	201.87	262.76	320.07	376.72	266.77	**285.64**
D_2	235.39	308.79	377.60	438.16	327.14	**337.42**
D_3	199.45	244.13	311.27	387.39	295.70	**287.59**
D_4	172.42	224.46	276.36	324.61	262.91	**252.15**
Mean	**202.28**	**260.03**	**321.32**	**381.72**	**288.13**	**290.70**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	2.09			7.37		
F	3.62			10.46		
D×F	6.79			20.08		
Y_2 (2023-2024)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	260.91	337.97	412.76	445.80	317.15	**354.92**
D_2	297.84	385.87	474.69	493.45	365.20	**403.41**
D_3	229.26	301.72	366.01	435.17	356.40	**337.71**
D_4	209.75	274.69	330.85	387.91	312.20	**303.08**
Mean	**249.44**	**325.06**	**396.08**	**440.58**	**337.74**	**349.78**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	4.18			14.74		
F	2.61			7.54		
D×F	6.26			19.88		
Pooled						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	231.39	300.36	366.42	411.26	291.96	**320.28**
D_2	266.61	347.33	426.14	465.81	346.17	**370.41**
D_3	214.35	272.93	338.64	411.28	326.05	**312.65**
D_4	194.08	249.57	303.60	356.26	287.55	**278.21**
Mean	**226.60**	**292.55**	**358.70**	**411.15**	**312.93**	**320.38**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	1.54			4.67		
F	2.18			6.60		
D×F	3.08			9.34		
Y	2.23			6.30		
Y×D	3.15			8.91		
Y×F	4.46			12.60		
Y×D×F	6.30			17.81		

***D =** Sowing dates; D_1= 15th April; D_2 = 30th April; D_3 = 15th May; D_4 = 30th May
***F =** Fruit load; F_1 = 3 fruits; F_2 = 4 fruits; F_3 = 5 fruits; F_4 = 6 fruits; F_5 = all fruits retained (control)
***Y =** Year; Y_1 = 2022-2023; Y_2 = 2023-2024

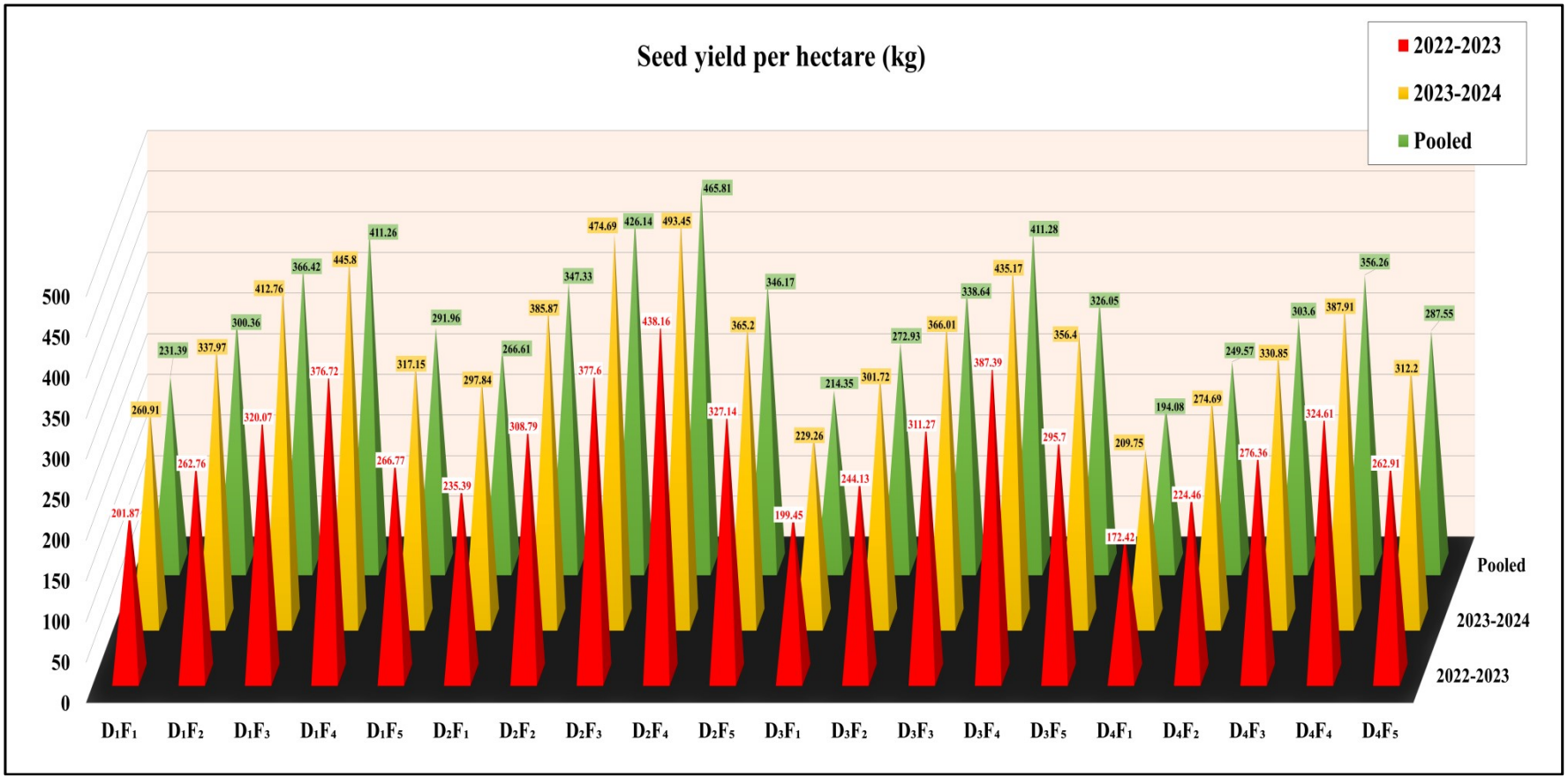


Figure 4.2.5: Effect of sowing dates and fruit load on seed yield per hectare

Regarding fruit load treatments, the highest seed yield per hectare (440.58 kg) was recorded when 6 fruits per plant (F_4) were retained, whereas the lowest seed yield per hectare (249.44 kg) was observed when 3 fruits per plant (F_1) were retained. The interaction between sowing dates and fruit load revealed that the highest seed yield per hectare (493.45 kg) was obtained when sowing was done on 30th April and 6 fruits per plant were retained (D_2F_4) which was at par with sowing on 30th April and 5 fruits per plant retained (D_2F_3), while the lowest seed yield per hectare (209.75 kg) was recorded when sowing was done on 30th May and 3 fruits per plant were retained (D_4F_1).

The pooled data for both years showed significant effects of sowing dates and fruit load on the seed yield per hectare (kg), with their interaction remaining significant. The highest seed yield per hectare (370.41 kg) was recorded when sowing was done on 30th April (D_2), while the lowest seed yield per hectare (278.21 kg) was observed with sowing on 30th May (D_4). Regarding fruit load treatments, the highest seed yield per hectare (411.15 kg) was recorded when 6 fruits per plant (F_4) were retained, while the lowest seed yield per hectare (226.60 kg) was recorded when 3 fruits per plant were retained (F_1). The interaction between sowing dates and fruit load showed that the highest seed yield per hectare (465.81 kg) was recorded when sowing was done on 30th April and 6 fruits per plant were retained (D_2F_4), while the lowest seed yield per hectare (194.08 kg) was recorded when sowing was done on 30th May and 3 fruits per plant were retained (D_4F_1).

Between the two years, the higher seed yield per hectare (349.78 kg) was recorded in the second year 2023-2024, compared to first year 2022-2023 with lower seed yield per hectare (290.70 kg). The interaction between years and sowing dates (Y × D) showed significant effects, with the highest seed yield per hectare (403.41 kg) recorded in the second year 2023-2024 with sowing on 30th April (Y_2D_2), while the lowest (252.15 kg) was recorded in the first year 2022-2023 with sowing on 30th May (Y_1D_4). The interaction between years and fruit load (Y × F) was also significant with the highest seed yield per hectare (440.58 kg) recorded in the second year 2023-2024 when 6 fruits per plant were retained (Y_2F_4), while the lowest seed yield per hectare (202.28 kg) was recorded in first year 2022-2023 when 3 fruits per plant were retained (Y_1F_1).

The three-way interaction between years, sowing dates and fruit load (Y × D × F) also showed significant effects, with the highest seed yield per hectare (493.45 kg) recorded in the second year 2023-2024 with sowing on 30th April and 6 fruits per plant retained ($Y_2D_2F_4$),

while the lowest seed yield per plot (172.42 kg) was recorded in the first year 2022-2023 with sowing on 30th May and 3 fruits per plant retained ($Y_1D_4F_1$).

The analysis of seed yield per hectare (kg) revealed a significant influence of sowing dates, fruit load and their interaction, highlighting their importance in optimizing productivity. In both the years, the higher seed yield per hectare (kg) was obtained when sowing was done on 30th April (D_2). This could be attributed to more favourable climatic for growth and production during the early sowing dates as reported by Nagendra et al. (2017) and Paul et al. (2016). Across both years, higher seed yields were observed when 6 fruits per plant were retained (F_4), while the lowest yields were recorded with only 3 fruits retained (F_1). This underscores the positive correlation between fruit retention and yield, with increased fruit load directly enhancing seed yield per hectare. However, this strategy raises concerns about the potential impact on seed quality, as greater fruit retention can lead to resource competition, which may reduce the vigour and viability of individual seeds (Gupta et al. 2021b).

In both years, the highest seed yield per hectare (kg) was achieved with early sowing on 30th April and 6 fruits per plant retained (D_2F_4). These results demonstrate that early sowing aligns well with the crop's growth cycle, allowing better utilization of environmental resources, while high fruit retention maximizes reproductive output.

Year-to-year differences were also notable, with higher overall yields recorded in the second year 2023-2024 compared to the first year 2022-2023. This could be attributed to more favourable climatic conditions in 2023-2024, which may have enhanced pollination, fruit set and seed development. The interaction between years, sowing dates and fruit load (Y × D × F) further supported the conclusion that early sowing with maximum fruit retention consistently led to superior yields, with the highest yield observed under this combination in 2023-2024.

While high fruit retention substantially increases seed yield per hectare (kg), it may negatively affect seed quality parameters such as germination percentage, seed vigour and uniformity. This occurs due to resource dilution, as the plant allocates its resources across a larger number of developing fruits, potentially compromising the nutrient content and maturation of individual seeds. In contrast, retaining fewer fruits per plant often results in lower yields but may enhance seed quality by allowing better resource partitioning. These

insights align with previous studies by Gupta et al. (2021a), which emphasize the importance of integrating agronomic practices with market demands and crop physiology.

These findings suggest that for large-scale seed production, strategies balancing seed yield and quality are essential. Farmers aiming for maximum productivity should consider early sowing with higher fruit retention but be mindful of quality trade-offs. For quality-oriented markets, moderate fruit retention might be more appropriate to ensure robust seed characteristics. Also, as reported by Bhanuje (2016), plucking the initial 3 fruits at the green stage for vegetable use and retaining the rest for seed production can also be considered for extra income from green fruits, as seed yield does not significantly decrease with the removal of 3 fruits for vegetable use.

4.2.6 Seed yield index

The seed yield index, proposed by Nerson et al. (1994), is calculated as the ratio of seed yield (g) to fruit weight (kg). This index serves as a measure of the efficiency of seed production relative to the biomass of the fruit, providing valuable insights into the resource allocation dynamics within plants. The seed yield index, which indicates how assimilates are allocated between seeds and other parts of the fruit, may be an effective measure for identifying the environmental and genetic factors that enhance seed production. The seed yield index is particularly important because it encapsulates both the quantity (seed number) and quality (seed size and viability) of seeds within a single metric. Nerson et al. (1994) suggested that a higher seed yield is closely associated with a lower seed yield index.

The data from 2022-2023 and 2023-2024, along with the pooled analysis, showed significant variations in the seed yield index across treatments (Table 4.2.6 and Figure 4.2.6). In the first year 2022-2023, sowing dates, fruit load and their interaction significantly influenced the seed yield index. The highest seed yield index (19.67) was recorded with sowing on 30th May (D_4), while the lowest (14.81) was observed with sowing on 30th April (D_2). Among fruit load treatments, retaining all fruits per plant (F_5) resulted in the highest seed yield index (17.44), whereas retaining 3 fruits per plant (F_1) led to the lowest (15.77). The interaction of sowing dates and fruit load revealed that sowing on 30th May with all fruits retained per plant (D_4F_5) produced the maximum seed yield index (24.04), while sowing on 15th April with retaining of all fruits per plant (D_1F_5) resulted in the minimum (14.13).

Table 4.2.6: Effect of sowing dates and fruit load on seed yield index

Seed yield index						
Y_1 (2022-2023)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	14.91	15.06	15.22	15.34	14.13	**14.93**
D_2	14.63	14.68	14.95	14.81	14.98	**14.81**
D_3	16.93	16.32	16.90	17.99	16.60	**16.95**
D_4	16.63	17.23	19.32	21.12	24.04	**19.67**
Mean	**15.77**	**15.82**	**16.59**	**17.31**	**17.44**	**16.59**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.39			1.37		
F	0.23			0.68		
D×F	0.57			1.84		
Y_2 (2023-2024)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	18.50	19.25	20.35	18.57	18.62	**19.06**
D_2	18.68	18.70	18.69	16.66	15.04	**17.55**
D_3	20.28	21.00	21.87	22.91	24.33	**22.08**
D_4	25.70	25.76	27.97	31.28	34.82	**29.10**
Mean	**20.79**	**21.18**	**22.22**	**22.35**	**23.20**	**21.94**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.83			2.94		
F	0.24			0.70		
D×F	0.94			3.20		
Pooled						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	16.56	16.96	17.65	16.69	16.80	**16.93**
D_2	16.79	16.88	16.96	16.00	14.58	**16.24**
D_3	18.60	18.66	19.38	20.45	20.46	**19.51**
D_4	21.16	21.50	23.64	26.20	29.43	**24.39**
Mean	**18.28**	**18.50**	**19.41**	**19.83**	**20.32**	**19.26**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.45			1.36		
F	0.17			0.48		
D×F	0.34			0.96		
Y	0.31			0.97		
Y×D	0.63			1.93		
Y×F	0.24			NS		
Y×D×F	0.48			1.36		

***D =** Sowing dates; D_1= 15th April; D_2 = 30th April; D_3 = 15th May; D_4 = 30th May
***F =** Fruit load; F_1 = 3 fruits; F_2 = 4 fruits; F_3 = 5 fruits; F_4 = 6 fruits; F_5 = all fruits retained (control)
***Y =** Year; Y_1 = 2022-2023; Y_2 = 2023-2024

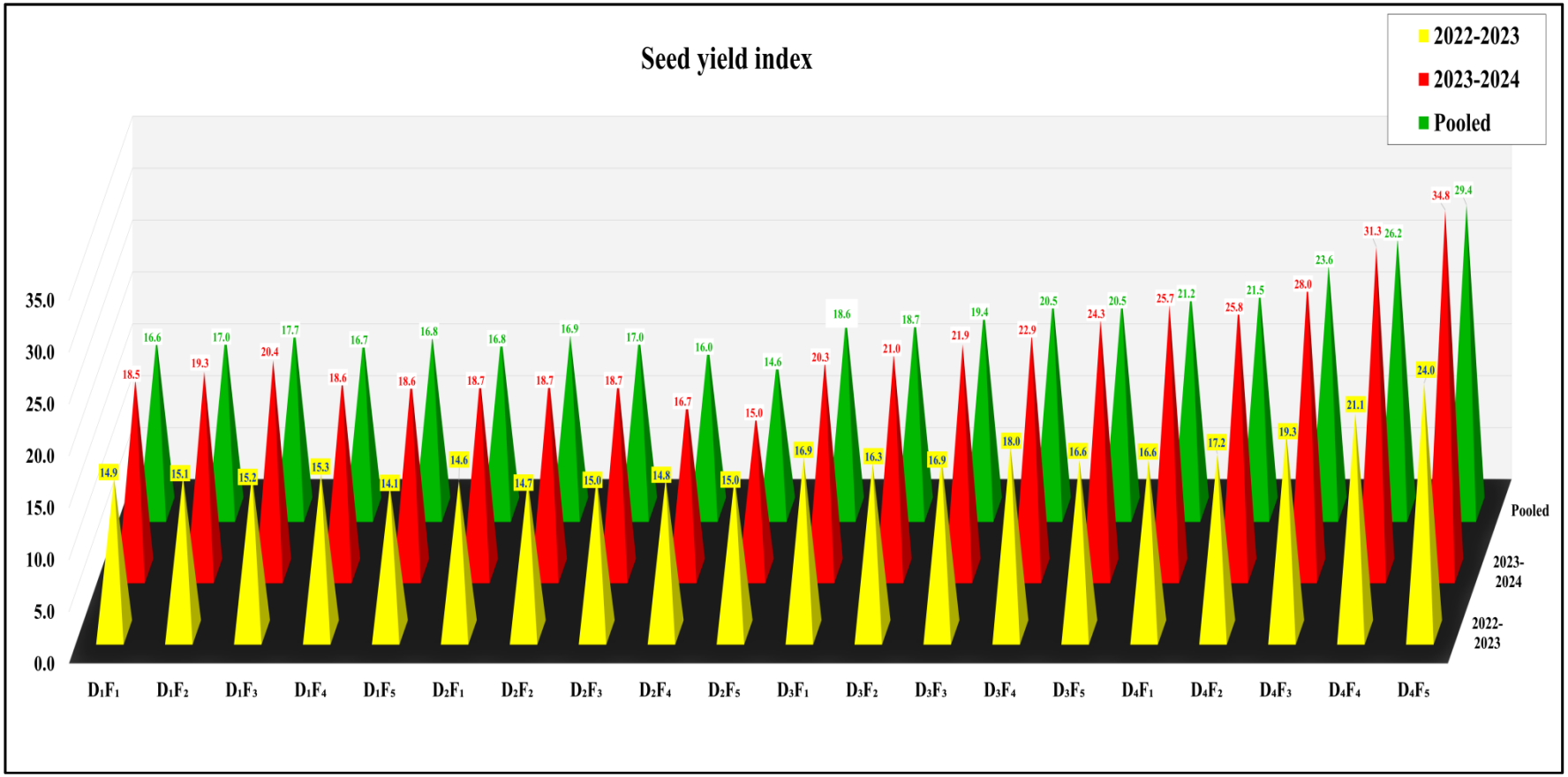


Figure 4.2.6: Effect of sowing dates and fruit load on seed yield index

During the second year 2023-2024, similar trends were observed. The seed yield index was again highest (29.10) with sowing on 30th May (D_4) and lowest (17.55) with sowing on 30th April (D_2). Retaining of all fruits per plant (F_5) recorded the maximum seed yield index (23.20), while retaining 3 fruits per plant (F_1) resulted in the minimum (20.79). The 30th May sowing with retaining all fruits per plant (D_2F_4) recorded the highest seed yield index (34.82), whereas 30th April sowing with retention of all fruits per plant (D_2F_5) had the lowest (15.04).

The pooled data for both years showed significant effects of sowing dates and fruit load on the seed yield index, with their interaction remaining significant. The highest seed yield index (24.39) was recorded when sowing was done on 30th May (D_4), while the lowest seed yield index (16.24) was observed with sowing on 30th April (D_1). Regarding fruit load treatments, the highest seed yield index (20.32) was recorded when all fruits per plant (F_5) were retained, while the lowest seed yield index (18.28) was recorded when 3 fruits per plant were retained (F_1). The interaction between sowing dates and fruit load showed that the highest seed yield index (29.43) was recorded when sowing was done on 30th May and all fruits per plant were retained (D_4F_5), while the lowest seed yield index (14.58) was recorded when sowing was done on 30th April and all fruits per plant were retained (D_2F_5).

Comparing the two years, the second year 2023-2024 had a higher overall seed yield index (21.94) than the first year 2022-2023 (16.59). The interaction of years and sowing dates (Y × D) indicated that 30th May sowing in the second year 2023-2024 (Y_2D_4) produced the highest seed yield index (29.10), while 30th April sowing in the first year (Y_1D_2) resulted in the lowest (14.81). The interaction between years and fruit load (Y × F) showed non-significant effects.

The three-way interaction of years, sowing dates and fruit load (Y × D × F) was significant. The highest seed yield index (34.82) was achieved in the second year 2023-2024 with 30th May sowing and all fruits per plant retained ($Y_2D_4F_5$). Conversely, the lowest seed yield index (14.13) was observed in the first year 2022-2023 with 15th April sowing and all fruits per plant retained ($Y_1D_1F_5$).

The results from the two consecutive years (2022-2023 and 2023-2024) provide valuable insights into the relationship between sowing dates, fruit load and the seed yield index. The seed yield index, as a parameter that encapsulates both the quantity (seed number)

and quality (seed size and viability) of seeds, is particularly important in understanding the efficiency of seed production. A higher seed yield index indicates a lower seed yield, meaning that a higher ratio of assimilates is being allocated to non-seed parts of the fruit, which can reduce the overall seed production efficiency.

The findings from this study align with the observations of Nerson et al. (1994) and Tomar et al. (2010), who suggested that a higher seed yield is closely linked to a lower seed yield index. This relationship underscores the importance of identifying optimal sowing dates and fruit load treatments that minimize the seed yield index and maximize the overall seed yield. In both years of the study, sowing on 30th May (D_4) consistently resulted in the highest seed yield index, indicating that this sowing date may lead to a less efficient seed production process.

On the other hand, early sowing dates of 30th April (D_1) resulted in a lower seed yield index, indicating more efficient seed production relative to the biomass of the fruit. This finding supports the notion that earlier sowing may allow plants to allocate more resources to seed development, improving both seed quantity and quality. However, it is important to note that sowing too early could expose plants to adverse environmental conditions, which might ultimately affect seed quality and viability.

Fruit load treatments also played a significant role in determining the seed yield index. Retaining all fruits per plant (F_5) resulted in a higher seed yield index in both years, which suggests that excessive fruit load led to a less efficient distribution of resources for seed production. In contrast, retaining 3 fruits per plant (F_1) resulted in a lower seed yield index, implying a more efficient allocation of resources to the seeds, which enhanced seed production efficiency.

The three-way interaction between years, sowing dates and fruit load revealed that the highest seed yield index occurred in the second year 2023-2024 with sowing on 30th May and all fruits retained per plant ($Y_2D_4F_5$). This combination resulted in a less efficient seed production process, with a higher allocation of assimilates to non-seed parts of the fruit. Conversely, the lowest seed yield index was observed in the first year (2022-2023) with sowing on 15th April and all fruits retained per plant ($Y_1D_2F_5$), indicating a more efficient seed production process in this combination. The variability in these results across different

years further emphasizes the importance of considering environmental factors and their interaction with sowing dates and fruit load when planning for optimal seed production.

The results reinforce the notion that a higher seed yield index corresponds to a less efficient seed production process, as it reflects the distribution of resources between seeds and other fruit parts. The data clearly indicate that late sowing dates and higher fruit load can increase the seed yield index, meaning that while the plants may produce more biomass, the efficiency of seed production decreases. To enhance seed production efficiency, it is essential to focus on managing sowing dates and fruit load in a way that minimizes the seed yield index, thus improving the overall seed yield.

4.2.7 1000 seed weight (g)

The 1000 seed weight (g), also known as test weight, is a vital parameter in agriculture and seed science, serving as an indicator of seed quality, size and vigour. It represents the weight of 1000 seeds and is widely used to evaluate seed health and its potential for successful germination and robust crop establishment. A higher 1000 seed weight is often associated with better-developed seeds containing more stored nutrients, leading to improved seedling vigour, higher germination rates and enhanced resistance to environmental stress.

The data from 2022-2023 and 2023-2024, along with the pooled analysis, showed significant variations in the 1000 seed weight (g) across treatments (Table 4.2.7 and Figure 4.2.7).

During the first year 2022-2023, significant effects of sowing dates, fruit load and their interaction were observed on the 1000 seed weight (g). The highest 1000 seed weight (23.01 g) was achieved with sowing on 30th April (D_2), while the lowest (20.47 g) was recorded with sowing on 30th May (D_4). Among the fruit load treatments, retaining 3 fruits per plant (F_1) resulted in the highest 1000 seed weight (22.32 g), whereas retaining all fruits per plant (F_5) led to the lowest value (20.80 g). The interaction between sowing dates and fruit load revealed that the combination of 30th April sowing and 3 fruits per plant retained (D_2F_1) produced the maximum 1000 seed weight (23.77 g) which was at par with D_2F_2, D_2F_3, D_2F_4 and D_3F_1, while the minimum (20.18 g) was recorded with 30th May sowing and all fruits per plant retained (D_4F_5).

Table 4.2.7: Effect of sowing dates and fruit load on 1000 seed weight

1000 seed weight (g)						
Y_1 (2022-2023)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	21.73	21.65	21.28	21.11	21.06	**21.37**
D_2	23.77	23.55	23.51	23.24	20.98	**23.01**
D_3	22.97	21.26	21.75	22.74	21.00	**21.94**
D_4	20.79	20.67	20.46	20.26	20.18	**20.47**
Mean	**22.32**	**21.78**	**21.75**	**21.83**	**20.80**	**21.69**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.13			0.48		
F	0.17			0.50		
D×F	0.34			1.02		
Y_2 (2023-2024)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	26.81	26.58	26.49	24.26	24.29	**25.68**
D_2	27.43	27.30	27.24	24.59	22.23	**25.76**
D_3	25.54	25.38	25.03	24.97	24.83	**25.15**
D_4	24.76	24.61	24.49	24.33	24.25	**24.49**
Mean	**26.13**	**25.97**	**25.81**	**24.54**	**23.90**	**25.27**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.09			0.32		
F	0.05			0.16		
D×F	0.13			0.42		
Pooled						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	24.27	24.12	23.88	22.69	22.67	**23.53**
D_2	25.60	25.42	25.37	23.91	21.61	**24.38**
D_3	24.25	23.32	23.39	23.86	22.92	**23.55**
D_4	22.78	22.64	22.47	22.29	22.21	**22.48**
Mean	**24.22**	**23.88**	**23.78**	**23.19**	**22.35**	**23.48**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.08			0.24		
F	0.09			0.25		
D×F	0.18			0.51		
Y	0.05			0.17		
Y×D	0.11			0.35		
Y×F	0.13			0.36		
Y×D×F	0.26			0.73		

***D =** Sowing dates; D_1= 15th April; D_2 = 30th April; D_3 = 15th May; D_4 = 30th May
***F =** Fruit load; F_1 = 3 fruits; F_2 = 4 fruits; F_3 = 5 fruits; F_4 = 6 fruits; F_5 = all fruits retained (control)
***Y =** Year; Y_1 = 2022-2023; Y_2 = 2023-2024

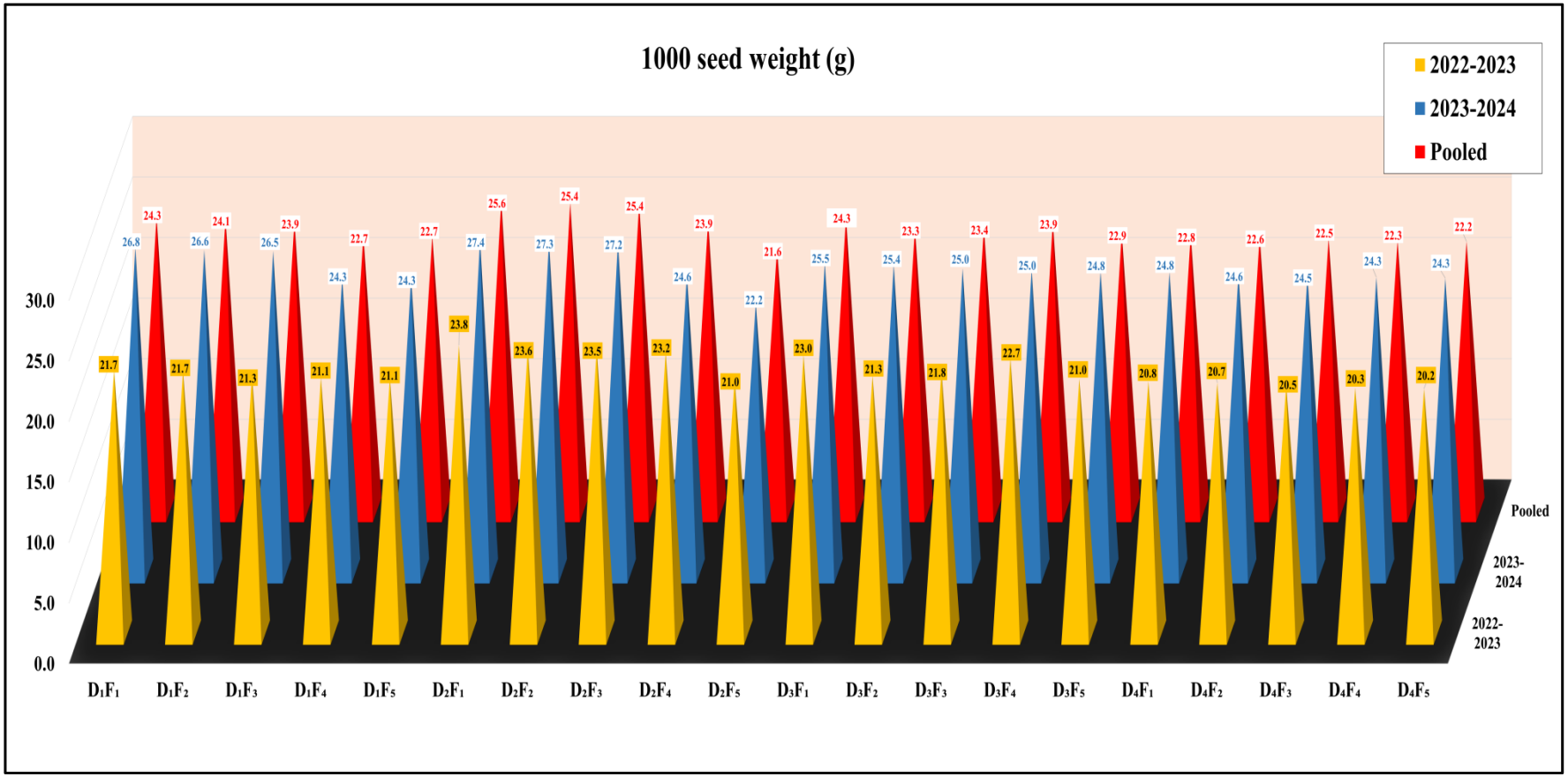


Figure 4.2.7: Effect of sowing dates and fruit load on 1000 seed weight

In the second year 2023-2024, similar trends were observed. The 1000 seed weight was significantly influenced by sowing dates, fruit load and their interaction. The highest 1000 seed weight (25.76 g) was noted with sowing on 30th April (D_2) and the lowest (24.49 g) was recorded with sowing on 30th May (D_4). Among the fruit load treatments, retaining 3 fruits per plant (F_1) recorded the highest 1000 seed weight (26.13 g) which was at par with retaining 4 fruits per plant (F_2), while the lowest (23.90 g) was recorded with all fruits per plant retained (F_5). The interaction of 30th April sowing with 3 fruits per plant retained (D_2F_1) gave the maximum 1000 seed weight (27.43 g) which was at par with D_2F_2 and D_2F_3, whereas the combination of 30th May sowing with all fruits per plant retained (D_4F_5) resulted in the minimum (24.25 g).

The pooled analysis for both years indicated significant effects of sowing dates and fruit load on the 1000 seed weight (g), along with their interaction. The highest 1000 seed weight (24.38 g) was recorded with sowing on 30th April (D_2), while the lowest (22.48 g) was observed with sowing on 30th May (D_4). Regarding fruit load treatments, retaining 3 fruits per plant (F_1) produced the highest 1000 seed weight (24.22 g), whereas retaining all fruits per plant (F_5) resulted in the lowest (22.35 g). The interaction analysis showed that the combination of 30th April sowing and 3 fruits per plant retained (D_2F_1) recorded the highest 1000 seed weight (25.60 g) which was at par with D_2F_2 and D_2F_3, while the lowest (22.21 g) was observed with 30th May sowing and all fruits per plant retained (D_4F_5).

Across the two years, the second year 2023-2024 recorded a higher average 1000 seed weight (25.27 g) compared to the first year 2022-2023 (21.69 g). The interaction between years and sowing dates (Y × D) showed that the highest 1000 seed weight (25.76 g) was achieved in the second year 2023-2024 with sowing on 30th April (Y_2D_2), while the lowest (20.47 g) occurred in the first year 2022-2023 with sowing on 30th May (Y_1D_4). Similarly, the interaction between years and fruit load (Y × F) revealed that the maximum 1000 seed weight (26.13 g) was recorded in the second year 2023-2024 with 3 fruits per plant retained (Y_2F_1), while the minimum (20.80 g) was recorded in the first year 2022-2023 with all fruits per plant retained (Y_1F_5).

The three-way interaction between years, sowing dates and fruit load (Y × D × F) was also significant. The highest 1000 seed weight (27.43 g) was achieved in the second year 2023-2024 with sowing on 30th April and retaining 3 fruits per plant ($Y_2D_2F_1$), while the

lowest (20.18 g) was observed in the first year 2022-2023 with sowing on 30th May and retaining all fruits per plant ($Y_1D_4F_5$).

The data clearly highlights significant variations in the 1000 seed weight across different sowing dates, fruit load and their interaction over two consecutive years (2022-2023 and 2023-2024), as well as the pooled analysis.

The highest 1000 seed weight was consistently recorded when sowing was done on 30th April (D_2) across all treatments. This can be attributed to the optimal growing conditions during this sowing period, which likely provided favourable temperature, photoperiod and resource availability during critical seed development stages. Similar results of higher 1000 seed weight with earlier sowing have been reported by Yadav et al. (2022); Behera et al. (2018); Paul et al. (2016) and Sharma and Kamboj (2015). Additionally, the retention of 3 fruits per plant (F_1) resulted in significantly larger and bolder seeds, as this reduced fruit competition for assimilates. This fruit load allowed for greater partitioning of nutrients and photo-assimilates to fewer developing seeds, thereby enhancing their size, weight and overall quality. Chandi et al. (2020); Sharma et al. (2017) and Dilrukshi et al. (2024) also reported similar results for higher 1000 seed weight with moderate fruit retention.

The interaction between 30th April sowing and retaining 3 fruits per plant (D_2F_1) further reinforced this trend, as this combination recorded the maximum 1000 seed weight across both years and in the pooled analysis. The optimal allocation of photosynthates to fewer fruits likely led to a better balance between seed number and seed quality, thereby improving seed weight. Moreover, larger seed size, as observed in the early sowing treatment, is associated with more vigourous seedlings. Vigourous seedlings gain an early advantage in light interception and resource assimilation, which are critical for establishing healthy seedlings that can efficiently use available resources. This early vigour ensures a stronger start during initial plant development, ultimately leading to better crop establishment and growth.

Conversely, the lowest 1000 seed weight was observed with late sowing on 30th May (D_4) and retaining all fruits per plant (F_5). Late sowing likely exposed the plants to suboptimal growing conditions, including higher temperatures, which can reduce fertility due to increased pollen mortality and stigma desiccation. Additionally, honeybee activity during peak summer is typically lower, further affecting pollination efficiency. Furthermore,

retaining all fruits per plant (F_5) increased competition for limited resources, reducing the availability of assimilates for individual seeds. This resource dilution effect led to smaller and lighter seeds, as evident in the minimum 1000 seed weight recorded under this treatment combination (D_4F_5).

Across the two years, the second year (2023-2024) consistently recorded higher 1000 seed weight compared to the first year (2022-2023). This may be attributed to better climatic conditions or more favourable environmental factors during the second year, which enhanced the seed-filling process.

4.2.8 Number of filled seeds

The number of filled seeds serves as an indicator of seed quality and reflects the reproductive success of a plant. Filled seeds are generally indicative of optimal pollination and efficient resource allocation during seed development. Achieving a higher proportion of filled seeds is essential for improving both seed quality and overall crop productivity. To maximize the number of filled seeds, successful pollination is critical. This can be promoted through favourable environmental conditions and the presence of effective pollinators, such as honeybees, during the peak flowering period. Additionally, the process of seed filling depends on the proper assimilation and distribution of nutrients to the developing seeds, which is essential for their optimal development.

The data from 2022-2023 and 2023-2024, along with the pooled analysis, showed significant variations in the number of filled seeds across treatments (Table 4.2.8 and Figure 4.2.8).

During the first year 2022-2023, significant effects of sowing dates and fruit load was observed in the number of filled seeds whereas, their interaction was non-significant. The highest number of filled seeds (321.46) were recorded with sowing on 30th April (D_2), while the lowest (269.73) were observed with sowing on 30th May (D_4). Among the fruit load treatments, retaining 3 fruits per plant (F_1) resulted in the highest number of filled seeds (301.66), whereas retaining all fruits per plant (F_5) led to the lowest number of filled seed (287.50). The interaction between sowing dates and fruit load was non-significant for number of filled seeds in the first year 2022-2023 and the values ranged from 330.33 -261.00.

In the second year 2023-2024, the number of filled seeds was significantly influenced by sowing dates, fruit load and their interaction. The highest number of filled seeds (349.26)

Table 4.2.8: Effect of sowing dates and fruit load on number of filled seeds

Number of filled seeds						
Y_1 (2022-2023)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	309.66	303.66	301.00	297.33	293.66	**301.06**
D_2	330.33	328.66	321.33	314.33	312.66	**321.46**
D_3	290.00	287.66	287.00	284.66	282.66	**286.40**
D_4	276.66	272.33	271.00	267.66	261.00	**269.73**
Mean	**301.66**	**298.08**	**295.08**	**291.00**	**287.50**	**294.66**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	1.10			3.89		
F	0.87			2.53		
D×F	2.47			NS		
Y_2 (2023-2024)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	329.00	322.66	315.33	309.33	304.66	**316.20**
D_2	366.33	356.33	353.00	337.33	333.33	**349.26**
D_3	302.33	300.66	295.33	293.66	291.00	**296.60**
D_4	286.33	283.00	273.66	270.33	265.33	**275.73**
Mean	**321.00**	**315.66**	**309.33**	**302.66**	**298.58**	**309.44**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	3.68			13.00		
F	1.30			3.77		
D×F	8.24			8.72		
Pooled						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	319.33	313.16	308.16	303.33	299.16	**308.63**
D_2	348.33	342.50	337.16	325.83	323.00	**335.36**
D_3	296.16	294.16	291.16	289.16	286.83	**291.50**
D_4	281.50	277.66	272.33	269.00	263.16	**272.73**
Mean	**311.33**	**306.87**	**302.20**	**296.83**	**293.04**	**302.05**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	1.19			5.82		
F	0.78			2.21		
D×F	1.57			4.43		
Y	1.35			4.11		
Y×D	2.71			8.23		
Y×F	1.11			3.13		
Y×D×F	2.22			NS		

***D =** Sowing dates; D_1= 15th April; D_2 = 30th April; D_3 = 15th May; D_4 = 30th May
***F =** Fruit load; F_1 = 3 fruits; F_2 = 4 fruits; F_3 = 5 fruits; F_4 = 6 fruits; F_5 = all fruits retained (control)
***Y =** Year; Y_1 = 2022-2023; Y_2 = 2023-2024

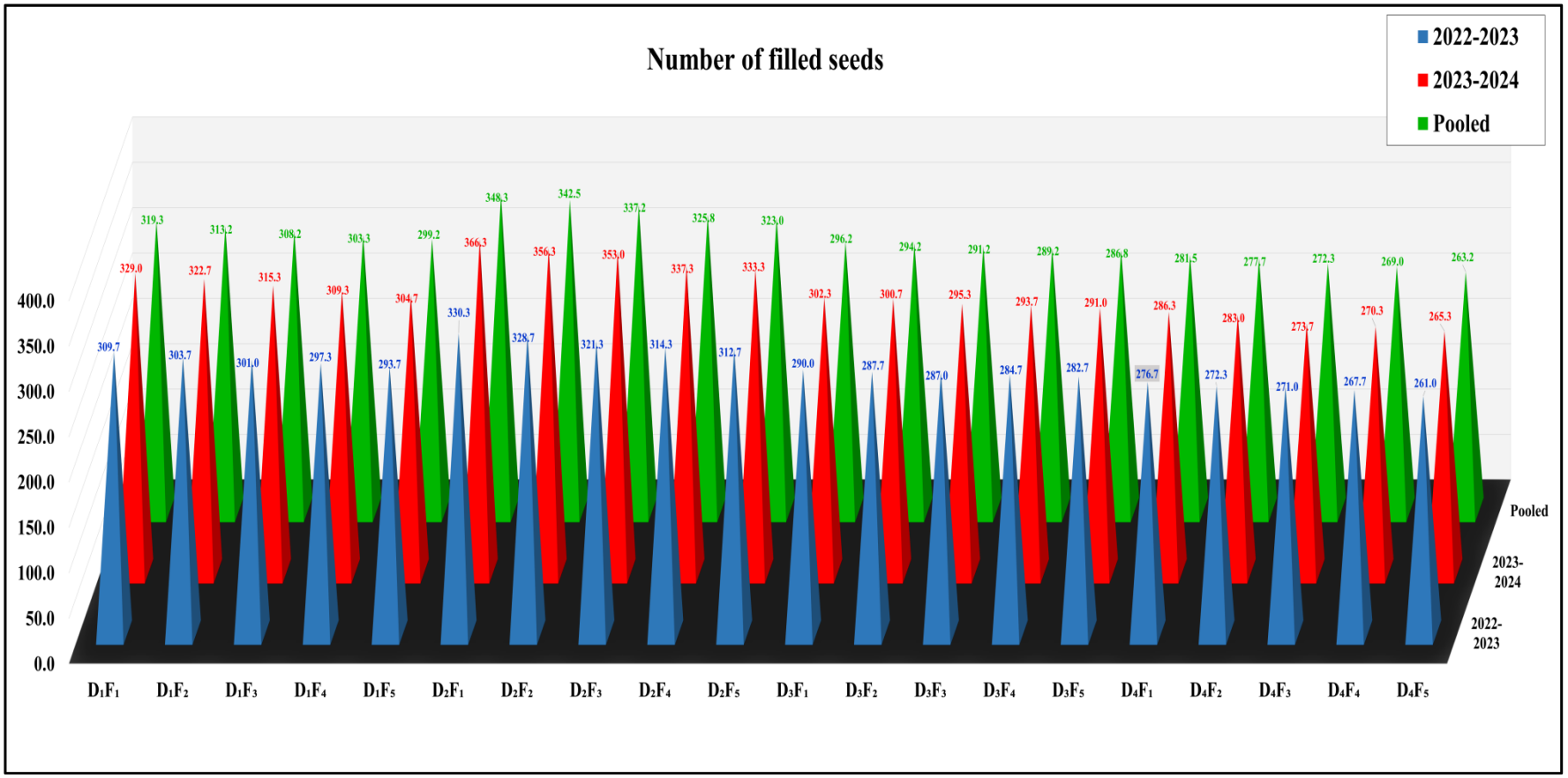


Figure 4.2.8: Effect of sowing dates and fruit load on number of filled seeds

were noted with sowing on 30th April (D_2), while the lowest (275.73) were recorded with sowing on 30th May (D_4). Among the fruit load treatments, retaining 3 fruits per plant (F_1) recorded the highest number of filled seeds (321.00), while retaining all fruits per plant (F_5) resulted in the lowest (298.58). The combination of 30th April sowing with 3 fruits per plant retained (D_2F_1) resulted in the maximum number of filled seeds (366.33), while the combination of 30th May sowing with all fruits per plant retained (D_4F_5) led to the lowest (265.33).

The pooled analysis for both years revealed significant effects of sowing dates and fruit load on the number of filled seeds, along with their interaction. The highest number of filled seeds (335.36) were recorded with sowing on 30th April (D_2), while the lowest (272.73) was observed with sowing on 30th May (D_4). Regarding fruit load treatments, retaining 3 fruits per plant (F_1) resulted in the highest number of filled seeds (311.33), whereas retaining all fruits per plant (F_5) resulted in the lowest (293.04). The interaction analysis showed that sowing on 30th April and retention of 3 fruits per plant (D_2F_1) recorded the highest number of filled seeds (348.33), while the lowest (263.16) was observed with 30th May sowing and all fruits per plant retained (D_4F_5).

Across both years, the second year 2023-2024 recorded a higher average number of filled seeds (309.44) compared to the first year 2022-2023 (294.66). The interaction between years and sowing dates (Y × D) showed that the highest number of filled seeds (349.26) were achieved in the second year 2023-2024 with sowing on 30th April (Y_2D_2), while the lowest (269.73) occurred in the first year 2022-2023, with sowing on 30th May (Y_1D_4). Similarly, the interaction between years and fruit load (Y × F) revealed that the maximum number of filled seeds (321.00) were recorded in the second year 2023-2024 with 3 fruits per plant retained (Y_2F_1), while the minimum number of filled seeds (287.50) were recorded in the first year with all fruits per plant retained (Y_1F_5). The three-way interaction between years, sowing dates and fruit load (Y × D × F) was non-significant.

The results from both years (2022-2023 and 2023-2024) and the pooled analysis clearly demonstrate significant differences in the number of filled seeds in response to sowing dates and fruit load treatments, with interaction being significant in the second year and non-significant in the first year.

In the first year 2022-2023, sowing on 30th April (D_2) consistently resulted in the highest number of filled seeds, while the 30th May sowing (D_4) resulted in the lowest number

of filled seeds. This indicates that early sowing conditions likely provided more favourable environmental factors, such as temperature and photoperiod, which may have contributed to better pollination and seed filling. The results are in conformity with that of Bellad (2012). Similarly, the fruit load treatment with 3 fruits per plant (F_1) resulted in a higher number of filled seeds compared to retaining all fruits per plant (F_5). This suggests that managing fruit load to reduce competition for assimilates allowed for better resource allocation to developing seeds, leading to an increase in the number of filled seeds. The results are in conformity with that Tomar et al. (2015).

The second year 2023-2024 showed significant interaction between sowing dates and fruit load, with the combination of 30th April sowing and 3 fruits per plant retained (D_2F_1) resulting in the highest number of filled seeds. This interaction highlights the importance of both early sowing and optimal fruit load management in improving seed quality. The higher number of filled seeds in the second year, compared to the first year, suggests that the environmental conditions during 2023-2024 were more favourable for seed development, possibly due to better climatic conditions or more effective pollinator activity.

The pooled analysis for both years further reinforces the influence of sowing dates and fruit load on the number of filled seeds. Sowing on 30th April and retaining 3 fruits per plant resulted in the highest number of filled seeds across both years, which supports the fact that these factors are crucial for achieving optimal seed quality. This also suggests that early sowing, along with reduced fruit load, can create conditions that facilitate better pollination and efficient resource allocation, leading to an increase in the number of filled seeds.

The significant interaction between years and sowing dates (Y × D) and between years and fruit load (Y × F) further emphasizes the importance of favourable sowing times and optimal fruit load management for achieving higher seed quality. The second year's higher average number of filled seeds reflects better overall environmental conditions, which may have promoted improved pollination and nutrient assimilation.

4.2.9 Number of unfilled seeds

The number of unfilled seeds is an important parameter for evaluating seed quality, as it reflects inefficiencies in the reproductive process. Unfilled seeds are typically a result of inadequate pollination, insufficient nutrient supply or poor seed filling during development. Factors such as environmental conditions, pollinator activity and resource allocation can

significantly influence the formation of unfilled seeds. The number of unfilled seeds tends to be higher when there is a reduced fruit load and early sowing, as the number of seeds per fruit increases in these conditions, leading to greater competition for available resources. In contrast, a higher fruit load generally results in fewer unfilled seeds, as the resource allocation is more distributed across the fruits.

The data from 2022-2023 and 2023-2024, along with the pooled analysis, showed significant variations in the number of unfilled seeds across treatments (Table 4.2.9 and Figure 4.2.9).

During the first year 2022-2023, significant effects of sowing dates and fruit load was observed in the number of unfilled seeds whereas, their interaction was non-significant. The highest number of unfilled seeds (91.26) were recorded with sowing on 30th April (D_2), while the lowest (76.26) were observed with sowing on 30th May (D_4). Among the fruit load treatments, retaining 3 fruits per plant (F_1) resulted in the highest number of unfilled seeds (85.75), whereas retaining all fruits per plant (F_5) led to the lowest number of unfilled seed (81.00). The interaction between sowing dates and fruit load was non-significant for number of unfilled seeds and the values ranged from 94.00 - 74.00.

In the second year 2023-2024, the number of unfilled seeds were significantly influenced by sowing dates, fruit load and their interaction were also significant. The highest number of unfilled seeds (94.73) were noted with sowing on 30th April (D_2), while the lowest (72.60) were recorded with sowing on 30th May (D_4). Among the fruit load treatments, retaining 3 fruits per plant (F_1) recorded the highest number of unfilled seeds (86.50), while retaining all fruits per plant (F_5) resulted in the lowest (79.08). The combination of 30th April sowing with 3 fruits per plant retained (D_2F_1) resulted in the maximum number of unfilled seeds (99.00) which was at par with 30th April sowing with 4 fruits per plant retained (D_2F_2) while the combination of 30th May sowing with all fruits per plant retained (D_4F_5) led to the lowest (65.66).

The pooled analysis for both years revealed significant effects of sowing dates and fruit load on the number of unfilled seeds, along with their interaction. The highest number of unfilled seeds (93.00) were recorded with sowing on 30th April (D_2), while the lowest (74.43) were observed with sowing on 30th May (D_4). Regarding fruit load treatments, retaining 3 fruits per plant (F_1) resulted in the highest number of unfilled seeds (86.12),

Table 4.2.9: Effect of sowing dates and fruit load on number of unfilled seeds

Number of unfilled seeds						
Y_1 (2022-2023)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	88.33	86.33	85.66	85.00	82.33	**85.53**
D_2	94.00	92.66	91.66	89.66	88.33	**91.26**
D_3	82.00	81.33	81.00	80.33	79.33	**80.80**
D_4	78.66	76.66	76.33	75.66	74.00	**76.26**
Mean	**85.75**	**84.25**	**83.66**	**82.66**	**81.00**	**83.46**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.49			1.74		
F	0.27			0.80		
D×F	1.10			NS		
Y_2 (2023-2024)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	88.00	86.00	85.33	84.33	83.66	**85.46**
D_2	99.00	98.00	95.00	92.66	89.00	**94.73**
D_3	82.33	81.33	80.66	79.66	78.00	**80.40**
D_4	76.66	75.66	73.66	71.33	65.66	**72.60**
Mean	**86.50**	**85.25**	**83.66**	**82.00**	**79.08**	**83.29**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.80			2.84		
F	0.54			1.57		
D×F	1.80			3.43		
Pooled						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	88.16	86.16	85.50	84.66	83.00	**85.50**
D_2	96.50	95.33	93.33	91.16	88.66	**93.00**
D_3	82.16	81.33	80.83	80.00	78.66	**80.60**
D_4	77.66	76.16	75.00	73.50	69.83	**74.43**
Mean	**86.12**	**84.75**	**83.66**	**82.33**	**80.04**	**83.23**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.79			2.39		
F	0.30			0.86		
D×F	1.73			1.73		
Y	0.55			NS		
Y×D	1.11			3.39		
Y×F	0.43			1.22		
Y×D×F	0.86			NS		

***D =** Sowing dates; D_1= 15th April; D_2 = 30th April; D_3 = 15th May; D_4 = 30th May
***F =** Fruit load; F_1 = 3 fruits; F_2 = 4 fruits; F_3 = 5 fruits; F_4 = 6 fruits; F_5 = all fruits retained (control)
***Y =** Year; Y_1 = 2022-2023; Y_2 = 2023-2024

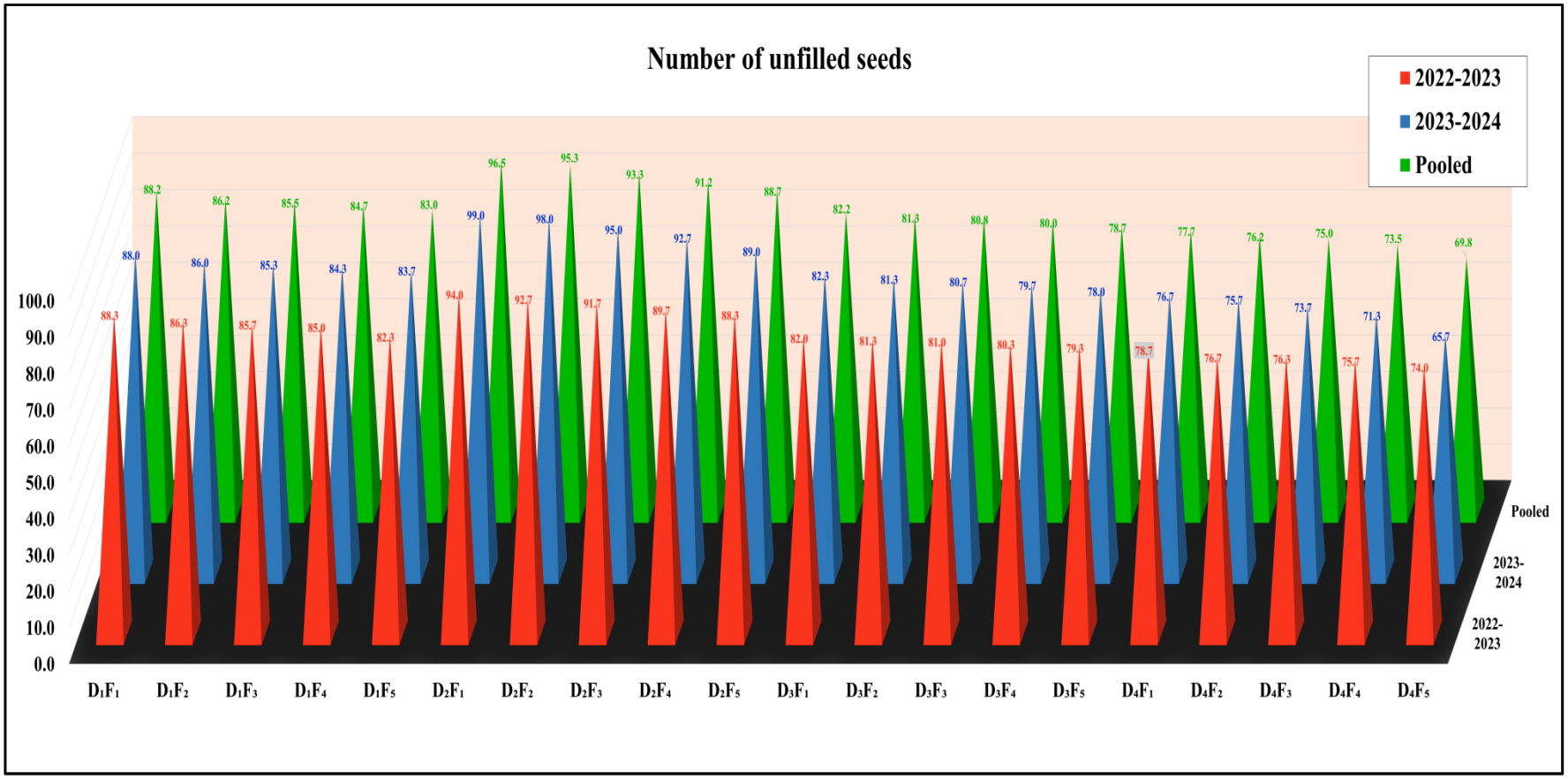


Figure 4.2.9: Effect of sowing dates and fruit load on number of unfilled seeds

whereas retaining all fruits per plant (F_5) resulted in the lowest (80.04). The interaction analysis showed that sowing on 30th April and retention of 3 fruits per plant (D_2F_1) recorded the highest number of unfilled seeds (96.50) which was at par with 30th April sowing with 4 fruits per plant retained (D_2F_2), while the lowest (69.83) was observed with 30th May sowing and all fruits per plant retained (D_4F_5).

Across both years, the first year 2022-2023 recorded a higher average number of unfilled seeds (83.46) compared to the second year 2023-2024 (83.29). The interaction between years and sowing dates (Y × D) showed that the highest number of unfilled seeds (94.73) were achieved in the second year 2023-2024 with sowing on 30th April (Y_2D_2), while the lowest (72.60) also occurred in the second year 2023-2024, with sowing on 30th May (Y_2D_4). Similarly, the interaction between years and fruit load (Y × F) revealed that the maximum number of unfilled seeds (86.50) were recorded in the second year 2023-2024 with 3 fruits per plant retained (Y_2F_1), while the minimum number of unfilled seeds (79.08) were also recorded in the second year 2023-2024 with all fruits per plant retained (Y_2F_5). The three-way interaction between years, sowing dates and fruit load (Y × D × F) was non-significant.

In this study, significant effects of sowing dates and fruit load on the number of unfilled seeds were observed, with their interaction found to be non-significant in the first year (2022-2023), but significant in the second year (2023-2024).

In the first year 2022-2023, the highest number of unfilled seeds were recorded with sowing on 30th April (D_2), while the lowest was observed with sowing on 30th May (D_4). Similarly, the number of unfilled seeds were higher when retaining 3 fruits per plant (F_1) compared to retaining all fruits per plant (F_5). The increased number of unfilled seeds in the early sowing treatment (D_2) can be attributed to the higher number of seeds per fruit, which led to increased competition for resources like nutrients and assimilates.

In the second year (2023-2024), the interaction between sowing dates and fruit load significantly influenced the number of unfilled seeds. The highest number of unfilled seeds were recorded with sowing on 30th April (D_2), which aligns with the earlier findings. However, sowing on 30th May (D_4) resulted in the lowest number of unfilled seeds. This suggests that late sowing, possibly due to cooler temperatures or extended vegetative growth, reduces the number of unfilled seeds by allowing for better resource allocation to developing

seeds. The interaction between sowing dates and fruit load played a role in the distribution of resources, with retaining 3 fruits per plant (F_1) leading to a higher number of unfilled seeds compared to retaining all fruits per plant (F_5). This outcome indicates that a higher number of fruits per plant reduces the competition for assimilates, thereby improving the seed filling process.

The findings suggest that the number of unfilled seeds is higher in cases of early sowing and moderate fruit load, as these conditions result in an increased number of seeds per fruit, intensifying the competition for resources. On the other hand, a higher fruit load and later sowing typically result in fewer unfilled seeds due to a more favourable distribution of nutrients and reduced competition among seeds. These insights highlight the importance of managing sowing dates and fruit load to optimize seed filling and reduce the occurrence of unfilled seeds, which is critical for improving overall seed quality.

4.2.10 Seed fresh weight (g)

Seed fresh weight is an important parameter that reflects the overall health and vitality of seeds. It provides valuable information about the seed's developmental processes, nutrient content and potential for germination. Fresh weight is typically influenced by various factors during seed development, such as the genetic makeup of the plant, environmental conditions and resource allocation. A higher seed fresh weight often indicates optimal conditions for seed growth, sufficient nutrient supply and efficient seed filling, which are essential for high germination rates and strong seedling establishment.

The data from 2022-2023 and 2023-2024, along with the pooled analysis, showed significant variations in the seed fresh weight (g) across treatments (Table 4.2.10 and Figure 4.2.10).

During the first year 2022-2023, significant effects of sowing dates and fruit load were observed on seed fresh weight (g), whereas their interaction was non-significant. The maximum seed fresh weight (2.507 g) was recorded with sowing on 30th April (D_2), while the minimum (2.191 g) was observed with sowing on 30th May (D_4).

Among the fruit load treatments, retaining 3 fruits per plant (F_1) resulted in the maximum seed fresh weight (2.368 g), whereas retaining all fruits per plant (F_5) led to the minimum seed fresh weight (2.332 g). The interaction between sowing dates and fruit load was non-significant for seed fresh weight (g) and the values ranged from 2.528 g – 2.171 g.

Table 4.2.10: Effect of sowing dates and fruit load on seed fresh weight

Seed fresh weight (g)						
Y_1 (2022-2023)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	2.425	2.414	2.407	2.395	2.388	**2.406**
D_2	2.528	2.521	2.507	2.493	2.486	**2.507**
D_3	2.311	2.304	2.297	2.290	2.283	**2.297**
D_4	2.206	2.199	2.192	2.185	2.171	**2.191**
Mean	**2.368**	**2.359**	**2.351**	**2.341**	**2.332**	**2.350**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.004			0.013		
F	0.001			0.004		
D×F	0.008			NS		
Y_2 (2023-2024)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	2.475	2.462	2.448	2.435	2.421	**2.448**
D_2	2.678	2.664	2.651	2.637	2.624	**2.651**
D_3	2.273	2.259	2.246	2.232	2.219	**2.246**
D_4	2.074	2.064	2.054	2.044	2.034	**2.054**
Mean	**2.375**	**2.362**	**2.350**	**2.337**	**2.324**	**2.349**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.005			0.019		
F	0.001			0.004		
D×F	0.012			NS		
Pooled						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	2.450	2.438	2.428	2.415	2.405	**2.427**
D_2	2.603	2.593	2.579	2.565	2.555	**2.579**
D_3	2.292	2.282	2.271	2.261	2.251	**2.271**
D_4	2.140	2.131	2.123	2.114	2.102	**2.122**
Mean	**2.371**	**2.361**	**2.350**	**2.339**	**2.328**	**2.349**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.008			0.022		
F	0.001			0.003		
D×F	0.002			NS		
Y	0.005			NS		
Y×D	0.010			0.031		
Y×F	0.001			0.004		
Y×D×F	0.003			NS		

***D =** Sowing dates; D_1= 15th April; D_2 = 30th April; D_3 = 15th May; D_4 = 30th May
***F =** Fruit load; F_1 = 3 fruits; F_2 = 4 fruits; F_3 = 5 fruits; F_4 = 6 fruits; F_5 = all fruits retained (control)
***Y =** Year; Y_1 = 2022-2023; Y_2 = 2023-2024

In the second year 2022-2023, significant effects of sowing dates and fruit load were observed on seed fresh weight (g), whereas their interaction was non-significant. The maximum seed fresh weight (2.651 g) was recorded with sowing on 30th April (D_2), while the minimum (2.054 g) was observed with sowing on 30th May (D_4). Among the fruit load treatments, retaining 3 fruits per plant (F_1) resulted in the maximum seed fresh weight (2.375 g), whereas retaining all fruits per plant (F_5) led to the minimum seed fresh weight (2.324 g). The interaction between sowing dates and fruit load was non-significant for seed fresh weight (g) in the second year and the values ranged from 2.678 g – 2.034 g.

The pooled analysis for both years revealed significant effects of sowing dates and fruit load on seed fresh weight (g), while their interaction. The maximum seed fresh weight (2.579 g) was recorded with sowing on 30th April (D_2), while the minimum (2.122 g) was observed with sowing on 30th May (D_4). Regarding fruit load treatments, retaining 3 fruits per plant (F_1) resulted in the maximum seed fresh weight (2.371 g), whereas retaining all fruits per plant (F_5) resulted in the minimum (2.328 g). The interaction between sowing dates and fruit load was non-significant for seed fresh weight (g) and the values ranged from 2.603 g – 2.102 g in the pooled analysis.

Across both years, the first year 2022-2023 recorded a higher average seed fresh weight (2.350 g) compared to the second year 2023-2024 (2.349 g). The interaction between years and sowing dates (Y × D) showed that the maximum seed fresh weight (2.651 g) was achieved in the second year 2023-2024 with sowing on 30th April (Y_2D_2), while the minimum (2.054 g) also occurred in the second year 2023-2024, with sowing on 30th May (Y_2D_4). Similarly, the interaction between years and fruit load (Y × F) revealed that the maximum seed fresh weight (2.375 g) was recorded in the second year 2023-2024 with 3 fruits per plant retained (Y_2F_1), while the minimum seed fresh weight (2.324 g) was also recorded in the second year 2023-2024 with all fruits per plant retained (Y_2F_5). The three-way interaction between years, sowing dates and fruit load (Y × D × F) was non-significant.

In this study, significant effects of sowing dates and fruit load on seed fresh weight (g) was observed, with their interaction found to be non-significant in both the years.

The maximum seed fresh weight observed with the 30th April sowing (D_2) can be attributed to favourable environmental conditions, such as optimal temperature, light availability and a longer growth period. These factors support better seed filling and nutrient

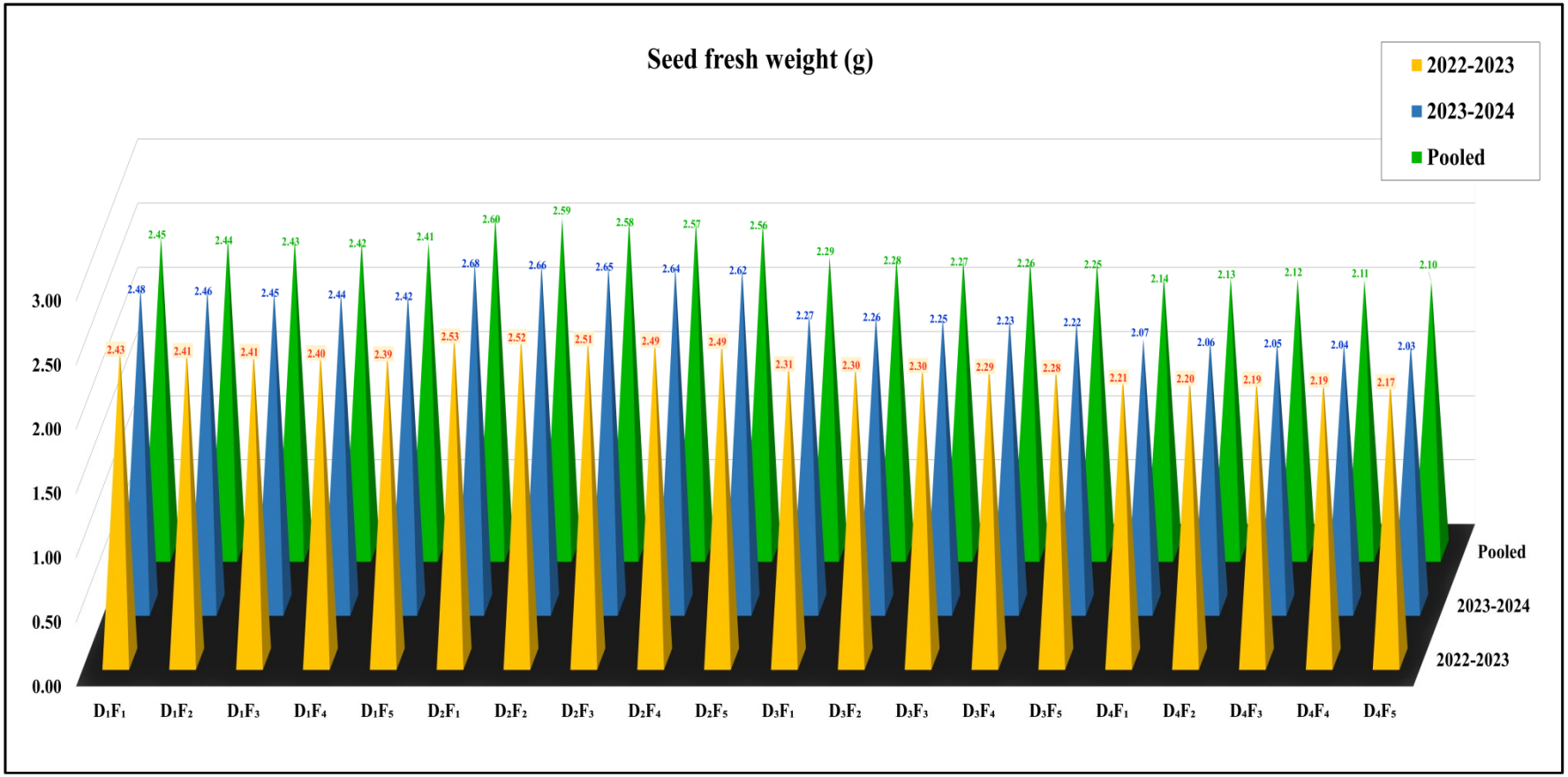


Figure 4.2.10: Effect of sowing dates and fruit load on seed fresh weight

accumulation during the developmental phase. In contrast, the minimum seed fresh weight recorded with the 30th May sowing (D_4) is likely due to unfavourable conditions, such as higher temperatures and a shorter growth period, which can impair physiological processes like photosynthesis and nutrient translocation. These conditions limit the resources available for developing seeds, reducing their fresh weight.

Fruit load also significantly influenced seed fresh weight, with the maximum fresh weight recorded when only 3 fruits per plant (F_1) were retained. This can be explained by reduced competition for nutrients and assimilates among a smaller number of fruits, allowing better resource allocation to each fruit. On the other hand, retaining all fruits per plant (F_5) resulted in the minimum seed fresh weight, likely due to increased resource competition, which restricts nutrient availability for individual fruits.

The pooled analysis of both years confirmed the significant effects of sowing dates and fruit load, reinforcing the role of these factors in determining seed fresh weight. The consistent trend across years highlights the robustness of the results. The significant interaction between years and sowing dates (Y × D) indicated that environmental conditions across years influenced the effects of sowing dates, with the second year showing higher fresh weight for early sowing dates. Similarly, the significant interaction between years and fruit load (Y × F) demonstrated that fruit retention strategies consistently impacted seed fresh weight across different environmental conditions.

The lack of significant three-way interaction (Y × D × F) suggests that the effects of sowing dates and fruit load on seed fresh weight are additive rather than synergistic. The results indicates that these factors can be managed independently to optimize seed production.

4.2.11 Seed dry weight (g)

Seed dry weight is a critical parameter that reflects the final accumulation of reserves in seeds, which is directly associated with seed maturity, quality and storage potential. Unlike fresh weight, which includes moisture content, dry weight provides a more accurate measure of the actual biomass of seeds, including carbohydrates, proteins, lipids and other essential reserves. These components are crucial for seed vigour, germination and subsequent seedling establishment. The seed dry weight is influenced by several factors during their developmental phase, including the genetic potential of the plant, environmental conditions, nutrient availability and the management of crop practices such as sowing time and fruit load.

The data from 2022-2023 and 2023-2024, along with the pooled analysis, showed significant variations in the seed dry weight (g) across treatments (Table 4.2.11 and Figure 4.2.11). During the first year 2022-2023, significant effects of sowing dates, fruit load and their interaction were observed on the seed dry weight (g). The maximum seed dry weight (1.504 g) was recorded with sowing on 30th April (D_2), while the minimum (1.314 g) was observed with sowing on 30th May (D_4). Among the fruit load treatments, retaining 3 fruits per plant (F_1) resulted in the maximum seed dry weight (1.420 g), whereas retaining all fruits per plant (F_5) led to the minimum seed dry weight (1.399 g). The 30th April sowing with 3 fruits per plant retained (D_2F_1) resulted in the maximum seed dry weight (1.517 g) which was at par with 30th April sowing with 4 fruits per plant retained (D_2F_2), while the combination of 30th May sowing with all fruits per plant retained (D_4F_5) led to the lowest (1.303 g).

In the second year 2023-2024, significant effects of sowing dates, fruit load and their interaction were observed on the seed dry weight (g). The maximum seed dry weight (1.723 g) was recorded with sowing on 30th April (D_2), while the minimum (1.335 g) was observed with sowing on 30th May (D_4). Among the fruit load treatments, retaining 3 fruits per plant (F_1) resulted in the maximum seed dry weight (1.544 g), whereas retaining all fruits per plant (F_5) led to the minimum seed dry weight (1.511 g). The interaction between sowing dates and fruit load was non-significant for seed dry weight (g) and the values ranged from 1.741 g – 1.322 g.

The pooled analysis for both years revealed significant effects of sowing dates and fruit load on seed dry weight (g), while their interaction was non-significant. The maximum seed dry weight (1.614 g) was recorded with sowing on 30th April (D_2), while the minimum (1.325 g) was observed with sowing on 30th May (D_4). Regarding fruit load treatments, retaining 3 fruits per plant (F_1) resulted in the maximum seed dry weight (1.482 g), whereas retaining all fruits per plant (F_5) resulted in the minimum (1.455 g). The interaction between sowing dates and fruit load was non-significant for seed dry weight (g) for the pooled analysis and the values ranged from 1.629 g – 1.312 g.

Across both years, the second year 2023-2024 recorded a higher average seed dry weight (1.527 g) compared to the first year 2022-2023 (1.409 g). The interaction between years and sowing dates (Y × D) showed that the maximum seed dry weight (1.723 g) was achieved in the second year 2023-2024 with sowing on 30th April (Y_2D_2), while the minimum

Table 4.2.11: Effect of sowing dates and fruit load on seed dry weight

Seed dry weight (g)						
Y_1 (2022-2023)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	1.450	1.445	1.452	1.437	1.433	**1.443**
D_2	1.517	1.512	1.504	1.496	1.492	**1.504**
D_3	1.387	1.382	1.378	1.374	1.370	**1.378**
D_4	1.324	1.319	1.315	1.311	1.303	**1.314**
Mean	**1.420**	**1.415**	**1.412**	**1.404**	**1.399**	**1.409**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.002			0.008		
F	0.001			0.003		
D×F	0.005			0.007		
Y_2 (2023-2024)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	1.609	1.600	1.591	1.583	1.574	**1.591**
D_2	1.741	1.732	1.723	1.714	1.705	**1.723**
D_3	1.477	1.469	1.460	1.451	1.442	**1.460**
D_4	1.348	1.342	1.335	1.329	1.322	**1.335**
Mean	**1.544**	**1.536**	**1.527**	**1.519**	**1.511**	**1.527**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.003			0.012		
F	0.001			0.003		
D×F	0.007			NS		
Pooled						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	1.530	1.523	1.522	1.510	1.504	**1.517**
D_2	1.629	1.622	1.614	1.605	1.599	**1.614**
D_3	1.432	1.425	1.419	1.413	1.406	**1.419**
D_4	1.336	1.330	1.325	1.320	1.312	**1.325**
Mean	**1.482**	**1.475**	**1.470**	**1.462**	**1.455**	**1.468**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.005			0.015		
F	0.001			0.002		
D×F	0.001			NS		
Y	0.004			0.011		
Y×D	0.007			0.021		
Y×F	0.001			0.003		
Y×D×F	0.002			0.006		

***D =** Sowing dates; D_1= 15th April; D_2 = 30th April; D_3 = 15th May; D_4 = 30th May
***F =** Fruit load; F_1 = 3 fruits; F_2 = 4 fruits; F_3 = 5 fruits; F_4 = 6 fruits; F_5 = all fruits retained (control)
***Y =** Year; Y_1 = 2022-2023; Y_2 = 2023-2024

(1.314 g) occurred in the first year 2022-2023, with sowing on 30th May (Y_1D_4). Similarly, the interaction between years and fruit load (Y × F) revealed that the maximum seed dry weight (1.544 g) was recorded in the second year 2023-2024 with 3 fruits per plant retained (Y_2F_1), while the minimum seed dry weight (1.399 g) was recorded in the first year 2022-2023 with all fruits per plant retained (Y_2F_5).

The three-way interaction between years, sowing dates and fruit load (Y × D × F) also showed significant effects, with the maximum seed dry weight (1.741 g) recorded in the second year 2023-2024 with sowing on 30th April and 3 fruits per plant retained ($Y_2D_2F_1$), while the minimum seed dry weight (1.303 g) was recorded in the first year 2022-2023 with sowing on 30th May and all fruits per plant retained ($Y_1D_4F_5$).

The results demonstrate that sowing dates and fruit load significantly affect seed dry weight, highlighting their role in optimizing seed production strategies. The maximum seed dry weight recorded with sowing on 30th April (D_2) across both years emphasizes the importance of early sowing for achieving optimal seed development. The higher seed dry weight observed in early sowing could be attributed to favourable climatic conditions such as moderate temperatures and extended growth periods, which promote efficient resource allocation to seed development. Conversely, the minimum seed dry weight with late sowing on 30th May (D_4) can be attributed to suboptimal growing conditions, including higher temperatures and shorter growing seasons, which may hinder the accumulation of seed reserves.

Fruit load also played a crucial role in determining seed dry weight. Retaining 3 fruits per plant (F_1) consistently resulted in higher seed dry weight compared to retaining all fruits per plant (F_5). This can be explained by the limited resource competition in plants with fewer fruits, allowing better nutrient partitioning and resource allocation to the seeds. In contrast, retaining all fruits increased competition among developing fruits, thereby reducing the resources available for individual seeds and resulting in lower dry weights.

The significant interaction between sowing dates and fruit load during the first year and pooled analysis indicate the combined impact of these factors on seed development. The combination of early sowing with 30th April and retaining 3 fruits per plant (D_2F_1) consistently resulted in the highest seed dry weights, emphasizing the synergistic effect of optimal sowing time and regulated fruit load on seed quality. Similarly, the three-way

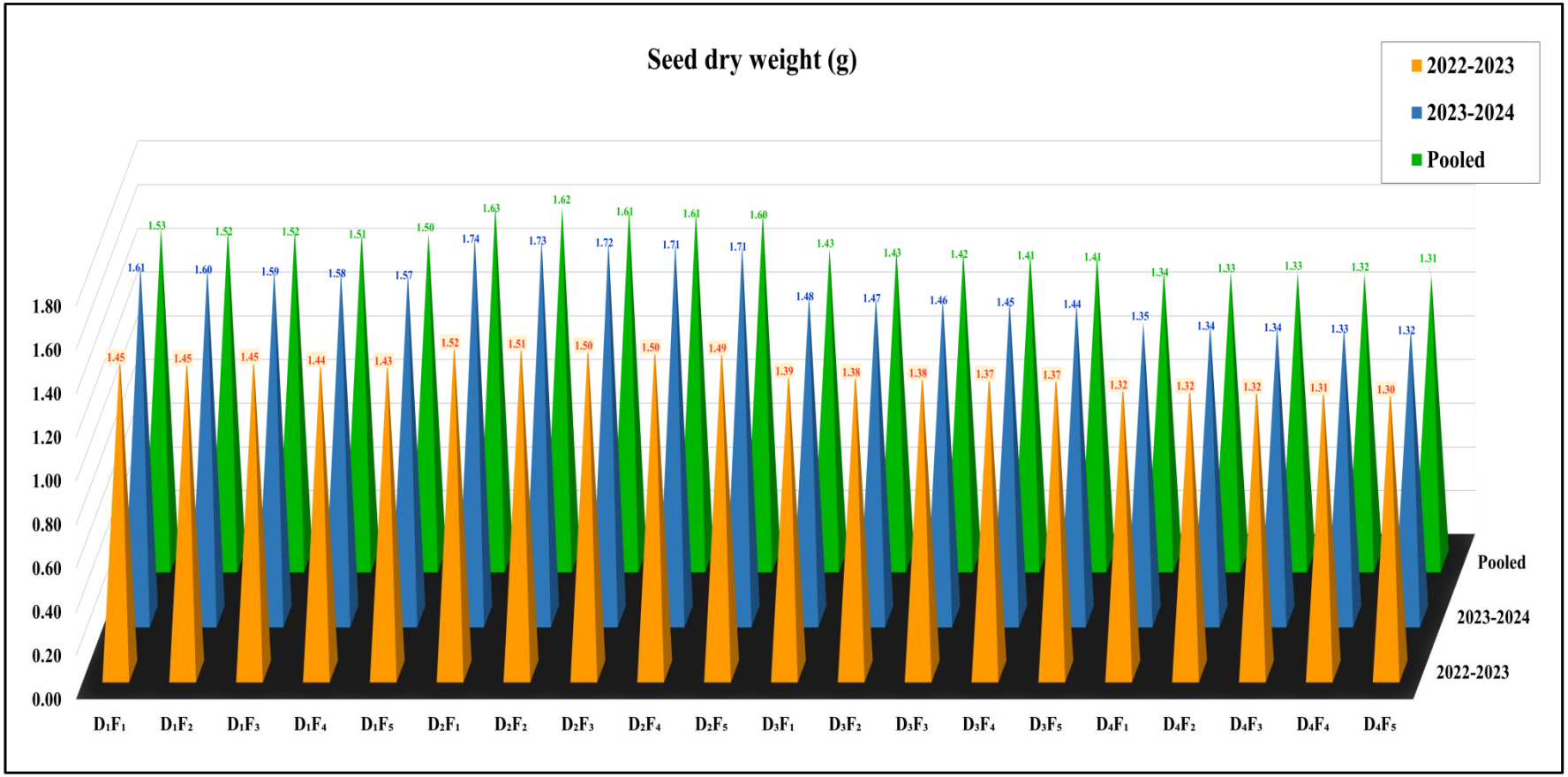


Figure 4.2.11: Effect of sowing dates and fruit load on seed dry weight

interaction (Y × D × F) showed the maximum seed dry weight in the second year with early sowing and 3 fruits per plant retained, indicating that the second year provided a more favourable environment for seed development under optimal management practices.

The higher average seed dry weight recorded in the second year compared to the first year reflects the variability in climatic conditions across years. This highlights the importance of year-specific adjustments in sowing dates and fruit load management to achieve consistent seed quality. The observed trends suggest that early sowing and regulated fruit load are effective strategies for maximizing seed dry weight, irrespective of the year.

The minimum seed dry weight recorded in late sowing with all fruits retained (D_4F_5) across all interaction demonstrates the detrimental effects of delayed sowing and high fruit load on seed quality. The results underscore the need for timely sowing and regulated fruit load management to avoid resource competition and environmental stress that adversely affect seed development.

Chord Diagram for seed yield traits

The chord diagram depicted in Figure 4.2.12 visually represents the interrelationships between various seed yield parameters, including the total number of seeds per fruit seed, seed yield per fruit, seed yield per plant, seed yield per plot, seed yield per hectare, 1000 seed weight, number of filled seeds, number of unfilled seeds, seed fresh weight and seed dry weight, across different treatments. The outer segments of the diagram correspond to the treatments and the measured parameters, while the connecting chords illustrate the interactions and contributions between them. This diagram highlights the variability in response of each parameter to the treatments and underscores their interdependence.

The number of seeds per fruit is positively correlated with seed yield per plant and seed yield per hectare, indicating that optimizing the number of seeds per fruit can significantly enhance overall seed productivity. Seed dry weight and seed yield per plant are strongly associated with the number of filled seeds and 1000 seed weight, suggesting that these factors play a crucial role in determining seed yield. Higher seed dry weight reflects more mature, well-developed seeds, contributing to higher seed yields. Seed fresh weight also directly affects seed yield per fruit, underlining the importance of seed moisture content during development. Treatments that result in higher seed fresh weight tend to produce more

seeds per fruit, which in turn impacts total seed yield, highlighting the need to manage moisture levels during seed development.

The 1000 seed weight is another key factor influencing overall seed yield, with larger seeds linked to higher seed yield per hectare, emphasizing the importance of seed size in maximizing production at the field level. The results also show that seed yield per plant, seed yield per plot and seed yield per hectare are closely related, with a positive impact from higher total number of seeds per fruit and higher seed fresh and dry weight, suggesting that optimizing both the number of seeds per fruit and their weight is crucial for boosting productivity.

Treatments in the D_2 and D_3 (30^{th} April and 15^{th} May) groups consistently perform better in terms of seed yield per hectare and 1000 seed weight, showcasing their potential for improving seed yield and productivity. Furthermore, there are trade-offs observed, such as higher number of unfilled seeds, which are associated with reduced seed yield, indicating the need for balanced management practices to ensure the development of filled seeds while minimizing unfilled ones.

The findings suggest that treatments in the D_2 and D_3 groups are particularly promising for enhancing seed yield, offering valuable insights for future interventions and management practices aimed at improving the economics of seed production.

4.3 Seed quality traits

4.3.1 Seed germination (%)

Germination is the process by which a seed emerges and develops into a seedling, reaching a stage where the essential structures of the seedling indicate whether it can continue to develop into a healthy plant under favourable soil conditions, as defined by the International Seed Testing Association (ISTA). It is a critical physiological indicator of seed quality, providing insight into the seed's ability to produce a normal and healthy seedling under field conditions. Seed germination percentage is a vital measure of seed quality, reflecting the potential for seeds to develop into vigourous seedlings (Bewley et al. 2013). The germination process is influenced by both intrinsic factors, such as seed viability, dormancy and genetic traits and extrinsic factors, including temperature, moisture, oxygen levels and light availability. For crops like cucumber, reliable germination ensures even plant stands, early vigour and effective resource utilization during the early growth stages (Finch-Savage and Bassel 2016).

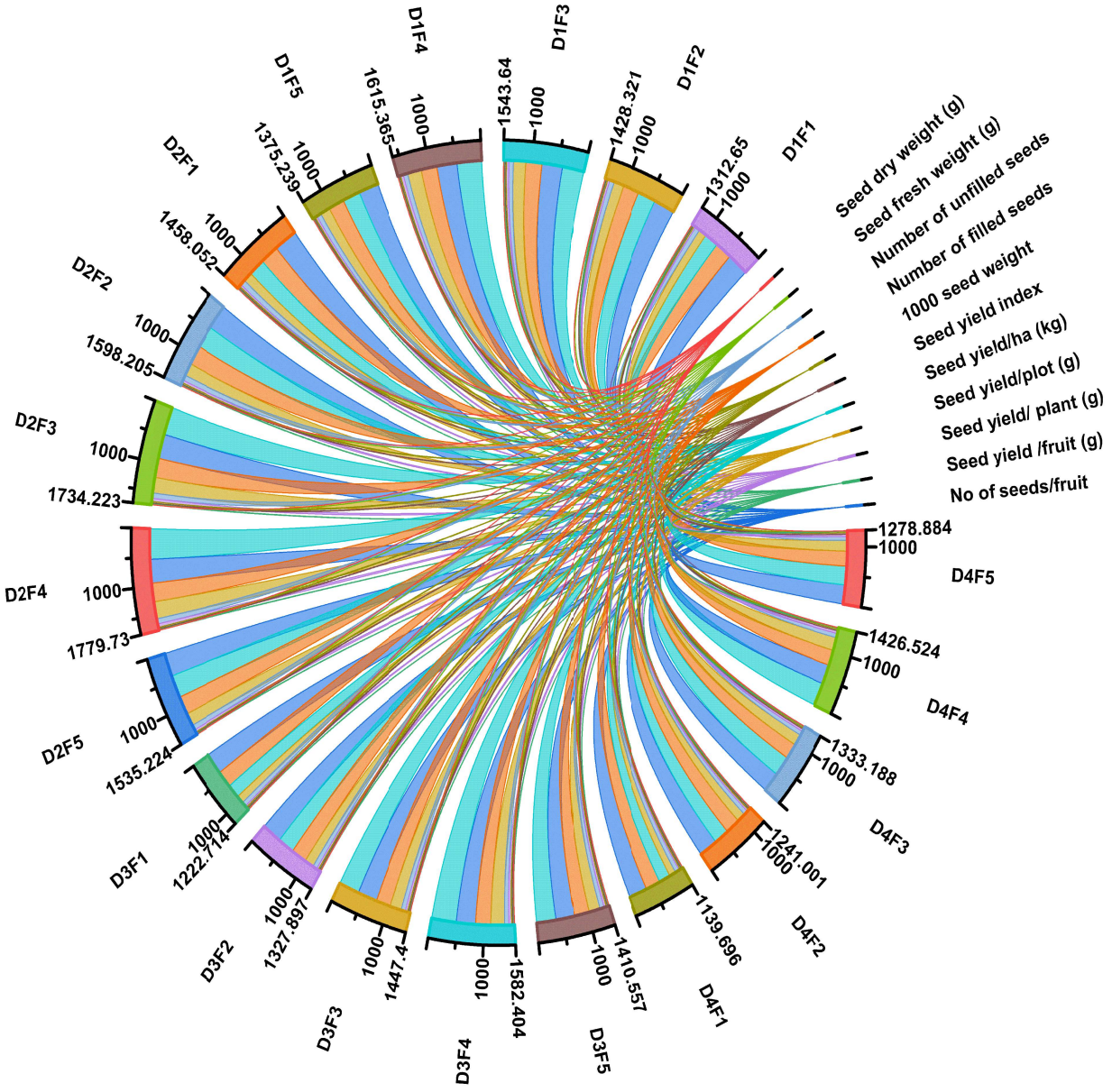


Figure 4.2.12: Analytical visualization of seed yield traits weightage using chord diagram

The data collected from the two consecutive years 2022-2023 and 2023-2024, along with pooled analysis, indicates significant differences in seed germination (%) across the treatments (Table 4.3.1 and Figure 4.3.1).

In the first year 2022-2023, the effects of sowing dates and fruit load remained significant, but their interaction showed non-significant effect on seed germination (%). The maximum seed germination (87.20 %) was recorded when sowing was done on 30th April (D_2), while the minimum seed germination (71.40 %) was observed when sowing was done on 30th May (D_4). Regarding fruit load treatments, the maximum seed germination (82.50 %) was recorded when 3 fruits per plant (F_1) were retained, whereas the minimum seed germination (77.66 %) was observed when all fruits per plant (F_5) were retained. The interaction between sowing dates and fruit load had no significant effect on seed germination (%) and the values ranged from 89.66 % - 69.00 %.

Similarly, in the second year 2023-2024, the effects of sowing dates and fruit load remained significant, but their interaction showed non-significant effect on seed germination (%). The maximum seed germination (88.26 %) was recorded when sowing was done on 30th April (D_2), while the minimum seed germination (72.86 %) was observed with sowing on 30th May (D_4). Among fruit load treatments, the maximum seed germination (82.33 %) was recorded when 3 fruits per plant (F_1) were retained, which was at par with 4 fruits per plant retained (F_2), whereas the minimum seed germination (77.75 %) was recorded when all fruits per plant (F_5) were retained. The interaction between sowing dates and fruit load also had no significant effect on seed germination (%) in the second year 2023-2024 and the values ranged from 91.33 % - 70.33 %.

The pooled data for both years showed significant effects of sowing dates and fruit load on seed germination (%), with their interaction remaining non-significant. The maximum seed germination (87.73 %) was recorded when sowing was done on 30th April (D_2), while the minimum seed germination (72.13 %) was observed with sowing on 30th May (D_4). Regarding fruit load treatments, the highest seed germination (82.41 %) was recorded when 3 fruits per plant (F_1) were retained, while the minimum (77.70 %) was recorded when all fruits per plant were retained (F_5). Similarly, the interaction between sowing dates and fruit load had no significant effect on seed germination (%) in the pooled analysis and the values ranged from 90.50 % - 69.66 %.

Table 4.3.1: Effect of sowing dates and fruit load on seed germination

Seed germination (%)						
Y_1 (2022-2023)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	85.33 (9.24)	85.00 (9.22)	84.00 (9.17)	82.33 (9.07)	81.00 (9.00)	**83.53 (9.14)**
D_2	89.66 (9.47)	87.67 (9.36)	86.66 (9.31)	86.33 (9.29)	85.66 (9.26)	**87.20 (9.34)**
D_3	80.66 (8.98)	78.00 (8.83)	77.33 (8.79)	76.67 (8.76)	75.00 (8.66)	**77.53 (8.81)**
D_4	74.33 (8.62)	73.00 (8.54)	71.00 (8.43)	69.66 (8.35)	69.00 (8.31)	**71.40 (8.45)**
Mean	**82.50 (9.08)**	**80.91 (8.99)**	**79.75 (8.93)**	**78.75 (8.81)**	**77.66 (8.81)**	**79.91 (8.94)**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	1.04			3.67		
F	0.36			1.05		
D×F	2.32			NS		
Y_2 (2023-2024)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	85.33 (9.24)	84.33 (9.18)	83.00 (9.11)	81.33 (9.02)	78.66 (8.87)	**82.53 (9.08)**
D_2	91.33 (9.56)	89.66 (9.47)	87.66 (9.36)	86.66 (9.31)	86.00 (9.27)	**88.26 (9.39)**
D_3	78.33 (8.85)	77.66 (8.81)	76.66 (8.76)	76.33 (8.74)	76.00 (8.72)	**77.00 (8.77)**
D_4	74.33 (8.62)	74.00 (8.60)	73.33 (8.56)	72.33 (8.50)	70.33 (8.39)	**72.86 (8.54)**
Mean	**82.33 (9.07)**	**81.41 (9.02)**	**80.16 (8.95)**	**79.16 (8.90)**	**77.75 (8.82)**	**80.16 (8.95)**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.78			2.77		
F	0.38			1.10		
D×F	1.76			NS		
Pooled						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	85.33 (9.24)	84.66 (9.20)	83.50 (9.14)	81.83 (9.05)	79.83 (8.93)	**83.03 (9.11)**
D_2	90.50 (9.51)	88.66 (9.42)	87.16 (9.34)	86.50 (9.30)	85.83 (9.26)	**87.73 (9.37)**
D_3	79.50 (8.92)	77.83 (8.82)	77.00 (8.77)	76.50 (8.75)	75.50 (8.69)	**77.26 (8.79)**
D_4	74.33 (8.62)	73.50 (8.57)	72.16 (8.49)	71.00 (8.43)	69.66 (8.35)	**72.13 (8.49)**
Mean	**82.41 (9.08)**	**81.16 (9.01)**	**79.95 (8.94)**	**78.95 (8.89)**	**77.70 (8.81)**	**80.03 (8.95)**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.61			1.86		
F	0.26			0.74		
D×F	0.52			NS		
Y	0.43			NS		
Y×D	0.86			NS		
Y×F	0.37			NS		
Y×D×F	0.74			NS		

***D =** Sowing dates; D_1= 15th April; D_2 = 30th April; D_3 = 15th May; D_4 = 30th May
***F =** Fruit load; F_1 = 3 fruits; F_2 = 4 fruits; F_3 = 5 fruits; F_4 = 6 fruits; F_5 = all fruits retained (control)
***Y =** Year; Y_1 = 2022-2023; Y_2 = 2023-2024
*Figures in parentheses are square root transformed values

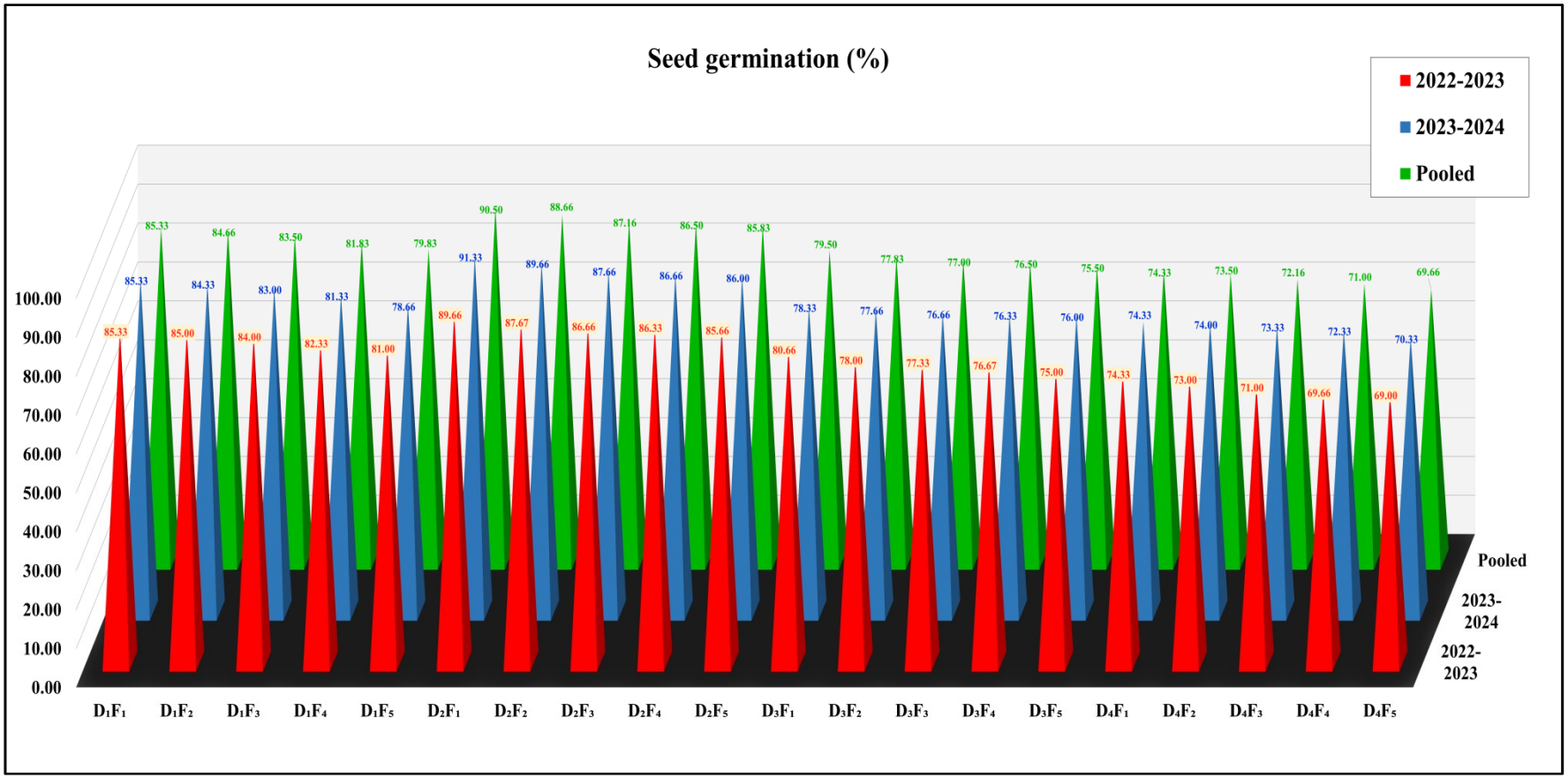


Figure 4.3.1: Effect of sowing dates and fruit load on seed germination

Between the two years, the maximum seed germination (80.16 %) was recorded in the second year 2023-2024, compared to lower seed germination (79.91 %) in the first year 2022-2023. The interaction between years and sowing dates (Y × D), as well as between years and fruit load (Y × F), was found to be non-significant. Additionally, the three-way interaction involving years, sowing dates and fruit load (Y × D × F) also showed non-significant effects.

The findings from the years 2022-2023 and 2023-2024 underscore the significant impact of sowing dates and fruit load management on seed germination (%) with their interaction remaining non-significant both in individual years and in the pooled analysis. The early sowing done on 30th April (D_2) consistently resulted in superior seed quality, with higher germination percentages compared to the later sowing date of 30th May (D_4). This can be attributed to better growth and reproductive performance of the plants sown earlier, which resulted in the accumulation of more dry matter in the seeds. The enhanced growth conditions allowed for the development of larger, more vigourous seeds, contributing to higher germination rates. In contrast, the later sowing dates led to less crop growth and reproductive performance, which resulted in lower seed quality and reduced germination. Similar trends for higher seed germination have been reported by Ali et al. (2021), Tandoh et al. (2019); Paul et al. (2016); Sharma and Kamboj (2015) and Tomar et al. (2010), reinforcing the pivotal role of sowing dates in influencing the seed germination (%).

The fruit load treatments also influenced seed quality. Retaining of 3 fruits per plant (F_1) allowed for the plant to act as a more efficient sink for photosynthates, which led to the accumulation of all available nutrients and energy without competition. This resulted in higher seed quality and better germination. As the number of fruits per vine increased, competition for food reserves also increased, which may have limited the resources available for seed development. Consequently, higher fruit load resulted in lower seed germination, as seen in the treatment where all fruits per plant (F_5) were retained. The research reported by Patil et al. (2024); Gupta et al. (2022); Gupta et al. (2021a); Chandi et al. (2020) and Bellad and Hiremath (2018); Tomar et al. (2015) and Cebeci and Padem (2014) are in conformity with the results of the present study.

In the pooled analysis of both years (2022-2023 and 2023-2024), the results confirmed the significant effects of sowing dates and fruit load on seed germination. The interaction between sowing dates and fruit load, both in the pooled analysis and individual years, was found to be non-significant. This suggests that the effects of sowing dates and fruit

load on seed germination were independent of each other, with each factor influencing seed quality without interacting with the other.

Additionally, the comparison between the two years showed a slight difference in seed germination, with the second year 2023-2024 having a marginally higher germination as compared to the first year 2023-2024. Despite this small difference, the interaction between years, sowing dates and fruit load (Y × D × F) was non-significant, indicating that the variations between the years were not influenced by the experimental treatments.

The pooled analysis and year-wise data both support the result that early sowing and a moderate fruit load are the most favourable conditions for optimizing seed germination. The non-significant interaction suggest that sowing dates and fruit load independently affect seed germination, with early sowing and controlled fruit load resulting in better seed quality and higher germination percentages.

4.3.2 Speed of germination

The concept of speed of germination is critical in evaluating the vigour and potential field performance of seeds, as it reflects the rate at which seeds germinate over time. Introduced by Maguire (1962), speed of germination provides a quantitative measure to compare seed lots under controlled conditions. This index is calculated by summing the daily germination percentages divided by their respective days of germination, providing insight into both the rapidity and uniformity of germination. Speed of germination has a practical application in seed selection and vigour testing, which suggests that faster germination is associated with superior seedling emergence and vigour, which are essential for achieving optimal stand establishment in field conditions.This parameter is particularly useful for comparing seeds subjected to different treatments or environmental conditions, making it a cornerstone of seed quality research. The data collected over two consecutive years, 2022-2023 and 2023-2024, along with pooled analysis, reveals significant variations in the speed of germination across the treatments (Table 4.3.2 and Figure 4.3.2).

Among the fruit load treatments, retaining 3 fruits per plant (F_1) resulted in the highest speed of germination (15.16), whereas retaining all fruits per plant (F_5) produced the lowest (14.58). Notably, the interaction between sowing dates and fruit load did not significantly influence the speed of germination and the values ranged from 16.21 -13.52.

Table 4.3.2: Effect of sowing dates and fruit load on speed of germination

Speed of germination						
Y_1 (2022-2023)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	15.45	15.37	15.29	15.13	15.00	**15.25**
D_2	16.21	16.11	15.91	15.79	15.57	**15.92**
D_3	14.83	14.72	14.60	14.40	14.24	**14.56**
D_4	14.17	14.03	13.85	13.66	13.52	**13.85**
Mean	**15.16**	**15.06**	**14.91**	**14.75**	**14.58**	**14.89**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.03			0.10		
F	0.03			0.09		
D×F	0.06			NS		
Y_2 (2023-2024)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	15.57	15.45	15.27	15.12	14.94	**15.27**
D_2	16.26	16.02	15.90	15.76	15.66	**15.90**
D_3	14.82	14.72	14.52	14.43	14.32	**14.56**
D_4	14.28	14.24	13.88	13.72	13.59	**13.94**
Mean	**15.23**	**15.10**	**14.89**	**14.76**	**14.62**	**14.91**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.06			0.24		
F	0.03			0.08		
D×F	0.15			NS		
Pooled						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	15.51	15.41	15.28	15.13	14.97	**15.26**
D_2	16.23	16.06	15.90	15.78	15.61	**15.92**
D_3	14.82	14.72	14.56	14.41	14.28	**14.56**
D_4	14.22	14.13	13.87	13.69	13.56	**13.89**
Mean	**15.20**	**15.08**	**14.90**	**14.75**	**14.60**	**14.90**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.04			0.14		
F	0.02			0.06		
D×F	0.04			NS		
Y	0.03			NS		
Y×D	0.06			NS		
Y×F	0.03			NS		
Y×D×F	0.06			NS		

***D =** Sowing dates; D_1= 15th April; D_2 = 30th April; D_3 = 15th May; D_4 = 30th May
***F =** Fruit load; F_1 = 3 fruits; F_2 = 4 fruits; F_3 = 5 fruits; F_4 = 6 fruits; F_5 = all fruits retained (control)
***Y =** Year; Y_1 = 2022-2023; Y_2 = 2023-2024

During the second year 2023-2024, sowing dates and fruit load demonstrated significant effects on the speed of germination, while their interaction was also found to be non-significant. The maximum speed of germination (15.90) was recorded by seeds obtained with sowing on 30th April (D_2), whereas the minimum (13.94) was observed by seeds obtained with sowing on 30th May (D_4). Among the fruit load treatments, retaining 3 fruits per plant (F_1) resulted in the highest speed of germination (15.23), while retaining all fruits per plant (F_5) yielded the lowest (14.62). The interaction between sowing dates and fruit load did not significantly influence the speed of germination and the values ranged from 16.26 - 13.59.

The pooled analysis of data from both years revealed significant effects of sowing dates and fruit load on the speed of germination, while their interaction remained non-significant. The highest speed of germination (15.92) was achieved by seeds obtained with sowing on 30th April (D_2), whereas the lowest (13.89) was recorded by seeds obtained with sowing on 30th May (D_4). Among the fruit load treatments, retaining 3 fruits per plant (F_1) resulted in the highest speed of germination (15.20), while retaining all fruits per plant (F_5) produced the lowest (14.60). The interaction between sowing dates and fruit load had no significant effect on speed of germination and the values ranged from 16.23 -13.56.

Between the two years, the highest speed of germination (14.91) was observed in the second year 2023-2024, compared to a lower speed of germination (14.89) in the first year 2022-2023. The interaction between years and sowing dates (Y × D), as well as between years and fruit load (Y × F), were non-significant. Furthermore, the three-way interaction involving years, sowing dates and fruit load (Y × D × F) also did not exhibit significant effects.

The results highlight the significant effects of sowing dates and fruit load on the speed of germination, while their interactions remained non-significant across both years. Speed of germination is a critical parameter for assessing seed vigour and quality, as it reflects the ability of seeds to initiate and complete germination processes efficiently. Higher speed of germination ensures rapid and uniform seedling emergence, which is crucial for achieving better crop establishment and productivity (Maguire 1962).

During the first and second year, seeds obtained from sowing on 30th April (D_2) exhibited the highest speed of germination, whereas those from sowing on 30th May (D_4)

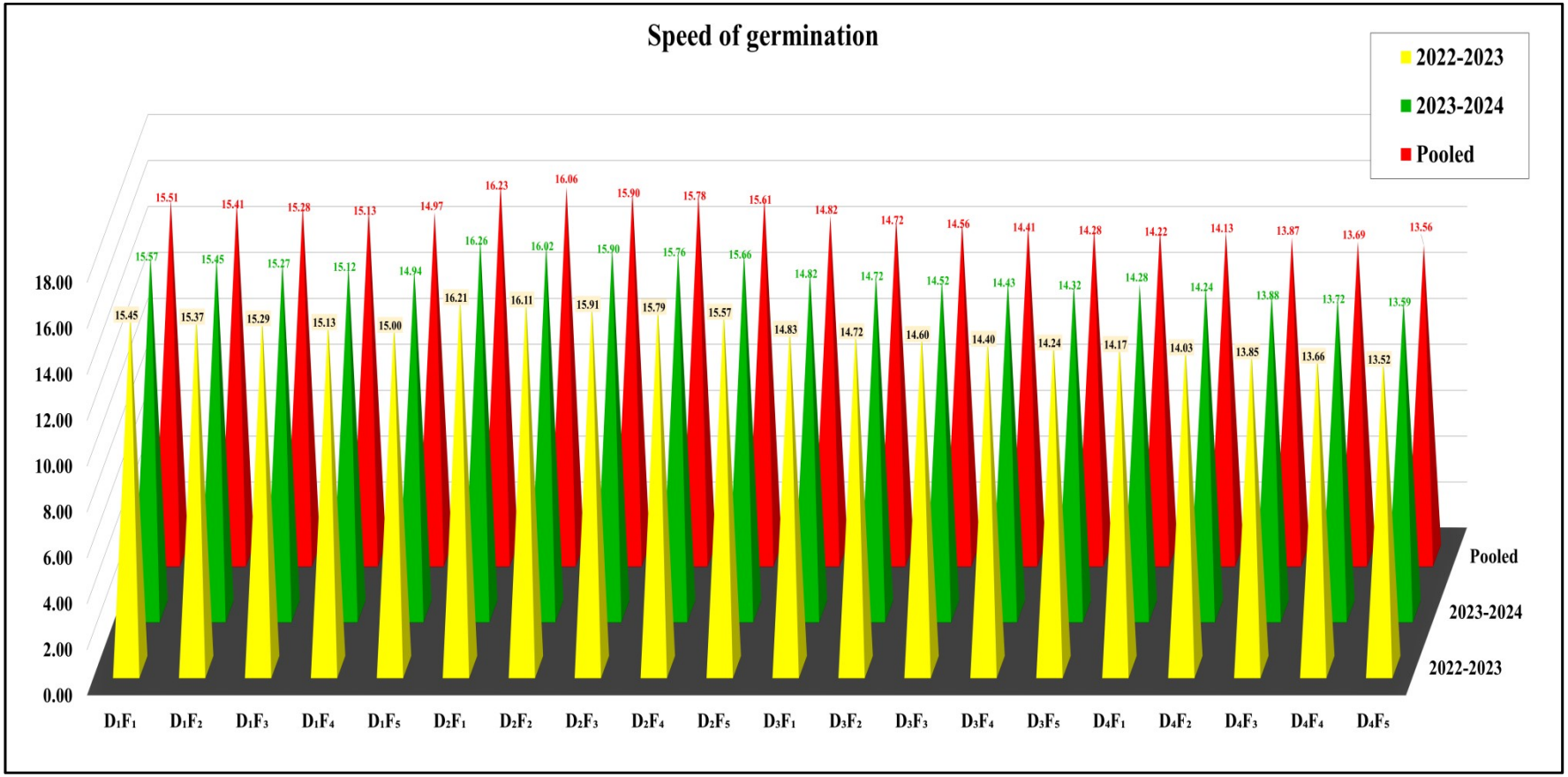


Figure 4.3.2: Effect of sowing dates and fruit load on speed of germination

recorded the lowest. The pooled analysis further reinforced the superiority of seeds produced from the early sowing date, which consistently resulted in a higher speed of germination. These results indicate that early sowing likely provided favourable conditions for seed development and maturation, such as optimal temperature and soil moisture availability, which contributed to improved seed vigour and germination performance.

Regarding fruit load treatments, retaining 3 fruits per plant (F_1) consistently resulted in the highest speed of germination across both years and the pooled analysis. In contrast, retaining all fruits per plant (F_5) resulted in the lowest germination speed. The reduction in germination speed under higher fruit load can be attributed to increased competition among developing fruits for assimilates, leading to reduced seed size, lower dry matter accumulation and subsequently lower seed vigour. This finding aligns with previous studies that suggest seeds from plants with fewer fruits tend to be of higher quality due to better resource allocation.

The non-significant interactions between sowing dates and fruit load across both years and in the pooled analysis suggest that the effects of these factors are largely independent of each other. The absence of significant interactions implies that the observed trends in speed of germination are consistent regardless of the combinations of sowing dates and fruit load.

Interestingly, between the two years, the second year (2023-2024) recorded a slightly higher average speed of germination compared to the first year. This marginal improvement may be attributed to favourable environmental conditions during the second year, such as better rainfall distribution or temperature regimes, which positively influenced seed quality.

The overall findings emphasize the importance of optimizing sowing dates and managing fruit load to enhance seed vigour due to better nutrient and assimilate partitioning, as evidenced by the improved speed of germination. These factors promote faster seed metabolism, leading to better matrix formation in seeds, which supports faster germination and stronger seedling development. Additionally, early sowing enhances the availability of carbohydrates and other energy sources stored in the seed, which are crucial for the initial growth stages.

Seed size is a major determinant of speed of germination, as larger seeds generally result in faster germination due to their higher energy reserves. Maguire (1962) emphasized that the speed of germination is a critical indicator of seedling vigour, particularly in relation

to seed size within a variety. This aligns with the findings of Chandi et al. (2020) who reported high speed of germination.

In the pooled analysis of both years, the results demonstrated significant effects of sowing dates and fruit load on the speed of germination. However, the interaction between sowing dates and fruit load, both in the pooled analysis and in individual years, was found to be non-significant. This suggests that the effects of sowing dates and fruit load on speed of germination are independent of one another, with each factor influencing seedling vigour without interacting with the other.

Furthermore, a comparison between the two years showed a slight difference in the speed of germination, with the second year 2023-2024 exhibiting a marginally higher speed of germination compared to the first year 2022-2023. Despite this small variation, the interaction between years, sowing dates and fruit load (Y × D × F) remained non-significant, indicating that the observed differences between the years were not influenced by the experimental treatments.

4.3.3 Field emergence (%)

The laboratory germination test is widely used to assess the potential of seedling emergence under optimal conditions, providing valuable insights into seed viability and vigour (Perry 1978). However, it is important to recognize that the conditions during laboratory testing are typically more favourable than those found in the field. In field conditions, seeds often encounter suboptimal factors such as low temperatures, mechanical stress and varying salinity, all of which can negatively affect seedling emergence (Robinson and Decker-Walters 1999). Consequently, while laboratory germination tests offer a useful approximation of seedling potential, testing emergence under actual field conditions is critical to fully understand how seeds will perform in real-world environments.

Field emergence (%), a key attribute of seed quality, reflects the proportion of seeds that successfully develop into seedlings in the field. Field emergence testing not only evaluates the impact of environmental factors but also considers the interaction between seed quality and external abiotic stresses, offering a more comprehensive assessment of seed performance in the field.

The data collected over the two consecutive years (2022-2023 and 2023-2024), along with the pooled analysis, revealed significant variations in field emergence (%) across the treatments (Table 4.3.3 and Figure 4.3.3).

In the first year 2022-2023, the effects of sowing dates and fruit load remained significant, but their interaction showed non-significant effect on field emergence (%). The maximum field emergence (68.00 %) was recorded when sowing was done on 30th April (D_2), while the minimum field emergence (52.53 %) was observed when sowing was done on 30th May (D_4). Regarding fruit load treatments, the maximum field emergence (61.83 %) was recorded when 3 fruits per plant (F_1) were retained which was at par with F_2 and F_3, whereas the minimum field emergence (58.50 %) was observed when all fruits per plant (F_5) were retained. The interaction between sowing dates and fruit load had no significant effect on field emergence (%) and the values ranged from 70.00 % - 50.00 %.

Similarly, in the second year 2023-2024, the effects of sowing dates and fruit load remained significant, but their interaction showed non-significant effect on field emergence (%). The maximum field emergence (68.40 %) was recorded when sowing was done on 30th April (D_2), while the minimum field emergence (52.80 %) was observed with sowing on 30th May (D_4). Among fruit load treatments, the maximum field emergence (63.16 %) was recorded when 3 fruits per plant (F_1) were retained, whereas the minimum field emergence (58.83 %) was recorded when all fruits per plant (F_5) were retained. The interaction between sowing dates and fruit load also had no significant effect on field emergence (%) in the second year 2023-2024 and the values ranged from 70.00 % - 50.00 %.

The pooled data for both years showed significant effects of sowing dates and fruit load on field emergence (%), with their interaction remaining non-significant. The maximum field emergence (68.20 %) was recorded when sowing was done on 30th April (D_2), while the minimum field emergence (52.66 %) was observed with sowing on 30th May (D_4). Regarding fruit load treatments, the highest field emergence (62.50 %) was recorded when 3 fruits per plant (F_1) were retained which was at par with F_2, while the minimum (58.66 %) was recorded when all fruits per plant were retained (F_5). Similarly, the interaction between sowing dates and fruit load had no significant effect on field emergence (%) in the pooled analysis and the values ranged from 70.00 % - 50.00 %.

Between the two years, the maximum field emergence (60.93 %) was recorded in the second year 2023-2024, compared to slightly lower field emergence (60.56 %) in the first year 2022-2023.

Table 4.3.3: Effect of sowing dates and fruit load on field emergence

Field emergence (%)						
Y_1 (2022-2023)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	65.33 (53.93)	64.66 (53.52)	63.33 (52.73)	62.66 (52.33)	61.33 (51.55)	**63.46 (52.81)**
D_2	66.66 (54.73)	70.00 (56.79)	68.66 (55.96)	68.00 (55.55)	66.66 (54.73)	**68.00 (55.55)**
D_3	60.66 (51.15)	59.33 (50.38)	58.00 (49.60)	57.33 (49.21)	56.00 (48.45)	**58.26 (49.75)**
D_4	54.66 (47.67)	53.33 (46.91)	52.66 (46.52)	52.00 (46.15)	50.00 (45.00)	**52.53 (46.45)**
Mean	**61.83 (51.84)**	**61.83 (51.84)**	**60.66 (51.15)**	**60.00 (50.77)**	**58.50 (49.89)**	**60.56 (51.10)**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.57			2.01		
F	0.47			1.37		
D×F	1.27			NS		
Y_2 (2023-2024)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	65.33 (53.93)	64.66 (53.52)	64.00 (53.13)	62.66 (52.33)	61.33 (51.55)	**63.60 (52.89)**
D_2	70.00 (56.79)	70.00 (56.79)	68.00 (55.55)	67.33 (55.14)	66.66 (54.73)	**68.40 (55.80)**
D_3	61.33 (51.55)	60.00 (50.77)	58.66 (49.99)	57.33 (49.21)	57.33 (49.21)	**58.93 (50.14)**
D_4	56.00 (48.45)	53.33 (46.91)	52.66 (46.52)	52.00 (46.15)	50.00 (45.00)	**52.80 (46.61)**
Mean	**63.16 (52.63)**	**62.00 (51.94)**	**60.83 (51.25)**	**59.83 (50.67)**	**58.83 (50.59)**	**60.93 (51.31)**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.62			2.19		
F	0.27			0.78		
D×F	1.39			NS		
Pooled						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	65.33 (53.93)	64.66 (53.52)	63.66 (52.93)	62.66 (52.33)	61.33 (51.55)	**63.53 (52.85)**
D_2	68.33 (55.75)	70.00 (56.79)	68.33 (55.75)	67.66 (55.34)	66.66 (54.73)	**68.20 (55.67)**
D_3	61.00 (51.35)	59.66 (50.57)	58.33 (49.80)	57.33 (49.21)	56.66 (48.83)	**58.60 (49.95)**
D_4	55.33 (48.06)	53.33 (46.91)	52.66 (46.52)	52.00 (46.15)	50.00 (45.00)	**52.66 (46.52)**
Mean	**62.50 (52.24)**	**61.91 (51.89)**	**60.75 (51.21)**	**59.91 (50.72)**	**58.66 (49.99)**	**60.74 (51.20)**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.41			1.25		
F	0.27			0.77		
D×F	0.54			NS		
Y	0.29			NS		
Y×D	0.58			NS		
Y×F	0.38			NS		
Y×D×F	0.77			NS		

***D =** Sowing dates; D_1= 15th April; D_2 = 30th April; D_3 = 15th May; D_4 = 30th May
***F =** Fruit load; F_1 = 3 fruits; F_2 = 4 fruits; F_3 = 5 fruits; F_4 = 6 fruits; F_5 = all fruits retained (control)
***Y =** Year; Y_1 = 2022-2023; Y_2 = 2023-2024
* Figures in parenthesis are arc sine transformed values

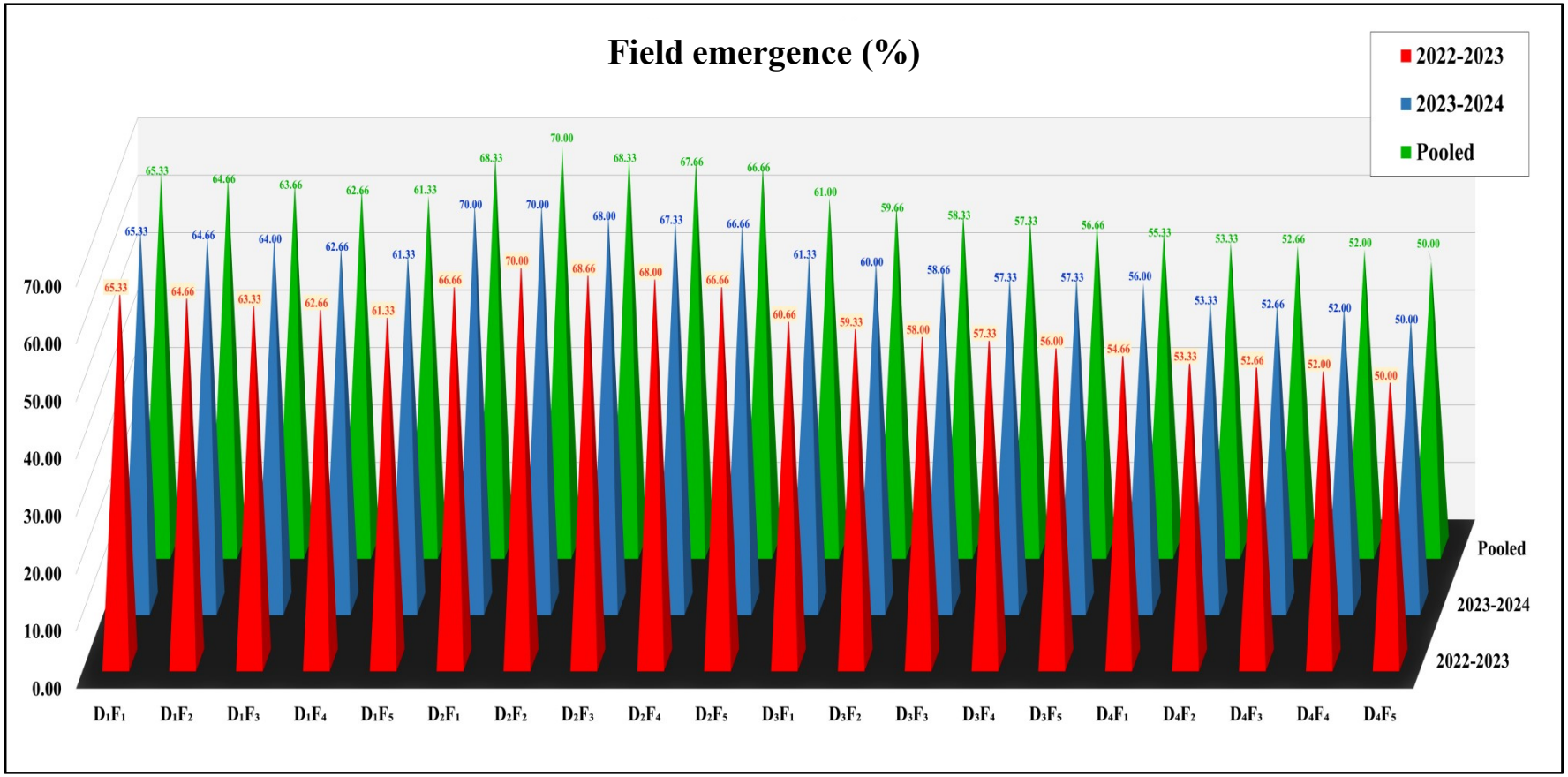


Figure 4.3.3: Effect of sowing dates and fruit load on field emergence

The interaction between years and sowing dates (Y × D), as well as between years and fruit load (Y × F), was found to be non-significant. Additionally, the three-way interaction involving years, sowing dates and fruit load (Y × D × F) also showed non-significant effects.

The findings reveal that both sowing dates and fruit load treatments significantly influenced field emergence (%), consistent across the two years (2022-2023 and 2023-2024) as well as in the pooled analysis. However, their interaction was non-significant, indicating that the effects of sowing dates and fruit load were independent of each other. The highest field emergence was consistently observed with sowing on 30th April (D_2) and retaining 3 fruits per plant (F_1), underscoring the importance of early sowing and moderate fruit load in enhancing seed emergence. Conversely, the lowest field emergence was recorded with sowing on 30th May (D_4) and retaining all fruits per plant (F_5), likely due to suboptimal resource allocation and adverse environmental conditions during late sowing.

The consistency of results across individual years and pooled data highlights the reliability of early sowing on 30th April (D_2) and retaining 3 fruits per plant (F_1) for achieving optimal field emergence. The second year (2023-2024) recorded slightly higher emergence (%) compared to the first year (2022-2023), potentially attributable to marginally better environmental conditions. However, the interaction between years, sowing dates and fruit load (Y × D, Y × F and Y × D × F) were non-significant, confirming that the observed variations were consistent and not influenced by temporal differences.

The correlation between seed germination and field emergence is evident from this study. Higher germination percentages, particularly under early sowing on 30th April (D_2) and retaining 3 fruits per plant (F_1), align with improved field emergence in field settings. This relationship underscores that favourable laboratory seed germination results translate to better field emergence, provided environmental conditions are conducive. Early sowing likely ensures optimal temperature, moisture availability and light exposure, which enhance both germination and subsequent emergence. Similarly, moderate fruit load facilitates adequate resource allocation, leading to the production of high-quality seeds with better vigour and emergence potential. Higher values for seed emergence (%) were also recorded by Bellad (2012), similar to results obtained in the current study.

4.3.4 Seedling length (cm)

Seedling length, measured in laboratory conditions, is a critical parameter for evaluating seed quality and vigour. It reflects the combined growth of roots and shoots and

serves as an indicator of a seed's potential to establish healthy and robust plants. Greater seedling length correlates with enhanced resource utilization, better nutrient and water uptake and increased resilience to early-stage environmental stresses (Copeland and McDonald 2001). Seedling length plays a pivotal role in assessing seed vigour, which is essential for predicting field performance under both optimal and suboptimal conditions. Vigourous seedlings with greater lengths often exhibit stronger metabolic activity and higher survival rates, contributing to improved crop establishment and yield potential (Abdul-Baki and Anderson 1973).

The data collected over two consecutive years (2022-2023 and 2023-2024), along with pooled analysis, demonstrated significant differences in seedling length (cm) among the treatments (Table 4.3.4 and Figure 4.3.4).

During the first year 2022-2023, sowing dates and fruit load exhibited significant effects on the seedling length (cm); however, their interaction was found to be non-significant. The longest seedling length (25.62 cm) was observed with sowing on 30th April (D_2), while the shortest (18.97 cm) was recorded with sowing on 30th May (D_4). Among the fruit load treatments, retaining 3 fruits per plant (F_1) resulted in the longest seedling length (22.93 cm) which was at par with 4 fruits per plant retained (F_2), whereas retaining all fruits per plant (F_5) resulted in the minimum seedling length (21.02 cm). Notably, the interaction between sowing dates and fruit load did not significantly influence the seedling length (cm) and the values ranged from 27.01 – 18.18 cm.

During the second year 2023-2024, sowing dates and fruit load demonstrated significant effects on the seedling length (cm), while their interaction was also found to be significant. The longest seedling length (25.77 cm) was recorded with sowing on 30th April (D_2), whereas the shortest (19.72 cm) was observed with sowing on 30th May (D_4). Among the fruit load treatments, retaining 3 fruits per plant (F_1) resulted in the longest seedling length (23.40 cm), while retaining all fruits per plant (F_5) recorded the shortest (21.45 cm). The interaction between sowing dates and fruit load showed that when sowing was done on 30th April and 3 fruits per plant were retained (D_2F_1), it produced the longest seedling length (27.97 cm), whereas when sowing was done on 30th May and all fruits per plant were retained (D_4F_5) it resulted in the shortest seedling length (18.99 cm).

Table 4.3.4: Effect of sowing dates and fruit load on seedling length

Seedling length (cm)						
Y_1 (2022-2023)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	23.26	22.87	22.64	22.13	22.04	**22.58**
D_2	27.01	26.55	25.95	24.66	23.97	**25.62**
D_3	21.88	21.22	20.89	20.28	19.92	**20.84**
D_4	19.56	19.45	19.20	18.48	18.18	**18.97**
Mean	**22.93**	**22.52**	**22.17**	**21.39**	**21.02**	**22.00**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.32			1.13		
F	0.19			0.55		
D×F	0.71			NS		
Y_2 (2023-2024)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	23.42	23.40	22.97	22.53	22.05	**22.87**
D_2	27.97	26.64	25.56	24.54	24.13	**25.77**
D_3	21.74	21.14	20.88	20.85	20.65	**21.05**
D_4	20.47	20.27	19.74	19.15	18.99	**19.72**
Mean	**23.40**	**22.86**	**22.29**	**21.77**	**21.45**	**22.35**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.22			0.77		
F	0.08			0.23		
D×F	0.49			0.54		
Pooled						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	23.34	23.13	22.81	22.33	22.04	**22.73**
D_2	27.49	26.60	25.75	24.60	24.05	**25.70**
D_3	21.81	21.18	20.88	20.57	20.28	**20.94**
D_4	20.01	19.86	19.47	18.81	18.58	**19.35**
Mean	**23.16**	**22.69**	**22.23**	**21.58**	**21.24**	**22.18**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.18			0.55		
F	0.10			0.29		
D×F	0.20			0.58		
Y	0.12			NS		
Y×D	0.25			NS		
Y×F	0.14			NS		
Y×D×F	0.29			NS		

***D =** Sowing dates; D_1= 15th April; D_2 = 30th April; D_3 = 15th May; D_4 = 30th May
***F =** Fruit load; F_1 = 3 fruits; F_2 = 4 fruits; F_3 = 5 fruits; F_4 = 6 fruits; F_5 = all fruits retained (control)
***Y =** Year; Y_1 = 2022-2023; Y_2 = 2023-2024

The pooled analysis of data from both years revealed that sowing dates and fruit load demonstrated significant effects on the seedling length (cm), while their interaction was also found to be significant. The longest seedling length (25.70 cm) was achieved with sowing on 30th April (D_2), whereas the shortest (19.35 cm) was recorded with sowing on 30th May (D_4). Among the fruit load treatments, retaining 3 fruits per plant (F_1) resulted in the longest seedling length (23.16 cm), while retaining all fruits per plant (F_5) resulted in shortest (21.24 cm). The interaction between sowing dates and fruit load showed that when sowing was done on 30th April and 3 fruits per plant were retained (D_2F_1), it produced the longest seedling length (27.49 cm), whereas when sowing was done on 30th May and all fruits per plant were retained (D_4F_5) it resulted in the shortest seedling length (18.58 cm).

Between the two years, the longer seedling length (22.35 cm) was observed in the second year 2023-2024, compared to a shorter seedling length (22.0 cm) in the first year 2022-2023. The interaction between years and sowing dates (Y × D), as well as between years and fruit load (Y × F), were not statistically significant. Furthermore, the three-way interaction involving years, sowing dates and fruit load (Y × D × F) also did not exhibit significant effects.

The results from both years indicate that sowing dates and fruit load treatments significantly influenced seedling length in laboratory conditions, with longer seedlings produced from seeds harvested under earlier sowing dates of 30th April (D_2) and 3 fruits retained per plant (F_1). Laboratory conditions generally exhibited better seedling length due to the superior quality of seeds produced under these favourable treatments.

Seeds from earlier sowing dates of 30th April (D_2) demonstrated longer seedling lengths, as they likely benefitted from optimal temperature, better moisture availability and sufficient light during the seed development phase. These factors are essential for producing seeds with larger reserves and superior physiological maturity, which directly contribute to better seedling length (Finch-Savage and Bassel 2016). Similar results have been recorded by Sonu et al. (2013) and Tomar et al. (2010) for longer seedling length under early sowing.

Similarly, retaining 3 fruits per plant (F_1) resulted in the longer seedling length, which can be attributed to improved resource allocation. Moderate fruit retention reduces competition among developing fruits, allowing to produce larger seeds with enhanced reserves. Seeds with larger endosperm and embryonic reserves translate into higher seedling

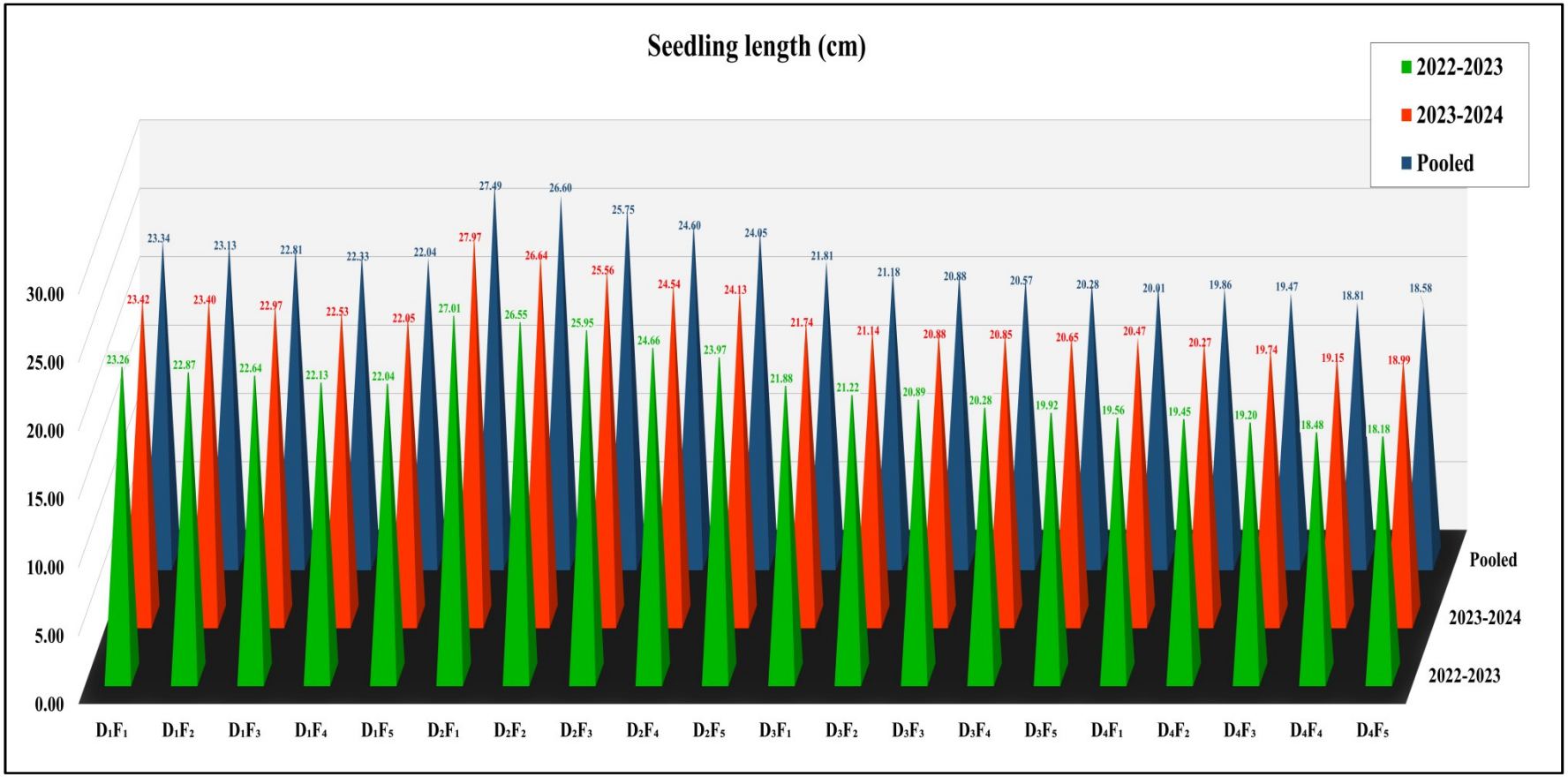


Figure 4.3.4: Effect of sowing dates and fruit load on seedling length

lengths due to the greater availability of stored energy and nutrients (Egli 1998). In contrast, retaining all fruits per plant (F_5) produced seeds with smaller reserves, which likely contributed to shorter seedling lengths. These results align with findings by Patil et al. (2024); Bellad and Hiremath (2018) and Tomar et al. (2015), emphasizing the role of fruit load management in balancing source-sink dynamics and optimizing seed quality.

The observed differences between years may be attributed to environmental factors such as temperature, rainfall and other abiotic conditions, which can vary annually and affect seedling growth (Robinson and Deckar-Walters 1999). However, the non-significant interaction between years and other factors indicate that the effects of sowing dates and fruit load were consistent across the years, reinforcing the reliability of these findings.

4.3.5 Seedling dry weight (mg)

Seedling dry weight is a critical parameter in evaluating seedling vigour and overall seed quality. It represents the biomass accumulation after removing all moisture, providing a direct measure of the reserves mobilized during germination and early growth stages. Higher seedling dry weight often indicates better seed quality, efficient nutrient utilization and robust seedling establishment (Perry 1978). The importance of seedling dry weight lies in its ability to reflect the seed's metabolic efficiency. Seeds with higher dry weight typically originate from larger seeds with better assimilate accumulation during development. These seeds are more likely to produce vigourous seedlings, which are essential for optimal crop establishment under field conditions (Egli 1998).

The data collected over two consecutive years (2022-2023 and 2023-2024), along with pooled analysis, demonstrated significant differences in seedling dry weight (mg) among the treatments (Table 4.3.5 and Figure 4.3.5).

During the first year 2022-2023, both sowing dates and fruit load significantly influenced seedling dry weight (mg) and their interaction was also statistically significant. The maximum seedling dry weight (13.92 mg) was observed with sowing on 30th April (D_2), while the minimum seedling dry weight (10.67 mg) was recorded with sowing on 30th May (D_4). Among the fruit load treatments, retaining 3 fruits per plant (F_1) resulted in the maximum seedling dry weight (12.91 mg) which was at par with F_2 and F_3, whereas retaining all fruits per plant (F_5) resulted in the minimum seedling dry weight (11.95 mg). The interaction between sowing dates and fruit load revealed that when sowing was done on

Table 4.3.5: Effect of sowing dates and fruit load on seedling dry weight

Seedling dry weight (mg)						
Y_1 (2022-2023)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	13.50	13.36	13.23	13.00	12.76	**13.17**
D_2	14.13	14.06	13.96	13.83	13.63	**13.92**
D_3	12.60	12.33	12.06	11.86	11.60	**12.09**
D_4	11.43	11.03	10.63	10.46	9.80	**10.67**
Mean	**12.91**	**12.70**	**12.47**	**12.29**	**11.95**	**12.46**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.09			0.32		
F	0.03			0.10		
D×F	0.20			0.24		
Y_2 (2023-2024)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	13.66	13.53	13.40	13.16	13.06	**13.36**
D_2	14.26	14.06	13.96	13.83	13.80	**13.98**
D_3	12.66	12.40	12.23	11.90	11.46	**12.13**
D_4	11.30	10.93	10.80	10.63	10.03	**10.74**
Mean	**12.97**	**12.73**	**12.60**	**12.38**	**12.09**	**12.55**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.12			0.44		
F	0.05			0.14		
D×F	0.28			0.33		
Pooled						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	13.58	13.45	13.31	13.08	12.91	**13.27**
D_2	14.20	14.06	13.96	13.83	13.71	**13.95**
D_3	12.63	12.36	12.15	11.88	11.53	**12.11**
D_4	11.36	10.98	10.71	10.55	9.91	**10.70**
Mean	**12.94**	**12.71**	**12.53**	**12.33**	**12.02**	**12.50**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.07			0.22		
F	0.03			0.08		
D×F	0.06			0.17		
Y	0.05			NS		
Y×D	0.10			NS		
Y×F	0.04			NS		
Y×D×F	0.08			NS		

***D =** Sowing dates; D_1= 15th April; D_2 = 30th April; D_3 = 15th May; D_4 = 30th May
***F =** Fruit load; F_1 = 3 fruits; F_2 = 4 fruits; F_3 = 5 fruits; F_4 = 6 fruits; F_5 = all fruits retained (control)
***Y =** Year; Y_1 = 2022-2023; Y_2 = 2023-2024

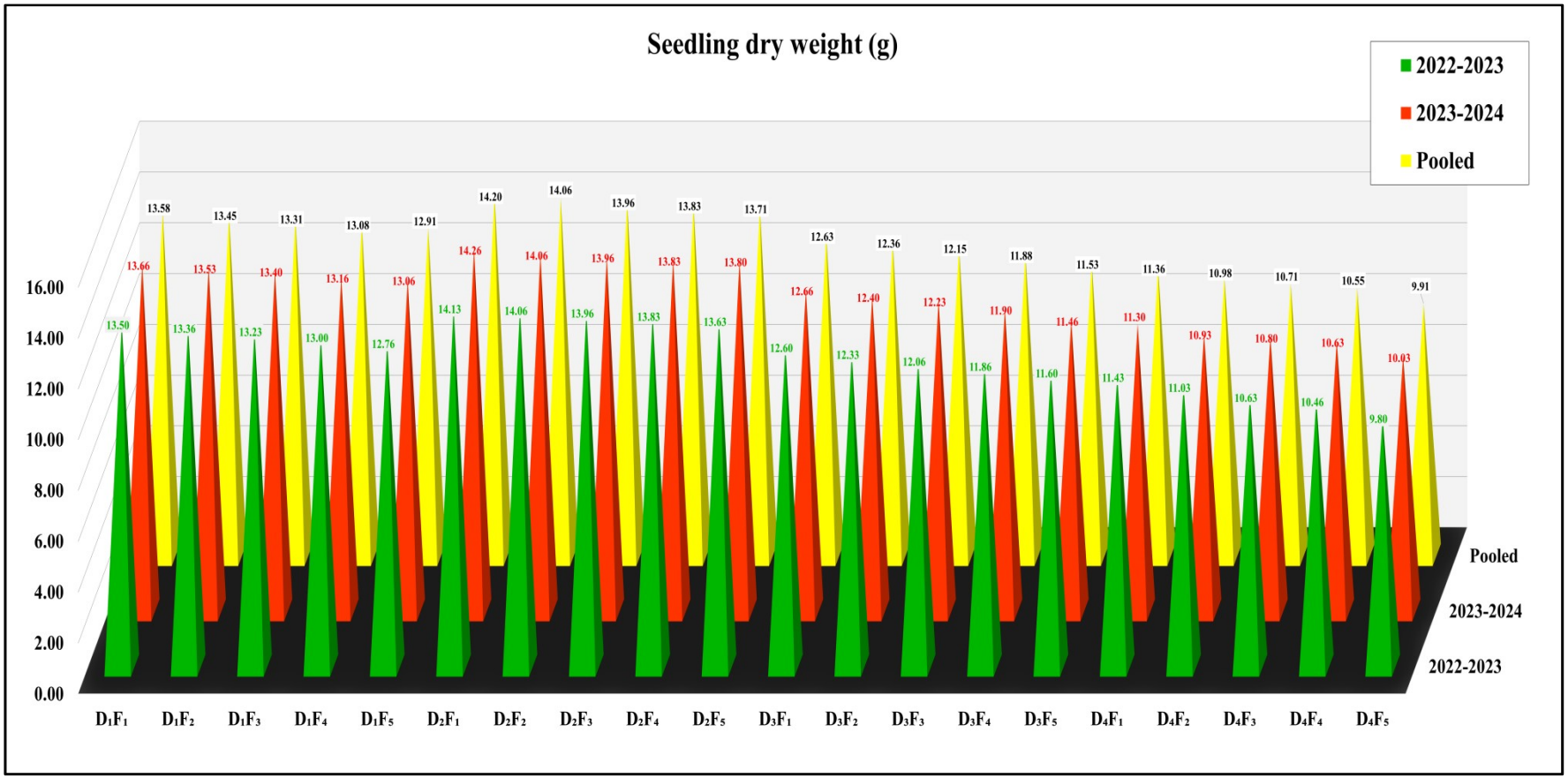


Figure 4.3.5: Effect of sowing dates and fruit load on seedling dry weight

30th April and 3 fruits per plant were retained (D_2F_1), it produced the maximum seedling dry weight (14.13 mg), while the minimum seedling dry weight (9.80 mg) was recorded when sowing was done on 30th May and all fruits per plant were retained (D_4F_5).

During the second year 2023-2024, both sowing dates and fruit load significantly influenced seedling dry weight (mg) and their interaction was also statistically significant. The maximum seedling dry weight (13.98 mg) was observed with sowing on 30th April (D_2), while the minimum seedling dry weight (10.74 mg) was recorded with sowing on 30th May (D_4). Among the fruit load treatments, retaining 3 fruits per plant (F_1) resulted in the maximum seedling dry weight (12.97 mg) which was at par with F_2 and F_3, whereas retaining all fruits per plant (F_5) resulted in the minimum seedling dry weight (12.09 mg). The interaction between sowing dates and fruit load revealed that when sowing was done on 30th April and 3 fruits per plant were retained (D_2F_1), it produced the maximum seedling dry weight (14.26 mg), while the minimum seedling dry weight (10.03 mg) was recorded when sowing was done on 30th May and all fruits per plant were retained (D_4F_5).

The pooled analysis of data from both years revealed significant effects of sowing dates and fruit load on the seedling dry weight (mg), while their interaction was also significant. The maximum seedling dry weight (13.95 mg) was achieved with sowing on 30th April (D_2), whereas the minimum seedling dry weight (10.70 mg) was recorded with sowing on 30th May (D_4). Among the fruit load treatments, retaining 3 fruits per plant (F_1) resulted in the maximum seedling dry weight (12.94 mg) which was at par with 4 fruits per plant (F_2), while retaining all fruits per plant (F_5) resulted in minimum seedling dry weight (12.02 mg). The interaction between sowing dates and fruit load revealed that when sowing was done on 30th April and 3 fruits per plant were retained (D_2F_1), it produced the maximum seedling dry weight (14.20 mg), while the minimum seedling dry weight (9.91 mg) was recorded when sowing was done on 30th May and all fruits per plant were retained (D_4F_5).

Between the two years, a higher seedling dry weight (12.55 mg) was observed in the second year 2023-2024, compared to a lesser seedling dry weight (12.46 mg) in the first year 2022-2023. The interaction between years and sowing dates (Y × D), as well as between years and fruit load (Y × F), were not statistically significant. Furthermore, the three-way interaction involving years, sowing dates and fruit load (Y × D × F) also did not exhibit significant effects.

The results from the two consecutive years (2022-2023 and 2023-2024) clearly indicate that both sowing dates and fruit load treatments had significant effects on seedling dry weight, with their interaction also proving significant. The maximum seedling dry weight observed from seeds harvested under the earlier sowing date of 30th April (D_2) and the retention of 3 fruits per plant (F_1). These treatments produced seeds of superior quality, which directly contributed to increased seedling dry weight in the laboratory.

The seeds from the earlier sowing date showed higher seedling dry weight, likely due to favourable environmental conditions during seed development, such as optimal temperature, moisture and light. These conditions promote seed physiological maturity, resulting in larger nutrient reserves, which contribute to increased seedling dry weight (Finch-Savage and Bassel 2016). Similar results were observed by Sonu et al. (2013) and Tomar et al. (2010) who found that early sowing produces seeds with greater reserves, supporting better seedling growth.

Retaining 3 fruits per plant (F_1) resulted in higher seedling dry weight due to improved resource allocation. A moderate fruit load reduces competition among developing fruits, allowing for more nutrient storage in the seeds. These larger seeds, with more reserves, provide better support for seedling growth (Egli 1998). Similar results have been observed by Patil et al. (2024); Bellad and Hiremath (2018); Bhanuje (2016) and Tomar et al. (2015), emphasizing the importance of fruit load management in optimizing seed quality and seedling biomass.

The interaction between sowing dates and fruit load revealed that when sowing occurred on 30th April and 3 fruits per plant were retained (D_2F_1), the seedling dry weight was maximum, further suggesting that optimal conditions for both sowing and fruit retention led to enhanced seedling biomass.

The pooled data from both years also showed significant effects of sowing dates and fruit load on seedling dry weight, with the interaction between these factors again proving to be significant. The results highlight the detrimental effects of suboptimal sowing timing and excessive fruit load on seedling growth.

The non-significant interaction between years, sowing dates and fruit load (Y × D, Y × F and Y × D × F) suggest that the effects of sowing dates and fruit load treatments on

seedling dry weight were consistent across both years. This indicates that environmental factors, which may have varied slightly between the years, did not significantly alter the overall trends observed in seedling dry weight. This consistency supports the reliability of sowing dates and fruit load management as key determinants of seedling dry weight.

4.3.6 Seedling vigour index - I

The seedling vigour index - I is an essential parameter for evaluating seed quality and predicting seed performance under various conditions. Developed by Abdul-Baki and Anderson (1973), seedling vigour index - I is calculated as the product of germination percentage and mean seedling length. This index provides a comprehensive measure of seed vigour, combining both the ability of seeds to germinate and the strength of the resulting seedlings. Unlike germination percentage alone, Seedling vigour index - I captures the overall potential of seeds to produce robust and competitive seedlings, making it a reliable indicator of seed quality. Seedling vigour is critical for determining the capacity of seeds to establish healthy plants in the field. Higher Seedling vigour index - I value are associated with seeds that can withstand biotic and abiotic stresses, ensuring better crop establishment, early growth and high yield potential. Its application has been widely supported by studies that underscore its correlation with field emergence and growth under diverse conditions.

The data collected over two consecutive years (2022-2023 and 2023-2024), along with pooled analysis, demonstrated significant differences in seedling vigour index - I among the treatments (Table 4.3.6 and Figure 4.3.6).

In the first year 2022-2023, the effects of sowing dates and fruit load remained significant, but their interaction showed non-significant effect on seedling vigour index - I. The maximum seedling vigour index - I (2235.93) was recorded when sowing was done on 30th April (D_2), while the minimum seedling vigour index - I (1356.13) was observed when sowing was done on 30th May (D_4). Regarding fruit load treatments, the maximum seedling vigour index - I (1906.33) was recorded when 3 fruits per plant (F_1) were retained, whereas the minimum seedling vigour index - I (1646.75) was observed when all fruits per plant (F_5) were retained. The interaction between sowing dates and fruit load had no significant effect on seedling vigour index – I and the values ranged from 2421.00 – 1254.33.

During the second year 2023-2024, both sowing dates and fruit load significantly influenced seedling vigour index - I and their interaction was also statistically significant. The

Table 4.3.6: Effect of sowing dates and fruit load on seedling vigour index – I

Seedling vigour index - I						
Y_1 (2022-2023)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	1984.33	1943.33	1902.00	1821.66	1785.66	**1887.40**
D_2	2421.00	2327.66	2249.00	2128.66	2053.33	**2235.93**
D_3	1765.66	1656.33	1616.66	1555.66	1493.66	**1617.60**
D_4	1454.33	1419.66	1364.00	1288.33	1254.33	**1356.13**
Mean	**1906.33**	**1836.75**	**1782.91**	**1698.58**	**1646.75**	**1774.26**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	34.72			122.50		
F	16.49			47.74		
D×F	77.65			NS		
Y_2 (2023-2024)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	1999.00	1973.33	1908.00	1833.33	1735.33	**1889.80**
D_2	2556.33	2390.66	2240.33	2127.33	2076.33	**2278.20**
D_3	1703.66	1643.00	1602.00	1592.66	1570.33	**1622.33**
D_4	1523.00	1501.00	1448.66	1385.33	1335.33	**1438.66**
Mean	**1945.50**	**1877.00**	**1799.75**	**1734.66**	**1679.33**	**1807.24**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	34.95			123.30		
F	11.78			34.10		
D×F	78.16			79.14		
Pooled						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	1991.66	1958.33	1905.00	1827.50	1760.50	**1888.60**
D_2	2488.66	2359.16	2244.66	2128.00	2064.83	**2257.06**
D_3	1734.66	1649.66	1609.33	1574.16	1532.00	**1619.96**
D_4	1488.66	1460.33	1406.33	1336.83	1294.83	**1397.40**
Mean	**1925.91**	**1856.87**	**1791.33**	**1716.62**	**1663.04**	**1790.75**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	22.96			69.99		
F	10.13			28.64		
D×F	20.27			57.29		
Y	16.24			NS		
Y×D	32.48			NS		
Y×F	14.33			NS		
Y×D×F	28.67			NS		

***D =** Sowing dates; D_1= 15th April; D_2 = 30th April; D_3 = 15th May; D_4 = 30th May
***F =** Fruit load; F_1 = 3 fruits; F_2 = 4 fruits; F_3 = 5 fruits; F_4 = 6 fruits; F_5 = all fruits retained (control)
***Y =** Year; Y_1 = 2022-2023; Y_2 = 2023-2024

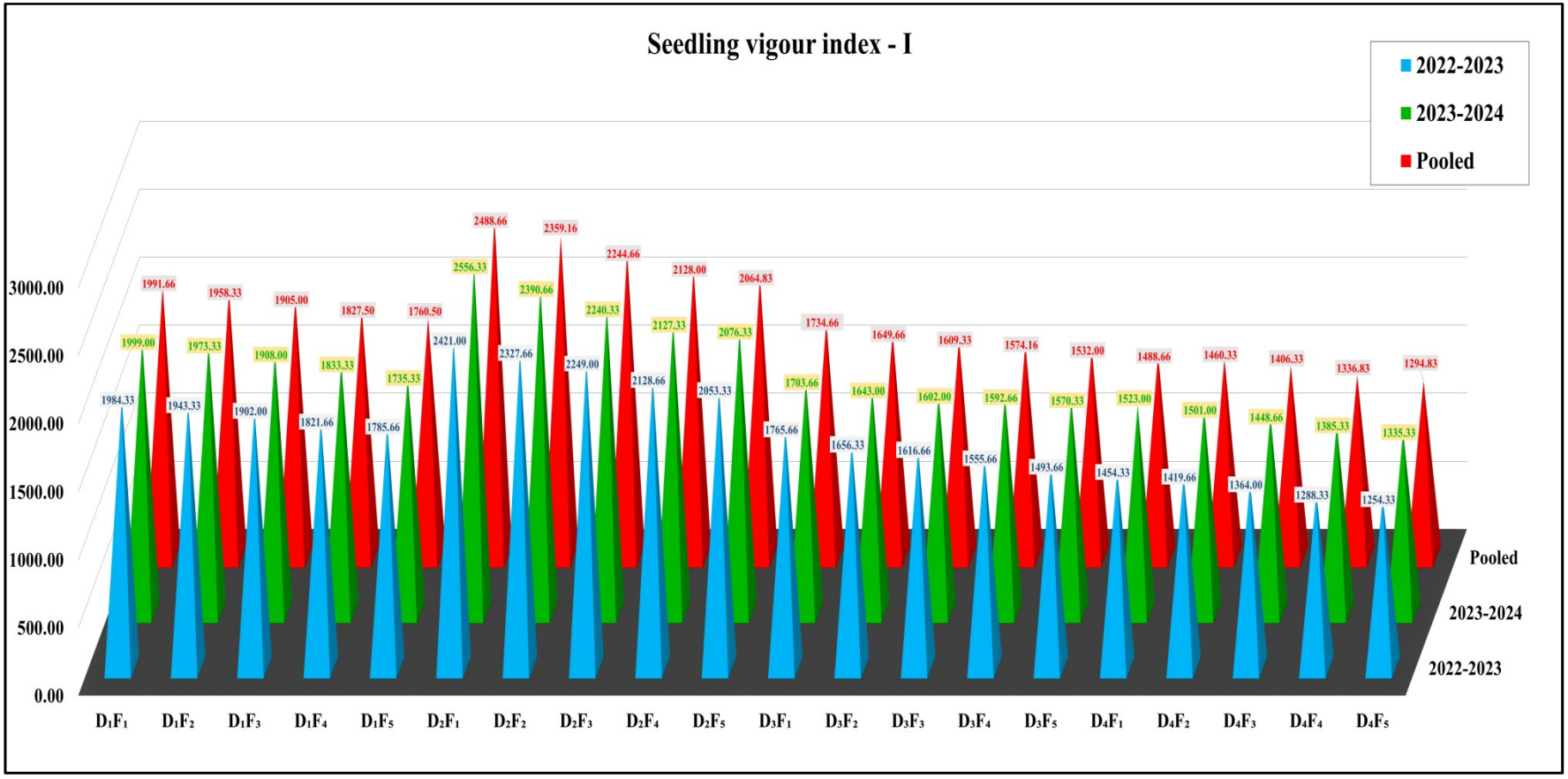


Figure 4.3.6: Effect of sowing dates and fruit load on seedling vigour index - I

maximum seedling vigour index - I (2278.20) was observed with sowing on 30th April (D_2), while the minimum seedling vigour index - I (1438.66) was recorded with sowing on 30th May (D_4). Among the fruit load treatments, retaining 3 fruits per plant (F_1) resulted in the maximum seedling vigour index - I (1945.50), whereas retaining all fruits per plant (F_5) resulted in the minimum seedling vigour index - I (1679.33). The interaction between sowing dates and fruit load revealed that when sowing was done on 30th April and 3 fruits per plant were retained (D_2F_1), it produced the maximum seedling vigour index - I (2556.33), while the minimum seedling vigour index - I (1335.33) was recorded when sowing was done on 30th May and all fruits per plant were retained (D_4F_5).

The pooled analysis of data from both years revealed significant effects of sowing dates and fruit load on the seedling vigour index - I while their interaction was also significant.

The maximum seedling vigour index - I (2257.06) was achieved with sowing on 30th April (D_2), whereas the minimum seedling vigour index - I (1397.40) was recorded with sowing on 30th May (D_4). Among the fruit load treatments, retaining 3 fruits per plant (F_1) resulted in the maximum seedling vigour index - I (1925.91), while retaining all fruits per plant (F_5) resulted in minimum seedling vigour index - I (1663.04). The interaction between sowing dates and fruit load revealed that when sowing was done on 30th April and 3 fruits per plant were retained (D_2F_1), it produced the maximum seedling vigour index - I (2488.66), while the minimum seedling vigour index - I (1294.83) was recorded when sowing was done on 30th May and all fruits per plant were retained (D_4F_5).

Between the two years, a higher seedling vigour index - I (1807.24) was observed in the second year 2023-2024, compared to a lesser seedling vigour index - I (1774.26) in the first year 2022-2023. The interaction between years and sowing dates (Y × D), as well as between years and fruit load (Y × F), were not statistically significant. Furthermore, the three-way interaction involving years, sowing dates and fruit load (Y × D × F) also did not exhibit significant effects for seedling vigour index - I.

The results from the two consecutive years (2022-2023 and 2023-2024) clearly indicate that both sowing dates and fruit load treatments had significant effects on seedling vigour index - I, with their interaction also proving significant. The maximum seedling vigour index - I values observed with earlier sowing dates of 30th April (D_2) can be attributed

to the optimal environmental conditions prevailing during seed development. Favourable factors such as adequate temperature, sufficient sunlight and proper moisture availability contribute to the development of physiologically mature seeds with enhanced germination capacity and seedling growth potential (Finch-Savage and Bassel 2016). These findings align with those of Paul et al. (2016); Sonu et al. (2013); Chattopadhyay et al. (2011); Tomar et al. (2010), who also reported higher seedling vigour indices under early sowing dates due to improved seed quality parameters.

The positive influence of retaining 3 fruits per plant (F_1) on seedling vigour index – I is likely due to balanced resource allocation. Moderate fruit retention reduces competition among fruits, allowing the plant to invest more resources into fewer seeds, enhancing their size, nutrient reserves and vigour. Conversely, retaining all fruits (F_5) may lead to resource dilution, resulting in smaller seeds with lower physiological maturity, ultimately affecting seedling vigour adversely. Similar observations have been noted by Patil et al. (2024); Chandi et al. (2020); Sharma et al. (2017); Bhanuje and Raiker (2016) and Tomar et al. (2015), who documented reduced seed quality with excessive fruit retention.

The interaction between sowing dates and fruit load, significant in the second year and the pooled analysis, underscores the combined effects of environmental and physiological factors. The highest seedling vigour index – I observed in early sowing of 30th April and retention of 3 fruits per plant (D_2F_1) further validate the critical role of optimizing both factors for superior seed quality. Such synergies have been reported in seed quality studies across various crops, emphasizing the interplay of developmental timing and source-sink balance.

The slight year-to-year variation in seedling vigour index – I, with higher values in 2023-2024, may be attributed to differences in climatic conditions, such as temperature and precipitation, influencing seed development. However, the non-significance of interaction involving years suggests a consistent trend across the study period, further validating the robustness of the observed effects.

4.3.7 Seedling vigour index – II

Seedling vigour index - II, given by Abdul-Baki and Anderson (1973), is a key parameter for assessing seed quality. It is calculated by multiplying the germination percentage with seedling dry weight, providing insights into the seed's nutrient reserves and

capacity for strong early growth. Unlike seedling vigour index - I, which focuses on seedling length, seedling vigour index - II emphasizes the physiological robustness of seeds. Seedling vigour index - II is crucial for predicting field performance, especially in crops like cucumber, where seedling biomass significantly impacts establishment and productivity. Higher seedling vigour index - II values correlate with better resource allocation, stress tolerance and overall seed quality, making it a valuable tool in seed evaluation and crop management.

The data collected over two consecutive years (2022-2023 and 2023-2024), along with pooled analysis, demonstrated significant differences in seedling vigour index - II among the treatments (Table 4.3.7 and Figure 4.3.7).

In the first year 2022-2023, both sowing dates and fruit load significantly influenced seedling vigour index - II and their interaction was also statistically significant. The maximum seedling vigour index - II (1163.73) was recorded when sowing was done on 30th April (D_2), while the minimum seedling vigour index - II (785.46) was observed when sowing was done on 30th May (D_4). Regarding fruit load treatments, the maximum seedling vigour index - II (1039.08) was recorded when 3 fruits per plant (F_1) were retained, whereas the minimum seedling vigour index - II (960.83) was observed when all fruits per plant (F_5) were retained. The interaction between sowing dates and fruit load revealed that when sowing was done on 30th April and 3 fruits per plant were retained (D_2F_1), it produced the maximum seedling vigour index - II (1206.00), while the minimum seedling vigour index – II (715.00) was recorded when sowing was done on 30th May and all fruits per plant were retained (D_4F_5).

During the second year 2023-2024, both sowing dates and fruit load significantly influenced seedling vigour index - II and their interaction was also statistically significant. The maximum seedling vigour index - II (1162.60) was observed with sowing on 30th April (D_2), while the minimum seedling vigour index - II (831.13) was recorded with sowing on 30th May (D_4). Among the fruit load treatments, retaining 3 fruits per plant (F_1) resulted in the maximum seedling vigour index - II (1050.83), whereas retaining all fruits per plant (F_5) resulted in the minimum seedling vigour index - II (989.75). The interaction between sowing dates and fruit load revealed that when sowing was done on 30th April and 3 fruits per plant were retained (D_2F_1), it produced the maximum seedling vigour index - II (1236.00), while the

Table 4.3.7: Effect of sowing dates and fruit load on seedling vigour index – II

Seedling vigour index -II						
Y_1 (2022-2023)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	1198.66	1160.33	1126.66	1102.00	1079.66	**1133.46**
D_2	1206.00	1196.00	1173.33	1139.00	1104.33	**1163.73**
D_3	973.33	925.66	897.33	877.00	828.00	**900.26**
D_4	835.33	831.33	778.33	767.33	715.00	**785.46**
Mean	**1039.08**	**999.25**	**991.16**	**988.33**	**960.83**	**995.72**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	25.11			88.60		
F	8.31			24.05		
D×F	56.15			55.90		
Y_2 (2023-2024)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	1217.66	1186.33	1159.66	1125.33	1085.66	**1154.93**
D_2	1236.00	1201.33	1154.00	1132.00	1089.66	**1162.60**
D_3	958.33	924.66	879.66	863.00	831.66	**891.46**
D_4	952.00	881.33	791.33	788.667	742.33	**831.13**
Mean	**1050.83**	**1013.66**	**1018.66**	**977.25**	**989.75**	**1010.03**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	21.84			77.07		
F	9.77			28.29		
D×F	48.85			64.14		
Pooled						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	1211.83	1180.83	1140.33	1117.00	1084.66	**1148.03**
D_2	1217.33	1191.16	1166.50	1132.16	1095.00	**1159.33**
D_3	965.83	925.16	888.50	870.00	829.83	**895.86**
D_4	891.66	824.33	812.00	784.83	728.66	**808.30**
Mean	**1044.95**	**1006.45**	**1004.91**	**982.79**	**975.29**	**1002.88**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	15.53			47.11		
F	6.41			18.13		
D×F	12.83			36.26		
Y	10.98			NS		
Y×D	21.96			NS		
Y×F	9.07			NS		
Y×D×F	18.14			51.28		

***D =** Sowing dates; D_1= 15th April; D_2 = 30th April; D_3 = 15th May; D_4 = 30th May
***F =** Fruit load; F_1 = 3 fruits; F_2 = 4 fruits; F_3 = 5 fruits; F_4 = 6 fruits; F_5 = all fruits retained (control)
***Y =** Year; Y_1 = 2022-2023; Y_2 = 2023-2024

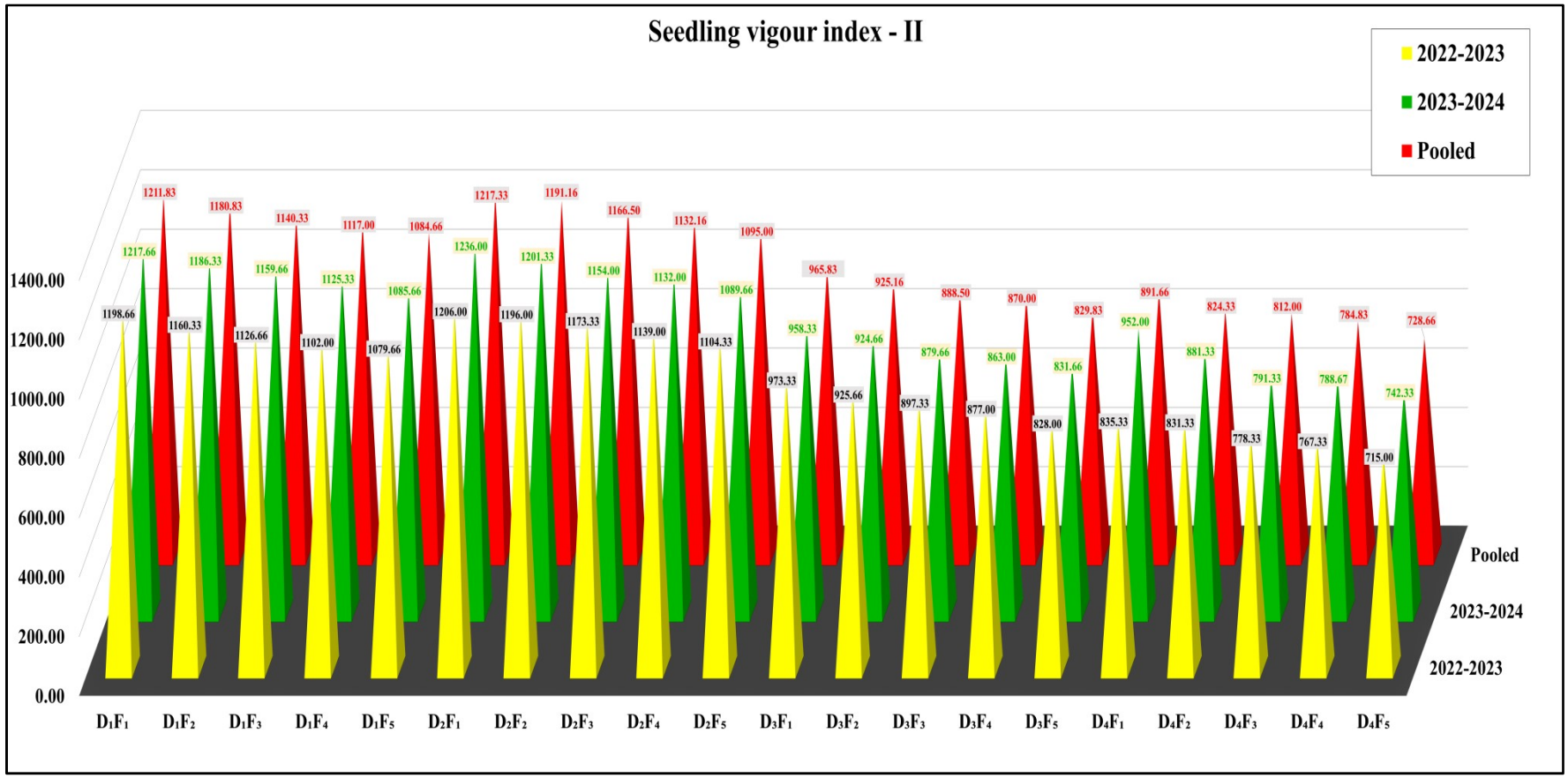


Figure 4.3.7: Effect of sowing dates and fruit load on seedling vigour index - II

minimum seedling vigour index - II (742.33) was recorded when sowing was done on 30th May and all fruits per plant were retained (D_4F_5).

The pooled analysis of data from both years revealed significant effects of sowing dates and fruit load on the seedling vigour index - II while their interaction was also significant. The maximum seedling vigour index - II (1159.33) was achieved with sowing on 30th April (D_2), whereas the minimum seedling vigour index - II (808.30) was recorded with sowing on 30th May (D_4). Among the fruit load treatments, retaining 3 fruits per plant (F_1) resulted in the maximum seedling vigour index - II (1044.95), while retaining all fruits per plant (F_5) resulted in minimum seedling vigour index - II (975.29).

The interaction between sowing dates and fruit load revealed that when sowing was done on 30th April and 3 fruits per plant were retained (D_2F_1), it produced the maximum seedling vigour index - II (1217.33), while the minimum seedling vigour index - I (728.66) was recorded when sowing was done on 30th May and all fruits per plant were retained (D_4F_5).

Between the two years, a higher seedling vigour index - II (1010.03) was observed in the second year 2023-2024, compared to a lesser seedling vigour index - II (995.72) in the first year 2022-2023. The interaction between years and sowing dates (Y × D), as well as between years and fruit load (Y × F), were not statistically significant. The interaction between years, date of sowings and fruit load (Y × D × F) resulted in significant effect and the maximum seedling vigour index - II (1236.00) was recorded in the second year 2023-2024 when sowing was done on 30th April and 3 fruits per plant were retained ($Y_2D_2F_1$) whereas the minimum seedling vigour index - II (715.00) was recorded in the first year 2022-2023 when sowing was done on 30th May and all fruits per plant were retained ($Y_1D_4F_5$).

The results demonstrated that sowing dates and fruit load treatments significantly influenced seedling vigour index - II, with notable interaction observed in certain conditions. Higher seedling vigour index - II values were consistently recorded for seeds produced under the earlier sowing date of 30th April (D_2) and moderate fruit load retention of 3 fruits per plant (F_1). The superior performance of seeds from earlier sowing (D_2) can be attributed to the favourable environmental conditions during the seed development phase, including optimal temperature, light and moisture availability. These conditions enhance the physiological maturity of seeds, resulting in greater nutrient reserves that support higher

seedling dry weight, a critical component of seedling vigour index - II (Finch-Savage and Bassel 2016). Similar findings by Paul et al. (2016); Sonu et al. (2013); Chattopadhyay et al. (2011); Tomar et al. (2010), have highlighted the importance of appropriate sowing timings in producing high-vigour seeds.

Moderate fruit retention of 3 fruits per plant (F_1) likely improved resource allocation, reducing competition among developing fruits and allowing for the formation of seeds with larger reserves. These seeds exhibited higher seedling vigour index - II due to enhanced seedling biomass, which indicates better seed quality and vigour. Similar conclusions were drawn by Patil et al. (2024); Chandi et al. (2020); Sharma et al. (2017); Bhanuje and Raiker (2016) and Tomar et al. (2015), who emphasized that balancing source-sink dynamics is critical in optimizing seed quality.

The significant interaction between sowing dates and fruit load indicates that the combination of favourable environmental conditions and balanced resource allocation maximizes seedling vigour. The maximum seedling vigour index - II recorded for the 30^{th} April sowing with 3 fruits retained (D_2F_1) underscores the synergistic effects of these factors. The pooled analysis further confirmed these trends, reinforcing that early sowing and moderate fruit load consistently yield seeds with superior vigour. The higher seedling vigour index - II observed in the second year 2023-2024 compared to the first year 2022-2023 might be due to slight variations in environmental factors, such as rainfall or temperature, which may have been more favourable for seed development in the second year. However, the non-significant interaction between years and individual factors (Y × D and Y × F) suggests that the effects of sowing dates and fruit load were consistent across both years.

The significant three-way interaction (Y × D × F) highlights the importance of integrating year-specific environmental conditions with optimized agronomic practices to maximize seed quality. The highest seedling vigour index - II from the first year 2023-2024 sowing on 30^{th} April with 3 fruits retained ($Y_2D_2F_1$) underscores the potential of this combination for achieving superior seed vigour under ideal conditions.

In the current study, seedling vigour index - I and seedling vigour index - II were both significantly influenced by sowing dates and fruit load, demonstrating their complementary roles in assessing seed vigour. While seedling vigour index - I highlighted early seedling growth potential through length, seedling vigour index – II reflected the seed's capacity for

biomass accumulation, with trends showing higher values for both indices under optimal conditions.

Chord Diagram for seed quality traits

The chord diagram depicted in Figure 4.3.8 visually represents the interconnections between various seed quality parameters, such as seed germination percentage, speed of germination, seed emergence percentage, seedling length, seedling dry weight, seedling vigour index - I and seedling vigour index - II, across different treatments. The diagram displays the parameters and treatments in the outer segments, with the connecting chords illustrating how these factors influence each other. It underscores the intricate relationships among the parameters and how each one responds to the treatments.

Focusing on the arcs inside the diagram, these arcs connect the combinations to the traits they influence. For instance, the D_2F_1 combination shows strong connections with seed germination percentage, speed of germination, seed emergence percentage, seedling length, seedling dry weight, seedling vigour index - I and seedling vigour index - II. For the seed germination, the results indicate that the seed germination percentage plays a pivotal role in seedling establishment. A higher seed germination percentage leads to better seedling emergence and contributes positively to overall plant growth. The speed of germination, which is closely related to the germination percentage, also plays a critical role in early seedling development. Faster germination is often associated with quicker seedling establishment, enabling plants to grow more vigorously from the start. The seed emergence percentage, which measures how many seeds successfully emerge from the soil, shows a positive correlation with seed germination percentage, suggesting that more uniform and timely emergence leads to more effective germination outcomes.

Seedling length and seedling dry weight are closely linked to seedling vigour index - I and seedling vigour index - II, both of which serve as key indicators of seedling growth and overall plant health. Treatments that promote better seedling growth tend to result in higher values for these vigour indices. Seedling length, which indicates how tall the seedlings grow and seedling dry weight, which reflects the biomass of the seedlings, are important measures of seedling quality.

Treatments in the D_2 and D_3 groups consistently yield superior performance for key growth parameters, including seedling vigour indices, seedling length and seedling dry

weight. These treatments show the potential to improve seedling growth and vigour significantly, emphasizing their effectiveness in enhancing early-stage seedling development. In contrast, certain treatments lead to lower seedling vigour, low germination rates and reduced seedling quality. These results suggest that these treatments may involve suboptimal conditions or less effective management practices. Overall, the chord diagram emphasizes the importance of targeting multiple quality traits to improve seedling vigour and establishment.

4.4 Seed physiological assays

4.4.1 Electrical conductance (μS cm^{-1} g^{-1}) from seed leachates

Electrical conductance (μS cm^{-1} g^{-1}) from seed leachates is a key parameter for assessing seed quality, reflecting membrane integrity and physiological vigour. When seeds imbibe water, solutes such as ions and sugars leak into the surrounding medium. Seeds with intact membranes show lower electrical conductance, indicating high vigour and viability, while damaged or deteriorated seeds exhibit higher values due to increased solute leakage. This quick, non-destructive method effectively differentiates high-quality seeds from low-vigour ones, making it vital for seed quality evaluation.

The data collected over two consecutive years (2022-2023 and 2023-2024), along with pooled analysis, demonstrated significant differences in electrical conductance (μS cm^{-1} g^{-1}) from seed leachates (Table 4.4.1 and Figure 4.4.1).

During the first year 2022-2023, significant effects of sowing dates and fruit load were observed on the electrical conductance of seed leachates while their interaction were non- significant. The maximum electrical conductance (96.51 μS cm^{-1} g^{-1}) was recorded with sowing on 30th May (D_4), while the minimum (60.24 μS cm^{-1} g^{-1}) was observed with sowing on 30th April (D_2). Among the fruit load treatments, retaining all fruits per plant (F_5) resulted in the maximum electrical conductance (82.38 μS cm^{-1} g^{-1}), whereas retaining 3 fruits per plant (F_1) led to the minimum electrical conductance (71.97 μS cm^{-1} g^{-1}). The interaction between sowing dates and fruit load was non-significant for electrical conductance from seed leachates in the first year and the values ranged from 104.61 - 57.36 μS cm^{-1} g^{-1}.

In the second year 2023-2024, significant effects of sowing dates, fruit load and their interaction were observed on the electrical conductance of seed leachates. The maximum

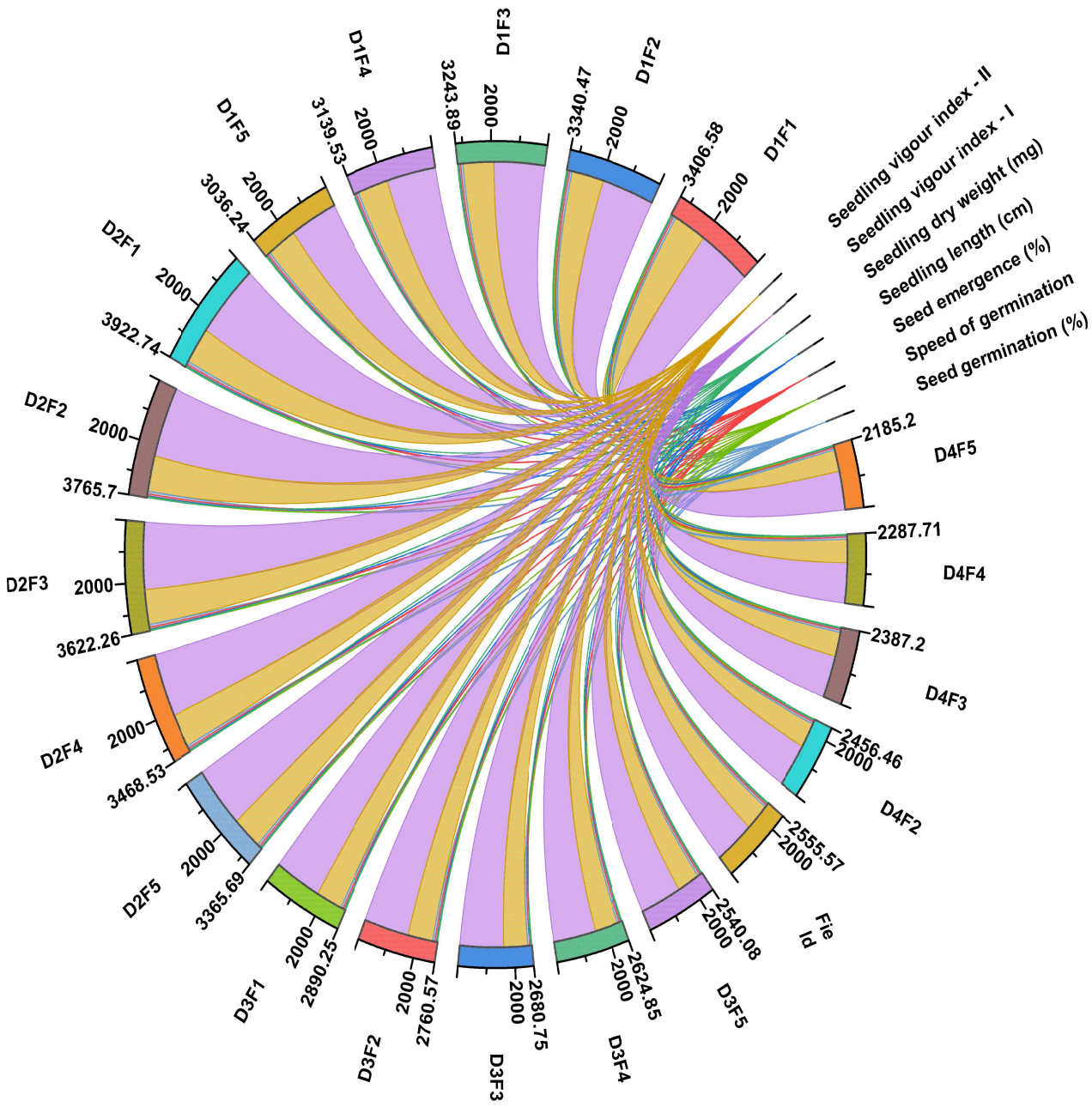


Figure 4.3.8: Analytical visualization of seed quality traits weightage using chord diagram

Table 4.4.1: Effect of sowing dates and fruit load on electrical conductance from seed leachates

Electrical conductance (µS cm^{-1} g^{-1}) from seed leachates						
Y_1 (2022-2023)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	64.32	66.37	68.25	71.84	73.14	**68.78**
D_2	57.96	57.36	60.32	62.24	63.34	**60.24**
D_3	75.68	78.29	79.12	83.52	88.44	**81.01**
D_4	89.94	92.65	96.36	99.00	104.61	**96.51**
Mean	**71.97**	**73.67**	**76.01**	**79.15**	**82.38**	**76.63**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.83			2.92		
F	0.57			1.67		
D×F	1.85			NS		
Y_2 (2023-2024)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	59.95	62.41	64.44	67.27	69.50	**64.71**
D_2	47.50	44.08	51.89	54.51	57.61	**51.12**
D_3	70.31	74.45	78.93	80.62	84.23	**77.71**
D_4	87.38	89.24	91.72	95.41	97.11	**92.17**
Mean	**66.28**	**67.54**	**71.74**	**74.45**	**77.11**	**71.42**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.91			3.23		
F	0.39			1.13		
D×F	2.05			2.58		
Pooled						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	62.13	64.39	66.34	69.55	71.32	**66.75**
D_2	52.73	50.72	56.10	58.37	60.48	**55.68**
D_3	72.99	76.37	79.02	82.07	86.33	**79.36**
D_4	88.66	90.94	94.04	97.20	100.86	**94.34**
Mean	**69.13**	**70.60**	**73.88**	**76.80**	**79.75**	**74.03**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	1.09			3.31		
F	0.34			0.98		
D×F	0.69			1.97		
Y	0.77			2.34		
Y×D	1.54			NS		
Y×F	0.49			NS		
Y×D×F	0.98			2.79		

***D =** Sowing dates; D_1= 15th April; D_2 = 30th April; D_3 = 15th May; D_4 = 30th May
***F =** Fruit load; F_1 = 3 fruits; F_2 = 4 fruits; F_3 = 5 fruits; F_4 = 6 fruits; F_5 = all fruits retained (control)
***Y =** Year; Y_1 = 2022-2023; Y_2 = 2023-2024

electrical conductance (92.17 µS cm^{-1} g^{-1}) was recorded with sowing on 30th May (D_4), while the minimum (51.12 µS cm^{-1} g^{-1}) was observed with sowing on 30th April (D_2). Among the fruit load treatments, retaining all fruits per plant (F_5) resulted in the maximum electrical conductance (77.11 µS cm^{-1} g^{-1}), whereas retaining 3 fruits per plant (F_1) led to the minimum electrical conductance (66.28 µS cm^{-1} g^{-1}). The combination of 30th May sowing with all fruits per plant retained (D_4F_5) resulted in the maximum electrical conductance (97.11 µS cm^{-1} g^{-1}), while the combination of 30th April sowing with 4 fruits per plant retained (D_2F_2) led to the lowest (44.08 µS cm^{-1} g^{-1}).

The pooled analysis for both years significant effects of sowing dates, fruit load and their interaction were observed on the electrical conductance of seed leachates. The maximum electrical conductance (94.34 µS cm^{-1} g^{-1}) was recorded with sowing on 30th May (D_4), while the minimum (55.68 µS cm^{-1} g^{-1}) was observed with sowing on 30th April (D_2). Regarding fruit load treatments, retaining all fruits per plant (F_5) resulted in the maximum electrical conductance (79.75 µS cm^{-1} g^{-1}), whereas retaining 3 fruits per plant (F_1) resulted in the minimum (69.13 µS cm^{-1} g^{-1}). The combination of 30th May sowing with all fruits per plant retained (D_4F_5) resulted in the maximum electrical conductance (100.86 µS cm^{-1} g^{-1}), while the combination of 30th April sowing with 4 fruits per plant retained (D_2F_2) led to the lowest (50.72 µS cm^{-1} g^{-1}).

Across both years, the first year 2022-2023 recorded a higher average electrical conductance (76.63 µS cm^{-1} g^{-1}) compared to the second year 2023-2024 (71.42 µS cm^{-1} g^{-1}). The interaction between years and sowing dates (Y × D) and years and fruit load (Y × F) were non-significant for electrical conductance (µS cm^{-1} g^{-1}) from seed leachates.

The three-way interaction between years, sowing dates and fruit load (Y × D × F) showed significant effects, with the maximum electrical conductance (104.61 µS cm^{-1} g^{-1}) recorded in the first year 2022-2023 with sowing on 30th May and all fruits per plant retained ($Y_1D_4F_5$), while the minimum electrical conductance (44.08 µS cm^{-1} g^{-1}) was recorded in the second year 2023-2024 with sowing on 30th April and 4 fruits per plant retained ($Y_2D_2F_2$).

The present study revealed that sowing dates, fruit load and their interaction significantly influenced the electrical conductance of seed leachates (µS cm^{-1} g^{-1}), a key indicator of seed quality. Higher electrical conductance values reflect poor seed quality due to

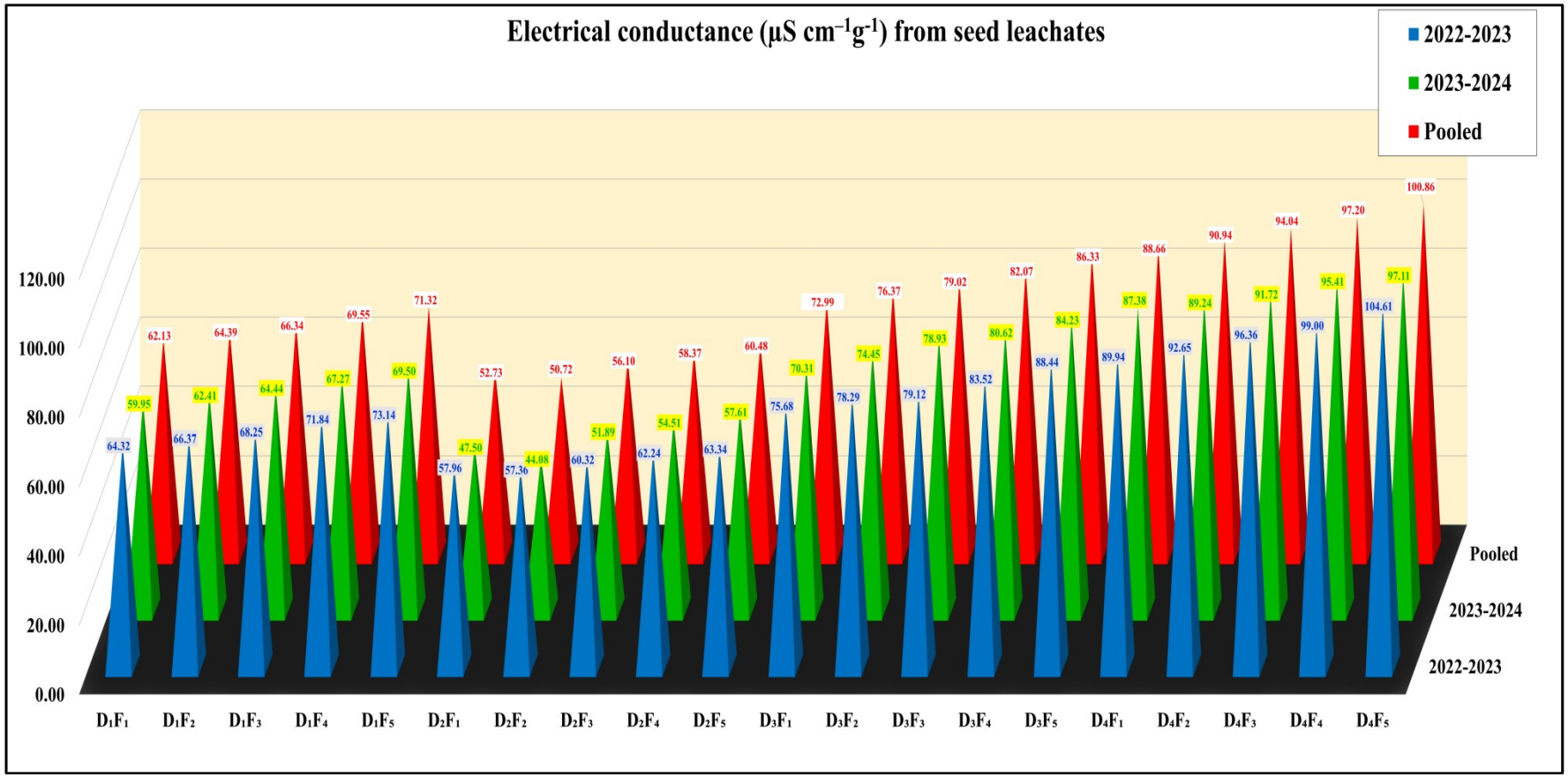


Figure 4.4.1: Effect of sowing dates and fruit load on electrical conductance from seed leachates

compromised membrane integrity, leading to greater solute leakage, while lower electrical conductance indicates better membrane stability, seed vigour and physiological quality.

Delayed sowing on 30th May (D_4) consistently resulted in higher electrical conductance, which can be attributed to unfavourable environmental conditions, such as elevated temperatures and shortened seed maturation periods, that disrupt membrane stability and increase solute permeability. In contrast, early sowing on 30th April (D_2) produced seeds with lower electrical conductance, suggesting that favourable conditions during early sowing ensure proper seed development and improved physiological integrity. These findings align with Tajbakhsh (2000), who reported that seeds with low viability exhibited higher electrical conductance compared to highly viable seeds, emphasizing that the degree of deterioration directly influences solute leakage.

Fruit load also significantly influenced electrical conductance, with higher fruit load of retaining all fruits per plant (F_4) leading to increased values due to intense competition for assimilates among developing fruits. Retaining 3 fruits per plant (F_1) improved seed quality by ensuring better nutrient allocation, thereby enhancing membrane stability and reducing solute leakage. Seeds produced under optimal fruit load exhibited lower electrical conductance, highlighting the benefits of managing fruit load to maintain seed vigour.

The observed trends suggest that environmental stresses, such as late-season conditions and nutrient competition, play critical roles in membrane degradation and increased electrical conductance. Similar results were reported by researchers such as Chandi et al. (2020); Thakur et al. (2018) and Tajbakhsh (2000) where seeds subjected to unfavourable growing conditions and deteriorative factors exhibited higher electrical conductance due to reduced cellular integrity. Conversely, seeds produced under favourable conditions showed lower electrical conductance, reflecting better viability and vigour.

Overall, the study underscores the importance of optimal agronomic practices, including early sowing and regulated fruit load, to minimize solute leakage and maintain seed quality. Electrical conductance, as an indicator of membrane integrity, provides a reliable means of assessing seed vigour, with higher electrical conductance values reflecting poor-quality, deteriorated seeds and lower electrical conductance values signifying high-quality, viable seeds.

4.4.2 Total soluble sugars in seed leachates (mg g^{-1})

Total soluble sugars in seed leachates (mg g^{-1}) are a key indicator of seed quality, reflecting membrane integrity and physiological vigour. Soluble sugars play a crucial role in seeds as energy reserves and protectants during germination. Seeds with intact membranes retain these sugars, resulting in minimal leakage and indicating high-quality seeds. Conversely, seeds with damaged membranes or deterioration exhibit increased sugar leakage, reflecting poor vigour and reduced germination potential. Environmental stress during seed development and storage conditions can significantly influence membrane stability and sugar loss. Thus, the quantification of total soluble sugars in seed leachates (mg g^{-1}) serves as a reliable, indirect indicator of seed quality, where lower sugar concentrations are associated with high-quality seeds and higher concentrations signify deteriorated or low-vigour seeds.

The data collected over two consecutive years (2022-2023 and 2023-2024), along with pooled analysis, revealed significant variations in total soluble sugars in seed leachates (mg g^{-1}) (Table 4.4.2 and Figure 4.4.2).

During the first year 2022-2023, significant effects of sowing dates were observed on the total soluble sugars in seed leachates (mg g^{-1}), while the effect of fruit load and interaction were non-significant. The maximum total soluble sugars (0.667 mg g^{-1}) were recorded with sowing on 30th May (D_4), while the minimum (0.606 mg g^{-1}) were observed with sowing on 30th April (D_1). The fruit load treatments and interaction between sowing dates and fruit load were non-significant for total soluble sugars (mg g^{-1}) in seed leachates in the first year and the values ranged from 0.687 - 0.600 mg g^{-1}.

In the second year 2023-2024 also, significant effects of sowing dates were observed on the total soluble sugars in seed leachates (mg g^{-1}), while the effect of fruit load and interaction were non-significant. The maximum total soluble sugars (0.729 mg g^{-1}) were recorded with sowing on 30th May (D_4), while the minimum (0.669 mg g^{-1}) was observed with sowing on 30th April (D_2). The fruit load treatments and interaction between sowing in dates and fruit load were non-significant for total soluble sugars (mg g^{-1}) in seed leachates the second year also and the values ranged from 0.740 - 0.660 mg g^{-1}.

The pooled analysis for both years showed significant effects of sowing dates and fruit load, while their interaction was non-significant for the total soluble sugars in seed leachates (mg g^{-1}). The maximum total soluble sugars (0.698 mg g^{-1}) were recorded with

Table 4.4.2: Effect of sowing dates and fruit load on total soluble sugars in seed leachates

Total soluble sugars in seed leachates (mg g^{-1})						
Y_1 (2022-2023)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	0.615	0.618	0.621	0.627	0.624	**0.621**
D_2	0.600	0.603	0.606	0.612	0.609	**0.606**
D_3	0.630	0.633	0.636	0.642	0.639	**0.636**
D_4	0.645	0.648	0.684	0.669	0.687	**0.667**
Mean	**0.623**	**0.626**	**0.637**	**0.638**	**0.640**	**0.632**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.006			0.022		
F	0.005			NS		
D×F	0.014			NS		
Y_2 (2023-2024)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	0.683	0.688	0.702	0.692	0.697	**0.692**
D_2	0.660	0.664	0.678	0.669	0.674	**0.669**
D_3	0.706	0.711	0.725	0.716	0.720	**0.716**
D_4	0.730	0.734	0.705	0.737	0.740	**0.729**
Mean	**0.695**	**0.699**	**0.702**	**0.704**	**0.708**	**0.701**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.003			0.011		
F	0.005			NS		
D×F	0.007			NS		
Pooled						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	0.649	0.653	0.664	0.657	0.661	**0.657**
D_2	0.630	0.634	0.645	0.638	0.641	**0.638**
D_3	0.668	0.672	0.684	0.676	0.680	**0.676**
D_4	0.687	0.691	0.687	0.711	0.714	**0.698**
Mean	**0.659**	**0.662**	**0.670**	**0.670**	**0.674**	**0.667**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.008			0.023		
F	0.003			0.010		
D×F	0.007			NS		
Y	0.005			0.017		
Y×D	0.011			NS		
Y×F	0.005			NS		
Y×D×F	0.010			NS		

***D =** Sowing dates; D_1= 15th April; D_2 = 30th April; D_3 = 15th May; D_4 = 30th May
***F =** Fruit load; F_1 = 3 fruits; F_2 = 4 fruits; F_3 = 5 fruits; F_4 = 6 fruits; F_5 = all fruits retained (control)
***Y =** Year; Y_1 = 2022-2023; Y_2 = 2023-2024

sowing on 30th May (D_4), while the minimum (0.638 mg g^{-1}) was observed with sowing on 30th April (D_2). Regarding fruit load treatments, retaining all fruits per plant (F_5) resulted in the maximum total soluble sugars (0.674 mg g^{-1}), whereas retaining 3 fruits per plant (F_1) resulted in the minimum (0.659 mg g^{-1}). The interaction between sowing dates and fruit load were also non-significant for total soluble sugars (mg g^{-1}) in seed leachates in the pooled analysis and the values ranged from 0.714 - 0.630 mg g^{-1}.

Across both years, the second year 2023-2024 recorded a higher average total soluble sugar (0.701 mg g^{-1}) compared to the first year 2022-2023 (0.632 mg g^{-1}). The interaction between years and sowing dates (Y × D) and years and fruit load (Y × F) were non-significant for total soluble sugars (mg g^{-1}) in seed leachates. The three-way interaction between years, sowing dates and fruit load (Y × D × F) was also non-significant for total soluble sugars (mg g^{-1}) in seed leachates.

The present study revealed that sowing dates and fruit load significantly influenced the total soluble sugars in seed leachates (mg g^{-1}), which is an important indicator of seed quality, reflecting membrane integrity and seed vigour. Seeds with lower soluble sugar concentrations in leachates tend to exhibit higher quality, as this indicates intact cellular membranes and reduced solute leakage. On the other hand, higher total soluble sugars in leachates reflect seed deterioration, poor membrane stability and reduced physiological vigour.

In both years, sowing on 30th May (D_4) consistently resulted in the maximum total soluble sugars in seed leachates, while sowing on 30th April (D_2) produced the lowest values. This can be attributed to the unfavourable environmental conditions associated with delayed sowing, including high temperatures and moisture stress during the late reproductive stage. Such conditions adversely affect seed membrane stability, leading to increased sugar leakage and reduced seed quality (Hampton and Tekrony 1995). In contrast, early sowing provides optimal environmental conditions for seed development and physiological maturity, resulting in improved membrane integrity and reduced sugar loss.

The effect of fruit load on total soluble sugars was evident in the pooled analysis, where retaining all fruits per plant (F_5) resulted in higher sugar leakage compared to retaining 3 fruits per plant (F_1). This suggests that higher fruit load exerts significant competition for assimilates among developing fruits, leading to reduced nutrient allocation for seed

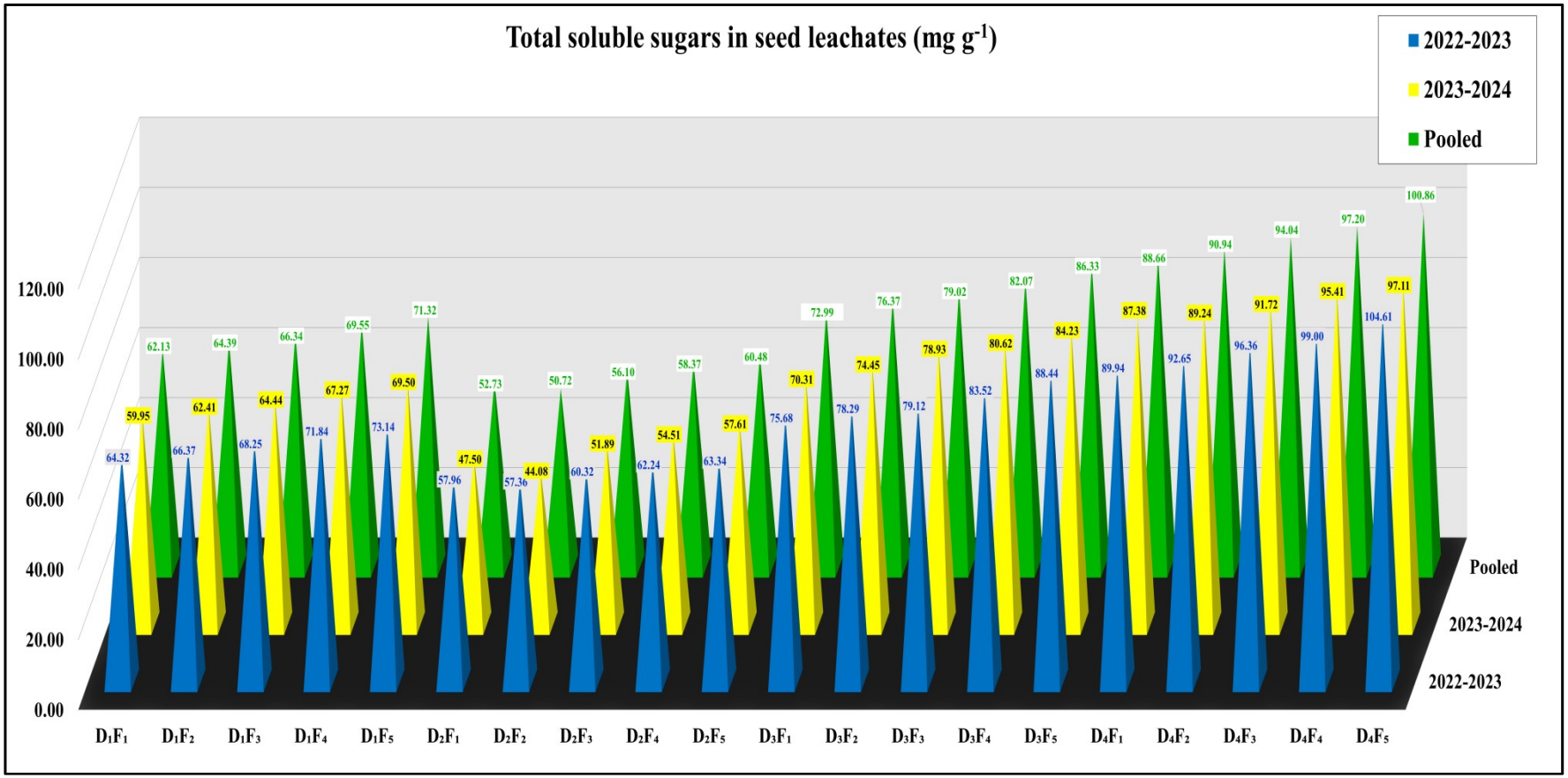


Figure 4.4.2: Effect of sowing dates and fruit load on total soluble sugars in seed leachates

development (Gupta 2020). The resulting nutritional stress may impair seed membrane stability, causing increased solute leakage. Retaining fewer fruits, on the other hand, allows for better nutrient allocation, which supports the development of seeds with higher vigour and intact membrane structures.

The non-significant interaction between sowing dates and fruit load, as well as the three-way interaction across years, indicate that the individual effects of sowing dates and fruit load dominate seed quality outcomes rather than their combined influence. Nonetheless, across both years, seeds from the second year 2023-2024 showed higher average total soluble sugar content in leachates compared to the first year 2022-2023. This could be due to more unfavourable environmental conditions in the second year, such as elevated temperatures and variable moisture availability, which may have exacerbated seed membrane damage during maturation and post-harvest handling.

4.4.3 Total soluble proteins in seed leachates (mg g^{-1})

Total soluble proteins in seed leachates (mg g^{-1}) serve as an important indicator of seed quality, reflecting membrane integrity and physiological vigour. Proteins play a vital role in seed development, functioning as structural components, enzymes and storage reserves essential for germination and seedling establishment. Seeds with intact cellular membranes retain soluble proteins within their cells, minimizing leakage into the external environment and indicating high-quality seeds. However, seeds with compromised membrane integrity, often resulting from deterioration or environmental stress during development and storage, exhibit increased protein leakage into seed leachates, signaling poor seed vigour and reduced germination potential. Increased protein leakage is often associated with reduced seed metabolic activity and a decline in viability, similar to patterns observed with total soluble sugars.

The data collected over two consecutive years (2022-2023 and 2023-2024), along with pooled analysis, revealed significant variations in total soluble proteins in seed leachates (mg g^{-1}) (Table 4.4.3 and Figure 4.4.3).

During the first year 2022-2023, significant effects of sowing dates and fruit load were observed on the total soluble proteins in seed leachates (mg g^{-1}), while their interaction were non-significant. The maximum total soluble proteins (8.32 mg g^{-1}) were recorded with sowing on 30th May (D_4), while the minimum (6.00 mg g^{-1}) was observed with sowing on

Table 4.4.3: Effect of sowing dates and fruit load on total soluble proteins in seed leachates

Total soluble proteins in seed leachates (mg g^{-1})						
Y_1 (2022-2023)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	6.37	6.49	6.62	6.69	6.88	**6.61**
D_2	5.76	5.82	5.95	6.17	6.30	**6.00**
D_3	7.25	7.31	7.52	7.64	7.93	**7.53**
D_4	8.07	8.18	8.44	8.51	8.42	**8.32**
Mean	**6.86**	**6.95**	**7.13**	**7.25**	**7.38**	**7.11**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.07			0.27		
F	0.03			0.09		
D×F	0.17			NS		
Y_2 (2023-2024)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	6.57	6.76	6.91	7.23	7.15	**6.92**
D_2	5.85	5.91	6.00	6.31	6.13	**6.04**
D_3	7.34	7.47	7.88	8.04	7.94	**7.73**
D_4	8.25	8.41	8.51	8.21	8.61	**8.40**
Mean	**7.00**	**7.14**	**7.32**	**7.45**	**7.46**	**7.27**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.07			0.26		
F	0.05			0.14		
D×F	0.16			0.32		
Pooled						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	6.47	6.62	6.76	6.92	7.06	**6.76**
D_2	5.80	5.86	5.97	6.15	6.30	**6.02**
D_3	7.29	7.39	7.70	7.79	7.99	**7.63**
D_4	8.16	8.30	8.47	8.56	8.31	**8.36**
Mean	**6.93**	**7.04**	**7.23**	**7.35**	**7.41**	**7.19**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.06			0.19		
F	0.03			0.08		
D×F	0.06			0.16		
Y	0.04			0.14		
Y×D	0.09			NS		
Y×F	0.04			NS		
Y×D×F	0.08			NS		

***D =** Sowing dates; D_1= 15th April; D_2 = 30th April; D_3 = 15th May; D_4 = 30th May
***F =** Fruit load; F_1 = 3 fruits; F_2 = 4 fruits; F_3 = 5 fruits; F_4 = 6 fruits; F_5 = all fruits retained (control)
***Y =** Year; Y_1 = 2022-2023; Y_2 = 2023-2024

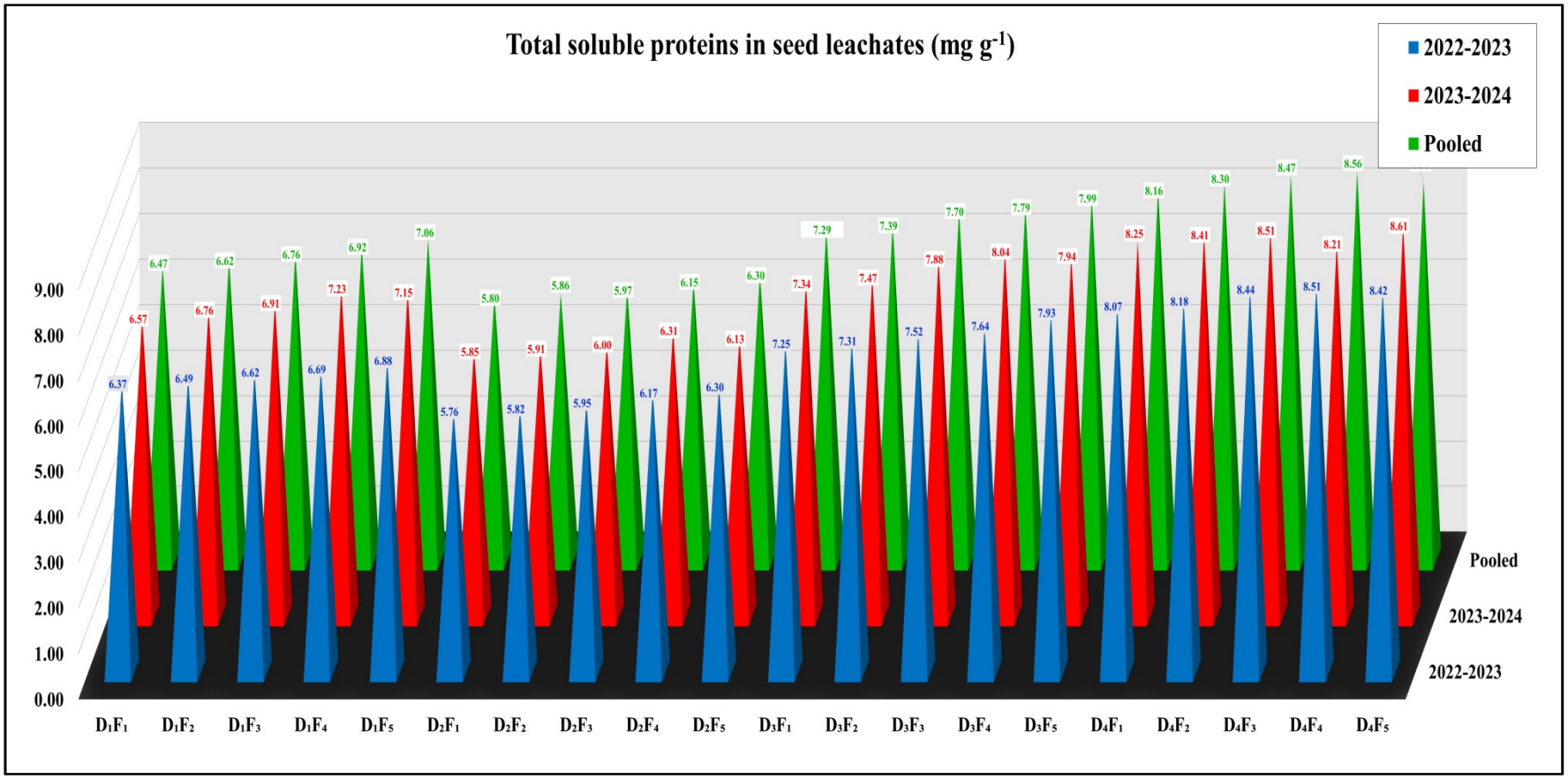


Figure 4.4.3: Effect of sowing dates and fruit load on total soluble proteins in seed leachates

30th April (D_2). For fruit load treatments, retaining all fruits per plant (F_5) resulted in the maximum total soluble proteins (7.38 mg g^{-1}), whereas retaining 3 fruits per plant (F_1) resulted in the minimum (6.86 mg g^{-1}). The interaction between sowing dates and fruit load were non-significant for total soluble proteins (mg g^{-1}) in seed leachates in the first year and the values ranged from 8.51 - 5.95 mg g^{-1}.

In the second year 2023-2024, significant effects of sowing dates, fruit load and their interaction were observed on the total soluble proteins in seed leachates (mg g^{-1}). The maximum total soluble proteins (8.40 mg g^{-1}) were recorded with sowing on 30th May (D_4), while the minimum (6.04 mg g^{-1}) was observed with sowing on 30th April (D_2). For fruit load treatments, retaining all fruits per plant (F_5) resulted in the maximum total soluble proteins (7.46 mg g^{-1}), whereas retaining 3 fruits per plant (F_1) resulted in the minimum (7.00 mg g^{-1}). The combination of 30th May sowing with all fruits per plant retained (D_4F_5) resulted in the maximum total soluble proteins (8.61 mg g^{-1}), while the combination of 30th April sowing with 3 fruits per plant retained (D_2F_1) led to the lowest (5.85) total soluble proteins.

The pooled analysis for both years showed significant effects of sowing dates, fruit load and their interaction were observed on the total soluble proteins in seed leachates (mg g^{-1}). The maximum total soluble proteins (8.36 mg g^{-1}) were recorded with sowing on 30th May (D_4), while the minimum (6.02 mg g^{-1}) was observed with sowing on 30th April (D_2). Regarding fruit load treatments, retaining all fruits per plant (F_5) resulted in the maximum total soluble proteins (7.41 mg g^{-1}), whereas retaining 3 fruits per plant (F_1) resulted in the minimum (6.93 mg g^{-1}). The combination of 30th May sowing with 6 fruits per plant retained (D_4F_4) resulted in the maximum total soluble proteins (8.56 mg g^{-1}), while the combination of 30th April sowing with 3 fruits per plant retained (D_2F_1) led to the lowest (5.85 mg g^{-1}) total soluble proteins.

Across both years, the second year 2023-2024 recorded a higher average total soluble protein (7.27 mg g^{-1}) compared to the first year 2022-2023 (7.11 mg g^{-1}). The interaction between years and sowing dates (Y × D) and years and fruit load (Y × F) were non-significant for total soluble proteins (mg g^{-1}) in seed leachates. The three-way interaction between years, sowing dates and fruit load (Y × D × F) was also non-significant for total soluble proteins (mg g^{-1}) in seed leachates.

The results indicate that the total soluble proteins in seed leachates are an important marker of seed quality, with higher protein concentrations typically correlating with lower seed quality. Soluble proteins play a crucial role in seed metabolism and energy reserves during germination. However, when the integrity of the seed membrane is compromised, proteins leak out into the leachates, reflecting seed deterioration and reduced vigour.

In the first year 2022-2023, the sowing dates had a significant effect on the total soluble protein content in seed leachates, with higher protein concentrations observed in seeds from the later sowing date of 30th May (D_4) compared to the earlier sowing on 30th April (D_1). This suggests that delayed sowing may lead to increased stress during seed development, causing compromised membrane integrity and subsequent leakage of soluble proteins into the seed leachates. Seed proteins, especially soluble proteins, are crucial for the energy and metabolic processes of seeds during germination. These higher protein levels are indicative of a reduction in seed quality, as the ability of the seed to retain proteins, along with other solutes, is directly linked to its physiological vigour.

In the second year (2023-2024), both sowing dates and fruit load treatments, as well as their interaction, significantly influenced the total soluble proteins in seed leachates. The highest protein content was again observed in seeds from the later sowing date (D_4). Furthermore, retaining all fruits per plant (F_5) led to higher protein content, while reduced fruit load (F_1) decreased protein leakage. The combination of later sowing and higher fruit load resulted in the highest total soluble protein levels in seed leachates, suggesting that these conditions led to increased stress and deteriorated seed quality. Similar results were recorded by Gupta (2020) for higher total soluble proteins in seed leachates (mg g^{-1}) with increased fruit retention in cucumber.

The pooled analysis for both years reinforced these findings, showing that delayed sowing consistently resulted in higher soluble protein levels in seed leachates, which are generally indicative of poor seed quality. Additionally, fruit load treatments also impacted protein leakage, with seeds from plants retaining all fruits showing higher protein content, further highlighting the role of resource competition in seed quality.

Across both years, the second year (2023-2024) showed a higher average total soluble protein content compared to the first year (2022-2023). This could be attributed to more

favourable environmental conditions in the second year, which might have led to better seed quality overall, despite the higher protein concentrations observed with delayed sowing.

4.4.4 Total soluble sugars in seed (mg g^{-1}_{dw})

Total soluble sugars in seeds (mg g^{-1}_{dw}) refer to the concentration of sugars such as glucose, fructose and sucrose present within the dry weight of seeds. These sugars play a fundamental role in seed physiology, serving as key energy reserves and osmotic regulators during seed development, maturation and germination. Soluble sugars are synthesized and stored during seed development through photosynthesis and translocation of assimilates from the source (leaves) to the sink (seeds). Higher total soluble sugars in seeds are directly associated with high seed quality, as they provide sufficient energy and metabolic support required for germination and early seedling establishment.

The data collected over two consecutive years (2022-2023 and 2023-2024), along with pooled analysis, revealed significant variations in total soluble sugars in seeds (mg g^{-1}_{dw}) (Table 4.4.4 and Figure 4.4.4).

During the first year 2022-2023, significant effects of sowing dates and fruit load were observed on the total soluble sugars in seeds (mg g^{-1}_{dw}), while their interaction were non-significant. The maximum total soluble sugars in seeds (2.680 mg g^{-1}_{dw}) were recorded with sowing on 30th April (D_2), while the minimum (2.192 mg g^{-1}_{dw}) was observed with sowing on 30th May (D_4). Regarding fruit load treatments, retaining 3 fruits per plant (F_1) resulted in the maximum total soluble sugars in seeds (2.468 mg g^{-1}_{dw}) which was at par with retaining 4 fruits per plant (F_2), whereas retaining all fruits per plant (F_5) resulted in the minimum (2.341 mg g^{-1}_{dw}). The interaction between sowing dates and fruit load were non-significant for total soluble sugars in seeds (mg g^{-1}_{dw}) in the first year and the values ranged from 2.801 - 2.146 mg g^{-1}_{dw}.

In the second year 2023-2024 also, significant effects of sowing dates and fruit load were observed on the total soluble sugars in seeds (mg g^{-1}_{dw}), while their interaction were non-significant. The maximum total soluble sugars in seeds (2.760 mg g^{-1}_{dw}) were recorded with sowing on 30th April (D_2), while the minimum (2.263 mg g^{-1}_{dw}) was observed with sowing on 30th May (D_4). Regarding fruit load treatments, retaining 3 fruits per plant (F_1)

Table 4.4.4: Effect of sowing dates and fruit load on total soluble sugars in seed

Total soluble sugars in seed (mg g^{-1}_{dw})						
Y_1 (2022-2023)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	2.494	2.466	2.426	2.396	2.387	**2.434**
D_2	2.783	2.801	2.639	2.603	2.574	**2.680**
D_3	2.350	2.337	2.319	2.275	2.258	**2.308**
D_4	2.245	2.229	2.172	2.167	2.146	**2.192**
Mean	**2.468**	**2.458**	**2.389**	**2.360**	**2.341**	**2.403**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.015			0.054		
F	0.012			0.035		
D×F	0.034			NS		
Y_2 (2023-2024)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	2.657	2.575	2.549	2.538	2.504	**2.565**
D_2	2.794	2.823	2.762	2.721	2.701	**2.760**
D_3	2.491	2.448	2.394	2.366	2.344	**2.409**
D_4	2.334	2.314	2.278	2.217	2.174	**2.263**
Mean	**2.569**	**2.540**	**2.496**	**2.460**	**2.431**	**2.499**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.014			0.051		
F	0.013			0.037		
D×F	0.032			NS		
Pooled						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	2.576	2.521	2.488	2.467	2.446	**2.499**
D_2	2.789	2.812	2.701	2.662	2.638	**2.720**
D_3	2.421	2.392	2.357	2.321	2.301	**2.358**
D_4	2.290	2.272	2.225	2.192	2.160	**2.228**
Mean	**2.519**	**2.499**	**2.443**	**2.410**	**2.386**	**2.451**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.018			0.054		
F	0.009			0.025		
D×F	0.017			NS		
Y	0.013			0.038		
Y×D	0.025			NS		
Y×F	0.012			NS		
Y×D×F	0.025			NS		

***D =** Sowing dates; D_1= 15th April; D_2 = 30th April; D_3 = 15th May; D_4 = 30th May
***F =** Fruit load; F_1 = 3 fruits; F_2 = 4 fruits; F_3 = 5 fruits; F_4 = 6 fruits; F_5 = all fruits retained (control)
***Y =** Year; Y_1 = 2022-2023; Y_2 = 2023-2024

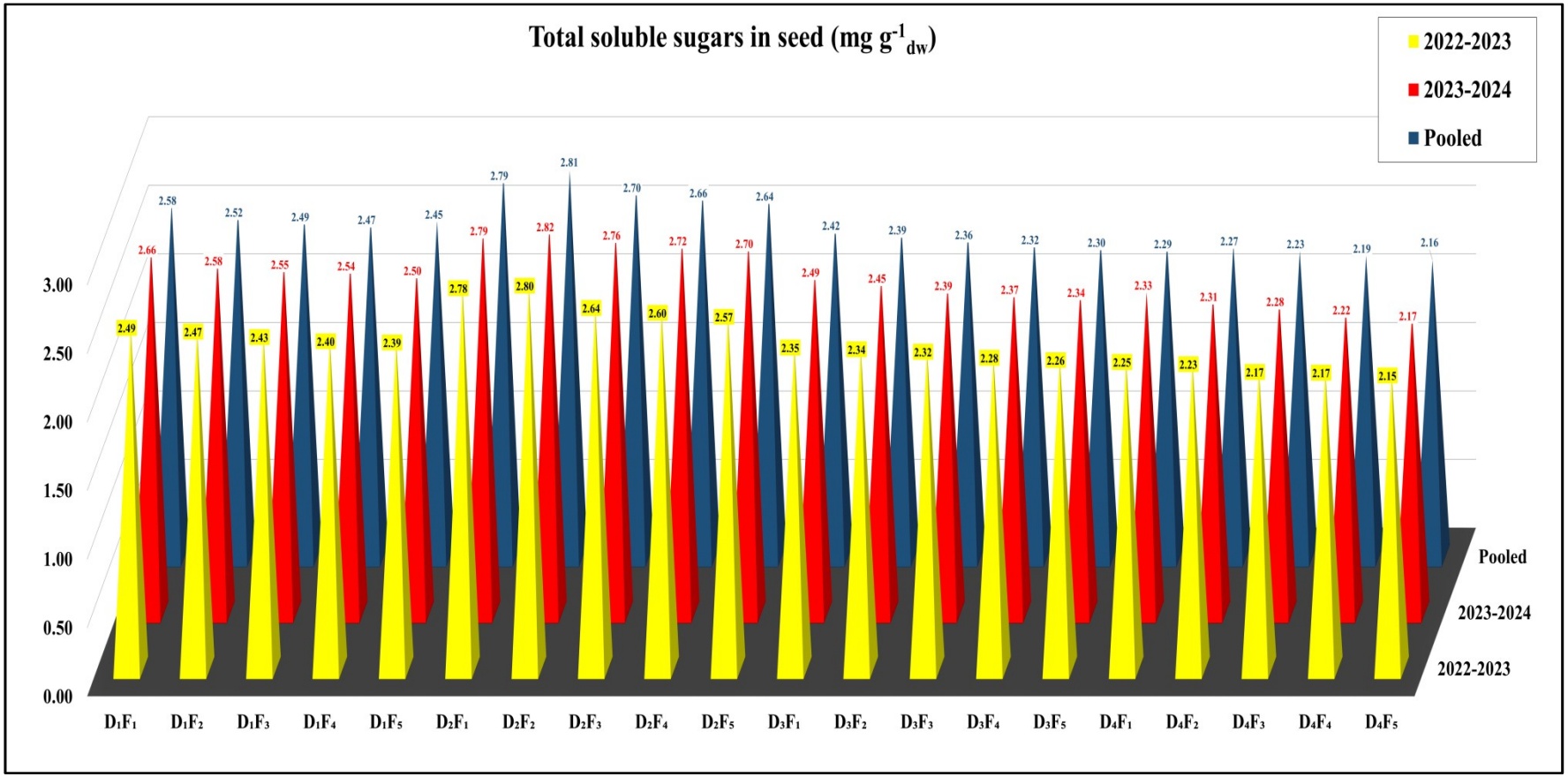


Figure 4.4.4: Effect of sowing dates and fruit load on total soluble sugars in seed

resulted in the maximum total soluble sugars in seeds (2.569 mg $g^{-1}{}_{dw}$) which was at par with retaining 4 fruits per plant (F_2), whereas retaining all fruits per plant (F_5) resulted in the minimum (2.431 mg $g^{-1}{}_{dw}$). The interaction between sowing dates and fruit load were non-significant for total soluble sugars in seeds (mg $g^{-1}{}_{dw}$) in the second year also and the values ranged from 2.823 - 2.174 mg $g^{-1}{}_{dw}$.

The pooled analysis for both years showed significant effects of sowing dates and fruit load, while their interaction was non-significant for the total soluble sugars in seeds (mg $g^{-1}{}_{dw}$). The maximum total soluble sugars in seeds (2.720 mg $g^{-1}{}_{dw}$) were recorded with sowing on 30th April (D_2), while the minimum (2.228 mg $g^{-1}{}_{dw}$) was observed with sowing on 30th May (D_2). Regarding fruit load treatments, retaining 3 fruits per plant (F_1) resulted in the maximum total soluble sugars in seeds (2.519 mg $g^{-1}{}_{dw}$) which was at par with retaining 4 fruits per plant (F_2), whereas retaining all fruits per plant (F_5) resulted in the minimum (2.386 mg $g^{-1}{}_{dw}$). The interaction between sowing dates and fruit load were also non-significant for total soluble sugars in seeds (mg $g^{-1}{}_{dw}$) in the pooled analysis and the values ranged from 2.812 - 2.160 mg $g^{-1}{}_{dw}$.

Across both years, the second year 2023-2024 recorded a higher average total soluble sugar in seeds (2.499 mg $g^{-1}{}_{dw}$) compared to the first year 2022-2023 (2.403 mg $g^{-1}{}_{dw}$). The interaction between years and sowing dates (Y × D) and years and fruit load (Y × F) were non-significant for total soluble sugars in seeds (mg $g^{-1}{}_{dw}$). The three-way interaction between years, sowing dates and fruit load (Y × D × F) was also non-significant for total soluble sugars in seeds (mg $g^{-1}{}_{dw}$).

The current study examined the effects of sowing dates and fruit load on total soluble sugars in seeds (mg $g^{-1}{}_{dw}$) over two years. In both years, sowing on April 30th (D_2) resulted in higher total soluble sugars compared to 30th May (D_4). The higher total soluble sugars in seeds observed with earlier sowing dates (D_2) may be attributed to favourable environmental conditions during seed development, promoting carbohydrate synthesis and storage. Conversely, delayed sowing (D_4) might expose plants to suboptimal conditions, reducing photosynthetic efficiency and sugar accumulation.

Similarly, plants with fewer fruits (F_1) likely allocate more resources per fruit, enhancing seed development and sugar content, whereas higher fruit load (F_5) may lead to resource competition, diminishing seed quality. Retaining 3 fruits per plant (F_1) consistently

led to higher total soluble sugars than retaining all fruits per plant (F_5). These findings suggest that earlier sowing and reduced fruit load enhance sugar accumulation in seeds, potentially improving seed quality.

Gupta et al. (2021a) reported that retaining fewer fruits per vine in cucumber improved seed quality parameters, including total soluble sugars in seeds (mg g^{-1}_{dw}). Their study found that retaining one or two fruits per vine increased sugar content, aligning with our observation that lower fruit load (F_1) enhance sugar accumulation. This consistency across studies underscores the importance of fruit load management in optimizing seed quality.

The second year (2023-2024) recorded higher average total soluble sugars in seeds (mg g^{-1}_{dw}) in seeds compared to the first year (2022-2023). This variation could be attributed to differences in environmental conditions between the two years, such as temperature, rainfall and soil moisture, which can influence carbohydrate metabolism and accumulation in seeds. Environmental factors play a crucial role in seed development and quality, affecting the synthesis and storage of soluble sugars.

The interaction between sowing dates and fruit load, as well as the three-way interaction with years, were non-significant for total soluble sugars in seeds (mg g^{-1}_{dw}) in seeds. This indicates that the effects of sowing dates and fruit load on total soluble sugars in seeds (mg g^{-1}_{dw}) are independent of each other and consistent across different years. Such consistency suggests that both factors can be managed separately to optimize seed quality without concern for their combined effects.

4.4.5 Total soluble proteins in seed (mg g^{-1}_{dw})

Total soluble proteins in seeds (mg g^{-1}_{dw}) refer to the concentration of total soluble protein molecules present within the dry weight of seeds. These proteins are essential macromolecules that play a crucial role in seed metabolism, development and germination. During seed maturation, proteins are synthesized and stored in various forms, primarily as storage proteins, which serve as vital reserves for the germinating seedling. Seeds with high protein content are considered superior as they ensure better germination, higher vigour and stronger seedling establishment.

The data collected over two consecutive years (2022-2023 and 2023-2024), along with pooled analysis, revealed significant variations in total soluble proteins in seeds (mg g^{-1}_{dw}) as illustrated in Table 4.4.5 and Figure 4.4.5.

During the first year 2022-2023, significant effects of sowing dates and fruit load were observed on the total soluble proteins in seeds (mg g^{-1}_{dw}), while their interaction were non-significant. The maximum total soluble proteins in seeds (155.79 mg g^{-1}_{dw}) were recorded with sowing on 30th April (D_2), while the minimum (125.05 mg g^{-1}_{dw}) was observed with sowing on 30th May (D_4). Regarding fruit load treatments, retaining 3 fruits per plant (F_1) resulted in the maximum total soluble proteins in seeds (144.04 mg g^{-1}_{dw}), whereas retaining all fruits per plant (F_5) resulted in the minimum (136.26 mg g^{-1}_{dw}). The interaction between sowing dates and fruit load were non-significant for total soluble proteins in seeds (mg g^{-1}_{dw}) in the first year and the values ranged from 159.39 - 122.05 mg g^{-1}_{dw}.

In the second year 2023-2024, significant effects of sowing dates and fruit load and their interaction were observed on the total soluble proteins in seeds (mg g^{-1}_{dw}). The maximum total soluble proteins in seeds (155.95 mg g^{-1}_{dw}) were recorded with sowing on 30th April (D_2), while the minimum (125.49 mg g^{-1}_{dw}) was observed with sowing on 30th May (D_4). Regarding fruit load treatments, retaining 3 fruits per plant (F_1) resulted in the maximum total soluble proteins in seeds (145.56 mg g^{-1}_{dw}) which was at par with retaining 4 fruits per plant (F_2), whereas retaining all fruits per plant (F_5) resulted in the minimum (137.80 mg g^{-1}_{dw}). The combination of 30th April sowing with 3 fruits per plant retained (D_2F_1) resulted in the maximum total soluble proteins in seeds (158.71 mg g^{-1}_{dw}), while the combination of 30th May sowing with all fruits per plant retained (D_4F_5) led to the lowest (120.90 mg g^{-1}_{dw}) total soluble proteins in seeds.

The pooled analysis for both years showed significant effects of sowing dates and fruit load, while their interaction was non-significant for the total soluble proteins in seeds (mg g^{-1}_{dw}). The maximum total soluble proteins in seeds (155.87 mg g^{-1}dw) were recorded with sowing on 30th April (D_2), while the minimum (125.27 mg g^{-1}_{dw}) was observed with sowing on 30th May (D_4). Regarding fruit load treatments, retaining 3 fruits per plant (F_1) resulted in the maximum total soluble proteins in seeds (144.80 mg g^{-1}_{dw}), whereas retaining all fruits per plant (F_5) resulted in the minimum (137.03 mg g^{-1}_{dw}). The interaction between sowing dates and fruit load were also non-significant for total soluble proteins in seeds (mg g^{-1}_{dw}) in the pooled analysis and the values ranged from 159.05 - 121.47 mg g^{-1}_{dw}.

Table 4.4.5: Effect of sowing dates and fruit load on total soluble proteins in seed

Total soluble proteins in seed (mg g^{-1}_{dw})						
Y_1 (2022-2023)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	149.77	148.03	145.93	143.29	141.01	**145.60**
D_2	159.39	157.73	155.43	154.05	152.36	**155.79**
D_3	139.25	136.33	135.35	132.92	129.62	**134.69**
D_4	127.77	127.04	124.75	123.63	122.05	**125.05**
Mean	**144.04**	**142.28**	**140.36**	**138.47**	**136.26**	**140.28**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.70			2.49		
F	0.29			0.84		
D×F	1.58			NS		
Y_2 (2023-2024)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	151.12	148.97	146.96	145.26	144.05	**147.27**
D_2	158.71	157.98	156.16	154.43	152.48	**155.95**
D_3	141.31	139.88	138.03	135.76	133.77	**137.75**
D_4	131.12	128.42	124.90	122.12	120.90	**125.49**
Mean	**145.56**	**143.81**	**141.51**	**139.39**	**137.80**	**141.61**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.50			1.76		
F	0.26			0.77		
D×F	1.11			1.73		
Pooled						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	150.44	148.50	146.44	144.27	142.53	**146.44**
D_2	159.05	157.85	155.79	154.24	152.42	**155.87**
D_3	140.28	138.10	136.69	134.34	131.70	**136.22**
D_4	129.44	127.73	124.82	122.88	121.47	**125.27**
Mean	**144.80**	**143.05**	**140.94**	**138.93**	**137.03**	**140.95**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.41			1.25		
F	0.19			0.56		
D×F	0.39			NS		
Y	0.29			0.88		
Y×D	0.58			NS		
Y×F	0.28			NS		
Y×D×F	0.56			1.58		

***D =** Sowing dates; D_1= 15th April; D_2 = 30th April; D_3 = 15th May; D_4 = 30th May
***F =** Fruit load; F_1 = 3 fruits; F_2 = 4 fruits; F_3 = 5 fruits; F_4 = 6 fruits; F_5 = all fruits retained (control)
***Y =** Year; Y_1 = 2022-2023; Y_2 = 2023-2024

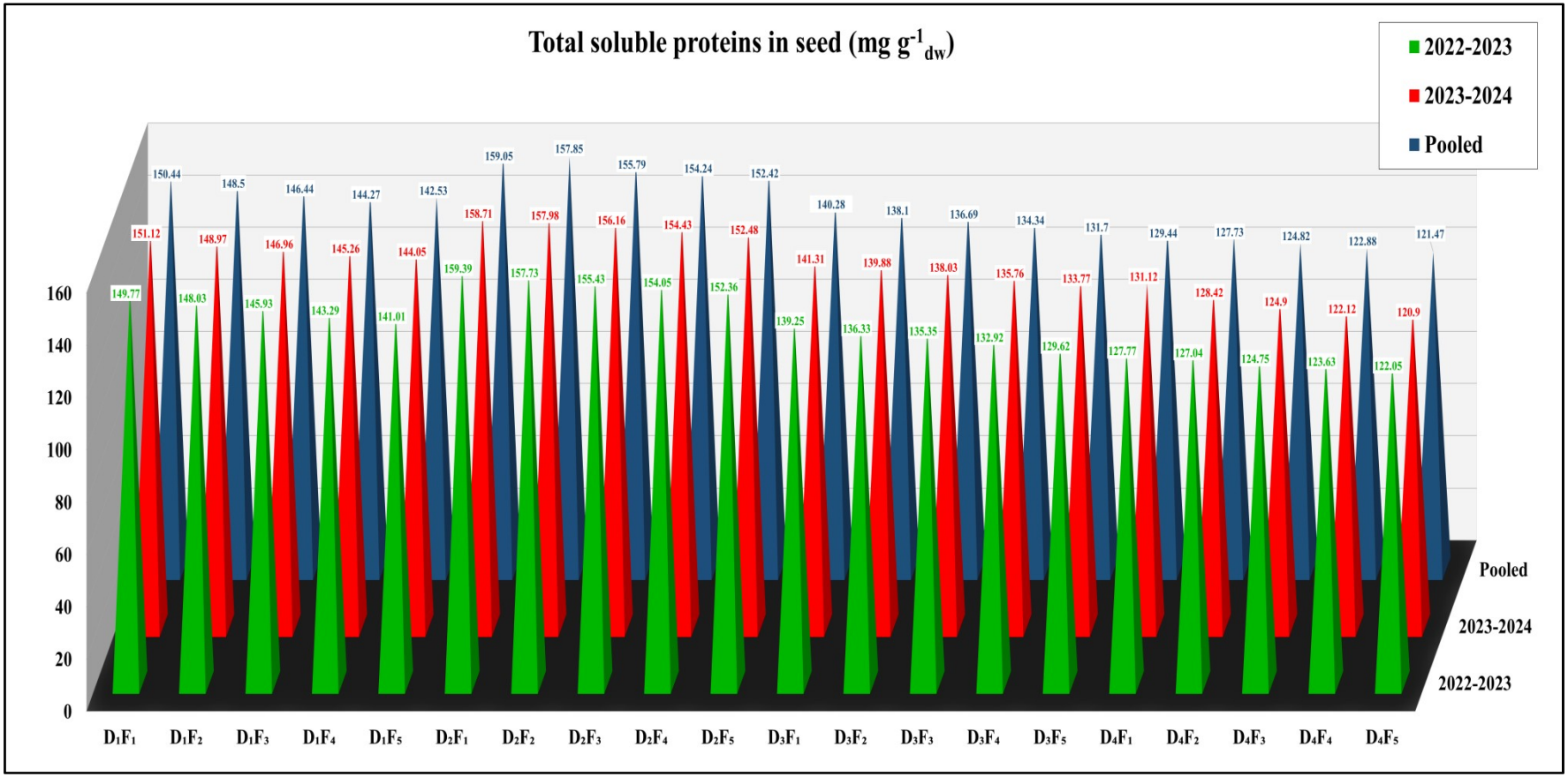


Figure 4.4.5: Effect of sowing dates and fruit load on total soluble proteins in seed

Across both years, the second year 2023-2024 recorded a higher average total soluble protein in seeds (141.61 mg g^{-1}_{dw}) compared to the first year 2022-2023 (140.28 mg g^{-1}_{dw}). The interaction between years and sowing dates (Y × D) and years and fruit load (Y × F) were non-significant for total soluble proteins in seeds (mg g^{-1}_{dw}). The three-way interaction between years, sowing dates and fruit load (Y × D × F) was also non-significant for total soluble proteins in seeds (mg g^{-1}_{dw}).

The results of this study demonstrate the significant impact of sowing dates and fruit load on total soluble proteins in seeds (mg g^{-1}_{dw}) across two consecutive years, 2022-2023 and 2023-2024. While the interaction between sowing dates and fruit load were non-significant, both factors independently influenced the total soluble protein content in seeds, underscoring their critical role in seed quality.

The highest total soluble proteins in seeds were consistently recorded with sowing on 30th April (D_2), both in the first and second years, with the lowest values observed from sowing on 30th May (D_4). This pattern suggests that earlier sowing dates are beneficial for seed protein accumulation. Environmental conditions at the time of sowing, such as temperature, light and soil moisture, are likely to have been more favourable in late April, contributing to better seed development and increased protein synthesis. The decrease in protein content with later sowing may reflect the potentially suboptimal growing conditions of late May, including higher temperatures or reduced rainfall, which could have negatively impacted seed development and nutrient accumulation. This aligns with the results of Borowska and Prusiński (2021) and Paul et al. (2016) where they recorded higher total soluble proteins in seeds (mg g^{-1}_{dw}) under early sowing conditions.

Similarly, the effect of fruit load treatments on total soluble proteins in seeds highlights the importance of managing plant reproductive resources. Retaining 3 fruits per plant (F_1) resulted in the highest levels of total soluble proteins in seeds, while retaining all fruits per plant (F_5) produced the lowest protein content. These findings suggest that a moderate fruit load allows for better allocation of resources to seed development, leading to improved seed quality. In contrast, a higher fruit load may spread the plant's resources thinly, leading to suboptimal seed quality. This aligns with the results of Gupta et al. (2021a), where a controlled fruit load, such as retaining one or two fruits per vine, led to the best balance of seed quality and yield.

In the second year (2023-2024), the interaction between sowing dates and fruit load also demonstrated significant effects on total soluble proteins in seeds, with the combination of sowing on 30th April and retaining 3 fruits per plant (D_2F_1) resulting in the highest protein content. This highlights that while both sowing dates and fruit load independently influence protein accumulation, their combined effects can lead to even more pronounced differences in seed quality. However, the non-significant interaction between sowing dates and fruit load across both years and the pooled data suggest that the individual effects of these factors are more prominent than any synergistic interaction.

Moreover, the second year of the study recorded a slightly higher average total soluble protein content compared to the first year, possibly due to variations in environmental conditions, crop management practices, or genetic differences in the plants.

4.4.6 Total starch contents in seed (mg g^{-1}_{dw})

Total starch content in seeds (mg g^{-1}_{dw}) is an important biochemical parameter that directly influences seed quality. Starch serves as a primary energy reserve in seeds, playing a crucial role during seed germination and early seedling development. It is synthesized and stored in the endosperm or cotyledons, depending on the seed type and is broken down into simpler sugars during germination to fuel the growth of the seedling. The higher the starch content in seeds, the more energy is available for the germination process, which can lead to improved seed vigour and better establishment of plants. In the context of seed quality, high starch content is generally associated with improved seed health, higher vigour and better field performance. It also impacts the seed's shelf life, as starch reserves help maintain seed viability during storage. Seeds with higher starch content tend to have enhanced germination rates and better early growth, which are essential traits for successful crop establishment.

The data collected over two consecutive years (2022-2023 and 2023-2024), along with pooled analysis, revealed significant variations in total starch contents in seeds (mg g^{-1}_{dw}) as given in Table 4.4.6 and illustrated in Figure 4.4.6.

During the first year 2022-2023, significant effects of sowing dates and fruit load were observed on the total starch contents in seeds (mg g^{-1}_{dw}), while their interaction were non-significant. The maximum total starch contents in seeds (118.62 mg g^{-1}_{dw}) were recorded with sowing on 30th April (D_2), while the minimum (111.03 mg g^{-1}_{dw}) was observed with sowing on 30th May (D_4). Regarding fruit load treatments, retaining 3 fruits per plant (F_1) resulted in the maximum total starch contents in seeds (115.89 mg g^{-1}_{dw}) whereas retaining all fruits per plant (F_5) resulted in the minimum (113.81 mg g^{-1}_{dw}).

Table 4.4.6: Effect of sowing dates and fruit load on total starch contents in seed

Total starch contents in seed (mg g^{-1}_{dw})						
Y_1 (2022-2023)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	117.36	117.03	116.10	115.63	115.06	**116.24**
D_2	119.40	119.10	118.73	118.23	117.63	**118.62**
D_3	114.70	114.46	113.80	112.86	112.40	**113.64**
D_4	112.10	111.33	110.96	110.60	110.17	**111.03**
Mean	**115.89**	**115.48**	**114.90**	**114.33**	**113.81**	**114.88**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.08			0.31		
F	0.09			0.26		
D×F	0.19			NS		
Y_2 (2023-2024)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	117.63	117.16	116.66	116.23	115.60	**116.66**
D_2	119.70	119.60	118.86	118.56	118.06	**118.96**
D_3	115.00	114.50	113.80	113.46	112.56	**113.86**
D_4	112.26	111.80	111.36	110.46	110.23	**111.22**
Mean	**116.15**	**115.76**	**115.17**	**114.68**	**114.11**	**115.17**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.07			0.26		
F	0.07			0.22		
D×F	0.17			NS		
Pooled						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	117.50	117.10	116.38	115.93	115.33	**116.45**
D_2	119.55	119.35	118.80	118.40	117.85	**118.79**
D_3	114.85	114.48	113.80	113.16	112.48	**113.75**
D_4	112.18	111.56	111.16	110.53	110.20	**111.13**
Mean	**116.02**	**115.62**	**115.03**	**114.50**	**113.96**	**115.03**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.07			0.21		
F	0.06			0.17		
D×F	0.12			NS		
Y	0.05			0.15		
Y×D	0.10			0.30		
Y×F	0.08			NS		
Y×D×F	0.17			NS		

***D =** Sowing dates; D_1= 15th April; D_2 = 30th April; D_3 = 15th May; D_4 = 30th May
***F =** Fruit load; F_1 = 3 fruits; F_2 = 4 fruits; F_3 = 5 fruits; F_4 = 6 fruits; F_5 = all fruits retained (control)
***Y =** Year; Y_1 = 2022-2023; Y_2 = 2023-2024

The interaction between sowing dates and fruit load were non-significant for total starch contents in seeds (mg g^{-1}_{dw}) in the first year and the values ranged from 119.40 - 110.17 mg g^{-1}_{dw}.In the second year 2023-2024, significant effects of sowing dates and fruit load was observed on the total starch contents in seeds (mg g^{-1}_{dw}), while their interaction were non-significant. The maximum total starch contents in seeds (118.96 mg g^{-1}_{dw}) were recorded with sowing on 30th April (D_2), while the minimum (111.22 mg g^{-1}_{dw}) was observed with sowing on 30th May (D_4). Regarding fruit load treatments, retaining 3 fruits per plant (F_1) resulted in the maximum total starch contents in seeds (116.15 mg g^{-1}_{dw}), whereas retaining all fruits per plant (F_5) resulted in the minimum (114.11 mg g^{-1}_{dw}). The interaction between sowing dates and fruit load were non-significant for total starch contents in seeds (mg g^{-1}_{dw}) in the second year and the values ranged from 119.70 - 110.23 mg g^{-1}_{dw}.

The pooled analysis for both years showed significant effects of sowing dates and fruit load, while their interaction was non-significant for the total starch contents in seeds (mg g^{-1}_{dw}). The maximum total starch contents in seeds (118.79 mg g^{-1}_{dw}) were recorded with sowing on 30th April (D_2), while the minimum (111.13 mg g^{-1}_{dw}) was observed with sowing on 30th May (D_4). Regarding fruit load treatments, retaining 3 fruits per plant (F_1) resulted in the maximum total starch contents in seeds (116.02 mg g^{-1}_{dw}), whereas retaining all fruits per plant (F_5) resulted in the minimum (113.96 mg g^{-1}_{dw}). The interaction between sowing dates and fruit load was also non-significant for total starch contents in seeds (mg g^{-1}_{dw}) in the pooled analysis and the values ranged from 119.55 - 110.20 mg g^{-1}_{dw}.

Across both years, the second year 2023-2024 recorded a higher average total starch content in seeds (115.17 mg g^{-1}_{dw}) compared to the first year 2022-2023 (114.88 mg g^{-1}_{dw}). The second year 2023-2024 sowing on 30th April (Y_2D_2) resulted in the maximum total starch contents in seeds (118.96 mg g^{-1}_{dw}), while the first year 2022-2023 sowing on 30th May (Y_2D_4) led to the lowest (111.03 mg g^{-1}_{dw}) total starch contents in seeds. The interaction between years and fruit load (Y × F) were non-significant for total starch contents in seeds (mg g^{-1}_{dw}). The three-way interaction between years, sowing dates and fruit load (Y × D × F) was also non-significant for total starch contents in seeds (mg g^{-1}_{dw}).

The results revealed that the effects of sowing dates and fruit load on the total starch contents in seeds (mg g^{-1}_{dw}) across two consecutive years (2022-2023 and 2023-2024). The results indicate significant effects of sowing dates and fruit load on total starch contents in

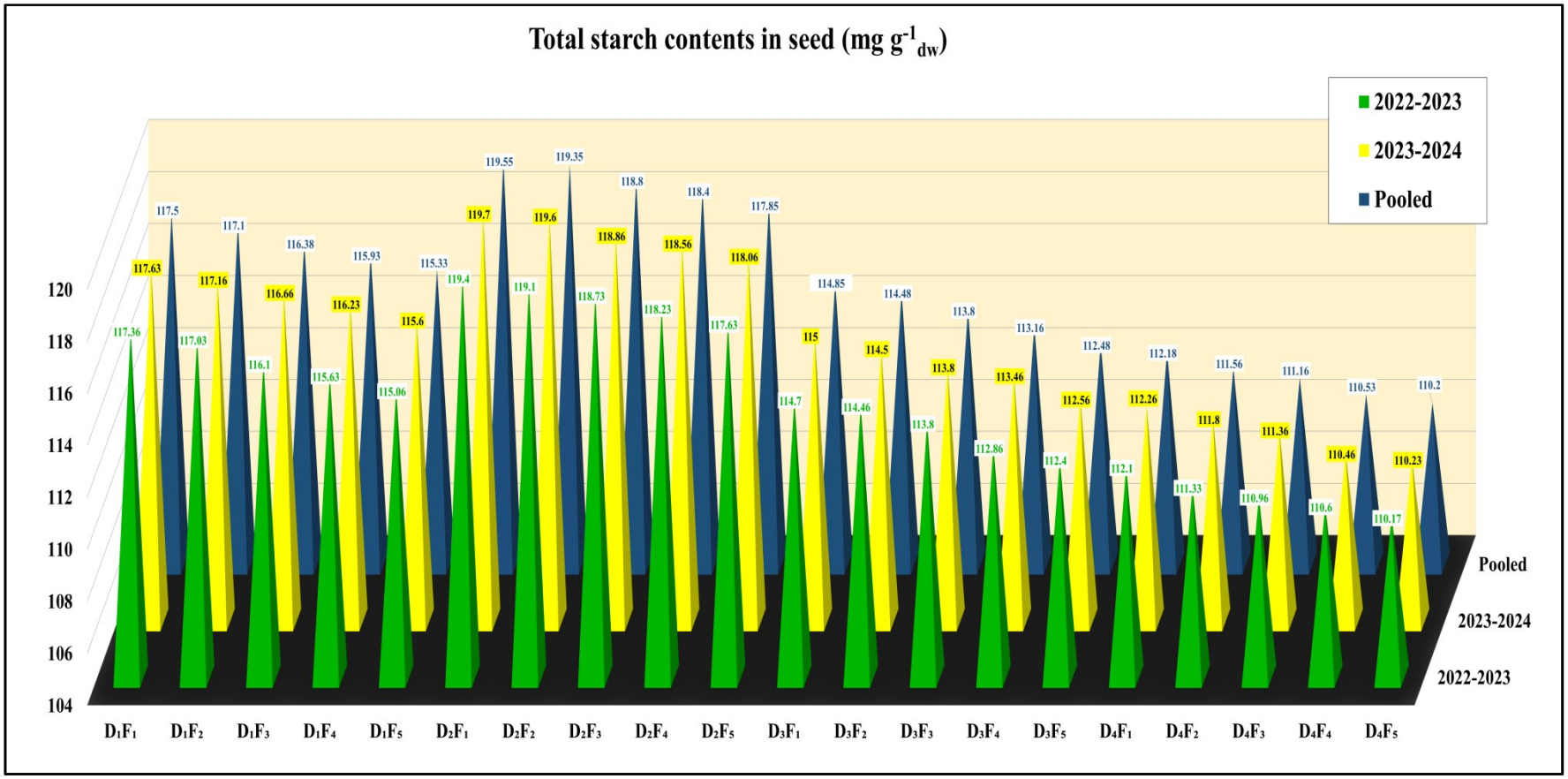


Figure 4.4.6: Effect of sowing dates and fruit load on total starch contents in seed

seeds (mg g^{-1}_{dw}), while their interactions were non-significant, suggesting that the individual effects of these factors are more influential than their combined influence.

In both years, sowing on 30th April (D_2) resulted in the highest starch content in seeds, while sowing on 30th May (D_4) led to the lowest starch content. The result aligns with the concept that earlier sowing generally provides better growing conditions for the plant, such as more favourable temperatures and sufficient sunlight, which may enhance the accumulation of starch in seeds. The higher starch content observed in seeds from plants sown earlier (D_2) could be attributed to the longer growing period and a more optimized developmental stage for starch biosynthesis and storage before the plant reaches maturity. This is consistent with other studies suggesting that sowing time plays a critical role in the physiological development of plants, influencing the synthesis and accumulation of storage compounds, including starch (Tomar et al. 2010).

Regarding the fruit load treatments, retaining 3 fruits per plant (F_1) resulted in the highest starch contents in seeds, while retaining all fruits per plant (F_5) led to the lowest starch contents. This can be explained by the competition for assimilates among the developing fruits. When fewer fruits are retained, more resources are available for each fruit, which can lead to higher starch accumulation in the seeds. In contrast, when all fruits are retained, the limited resources available for the development of each fruit and seed may result in reduced starch accumulation. This result supports findings from previous studies, which have shown that reducing the number of fruits per plant can improve the quality and nutrient content of seeds (Gupta et al. 2021a).

The non-significant interactions between sowing dates and fruit load suggest that the effects of these factors on starch content in seeds are independent of one another. While sowing dates and fruit load are both important factors influencing starch accumulation, their effects do not appear to depend on each other, which may reflect the distinct physiological processes involved in the formation of starch in seeds.

Across both years, the second year (2023-2024) recorded a slightly higher average total starch content in seeds compared to the first year (2022-2023). This could be due to various factors such as environmental conditions, soil fertility and weather patterns, which can vary from year to year and influence the overall growth and yield of plants. However, the overall trend of higher starch content with earlier sowing and lower fruit load remains

consistent across both years, indicating the robustness of these effects. The enhanced seed performance in terms of the higher total starch contents in seeds (mg g^{-1}_{dw}) may be associated with the 1000 seed weight, which is closely linked to seed size, indicating a greater accumulation of dry matter in larger seeds.

The pooled analysis of both years confirmed the significant effects of sowing dates and fruit load treatments on total starch contents in seeds (mg g^{-1}_{dw}), further supporting the notion that early sowing and a moderate fruit load are favourable for higher starch accumulation in seeds. The non-significant interactions between these factors across years suggest that the effects of sowing dates and fruit load on starch content in seeds are stable over time, which has important implications for optimizing crop management practices to improve seed quality.

4.4.7 Oil content in seeds (%)

Oil content in cucumber seeds is a crucial parameter in determining their overall quality. It plays a significant role in defining the nutritional and commercial value of the seeds. Higher oil content is often associated with better seed quality, as it indicates the presence of essential fatty acids, which are vital for various metabolic processes in the plant. Oil content in seeds is typically calculated by extracting the oil using solvent extraction methods, such as the Soxhlet apparatus method, followed by weighing the oil obtained. The oil content is expressed as a percentage of the total seed weight.

The data collected over two consecutive years (2022-2023 and 2023-2024), along with pooled analysis, revealed significant variations in oil content in seed (%) as given in Table 4.4.7 and illustrated in Figure 4.4.7.

During the first year 2022-2023, significant effects of sowing dates and fruit load were observed for the oil content in seeds (%), while their interactions were non-significant.

The maximum oil content in seeds (26.63 %) was recorded with sowing on 30th April (D_2), while the minimum (22.96 %) was observed with sowing on 30th May (D_4). Regarding fruit load treatments, retaining 3 fruits per plant (F_1) resulted in the maximum oil content in seeds (25.35 %), whereas retaining all fruits per plant (F_5) resulted in the minimum (24.36 %). The interaction between sowing dates and fruit load was non-significant for oil content in seeds (%) in the first year and the values ranged from 27.06 - 22.57 %.

In the second year 2023-2024, significant effects of sowing dates and fruit load were observed on the oil content in seeds (%), while their interactions were non-significant. The maximum oil content in seeds (27.94 %) was recorded with sowing on 30th April (D_2), while the minimum (22.19 %) was observed with sowing on 30th May (D_4). Regarding fruit load treatments, retaining 3 fruits per plant (F_1) resulted in the maximum oil content in seeds (25.81 %), whereas retaining all fruits per plant (F_5) resulted in the minimum (24.42 %). The interaction between sowing dates and fruit load was non-significant for oil content in seeds (%) in the second year as well and the values ranged from 28.49 - 21.71 %.

The pooled analysis for both years showed significant effects of sowing dates and fruit load and their interaction was also significant for the oil content in seeds (%). The maximum oil content in seeds (27.28 %) was recorded with sowing on 30th April (D_2), while the minimum (22.57 %) was observed with sowing on 30th May (D_4).

Regarding fruit load treatments, retaining 3 fruits per plant (F_1) resulted in the maximum oil content in seeds (25.58 %) which was at par with retaining 4 fruits per plant (F_2), whereas retaining all fruits per plant (F_5) resulted in the minimum (24.39 %). In the pooled analysis, sowing on 30th April with 3 fruits per plant retained (D_2F_1) resulted in the maximum oil content in seeds (27.77 %), while the sowing on 30th May with all fruits per plant retained (D_4F_5) led to the lowest (22.14 %) oil content in seeds.

Across both years, the second year 2023-2024 recorded a higher average oil content in seeds (25.13 %) compared to the first year 2022-2023 (24.82 %). The interaction between years and fruit load (Y × D) showed that in the second year 2023-2024 sowing on 30th April (Y_2D_2) resulted in the maximum oil content in seeds (27.94 %), while the second year 2023-2024 sowing on 30th May (Y_2D_4) led to the lowest (21.71 %) oil content in seeds. The interaction between years and fruit load (Y × F) revealed that in the second year 2023-2024 with retaining of 3 fruits per plant (Y_2F_2) resulted in the maximum oil content in seeds (25.81 %), while in the first year 2022-2023 with retaining of all fruits per plant (Y_2F_5) led to the lowest oil content (24.36 %) in seeds. The three-way interaction between years, sowing dates and fruit load (Y × D × F) revealed that maximum oil content in seeds (28.49 %) was recorded in the second year 2023-2024 with sowing on 30th April and 3 fruits per plant retained ($Y_2D_2F_1$) whereas the minimum oil content (21.71 %) in seeds was recorded in the second year with sowing on 30th May and all fruits per plant retained ($Y_2D_4F_5$).

Table 4.4.7: Effect of sowing dates and fruit load on oil content in seeds

Oil content in seeds (%)						
Y_1 (2022-2023)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	26.01 (5.10)	25.78 (5.08)	25.40 (5.04)	25.26 (5.03)	24.97 (5.00)	**25.48 (5.05)**
D_2	27.06 (5.20)	26.87 (5.18)	26.66 (5.16)	26.38 (5.14)	26.17 (5.12)	**26.63 (5.16)**
D_3	24.82 (4.98)	24.44 (4.94)	24.21 (4.92)	23.97 (4.90)	23.75 (4.87)	**24.24 (4.92)**
D_4	23.50 (4.85)	23.06 (4.80)	22.89 (4.78)	22.79 (4.77)	22.57 (4.75)	**22.96 (4.79)**
Mean	**25.35 (5.03)**	**25.04 (5.00)**	**24.79 (4.98)**	**24.60 (4.96)**	**24.36 (4.94)**	**24.82 (4.98)**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.02			0.09		
F	0.03			0.08		
D×F	0.05			NS		
Y_2 (2023-2024)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	26.91 (5.19)	26.73 (5.17)	26.15 (5.11)	25.86 (5.09)	25.38 (5.04)	**26.20 (5.12)**
D_2	28.49 (5.34)	28.34 (5.32)	27.99 (5.29)	27.68 (5.26)	27.20 (5.22)	**27.94 (5.29)**
D_3	25.07 (5.01)	24.60 (4.96)	24.27 (4.93)	23.76 (4.87)	23.39 (4.84)	**24.21 (4.92)**
D_4	22.77 (4.77)	22.54 (4.75)	22.11 (4.70)	21.81 (4.67)	21.71 (4.66)	**22.19 (4.71)**
Mean	**25.81 (5.08)**	**25.55 (5.05)**	**25.13 (5.01)**	**24.78 (4.98)**	**24.42 (4.94)**	**25.13 (5.01)**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.09			0.34		
F	0.05			0.15		
D×F	0.22			NS		
Pooled						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	26.46 (5.14)	26.25 (5.12)	25.78 (5.08)	25.56 (5.06)	25.18 (5.02)	**25.84 (5.08)**
D_2	27.77 (5.27)	27.61 (5.25)	27.32 (5.23)	27.03 (5.20)	26.68 (5.17)	**27.28 (5.22)**
D_3	24.94 (4.99)	24.52 (4.95)	24.24 (4.92)	23.86 (4.88)	23.57 (4.85)	**24.23 (4.92)**
D_4	23.13 (4.81)	22.80 (4.77)	22.50 (4.74)	22.30 (4.72)	22.14 (4.71)	**22.57 (4.75)**
Mean	**25.58 (5.06)**	**25.30 (5.03)**	**24.96 (5.00)**	**24.69 (4.97)**	**24.39 (4.94)**	**24.98 (5.00)**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.06			0.18		
F	0.03			0.08		
D×F	0.06			0.17		
Y	0.04			0.12		
Y×D	0.08			0.25		
Y×F	0.04			0.12		
Y×D×F	0.08			NS		

***D =** Sowing dates; D_1= 15th April; D_2 = 30th April; D_3 = 15th May; D_4 = 30th May
***F =** Fruit load; F_1 = 3 fruits; F_2 = 4 fruits; F_3 = 5 fruits; F_4 = 6 fruits; F_5 = all fruits retained (control)
***Y =** Year; Y_1 = 2022-2023; Y_2 = 2023-2024
*Figures in parentheses are square root transformed values

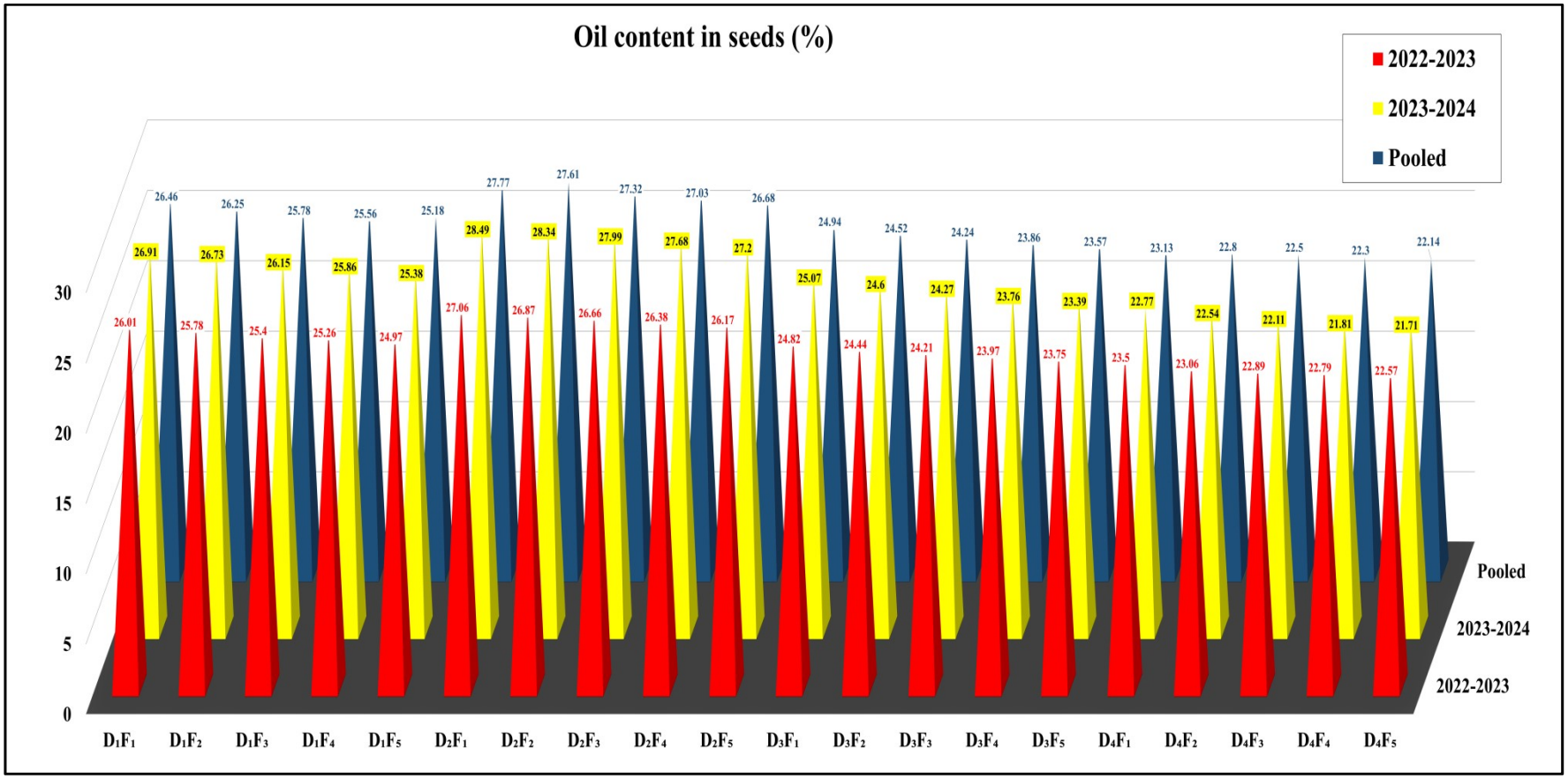


Figure 4.4.7: Effect of sowing dates and fruit load on oil content in seeds

The oil content in cucumber seeds was significantly influenced by sowing dates and fruit load treatments, though interactions between these factors were found to be non-significant in most cases. The sowing dates had a consistent impact on oil content, with seeds from plants sown on 30th April (D_2) consistently showing higher oil content than those sown on 30th May (D_4). This trend was observed across both years (2022-2023 and 2023-2024), with the highest oil content recorded in seeds from the 30th April (D_2) sowing. The lower oil content observed in the 30th May (D_4) sowing can be attributed to the different environmental conditions prevailing during these periods, which could affect the physiological processes such as photosynthesis and metabolic activities, leading to variation in oil accumulation. Gupta et al. (2021b) have mentioned that variable environmental factors may significantly affect oil content in seed of cucumber.

Fruit load also significantly influenced oil content in seeds, with the highest oil content found in seeds from plants that retained 3 fruits (F_1). The retention of all fruits per plant (F_5) resulted in the lowest oil content. This could be due to the resource allocation pattern in the plant, where retaining fewer fruits may allow more energy and nutrients to be diverted towards seed development, leading to higher oil accumulation. On the other hand, plants with a higher fruit load might have to allocate resources to support the development of multiple fruits, reducing the resources available for individual seed maturation and consequently lowering the oil content. These observations are consistent with Gupta et al. (2021a), who suggested that fruit load management plays a crucial role in seed composition, including oil content.

The interaction between sowing dates and fruit load was non-significant in both years and the pooled analysis, suggesting that the effects of sowing dates and fruit load on oil content are relatively independent of each other. However, when considering the combined effect of both factors, the highest oil content was observed when sowing occurred on 30th April with 3 fruits retained per plant (D_2F_1). This suggests that, while the factors individually impact seed oil content, their combined influence may lead to optimal conditions for oil accumulation in cucumber seeds.

When comparing across years, the second year (2023-2024) consistently recorded higher oil content than the first year (2022-2023), indicating that environmental factors such as temperature, humidity and sunlight during the growing seasons may have influenced oil accumulation. The significant Y × D interaction observed in the pooled analysis further

supports the notion that seasonal variations play an important role in the oil content of cucumber seeds. For instance, in 2023-2024, sowing on 30th April resulted in the highest oil content, while sowing on 30th May in the same year led to the lowest, suggesting that the conditions in 2023-2024 were more conducive to oil content in seeds than those in 2022-2023.

From the results, it can be concluded that both sowing dates and fruit load are critical factors influencing the oil content in cucumber seeds, with early sowing and fewer fruits per plant leading to higher oil content.

Chord Diagram for seed physiological assays

The chord diagram depicted in Figure 4.4.8 visually represents the interconnections between various seed physiological assays, such as electrical conductivity of seed leachates, total soluble sugar and protein content in seed leachates, total soluble sugar, protein content and starch content in seeds and oil content percentage in seeds, across different treatments. The diagram displays the parameters and treatments in the outer segments, with the connecting chords illustrating how these factors influence each other. It underscores the intricate relationships among the parameters and how each one responds to the treatments.

Focusing on the arcs inside the diagram, these arcs connect the combinations to the traits they influence. For instance, the D_2F_1 combination shows strong connections with parameters total soluble sugar, protein content and starch content in seeds and oil content percentage in seeds, highlighting its effectiveness in improving seed quality. Additionally, the lower values of electrical conductivity of seed leachates, total soluble sugar and protein content in seed leachates for D_2F_1 further emphasize the positive impact of this combination.

Electrical conductivity (EC) of seed leachates is a critical indicator of seed membrane integrity and overall seed health. Seeds with lower EC values tend to have more intact cellular membranes, enhancing their ability to absorb water efficiently during imbibition and supporting healthy metabolic activity during germination.

The total soluble sugars (TSS) and total soluble proteins (TSP) in both seeds and seed leachates serve as key markers of metabolic activity and seed health. Elevated TSS and TSP levels in seeds generally point to improved nutritional quality, which can promote vigorous seedling growth. Conversely, lower levels of TSS and TSP in seed leachates are indicative of

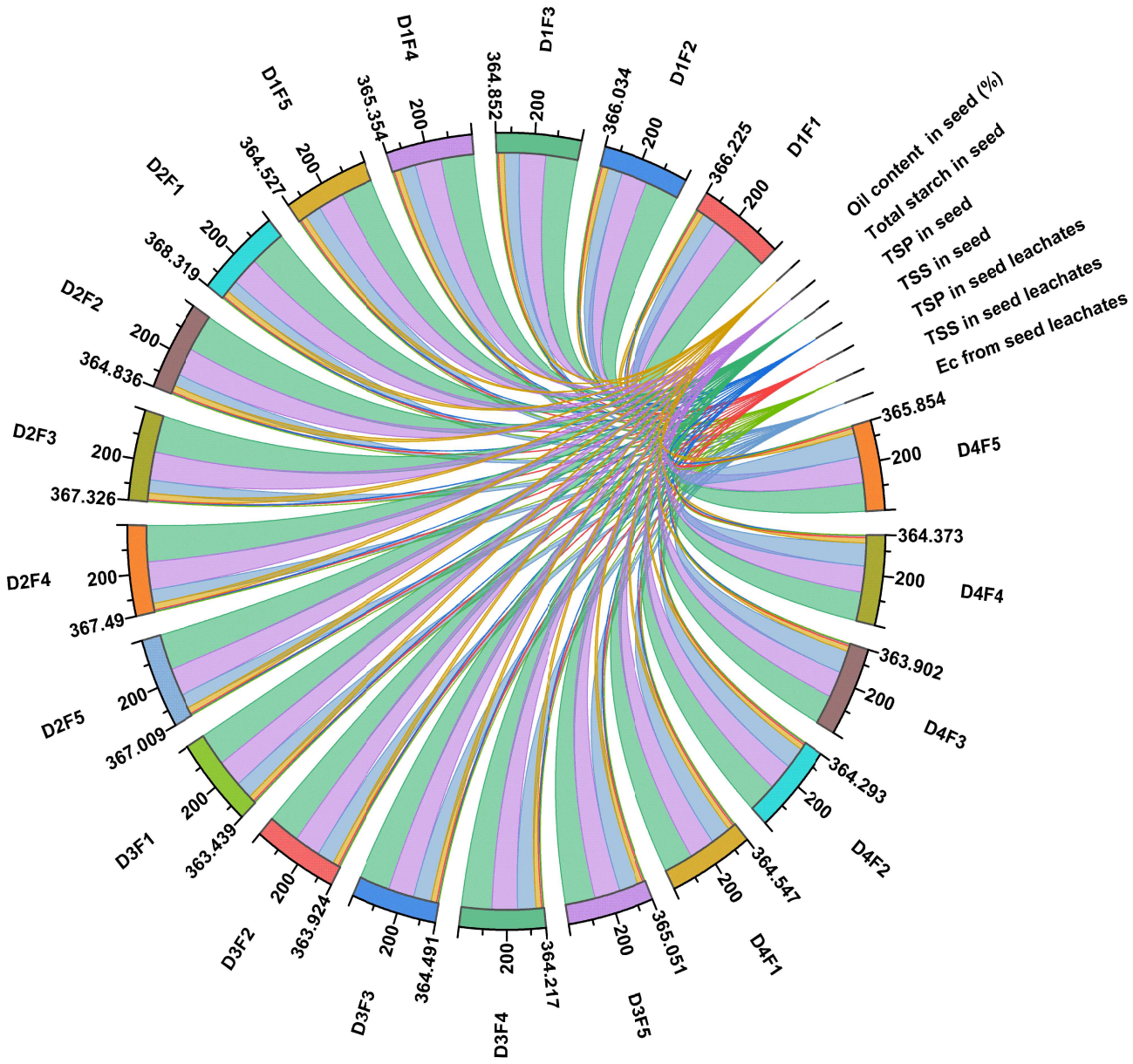


Figure 4.4.8: Analytical visualization of seed physiological assays weightage using chord diagram

better seed quality, as they suggest reduced leakage of cellular contents and more efficient metabolic regulation.

The starch content in seeds plays a crucial role in providing the energy necessary for germination. As a major carbohydrate reserve, starch breakdown during germination supplies energy for seedling growth, affecting both the speed and success of the germination process. Oil content in seeds is another important factor that directly impacts seed quality. Higher oil content often correlates with better energy reserves, contributing positively to seedling growth and development by providing additional resources during the early stages of seedling establishment.

The treatments in the D_2 and D_3 groups consistently show superior outcomes for key physiological parameters. These treatments result in higher oil content, starch, TSS and TSP levels in seeds, along with lower EC, TSS and TSP values in seed leachates. These results suggest that D_2 and D_3 treatments are particularly effective in enhancing seed quality and vigour, promoting healthier and more robust seedling growth. Conversely, certain treatments lead to lower seed quality, as evidenced by higher EC values and reduced seed performance. These findings imply that these treatments may involve less optimal conditions or ineffective management practices.

Overall, the diagram illustrates that the selection of sowing dates and fruit load plays a significant role in determining seed quality.

4.5 Soil analysis

4.5.1 Soil pH

Soil pH is a critical parameter that significantly influences plant growth and development by affecting the availability of nutrients, microbial activity and overall soil health. In agricultural systems, maintaining an optimal soil pH is essential as it directly impacts the efficiency of nutrient uptake by plants, enzymatic activities and the mobility of toxic elements.

Soil pH data, presented in Table 4.5.1, demonstrated no significant variations in pH values due to sowing dates or fruit load across the two years of the study. In the pooled analysis, the highest soil pH (7.47) was recorded with the sowing on 30th May and retaining all fruits per plant (D_4F_5).

Table 4.5.1: Effect of sowing dates and fruit load on soil pH

Soil pH						
Y_1 (2022-2023)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	7.39	7.40	7.41	7.39	7.35	**7.39**
D_2	7.43	7.38	7.40	7.40	7.38	**7.40**
D_3	7.39	7.41	7.42	7.40	7.37	**7.40**
D_4	7.41	7.42	7.40	7.43	7.44	**7.42**
Mean	**7.41**	**7.40**	**7.41**	**7.40**	**7.39**	**7.40**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.01			NS		
F	0.02			NS		
D×F	0.01			NS		
Y_2 (2023-2024)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	7.49	7.48	7.48	7.51	7.48	**7.49**
D_2	7.49	7.50	7.46	7.49	7.49	**7.48**
D_3	7.49	7.48	7.50	7.49	7.52	**7.49**
D_4	7.51	7.47	7.47	7.47	7.51	**7.49**
Mean	**7.49**	**7.48**	**7.48**	**7.49**	**7.50**	**7.48**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.01			NS		
F	0.02			NS		
D×F	0.01			NS		
Pooled						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	7.44	7.44	7.44	7.45	7.41	**7.44**
D_2	7.46	7.44	7.43	7.45	7.43	**7.44**
D_3	7.44	7.44	7.46	7.44	7.45	**7.45**
D_4	7.46	7.45	7.43	7.45	7.47	**7.45**
Mean	**7.45**	**7.44**	**7.44**	**7.4**	**7.44**	**7.44**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.05			NS		
F	0.06			NS		
D×F	0.01			NS		
Y	0.03			NS		
Y×D	0.07			NS		
Y×F	0.08			NS		
Y×D×F	0.06			NS		

***D =** Sowing dates; D_1= 15th April; D_2 = 30th April; D_3 = 15th May; D_4 = 30th May
***F =** Fruit load; F_1 = 3 fruits; F_2 = 4 fruits; F_3 = 5 fruits; F_4 = 6 fruits; F_5 = all fruits retained (control)
***Y =** Year; Y_1 = 2022-2023; Y_2 = 2023-2024

Conversely, the lowest soil pH (7.41) was observed with the sowing on 15th April and retaining all fruits per plant (D_1F_5). Despite minor differences, the pH values remained within a narrow range, with no significant interactions between sowing dates and fruit load or between years and treatments.

The pooled analysis also revealed an overall average soil pH of 7.44 across all treatments. These findings indicate that the imposed treatments, including sowing dates and fruit load, did not induce significant changes in soil pH across the two years.

In the present study, the relatively stable pH values across treatments highlight the buffering capacity of the soil under the experimental conditions. The lack of significant variation in soil pH due to sowing dates and fruit load suggests that the applied treatments had minimal impact on the soil's chemical properties. The slight increase in pH values compared to initial measurements could be attributed to improved organic matter decomposition or the effects of root exudates, which can modify the soil's microenvironment.

Cucumber plants thrive in slightly acidic to neutral soils (pH 6.0-7.5), which is essential for optimal nutrient uptake, particularly nitrogen, phosphorus and potassium (Havlin et al. 2014). The stable pH observed from the results supports nutrient availability and microbial activity, as reported by Fageria and Baligar (2008), who noted that maintaining soil pH within this range facilitates better nutrient solubility and biological processes essential for plant growth.

4.5.2 Soil EC (dSm^{-1})

Soil electrical conductivity (dSm^{-1}) is a measure of the soil's ability to conduct electrical current, reflecting the concentration of soluble salts present in the soil. It serves as an important indicator of soil health and fertility, influencing water movement, nutrient availability and plant growth. High soil EC indicates excessive salinity, which can hinder plant development, while low EC may suggest nutrient deficiencies or low organic matter.

The data pertaining to soil electrical conductivity (dSm^{-1}) has been presented in Table 4.5.2. The results indicate that sowing dates and fruit load had no significant effect on soil EC (dSm^{-1}) during both years of the study. Across the treatments, soil EC (dSm^{-1}) values showed minor variations but remained statistically non-significant.

Table 4.5.2: Effect of sowing dates and fruit load on soil EC

Soil EC (dSm^{-1})						
Y_1 (2022-2023)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	0.240	0.237	0.247	0.247	0.263	**0.247**
D_2	0.250	0.243	0.233	0.240	0.253	**0.244**
D_3	0.260	0.260	0.257	0.253	0.253	**0.257**
D_4	0.263	0.260	0.267	0.267	0.250	**0.261**
Mean	**0.253**	**0.250**	**0.251**	**0.252**	**0.255**	**0.252**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.005			NS		
F	0.003			NS		
D×F	0.007			NS		
Y_2 (2023-2024)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	0.240	0.237	0.247	0.247	0.263	**0.247**
D_2	0.260	0.260	0.257	0.253	0.253	**0.257**
D_3	0.250	0.243	0.233	0.240	0.253	**0.244**
D_4	0.240	0.237	0.247	0.247	0.263	**0.247**
Mean	**0.248**	**0.244**	**0.246**	**0.247**	**0.258**	**0.248**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.004			NS		
F	0.003			NS		
D×F	0.006			NS		
Pooled						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	0.240	0.237	0.247	0.247	0.263	**0.247**
D_2	0.255	0.252	0.245	0.247	0.253	**0.250**
D_3	0.255	0.252	0.245	0.247	0.253	**0.250**
D_4	0.252	0.248	0.257	0.257	0.257	**0.254**
Mean	**0.250**	**0.247**	**0.248**	**0.249**	**0.257**	**0.250**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.005			NS		
F	0.002			NS		
D×F	0.004			NS		
Y	0.003			NS		
Y×D	0.006			NS		
Y×F	0.003			NS		
Y×D×F	0.005			NS		

***D =** Sowing dates; D_1= 15th April; D_2 = 30th April; D_3 = 15th May; D_4 = 30th May
***F =** Fruit load; F_1 = 3 fruits; F_2 = 4 fruits; F_3 = 5 fruits; F_4 = 6 fruits; F_5 = all fruits retained (control)
***Y =** Year; Y_1 = 2022-2023; Y_2 = 2023-2024

The pooled analysis across years revealed no significant differences in soil EC values among treatments. From the pooled analysis, it was observed that the maximum soil EC (0.263 dSm^{-1}) was recorded with sowing on 15th April with all fruits per plant retained (D_1F_5) and the minimum (0.234 dSm^{-1}) was observed with sowing on 15th April with retaining of 4 fruits per plant (D_1F_2).

The pooled analysis also revealed an overall average soil EC of 0.250 dSm^{-1} across all treatments. The interaction between sowing dates, fruit load and years was also non-significant.

The non-significant differences in soil EC (dSm^{-1}) across treatments indicate that the imposed sowing dates and fruit load treatments did not substantially alter soil salinity levels.

This stability in soil EC (dSm^{-1}) could be attributed to consistent irrigation practices and balanced fertilization applied throughout the study period of two consecutive years.

Other researchers have also highlighted the significance of balanced soil EC (dSm^{-1}) for plant growth and soil health. According to Weil and Brady (2016), maintaining soil EC (dSm^{-1}) within the optimal range is crucial for avoiding nutrient imbalances and salt stress, both of which can adversely affect crop performance. Similarly, Rhoades et al. (1992) noted that stable soil EC (dSm^{-1}) supports consistent water uptake and nutrient absorption, creating favourable conditions for plant development. These findings are consistent with the current study, which observed no significant deviations in soil EC (dSm^{-1}) values across treatments, ensuring uniform nutrient availability for cucumber cultivation.

4.5.3 Organic carbon (%)

Soil organic carbon (%) represents the carbon component of organic compounds found in soil, serving as a key indicator of soil fertility, health and sustainability. It originates from the decomposition of plant residues, root exudates, microorganisms and animal waste, contributing to the soil's organic matter. Organic carbon plays a critical role in improving soil structure, water retention and nutrient availability while enhancing microbial activity. In agricultural systems, maintaining optimal organic carbon levels is essential for promoting plant growth, mitigating soil erosion and reducing the impact of climate change by sequestering atmospheric carbon.

Table 4.5.3: Effect of sowing dates and fruit load on organic carbon

Organic carbon (%)						
Y_1 (2022-2023)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	1.29	1.30	1.31	1.32	1.33	**1.31**
D_2	1.34	1.35	1.36	1.31	1.32	**1.33**
D_3	1.33	1.34	1.30	1.31	1.32	**1.32**
D_4	1.33	1.29	1.30	1.31	1.32	**1.31**
Mean	**1.32**	**1.32**	**1.31**	**1.31**	**1.32**	**1.31**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.02			NS		
F	0.01			NS		
D×F	0.03			NS		
Y_2 (2023-2024)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	1.30	1.31	1.32	1.33	1.29	**1.31**
D_2	1.30	1.31	1.32	1.33	1.34	**1.32**
D_3	1.35	1.36	1.31	1.32	1.33	**1.33**
D_4	1.34	1.30	1.31	1.32	1.33	**1.32**
Mean	**1.32**	**1.32**	**1.31**	**1.32**	**1.32**	**1.32**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.02			NS		
F	0.01			NS		
D×F	0.03			NS		
Pooled						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	1.29	1.30	1.31	1.32	1.31	**1.31**
D_2	1.32	1.33	1.34	1.32	1.33	**1.32**
D_3	1.34	1.35	1.31	1.32	1.33	**1.33**
D_4	1.34	1.29	1.30	1.31	1.32	**1.31**
Mean	**1.32**	**1.32**	**1.31**	**1.32**	**1.32**	**1.31**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.01			NS		
F	0.08			NS		
D×F	0.06			NS		
Y	0.01			NS		
Y×D	0.02			NS		
Y×F	0.02			NS		
Y×D×F	0.03			NS		

***D =** Sowing dates; D_1= 15th April; D_2 = 30th April; D_3 = 15th May; D_4 = 30th May
***F =** Fruit load; F_1 = 3 fruits; F_2 = 4 fruits; F_3 = 5 fruits; F_4 = 6 fruits; F_5 = all fruits retained (control)
***Y =** Year; Y_1 = 2022-2023; Y_2 = 2023-2024

The data pertaining to organic carbon in soil has been presented in Table 4.5.3. The results indicate that sowing dates and fruit load had no significant effect on organic carbon (%) during both years of the study. Across the treatments, organic carbon (%) values showed minor variations but remained statistically non-significant. The pooled analysis across years revealed no significant differences in the organic carbon (%) among treatments. From the pooled analysis, it was observed that the maximum organic carbon (1.35 %) was recorded with sowing on 15th May with 4 fruits per plant retained (D_3F_2) and the minimum (1.29 %) was observed with sowing on 15th April with retaining 3 fruits per plant (D_1F_1) and with sowing on 30th May with 4 fruits per plant retained (D_4F_2). The pooled analysis also revealed an overall average organic carbon of 1.31 % across all treatments. The interaction between sowing dates, fruit load and years was also non-significant.

The results indicate that neither sowing dates nor fruit load significantly influenced organic carbon (%) content in soil in both the years.

The observed variations in organic carbon (%) content in soil across different treatments were statistically non-significant, suggesting that these agronomic factors may not substantially affect organic carbon (%) content in soil for the studied conditions.

These findings align with research indicating that planting practices have a limited effect on organic carbon (%) content in deep soil layers, with differences becoming more pronounced in surface soils (Li et al. 2023).

The non-significant interaction between years, sowing dates and fruit load further suggests that these factors may not substantially influence organic carbon (%) content in soil in the studied context. This observation is consistent with studies indicating that various external factors, such as microbial decomposition, soil acidity and alkalinity and soil erosion, influence organic carbon (%) content in soil (Yao et al. 2023).

4.5.4 Available N (kg/ha) content in soil after termination of experiment

The availability of nitrogen (kg/ha) after the termination of an experiment is a crucial indicator of soil fertility and nutrient cycling. It reflects the amount of nitrogen remaining in the soil that is available for plant uptake, which plays a vital role in determining the success of subsequent crops. Nitrogen is a key macronutrient for plant growth, influencing yield, quality and overall productivity.

The data from 2022-2023 and 2023-2024, along with the pooled analysis, showed significant variations in the available nitrogen (kg/ha) after termination of experiment across treatments (Table 4.5.4 and Figure 4.5.4).

During the first year 2022-2023, the effect of fruit load was significant for available nitrogen (kg/ha) whereas, non-significant for sowing dates and interaction of sowing dates and fruit load. Regarding the effect of fruit load treatments, the maximum available nitrogen (289.59 kg/ha) was recorded when 3 fruits per plant (F_1) were retained, while the minimum available nitrogen (284.69 kg/ha) was observed when 6 fruits per plant (F_4) were retained. The interaction between sowing dates and fruit load was non-significant and the values ranged from 290.60 - 283.71 kg/ha.

In the second year 2023-2024, the effects of sowing dates, fruit load and their interaction were significant for available nitrogen (kg/ha). The maximum available nitrogen (303.07 kg/ha) was recorded when sowing was done on 30th April (D_2), while the minimum available nitrogen (295.38 kg/ha) was observed when sowing was done on 30th May (D_4). Among fruit load treatments, the maximum available nitrogen (307.01 kg/ha) was recorded when 3 fruits per plant (F_1) were retained, whereas when 6 fruits per plant (F_4) were retained, it recorded the minimum available nitrogen (293.05 kg/ha). The interaction between sowing dates and fruit load showed that when sowing was done on 30th April and 3 fruits per plant were retained (D_2F_1), it resulted in the maximum available nitrogen (311.06 kg/ha), whereas when sowing was done on 30th May and 6 fruits per plant were retained (D_4F_4), it resulted in the minimum available nitrogen (291.70 kg/ha).

The pooled data for both years revealed significant effects of sowing dates and fruit load on available nitrogen, while their interaction remained significant. The maximum available nitrogen (295.31 kg/ha) was recorded when sowing was done on 30th April (D_2), while the minimum (291.04 kg/ha) was observed when sowing was done on 30th May (D_4).

Regarding fruit load treatments, when 3 fruits per plant (F_1) were retained, it recorded the maximum available nitrogen (298.30 kg/ha), while it recorded the minimum (288.87 kg/ha) when 6 fruits per plant (F_4) were retained. The interaction between sowing dates and fruit load revealed that when sowing was done on 30th April and 3 fruits per plant were retained (D_2F_1), it again resulted in the maximum available nitrogen (300.83 kg/ha), whereas when sowing was done on 15th May and 6 fruits per plant were retained (D_3F_4), it resulted in the minimum available nitrogen (288.51 kg/ha).

Table 4.5.4: Effect of sowing dates and fruit load on available N content in soil after termination of experiment

Available N (kg/ha)						
Y_1 (2022-2023)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	290.27	286.26	283.90	283.71	287.10	**286.25**
D_2	290.60	288.05	286.56	284.78	287.80	**287.56**
D_3	289.82	288.18	285.87	284.42	286.96	**287.05**
D_4	287.66	286.54	286.68	285.84	286.82	**286.70**
Mean	**289.59**	**287.26**	**285.75**	**284.69**	**287.17**	**286.89**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.43			NS		
F	0.38			1.10		
D×F	0.80			NS		
Y_2 (2023-2024)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	307.00	306.40	298.00	293.50	295.34	**300.04**
D_2	311.06	307.30	302.80	294.40	299.80	**303.07**
D_3	306.89	304.96	296.50	292.60	296.20	**299.43**
D_4	303.10	295.36	292.55	291.70	294.22	**295.38**
Mean	**307.01**	**303.50**	**297.46**	**293.05**	**296.39**	**299.48**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.46			1.63		
F	0.47			1.37		
D×F	0.97			2.94		
Pooled						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	298.63	296.33	290.95	288.60	291.22	**293.14**
D_2	300.83	297.67	294.68	289.59	293.80	**295.31**
D_3	298.36	296.57	291.18	288.51	291.58	**293.24**
D_4	295.38	290.95	289.61	288.77	290.52	**291.04**
Mean	**298.30**	**295.38**	**291.60**	**288.87**	**291.78**	**293.18**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.67			2.03		
F	0.30			0.86		
D×F	0.60			1.72		
Y	0.47			1.43		
Y×D	0.94			2.87		
Y×F	0.43			1.21		
Y×D×F	0.86			2.43		

***D =** Sowing dates; D_1= 15th April; D_2 = 30th April; D_3 = 15th May; D_4 = 30th May
***F =** Fruit load; F_1 = 3 fruits; F_2 = 4 fruits; F_3 = 5 fruits; F_4 = 6 fruits; F_5 = all fruits retained (control)
***Y =** Year; Y_1 = 2022-2023; Y_2 = 2023-2024

Between the two years, the maximum available nitrogen (299.48 kg/ha) was recorded in the second year (2023-2024) compared to lower available nitrogen (286.89 kg/ha) in the first year (2022-2023). The interaction between years and sowing dates (Y × D) showed significant effects, with the maximum available nitrogen (303.07 kg/ha) recorded in the second year (2023-2024) when sowing was done on 30th April (Y_2D_2) and the minimum available nitrogen (286.25 kg/ha) was recorded in the first year (2022-2023) when sowing was done on 15th April (Y_1D_1). The interaction between years and fruit load (Y × F) showed significant effects, with the maximum available nitrogen (307.01 kg/ha) recorded in the second year (2023-2024) with 3 fruits per plant (Y_2F_1) retained and the minimum available nitrogen (284.69 kg/ha) was recorded in the first year (2022-2023) with retaining 6 fruits per plant (Y_1F_4).

The three-way interaction between years, sowing dates and fruit load (Y × D × F) showed significant effects, with the maximum available nitrogen (311.06 kg/ha) recorded in the second year (2023-2024) when sowing was on 30th April and 3 fruits per plant were retained ($Y_2D_2F_1$) and the minimum available nitrogen (283.71 kg/ha) was observed in the first year (2022-2023) when sowing was done on 15th April and 6 fruits per plant were retained ($Y_1D_1F_4$).

The results highlight a significant relationship between sowing dates and fruit load for available nitrogen in the soil. Sowing on earlier dates, such as 30th April (D_2), promoted better nitrogen availability, likely due to more favourable growing conditions like optimal temperature and moisture, which facilitated enhanced nutrient uptake and plant growth. Adequate nitrogen availability supports better photosynthesis, metabolism and seed yield, as nitrogen is essential for amino acid and protein synthesis (Fageria 2014). Conversely, delayed sowing may expose crops to stress conditions like high temperatures or moisture deficit, resulting in lower available nitrogen levels.

Fruit load also had a marked impact on soil nitrogen availability. Retaining 3 fruits per plant (F_1) resulted in significantly higher available nitrogen levels. This outcome can be attributed to reduced nutrient uptake due to lower reproductive demands, allowing more nitrogen to remain in the soil. Research has shown that fruit load influences the source-sink relationship, where fewer fruits per plant enhance nitrogen translocation to vegetative parts rather than reproductive organs, leading to better soil nitrogen retention (Ding et al. 2017). On the other hand, retaining more fruits increases nutrient demand, depleting available soil

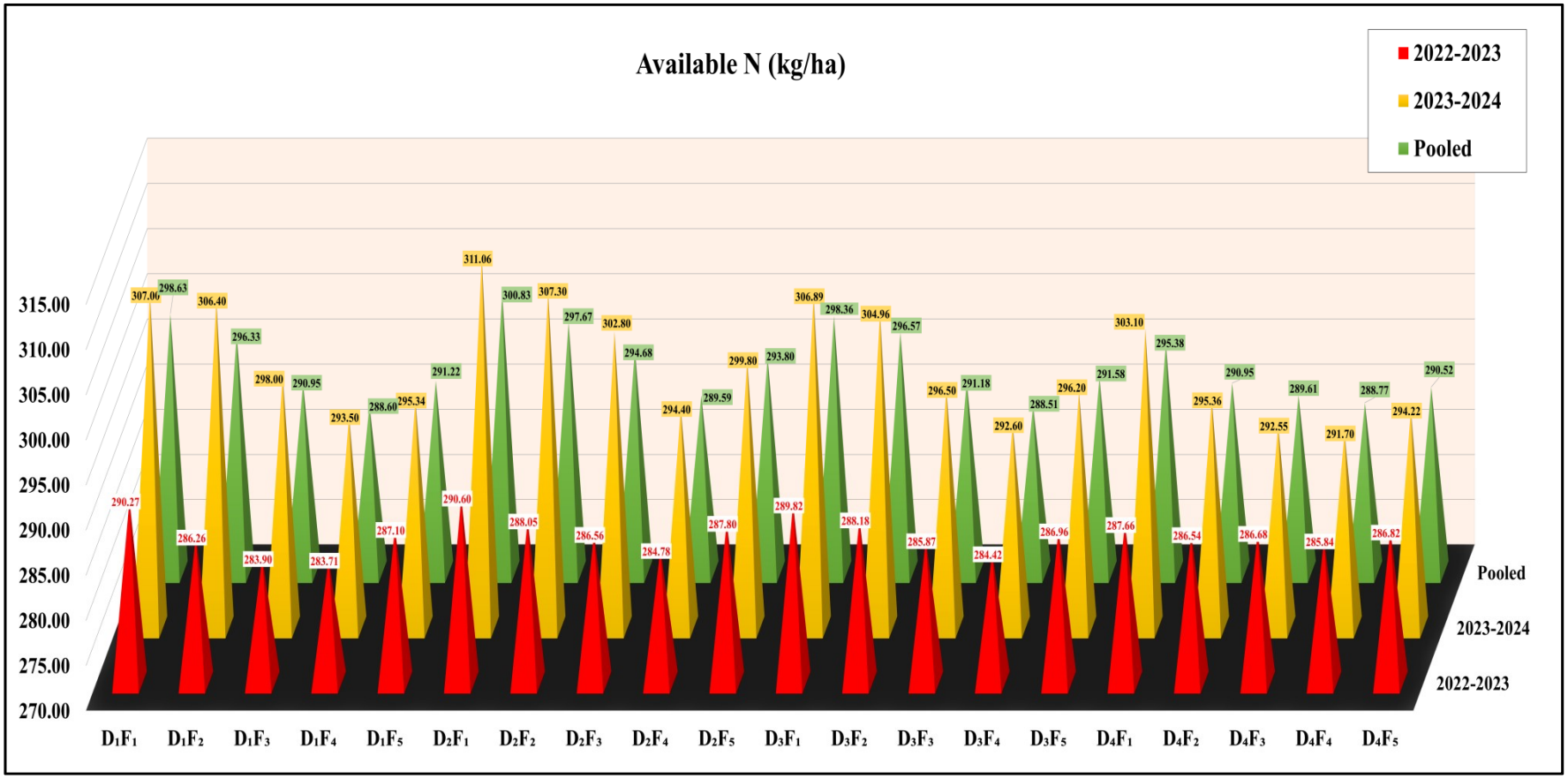


Figure 4.5.4: Effect of sowing dates and fruit load on available N content in soil after termination of experiment

nitrogen. The pooled analysis across two years highlighted the significant effects of sowing dates and fruit load on soil nitrogen levels. Early sowing combined with fewer retained fruits consistently resulted in higher available nitrogen, reinforcing the idea that synchronized agronomic practices optimize nitrogen dynamics in the soil.

Interactions between sowing dates and fruit load further underscored the complexity of these relationships. The combination of early sowing dates and reduced fruit load produced the highest available nitrogen levels, suggesting a synergistic effect where optimal timing amplifies the benefits of controlled fruit retention. Significant year-wise differences were also evident, with the second year showing higher soil nitrogen levels, likely due to better environmental conditions or cumulative fertility effects. Such findings corroborate studies indicating that inter-annual variations in weather and management practices significantly affect soil nutrient dynamics (Ghodsi et al. 2022). Furthermore, the three-way interaction between years, sowing dates and fruit load revealed the highest available nitrogen levels under conditions of early sowing and minimal fruit retention, emphasizing the need for holistic crop management strategies.

4.5.5 Available P (kg/ha) content in soil after termination of experiment

Available phosphorus (kg/ha) content in the soil is a crucial nutrient that directly influences plant growth, development and crop yield. It plays an essential role in energy transfer, root development and photosynthesis, making it integral to plant metabolism. After the termination of an experiment, measuring the available phosphorus content in soil provides valuable insights into the nutrient dynamics within the system. The available P content reflects the phosphorus that is accessible to plants, indicating the efficiency of nutrient cycling and the potential need for additional phosphorus inputs in future cropping cycles.

The data from 2022-2023 and 2023-2024, along with the pooled analysis, showed significant variations in the available phosphorus (kg/ha) after termination of experiment across treatments (Table 4.5.5 and Figure 4.5.5).

During the first year 2022-2023, the effect of fruit load was significant for available phosphorus (kg/ha) whereas, non-significant for sowing dates and interaction of sowing dates and fruit load. Regarding the effect of fruit load treatments, the maximum available phosphorus (59.64 kg/ha) was recorded when 3 fruits per plant (F_1) were retained, while the minimum available phosphorus (57.57 kg/ha) was observed when 6 fruits per plant (F_4) were

Table 4.5.5: Effect of sowing dates and fruit load on available P content in soil after termination of experiment

Available P (kg/ha)						
Y_1 (2022-2023)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	59.36	59.01	58.73	57.54	58.58	**58.64**
D_2	61.44	59.70	58.74	57.51	58.57	**59.19**
D_3	58.87	59.82	57.56	57.50	57.92	**58.33**
D_4	58.89	59.03	58.86	57.73	58.32	**58.56**
Mean	**59.64**	**59.39**	**58.47**	**57.57**	**58.35**	**58.68**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.16			NS		
F	0.21			0.62		
D×F	0.42			NS		
Y_2 (2023-2024)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	64.73	65.50	63.40	61.20	63.40	**63.64**
D_2	66.23	65.80	64.60	61.30	63.80	**64.34**
D_3	64.33	65.60	63.70	61.10	63.60	**63.66**
D_4	64.70	62.40	62.50	61.00	62.30	**62.58**
Mean	**65.00**	**64.82**	**63.55**	**61.15**	**63.27**	**63.55**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.11			0.38		
F	0.15			0.44		
D×F	0.29			0.87		
Pooled						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	62.04	62.25	60.99	59.37	61.06	**61.14**
D_2	63.84	62.75	61.58	59.40	61.27	**61.77**
D_3	61.60	62.71	60.81	59.30	60.58	**61.00**
D_4	61.79	60.71	60.41	59.36	60.58	**60.57**
Mean	**62.32**	**62.10**	**60.95**	**59.36**	**60.87**	**61.12**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.09			0.29		
F	0.13			0.37		
D×F	0.26			0.74		
Y	0.06			0.20		
Y×D	0.13			0.41		
Y×F	0.18			0.52		
Y×D×F	0.37			1.05		

***D =** Sowing dates; D_1= 15th April; D_2 = 30th April; D_3 = 15th May; D_4 = 30th May
***F =** Fruit load; F_1 = 3 fruits; F_2 = 4 fruits; F_3 = 5 fruits; F_4 = 6 fruits; F_5 = all fruits retained (control)
***Y =** Year; Y_1 = 2022-2023; Y_2 = 2023-2024

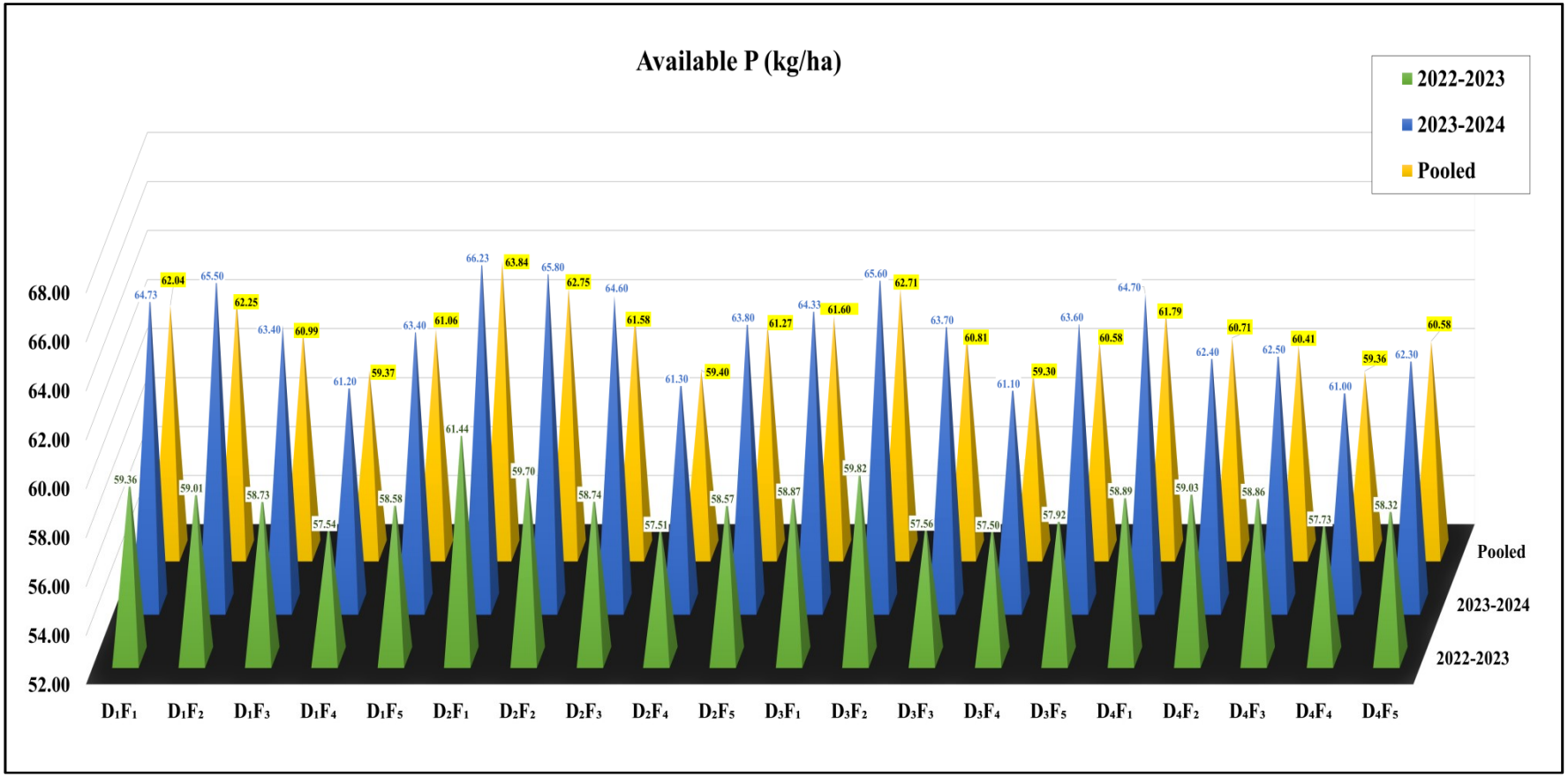


Figure 4.5.5: Effect of sowing dates and fruit load on available P content in soil after termination of experiment

retained. The interaction between sowing dates and fruit load was non-significant and the values ranged from 61.44 - 57.50 kg/ha.

In the second year 2023-2024, the effects of sowing dates, fruit load and their interaction were significant for available phosphorus (kg/ha). The maximum available phosphorus (64.34 kg/ha) was recorded when sowing was done on 30th April (D_2), while the minimum available phosphorus (62.58 kg/ha) was observed when sowing was done on 30th May (D_4). Among fruit load treatments, the maximum available phosphorus (65.00 kg/ha) was recorded when 3 fruits per plant (F_1) were retained, whereas when 6 fruits per plant (F_4) were retained, it recorded the minimum available phosphorus (61.15 kg/ha). The interaction between sowing dates and fruit load showed that when sowing was done on 30th April and 3 fruits per plant were retained (D_2F_1), it resulted in the maximum available phosphorus (66.23 kg/ha) which was at par with D_2F_2, D_2F_3 and D_1F_2, whereas when sowing was done on 30th May and 6 fruits per plant were retained (D_4F_4), it resulted in the minimum available phosphorus (61.00 kg/ha).

The pooled data for both years revealed significant effects of sowing dates and fruit load on available phosphorus, while their interaction remained significant. The maximum available phosphorus (61.77 kg/ha) was recorded when sowing was done on 30th April (D_2), while the minimum (60.57 kg/ha) was observed when sowing was done on 30th May (D_4). Regarding fruit load treatments, when 3 fruits per plant (F_1) were retained, it recorded the maximum available phosphorus (62.32 kg/ha), while it recorded the minimum (59.36 kg/ha) when 6 fruits per plant (F_1) were retained. The interaction between sowing dates and fruit load revealed that when sowing was done on 30th April and 3 fruits per plant were retained (D_2F_1), it again resulted in the maximum available phosphorus (63.84 kg/ha), whereas when sowing was done on 15th May and 6 fruits per plant were retained (D_3F_4), it resulted in the minimum available phosphorus (59.30 kg/ha).

Between the two years, the maximum available phosphorus (63.55 kg/ha) was recorded in the second year (2023-2024) compared to lower available phosphorus (58.68 kg/ha) in the first year (2022-2023). The interaction between years and sowing dates (Y × D) showed significant effects, with the maximum available phosphorus (64.34 kg/ha) recorded in the second year (2023-2024) when sowing was done on 30th April (Y_2D_2) and the minimum available phosphorus (58.33 kg/ha) was recorded in the first year (2022-2023) when sowing was done on 15th May (Y_1D_3). The interaction between years and fruit load

(Y × F) showed significant effects, with the maximum available phosphorus (65.00 kg/ha) recorded in the second year (2023-2024) with 3 fruits per plant (Y_2F_1) retained and the minimum available phosphorus (57.57 kg/ha) was recorded in the first year (2022-2023) with retaining 6 fruits per plant (Y_1F_4).

The three-way interaction between years, sowing dates and fruit load (Y × D × F) showed significant effects, with the maximum available phosphorus (66.23 kg/ha) recorded in the second year (2023-2024) when sowing was on 30th April and 3 fruits per plant were retained ($Y_2D_2F_1$) and the minimum available phosphorus (57.50 kg/ha) was observed in the first year (2022-2023) when sowing was done on 15th May and 6 fruits per plant were retained ($Y_1D_3F_4$).

The results revealed significant effects of sowing dates and fruit load on available phosphorus (kg/ha) content in soil after the termination of the experiment.

Phosphorus availability in soil plays a crucial role in plant growth and seed production as it is a key nutrient involved in energy transfer, root development and seed formation. The increased available P under early sowing on 30th April (D_2) can be attributed to better soil conditions during this period, including favourable soil moisture and microbial activity, which enhance phosphorus solubilization and uptake. Early sowing aligns with a critical growth period when phosphorus is in high demand for root development and subsequent reproductive processes. Previous studies have also highlighted that early planting ensures better nutrient availability and uptake efficiency, leading to improved soil phosphorus dynamics (Khan et al. 2023).

Fruit load significantly influenced phosphorus availability in both years, with 3 fruits per plant (F_1) consistently resulting in the highest phosphorus levels. This indicates that moderate fruit load balance the plant's nutrient uptake demands while maintaining sufficient residual phosphorus in the soil. Retaining 6 fruits per plant (F_4), however, led to the lowest phosphorus levels, likely due to higher nutrient extraction by the plants to support greater fruit production. These findings are consistent with studies that report increasing fruit load in high-yielding crops intensifies nutrient uptake, potentially depleting available soil phosphorus.

The interaction between sowing dates and fruit load showed a significant effect only in the second year and in pooled data, but not in the first year. The highest available P (kg/ha)

was recorded when sowing was done on 30th April and 3 fruits per plant were retained (D_2F_1), emphasizing the synergistic effect of early sowing and lower reproductive load on phosphorus dynamics. This indicates that the relationship between sowing dates and fruit load on available phosphorus is more prominent when external environmental conditions (such as temperature and moisture) are favourable.

Efficient nutrient uptake and utilization under conditions when sowing was done on 15th May and 6 fruits per plant (D_3F_4) were retained likely contributed to higher seed yield potential. These findings align with existing research on phosphorus dynamics, which emphasizes the importance of managing sowing dates and crop load to enhance nutrient use efficiency and soil health (Cheng et al. 2023).

4.5.6 Available K (kg/ha) content in soil after termination of experiment

Potassium (K) is one of the essential macronutrients required by plants, playing a pivotal role in numerous physiological processes, including enzyme activation, water regulation, photosynthesis and nutrient transport. In soil, available potassium (kg/ha) refers to the fraction of potassium that is readily accessible for plant uptake, typically present in the soil solution or loosely bound to exchange sites on clay particles and organic matter. It serves as a critical measure of soil fertility and reflects the balance between potassium removed by plants and the residual potassium left in the soil after cropping.

The data from first year 2022-2023 and second year 2023-2024, along with the pooled analysis, showed significant variations in the available potassium (kg/ha) after termination of experiment across treatments (Table 4.5.6 and Figure 4.5.6).

During the first year 2022-2023, the effect of fruit load was significant for available potassium (kg/ha) whereas, non-significant for sowing dates and interaction of sowing dates and fruit load. Regarding the effect of fruit load treatments, the maximum available potassium (393.20 kg/ha) was recorded when 3 fruits per plant (F_1) were retained, while the minimum available potassium (384.02 kg/ha) was observed when 6 fruits per plant (F_4) were retained. The interaction between sowing dates and fruit load was non-significant and the values ranged from 393.82 - 382.33 kg/ha.

In the second year 2023-2024, the effects of sowing dates, fruit load and their interaction were significant for available potassium (kg/ha). The maximum available

Table 4.5.6: Effect of sowing dates and fruit load on available K content in soil after termination of experiment

Available K (kg/ha)						
Y_1 (2022-2023)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	392.91	393.64	388.60	383.78	390.94	**389.97**
D_2	395.67	393.33	393.28	383.90	387.73	**390.78**
D_3	390.76	393.82	388.33	386.08	387.34	**389.26**
D_4	393.46	391.09	385.90	382.33	382.40	**387.03**
Mean	**393.20**	**392.97**	**389.02**	**384.02**	**387.10**	**389.26**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.87			NS		
F	0.79			2.30		
D×F	1.66			NS		
Y_2 (2023-2024)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	409.72	409.12	397.13	397.33	402.22	**403.10**
D_2	410.26	410.02	408.52	397.53	402.52	**405.77**
D_3	405.22	409.42	397.68	397.13	401.92	**402.27**
D_4	408.82	404.92	397.42	396.93	397.33	**401.08**
Mean	**408.50**	**408.37**	**400.19**	**397.23**	**400.99**	**403.05**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.28			0.99		
F	0.40			1.15		
D×F	0.76			2.29		
Pooled						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	401.31	401.38	392.86	390.55	396.58	**396.54**
D_2	402.97	401.67	400.90	390.71	395.12	**398.27**
D_3	397.99	401.62	393.01	391.60	394.63	**395.77**
D_4	401.14	398.00	391.66	389.63	389.86	**394.06**
Mean	**400.85**	**400.67**	**394.60**	**390.62**	**394.05**	**396.16**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.48			1.46		
F	0.44			1.25		
D×F	0.89			2.51		
Y	0.34			1.03		
Y×D	0.68			NS		
Y×F	0.63			1.78		
Y×D×F	1.25			NS		

***D =** Sowing dates; D_1= 15th April; D_2 = 30th April; D_3 = 15th May; D_4 = 30th May
***F =** Fruit load; F_1 = 3 fruits; F_2 = 4 fruits; F_3 = 5 fruits; F_4 = 6 fruits; F_5 = all fruits retained (control)
***Y =** Year; Y_1 = 2022-2023; Y_2 = 2023-2024

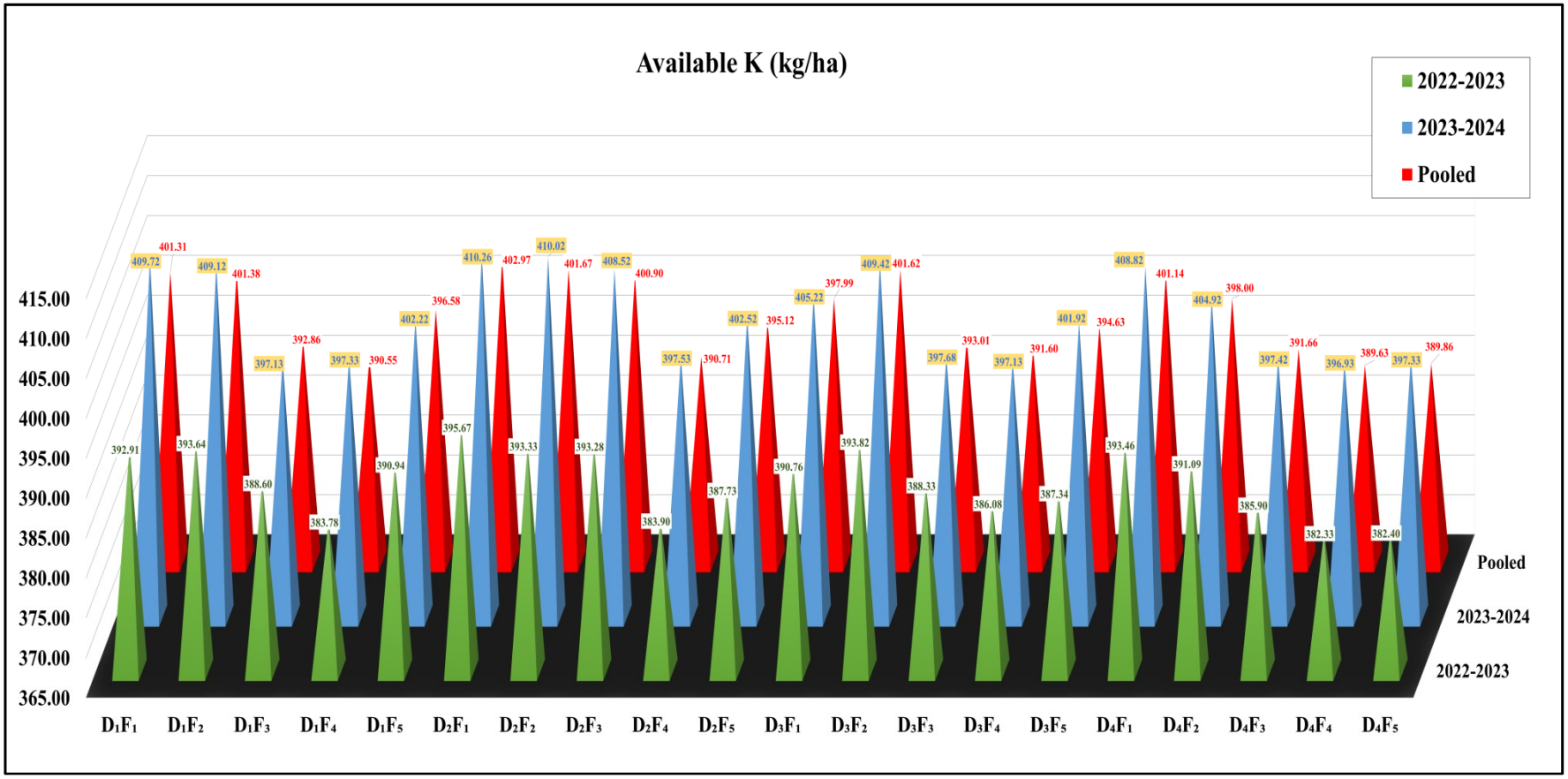


Figure 4.5.6: Effect of sowing dates and fruit load on available K content in soil after termination of experiment

potassium (405.77 kg/ha) was recorded when sowing was done on 30th April (D_2), while the minimum available potassium (401.08 kg/ha) was observed when sowing was done on 30th May (D_4). Among fruit load treatments, the maximum available potassium (408.50 kg/ha) was recorded when 3 fruits per plant (F_4) were retained which was at par with retaining 4 fruits per plant (F_2), whereas when 6 fruits per plant (F_1) were retained, it recorded the minimum available potassium (397.23 kg/ha).

The interaction between sowing dates and fruit load showed that when sowing was done on 30th April and 3 fruits per plant were retained (D_2F_1), it resulted in the maximum available potassium (410.26 kg/ha) which was at par with D_2F_2, D_1F_1, D_3F_2, D_1F_2 and D_2F_3, whereas when sowing was done on 30th May and 6 fruits per plant were retained (D_4F_4), it resulted in the minimum available potassium (396.93 kg/ha).

The pooled data for both years revealed significant effects of sowing dates and fruit load on available potassium, while their interaction remained significant. The maximum available potassium (398.27 kg/ha) was recorded when sowing was done on 30th April (D_2), while the minimum (394.06 kg/ha) was observed when sowing was done on 30th May (D_4). Regarding fruit load treatments, when 3 fruits per plant (F_1) were retained, it recorded the maximum available potassium (400.85 kg/ha) which was at par with retaining 4 fruits per plant (F_2), while it recorded the minimum (390.62 kg/ha) when 6 fruits per plant (F_4) were retained. The interaction between sowing dates and fruit load revealed that when sowing was done on 30th April and 3 fruits per plant were retained (D_2F_1), it again resulted in the maximum available potassium (402.97 kg/ha) which was at par with D_2F_2, D_3F_2, D_1F_2, D_1F_1, D_4F_1 and D_2F_3, whereas when sowing was done on 30th May and 6 fruits per plant were retained (D_4F_4), it resulted in the minimum available potassium (389.63 kg/ha).

Between the two years, the maximum available potassium (403.05 kg/ha) was recorded in the second year (2023-2024) compared to 389.26 kg/ha in the first year (2022-2023). The interaction between years and sowing dates (Y × D) showed non-significant effects. The interaction between years and fruit load (Y × F) showed significant effects, with the maximum available potassium (408.50 kg/ha) recorded in the second year (2023-2024) with 3 fruits per plant (Y_2F_1) retained and the minimum available potassium (384.02 kg/ha) was recorded in the first year (2022-2023) with retaining 6 fruits per plant (Y_1F_4). The three-way interaction between years, sowing dates and fruit load (Y × D × F) showed non-significant effects.

The results indicate that sowing dates and fruit load significantly affected available potassium (kg/ha) content in the soil. Sowing dates showed varying influences on potassium availability, with earlier sowing dates generally associated with higher soil potassium levels.

Potassium availability in soil plays a vital role in plant growth and seed production as it is involved in key physiological processes such as enzyme activation, photosynthesis and osmoregulation (Marschner 1995). The increased available K under early sowing on 30th April (D_2) can be attributed to favourable soil conditions during this period, including better soil moisture retention and microbial activity, which enhance potassium release and uptake. Early sowing aligns with critical growth stages, where potassium is in high demand to regulate water balance and support reproductive development. Previous studies have emphasized that early planting improves nutrient availability and uptake efficiency, positively influencing soil potassium dynamics (Rengel and Damon 2008; Johnston 2003).

The effect of fruit load on soil potassium was significant, with lower fruit load associated with higher available potassium in the soil. This could be due to reduced nutrient extraction by fewer fruits, allowing for greater residual nutrient availability in the soil. Higher fruit load, conversely, result in more nutrient uptake to support fruit development, which depletes the available soil potassium levels. This finding corroborates earlier research that links fruit load management to nutrient cycling and soil fertility (Kuzin and Solovchenko 2021).

Pooled analysis across the two years confirmed significant differences in soil potassium levels based on sowing dates and fruit load, emphasizing the consistent influence of these factors. The findings suggest that both earlier sowing dates and moderate fruit load are critical for maintaining higher soil potassium levels over time (Mekdad et al. 2021). This is likely due to a combination of optimal environmental conditions during earlier sowing and reduced nutrient competition under moderate fruit load, promoting nutrient retention and availability in the soil.

The interactions between sowing dates and fruit load, as well as between years, sowing dates and fruit load, demonstrated nuanced effects on potassium availability. While interactions between these factors were more pronounced in the second year, they highlight the dynamic interplay between environmental conditions, fruit load management practices and nutrient dynamics. The significant interaction effects underscore the importance of

tailoring sowing dates and fruit load strategies to specific growing conditions to optimize soil fertility and crop productivity.

4.6 Incidence (%) of economically important insect-pest /diseases of cucumber

4.6.1 Incidence of fruit fly (%) in cucumber

The cucumber fruit fly (*Bactrocera cucurbitae*) significantly impacts cucumber crops, especially in seed production. Its larvae infest the cucumber fruits, causing them to rot and degrade, resulting in reduced yield and quality. In seed production, the damage is particularly severe as the larvae feed on developing seeds, diminishing seed viability and germination rates. The timing of sowing also plays a crucial role in this dynamic. Early sowing can increase the risk of fruit fly infestation, as the pest population is higher during certain seasonal periods. Delayed sowing, on the other hand, may help avoid peak pest pressure, thus reducing damage and ensuring better seed quality.

The data from first year 2022-2023 and second year 2023-2024, along with the pooled analysis, showed significant variations in the incidence of fruit fly (%) across treatments (Table 4.6.1).

During the first year 2022-2023, the effect of sowing dates was significant for incidence of fruit fly (%) whereas, non-significant for fruit load and interaction of sowing dates and fruit load. Regarding the effect of sowing dates, the highest incidence of fruit fly (8.12 %) was recorded when sowing was done on 15th May (D_3), while the lowest incidence of fruit fly (3.57 %) was observed when sowing was done on 15th April (D_2).

During the second year 2023-2024, the effect of sowing dates was significant for incidence of fruit fly (%) whereas, non-significant for fruit load and interaction of sowing dates and fruit load. Regarding the effect of sowing dates, the highest incidence of fruit fly (7.91 %) was recorded when sowing was done on 15th May (D_3), while the lowest incidence of fruit fly (4.02 %) was observed when sowing was done on 15th April (D_2).

The pooled data across two years also showed that the effect of sowing dates was significant for incidence of fruit fly (%) whereas, non-significant for fruit load and interaction of sowing dates and fruit load. Regarding the effect of sowing dates, the highest incidence of fruit fly (8.02 %) was recorded when sowing was done on 15th May (D_3), while

Table 4.6.1: Effect of sowing dates and fruit load on incidence of fruit fly in cucumber

Incidence of fruit fly (%) in cucumber						
Y_1 (2022-2023)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	6.67 (2.58)	3.33 (1.83)	4.67 (2.16)	5.00 (2.24)	5.33 (2.31)	**5.00 (2.24)**
D_2	4.44 (2.11)	2.50 (1.58)	2.67 (1.63)	2.22 (1.49)	6.00 (2.45)	**3.57 (1.89)**
D_3	8.89 (2.98)	5.83 (2.42)	9.33 (3.06)	7.22 (2.69)	9.33 (3.06)	**8.12 (2.85)**
D_4	8.89 (2.98)	7.50 (2.74)	8.67 (2.94)	4.44 (2.11)	8.00 (2.83)	**7.50 (2.74)**
Mean	**7.22 (2.69)**	**4.79 (2.19)**	**6.33 (2.52)**	**4.72 (2.17)**	**7.17 (2.68)**	**6.05 (2.46)**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.58			2.02		
F	0.55			NS		
D×F	1.09			NS		
Y_2 (2023-2024)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	6.67 (2.58)	5.83 (2.42)	6.00 (2.45)	5.00 (2.24)	7.33 (2.71)	**6.17 (2.48)**
D_2	5.56 (2.36)	3.33 (1.83)	3.33 (1.83)	3.89 (1.97)	4.00 (2.00)	**4.02 (2.01)**
D_3	8.89 (2.98)	6.67 (2.58)	8.67 (2.94)	6.67 (2.58)	8.67 (2.94)	**7.91 (2.81)**
D_4	8.89 (2.98)	9.17 (3.03)	6.67 (2.58)	7.22 (2.69)	9.33 (3.06)	**8.26 (2.87)**
Mean	**7.50 (2.74)**	**6.25 (2.50)**	**6.17 (2.48)**	**5.69 (2.39)**	**7.33 (2.71)**	**6.59 (2.57)**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.75			2.60		
F	0.82			NS		
D×F	1.64			NS		
Pooled						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	6.67 (2.58)	4.58 (2.14)	5.33 (2.31)	5.00 (2.24)	6.33 (2.52)	**5.58 (2.36)**
D_2	5.00 (2.24)	2.92 (1.71)	3.00 (1.73)	3.06 (1.75)	5.00 (2.24)	**3.79 (1.95)**
D_3	8.89 (2.98)	6.25 (2.50)	9.00 (3.00)	6.94 (2.64)	9.00 (3.00)	**8.02 (2.83)**
D_4	8.89 (2.98)	8.33 (2.89)	7.67 (2.77)	5.83 (2.42)	8.67 (2.94)	**7.88 (2.81)**
Mean	**7.36 (2.71)**	**5.52 (2.35)**	**6.25 (2.50)**	**5.21 (2.28)**	**7.25 (2.69)**	**6.32 (2.51)**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.29			1.31		
F	0.33			NS		
D×F	0.67			NS		
Y	0.31			NS		
Y×D	0.66			NS		
Y×F	0.52			NS		
Y×D×F	0.40			NS		

***D =** Sowing dates; D_1= 15th April; D_2 = 30th April; D_3 = 15th May; D_4 = 30th May
***F =** Fruit load; F_1 = 3 fruits; F_2 = 4 fruits; F_3 = 5 fruits; F_4 = 6 fruits; F_5 = all fruits retained (control)
***Y =** Year; Y_1 = 2022-2023; Y_2 = 2023-2024
*Figures in parentheses are square root transformed values

the lowest incidence of fruit fly (3.79 %) was observed when sowing was done on 15th April (D_2).

From the perusal of data, sowing on 15th May (D_3) was the most vulnerable sowing dates for incidence of fruit fly (%) during the first year 2022-2023, second year 2023-2024 and pooled analysis. The interactions between years and sowing dates (Y × D), between years and fruit load (Y × F) and the three-way interaction among sowing dates, fruit load and years (D × F × Y) were found to be non-significant, suggesting that these factors independently influence fruit fly incidence.

The temporal variation in fruit fly incidence highlights the influence of sowing dates and environmental conditions. Higher incidences during late sowing on 15th May (D_3), may be attributed to favourable climatic conditions like higher temperatures and humidity, which enhance pest activity (Manoj et al. 2017). Conversely, earlier sowing on 15th April (D_2) likely escape the peak activity periods of fruit flies. Similar findings have been reported in other studies, indicating that sowing dates significantly affect fruit fly infestation levels in cucurbits (Nehra et al. 2019).

4.6.2 Incidence of powdery mildew (%) in cucumber

Powdery mildew is a prevalent fungal disease affecting cucumbers and other cucurbit crops. Primarily caused by the pathogens *Podosphaera xanthii* and *Erysiphe cichoracearum*, this disease manifests as white, powdery spots on leaves, stems and petioles. These spots can expand, leading to chlorosis (yellowing of leaves), reduced photosynthesis, impaired growth and diminished yields. The disease thrives in warm, dry conditions with high humidity, typically favouring temperatures between 20-27°C. Infections often begin on older or shaded leaves and can rapidly spread, especially under favourable environmental conditions. Sowing dates can significantly influence the incidence of powdery mildew in cucumbers. Early sowing, when soil temperatures have adequately warmed, allows plants to establish before the peak conditions favouring powdery mildew, potentially reducing disease impact.

The data from the first year 2022-2023 and second year 2023-2024, along with the pooled analysis, showed significant variations in the incidence of powdery mildew (%) across treatments (Table 4.6.2).

During the first year 2022-2023, the effect of sowing dates was significant for incidence of powdery mildew (%) whereas, non-significant for fruit load and interaction of

sowing dates and fruit load. Regarding the effect of sowing dates, the highest incidence of powdery mildew (10.6 %) was recorded when sowing was done on 30th May (D_4), while the lowest incidence of powdery mildew (4.89 %) was observed when sowing was done on 15th April (D_2).

During the second year 2023-2024, the effect of sowing dates, fruit load and their interaction was non-significant for incidence of powdery mildew (%) and the values ranged from 11.1 - 5.56 %.

The pooled data across two years showed that the effect of sowing dates was significant for incidence of powdery mildew (%) whereas, non-significant for fruit load and interaction of sowing dates and fruit load. Regarding the effect of sowing dates, the highest incidence of powdery mildew (10.1 %) was recorded when sowing was done on 30th May (D_4), while the lowest incidence of powdery mildew (5.56 %) was observed when sowing was done on 15th April (D_2).

From the perusal of data, sowing on 30th May (D_4) was the most vulnerable sowing date for incidence of powdery mildew (%). The interactions between years and sowing dates (Y × D), between years and fruit load (Y × F) and the three-way interaction among sowing dates, fruit load and years (D × F × Y) were found to be non-significant, suggesting that these factors independently influence powdery mildew incidence (%).

The findings of this study demonstrate significant variability in the incidence of powdery mildew (%) across different sowing dates, as evidenced by the data from the first and second years and the pooled analysis.

The sowing dates significantly influenced powdery mildew incidence, particularly during the first year (2022-2023) and in the pooled analysis, while fruit load and their interaction with sowing dates showed no significant effects. The observed higher incidence of powdery mildew (%) in cucumbers sown on 30th May (D_4) could be attributed to the environmental conditions during this period, such as higher relative humidity and temperatures, which are conducive to the development and proliferation of the pathogen responsible for powdery mildew.

Conversely, the lowest incidence recorded on 15th April (D_2) may be explained by less favourable climatic conditions for the pathogen during this sowing window.

Table 4.6.2: Effect of sowing dates and fruit load on incidence of powdery mildew in cucumber

Incidence of powdery mildew (%) in cucumber						
Y_1 (2022-2023)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	7.78 (2.79)	6.67 (2.58)	7.78 (2.79)	8.89 (2.98)	7.78 (2.79)	**7.78 (2.79)**
D_2	5.56 (2.36)	3.33 (1.82)	5.56 (2.36)	4.44 (2.11)	5.56 (2.36)	**4.89 (2.21)**
D_3	8.89 (2.98)	7.78 (2.79)	10.0 (3.16)	7.78 (2.79)	12.2 (3.50)	**9.33 (3.05)**
D_4	8.89 (2.98)	10.0 (3.16)	13.3 (3.65)	8.89 (2.98)	12.2 (3.50)	**10.6 (3.27)**
Mean	**7.78 (2.79)**	**6.95 (2.64)**	**9.17 (3.03)**	**7.50 (2.74)**	**9.45 (3.07)**	**8.17 (2.86)**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.83			2.87		
F	0.90			NS		
D×F	1.86			NS		
Y_2 (2023-2024)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	6.67 (2.58)	8.89 (2.98)	8.89 (2.98)	7.78 (2.79)	7.78 (2.79)	**8.00 (2.83)**
D_2	5.56 (2.36)	6.67 (2.58)	5.56 (2.36)	6.67 (2.58)	7.78 (2.79)	**6.45 (2.54)**
D_3	7.78 (2.79)	8.89 (2.98)	8.89 (2.98)	8.89 (2.98)	8.89 (2.98)	**8.67 (2.94)**
D_4	7.78 (2.79)	8.89 (2.98)	8.89 (2.98)	11.1 (3.33)	11.1 (3.33)	**9.56 (3.09)**
Mean	**6.95 (2.64)**	**8.34 (2.89)**	**8.11 (2.85)**	**8.61 (2.93)**	**8.89 (2.98)**	**8.18 (2.86)**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	2.25			NS		
F	0.57			NS		
D×F	1.13			NS		
Pooled						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	7.22 (2.69)	7.78 (2.79)	8.33 (2.89)	8.33 (2.89)	7.78 (2.79)	**7.89 (2.81)**
D_2	5.56 (2.36)	5.00 (2.24)	5.00 (2.24)	5.56 (2.36)	6.67 (2.58)	**5.56 (2.36)**
D_3	8.33 (2.89)	8.33 (2.89)	9.44 (3.07)	8.33 (2.89)	10.5 (3.25)	**9.00 (3.00)**
D_4	8.33 (2.89)	9.44 (3.07)	11.1 (3.33)	10.0 (3.16)	11.6 (3.42)	**10.1 (3.18)**
Mean	**7.36 (2.71)**	**7.64 (2.76)**	**8.47 (2.91)**	**8.06 (2.84)**	**9.17 (3.03)**	**8.14 (2.85)**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.59			2.65		
F	0.46			NS		
D×F	0.91			NS		
Y	0.56			NS		
Y×D	0.88			NS		
Y×F	0.54			NS		
Y×D×F	0.46			NS		

***D =** Sowing dates; D_1= 15th April; D_2 = 30th April; D_3 = 15th May; D_4 = 30th May
***F =** Fruit load; F_1 = 3 fruits; F_2 = 4 fruits; F_3 = 5 fruits; F_4 = 6 fruits; F_5 = all fruits retained (control)
***Y =** Year; Y_1 = 2022-2023; Y_2 = 2023-2024
*Figures in parentheses are square root transformed values

The non-significant effect of fruit load and their interaction with sowing dates on powdery mildew incidence indicates that environmental factors associated with sowing time play a more crucial role in disease development than plant physiological stress due to varying fruit load.

This aligns with previous research emphasizing the importance of environmental conditions in the epidemiology of powdery mildew (Trecate et al. 2019; Milod et al. 2021). The absence of significant interactions between years and sowing dates, years and fruit load and the three-way interaction among these factors suggests that their effects on powdery mildew incidence are independent. Adjusting sowing dates to avoid periods conducive to disease development can be an effective cultural practice to mitigate powdery mildew incidence (%) in cucumber.

4.6.3 Incidence of downy mildew (%) in cucumber

The downy mildew, caused by *Pseudoperonospora cubensis*, is a devastating foliar disease affecting cucurbits, including cucumber. This disease is characterized by the appearance of yellow spots on the upper surface of leaves, which eventually turn necrotic and the development of grayish to purple sporulation on the underside of leaves. Downy mildew significantly reduces photosynthetic capacity, leading to stunted plant growth, poor fruit development and substantial yield losses. The incidence of downy mildew are strongly influenced by environmental factors, particularly temperature, humidity and rainfall. These factors are closely linked to sowing dates, which determine the growth stages of the crop during periods favourable for disease development.

The data from the first year 2022-2023 and second year 2023-2024, along with the pooled analysis, showed significant variations in the incidence of downy mildew (%) across treatments (Table 4.6.3).

During the first year 2022-2023, the effect of sowing dates was significant for incidence of downy mildew (%) whereas, non-significant for fruit load and interaction of sowing dates and fruit load. Regarding the effect of sowing dates, the highest incidence of downy mildew (11.7 %) was recorded when sowing was done on 30th May (D_4), while the lowest incidence of downy mildew (5.87 %) was observed when sowing was done on 15th April (D_2).

Table 4.6.3 Effect of sowing dates and fruit load on incidence of downy mildew in cucumber

Incidence of downy mildew (%) in cucumber						
Y_1 (2022-2023)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	9.33 (3.05)	8.00 (2.83)	9.33 (3.05)	10.6 (3.27)	9.33 (3.05)	**9.33 (3.05)**
D_2	6.67 (2.85)	4.00 (2.00)	6.67 (2.58)	5.33 (2.31)	6.67 (2.58)	**5.87 (2.42)**
D_3	10.6 (3.27)	9.33 (3.05)	8.00 (2.83)	9.33 (3.05)	9.33 (3.05)	**9.33 (3.05)**
D_4	10.6 (3.27)	9.33 (3.05)	13.3 (3.65)	12.0 (3.46)	13.3 (3.65)	**11.7 (3.42)**
Mean	**9.33 (3.05)**	**7.67 (2.77)**	**9.33 (3.05)**	**9.33 (3.05)**	**9.67 (3.11)**	**9.07 (3.01)**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.89			3.09		
F	0.95			NS		
D×F	1.90			NS		
Y_2 (2023-2024)						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	5.33 (2.31)	6.67 (2.58)	5.33 (2.31)	8.00 (2.83)	6.67 (2.58)	**6.40 (2.53)**
D_2	4.00 (2.00)	5.33 (2.31)	4.00 (2.00)	8.00 (2.83)	5.33 (2.31)	**5.33 (2.31)**
D_3	10.6 (3.27)	5.33 (2.31)	10.6 (3.27)	9.33 (3.05)	8.00 (2.83)	**8.80 (2.97)**
D_4	12.0 (3.46)	10.6 (3.27)	6.67 (2.58)	9.33 (3.05)	6.67 (2.58)	**9.07 (3.01)**
Mean	**8.00 (2.83)**	**7.00 (2.65)**	**6.67 (2.58)**	**8.67 (2.94)**	**6.67 (2.58)**	**7.40 (2.72)**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	1.42			NS		
F	0.64			NS		
D×F	1.28			NS		
Pooled						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**Mean**
D_1	7.33 (2.71)	7.33 (2.71)	7.33 (2.71)	9.33 (3.05)	8.00 (2.83)	**7.87 (2.81)**
D_2	5.33 (2.31)	4.67 (2.16)	5.33 (2.31)	6.67 (2.58)	6.00 (2.45)	**5.60 (2.37)**
D_3	10.6 (3.27)	7.33 (2.71)	9.33 (3.05)	9.33 (3.05)	8.67 (2.94)	**9.07 (3.01)**
D_4	11.3 (3.37)	10.0 (3.16)	10.0 (3.16)	10.6 (3.27)	10.0 (3.16)	**10.4 (3.22)**
Mean	**8.67 (2.94)**	**7.33 (2.71)**	**8.00 (2.83)**	**9.00 (3.00)**	**8.17 (2.86)**	**8.23 (2.87)**
Factors	**SE (m)±**			**CD $_{(0.05)}$**		
D	0.66			NS		
F	0.67			NS		
D×F	1.35			NS		
Y	0.68			NS		
Y×D	0.62			NS		
Y×F	1.01			NS		
Y×D×F	0.68			NS		

***D =** Sowing dates; D_1= 15th April; D_2 = 30th April; D_3 = 15th May; D_4 = 30th May
***F =** Fruit load; F_1 = 3 fruits; F_2 = 4 fruits; F_3 = 5 fruits; F_4 = 6 fruits; F_5 = all fruits retained (control)
***Y =** Year; Y_1 = 2022-2023; Y_2 = 2023-2024
*Figures in parentheses are square root transformed values

During the second year 2023-2024, the effect of sowing dates, fruit load and their interaction was non-significant for incidence of downy mildew (%) and the values ranged from 4.00 - 13.3 %.

The pooled data across two years showed that the effect of sowing dates, fruit load and their interaction was non-significant for incidence of downy mildew (%). From the perusal of data, sowing on 30th May (D_4) was the most vulnerable sowing date for incidence of downy mildew (%).

The interactions between years and sowing dates (Y × D), between years and fruit load (Y × F) and the three-way interaction among sowing dates, fruit load and years (D × F × Y) were found to be non-significant, suggesting that these factors independently influence downy mildew incidence (%).

The results indicate that downy mildew incidence varied significantly with sowing dates during the first year, while fruit load and their interaction with sowing dates were non-significant. The highest incidence occurred when sowing was done on May 30th (D_4) and the lowest when sowing was done on 15th April (D_2). This suggests that later sowing dates may expose crops to environmental conditions more favourable for the pathogen responsible for downy mildew. Early sowing has been shown to help avoid peak periods of downy mildew pressure, thereby reducing disease incidence and potentially increasing yield (Meena et al. 2019.

During the second year, the effect of sowing dates, fruit load and their interaction on downy mildew incidence was non-significant. The variability in incidence across treatments reflects differences in environmental conditions between the two years, such as temperature and rainfall distribution, which could have mitigated or intensified disease pressure (Granke et al. 2014). The pooled analysis across the two years further indicated non-significant effects of sowing dates, fruit load and their interaction on downy mildew incidence, suggesting that environmental factors might overshadow the effects of these variables under certain conditions.

From the results, it is evident that late sowing on 30th May (D_4) presents the highest risk for downy mildew, emphasizing the need for strategic sowing to mitigate disease

incidence. Adjusting sowing schedules to earlier on 15th April (D_2), could help reduce disease pressure by avoiding periods with environmental conditions favourable for the pathogen.

4.7 Economics of the treatments

Economic analysis plays a critical role in evaluating the profitability and sustainability of agricultural practices. Key parameters such as cost of cultivation, gross return, net return and the benefit cost (B:C) ratio are integral to assessing the economic viability of farming interventions. The cost of cultivation accounts for all expenses incurred during production, including inputs like seeds, fertilizers, irrigation and labor. Gross return represents the total revenue from the sale of agricultural produce, while net return is derived by subtracting the cost of cultivation from the gross return, offering a clear measure of profitability. The B:C ratio, calculated by dividing gross return by the cost of cultivation, is a crucial indicator of economic efficiency, with a value greater than one signifying a profitable system.

In cucumber seed production, economic analysis becomes particularly important due to the influence of agronomic factors such as sowing dates and fruit load management on seed yield and quality. Research has shown that optimal sowing dates can significantly enhance yield and profitability by ensuring favourable growing conditions during critical growth phases (Akhi and Islam 2020). Similarly, fruit load per plant affects the allocation of plant resources, impacting both yield and economic outcomes (Gupta et al. 2021a). Retaining an appropriate number of fruits per plant ensures balanced nutrient distribution, maximizing seed quality and financial returns.

The calculation of economic metrics for cucumber seed production under varying sowing dates and fruit load provides essential insights for optimizing resource use and profitability. Strategic decisions based on such analyses can guide farmers in adopting practices that improve the economic efficiency of their operations while ensuring long-term sustainability. Similar findings related to seed production in cucumber have been reported by Jaiswal et al. (2015).

The treatment-wise mean cost of cultivation and return analysis (B:C ratio) over the two years of the study is presented in Table 4.7.1, with detailed breakdowns of fixed costs, variable costs and total costs provided in Appendix II.

Table 4.7.1: Effect of sowing dates and fruit load on economics of the treatments

Treatment	Treatment combinations	Seed yield (kg/ha)	Gross return	Cost of cultivation	Net return	B:C ratio
T_1	D_1F_1	231.39	925572	378584	546988	1.4
T_2	D_1F_2	300.37	1201472	382984	818488	2.1
T_3	D_1F_3	366.41	1465659	387384	1078276	2.8
T_4	D_1F_4	411.26	1645049	391784	1253266	3.2
T_5	D_1F_5	291.96	1167830	374184	793646	2.1
T_6	D_2F_1	266.61	1066438	378584	687855	1.8
T_7	D_2F_2	347.33	1389315	374184	1015132	2.7
T_8	D_2F_3	426.14	1704571	387384	1317188	3.4
T_9	D_2F_4	465.81	1863226	391784	1471443	3.8
T_{10}	D_2F_5	346.17	1384692	374184	1010508	2.7
T_{11}	D_3F_1	214.35	857409	378584	478826	1.3
T_{12}	D_3F_2	272.92	1091693	382984	708709	1.9
T_{13}	D_3F_3	338.64	1354548	387384	967165	2.5
T_{14}	D_3F_4	411.28	1645124	391784	1253340	3.2
T_{15}	D_3F_5	326.05	1304214	374184	930030	2.5
T_{16}	D_4F_1	194.08	776320	378584	397736	1.1
T_{17}	D_4F_2	249.57	998295	382984	615312	1.6
T_{18}	D_4F_3	303.60	1214404	387384	827020	2.1
T_{19}	D_4F_4	356.26	1425042	391784	1033258	2.6
T_{20}	D_4F_5	287.55	1150217	374184	776033	2.1
*** Sale rate of seeds - ₹ 4000 / kg**						

In the economic analysis, the treatment T_9 *i.e.* sowing on 30th April with 6 fruits per plant retained (D_2F_4) achieved the highest net returns of ₹ 1471443 per hectare, accompanied by the highest B:C ratio (3.8). This was followed by treatment T_8, which involved sowing on 30th April with 5 fruits per plant retained (D_2F_3), which gave net returns of ₹ 1317188 and a corresponding B:C ratio (3.4).

The superior performance of T_9 *i.e.* sowing on 30th April with 6 fruits per plant retained (D_2F_4) in terms of higher B:C ratio and high net return can be attributed to highest seed yield per hectare obtained in this treatment. The enhanced cucumber seed yield in this treatment, resulting from optimal growing conditions during the sowing period and increased fruit load, contributed to the highest gross returns of ₹ 1863226. Sowing on 30th April

provided optimal temperature and light conditions conducive to better fruit and seed development, while retaining 6 fruits per plant ensured efficient resource allocation, maximizing seed yield.

The substantial net income observed in T_9 (D_2F_4) and related treatments reflects increased seed yield, which garnered higher market value, significantly improving gross income. These findings align with previous research highlighting similar trends in economic returns across various crops (Gogoi et al. 2016; Nandre and Sahane 2011 and Jana 2005).

If seed quality is the primary objective, the treatment involving sowing on 30th April with 3 fruits per plant retained (D_2F_1) is the most suitable for cucumber seed production, as it recorded superior values for key seed quality parameters. However, if the goal is to maximize seed yield and economic returns, sowing on 30th April with 6 fruits per plant retained (D_2F_4) emerges as the best option. This treatment achieved the highest seed yield per hectare, leading to the maximum net returns of ₹1471443 and the highest benefit-cost ratio of 3.8, making it the most economically viable choice for large-scale seed production.

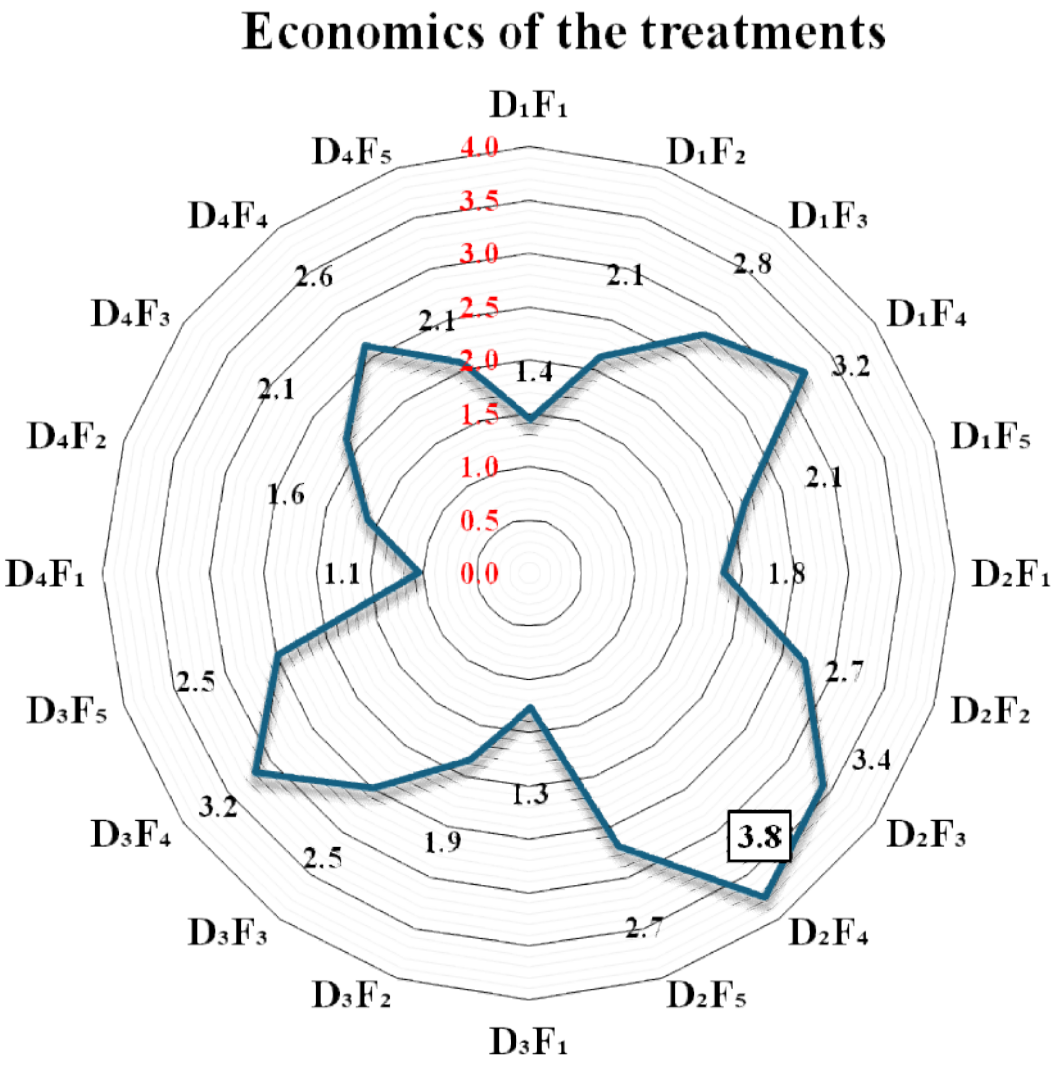


Figure 4.7.1: Effect of sowing dates and fruit load on economics of the treatments



Plate 4.1: Illustration of harvested fruits ready for seed extraction



Plate 4.2: Illustration of seed germination and seedling length in laboratory experiments

Chapter-5

SUMMARY AND CONCLUSION

The present research, titled **"Studies on Influence of Sowing Dates and Fruit Load on Seed Yield and Quality of Cucumber (*Cucumis sativus* L.)"**, was undertaken to optimize the sowing date and fruit load management for cucumber seed production. The study was conducted at the Experimental Farm and Laboratory of the Department of Vegetable Science, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, over two consecutive years, 2022-2023 and 2023-2024. The experiments focused on the cucumber variety Solan Srijan and were laid out in a split-plot design with three replications and twenty treatment combinations.

The experimental layout involved beds measuring 3.0 m × 1.5 m, with 30 cm wide channels on either side to facilitate irrigation and drainage. Seeds of the cucumber variety Solan Srijan were sown directly on the prepared beds at a plant spacing of 75 cm × 60 cm. Each plot measured 4.5 m^2 and accommodated 10 plants, resulting in a total of 60 plots. The treatments comprised four sowing dates (15^{th} April, 30^{th} April, 15^{th} May and 30^{th} May) and five levels of fruit load management (3 fruits per plant, 4 fruits per plant, 5 fruits per plant, 6 fruits per plant and all fruits per plant retained as control).

Standard cultural practices were employed to raise the cucumber crop. These included timely irrigation, application of fertilizers as per crop requirements, manual weeding and other intercultural operations. Pest and disease management practices were implemented to minimize biotic stress and ensure healthy crop growth. Observations were recorded systematically to evaluate the influence of sowing dates and fruit load on plant growth, fruit development, seed yield and quality.

Key plant and fruit characteristics assessed included vine length, fruit length, fruit breadth and fruit weight. These traits provided insight into the vegetative and reproductive performance of the crop under different treatments. Seed yield attributes were measured across multiple parameters, including the total number of seeds per fruit, seed yield per fruit, seed yield per plant, seed yield per plot, seed yield per hectare, seed yield index, 1000 seed weight, the number of filled and unfilled seeds and seed fresh and dry weights.

To assess seed quality, a comprehensive set of parameters was recorded. Germination percentage, speed of germination, field emergence percentage, seedling length and seedling dry weight were evaluated to understand seedling vigour and establishment potential. Seed vigour indices (I and II) were calculated for a more detailed assessment of seed quality. Physiological seed quality traits were examined through laboratory assays, including the electrical conductivity of seed leachates, soluble sugar and protein content in seed leachates, soluble sugar, protein content and starch content in seeds and oil content percentage in seeds.

In addition to plant and seed traits, soil health was monitored throughout the experiment. Soil samples were collected before planting and after harvest to analyze pH, electrical conductivity, organic carbon and available nitrogen, phosphorus and potassium levels. These analyses ensured that any variations in soil fertility or composition were accounted for in the interpretation of results.

The incidence of economically significant insect pests and diseases was recorded during the crop's growth period. Specific observations included the percentage incidence of fruit fly, powdery mildew and downy mildew of cucumber. These observations helped in understanding the potential impact of biotic stress on seed yield and quality under varying sowing dates and fruit load.

The economics of the treatments was calculated through the benefit-cost ratio for each treatment combination. This analysis aimed to evaluate the financial viability of adopting specific sowing dates and fruit load management practices.

Statistical analysis was conducted using analysis of variance to determine the significance of the effects of sowing dates, fruit load and their interactions on various growth, yield and quality parameters. The systematic collection of data across two years provided robust insights into the interaction between sowing dates and fruit load, with implications for seed yield and quality in cucumber.

The key experimental findings of the study are summarized below on the basis of pooled data of both the years:

5.1 Plant and fruit characters

- The maximum vine length (285.62 cm), fruit length (27.56 cm), fruit breadth (5.34 cm) and fruit weight (644.17 g) were observed when sowing was done on 30^{th} April (D_2) in the pooled data.

- The highest values for vine length (248.45 cm), fruit length (25.03 cm), fruit breadth (5.09 cm) and fruit weight (542.98 g) were recorded when 3 fruits per plant (F_1) were retained in the pooled data.
- The combination of sowing on 30th April and retaining 3 fruits per plant (D_2F_1) resulted in the maximum fruit length (29.68 cm), fruit breadth (5.75 cm) and fruit weight (680.19 g) in the pooled data.
- The interaction between sowing dates and fruit load was non-significant in the pooled analysis for vine length with values ranging from 301.67 - 163.76 cm.

5.2 Seed yield traits

- The maximum number of seeds per fruit (428.36), highest seed yield per fruit (10.48 g), highest seed yield per plant (47.62 g), highest seed yield per plot (238.12 g), highest seed yield per hectare (370.41 kg), lowest seed yield index (16.24), highest 1000 seed weight (24.38 g), highest number of filled seeds (335.36), highest number of unfilled seeds (93.00), maximum seed fresh weight (2.579 g) and maximum seed dry weight (1.614 g) were recorded when sowing was done on 30th April (D_2) in the pooled analysis from both years.
- The maximum number of seeds per fruit (397.45), highest seed yield per fruit (9.68 g), lowest seed yield index (18.28), highest 1000 seed weight (24.22 g), maximum number of filled seeds (311.33), maximum number of unfilled seeds (86.12), maximum seed fresh weight (2.371 g) and maximum seed dry weight (1.482 g) were recorded when 3 fruits per plant (F_1) were retained in the pooled analysis.
- The maximum seed yield per plant (52.86 g), highest seed yield per plot (264.31 g) and highest seed yield per hectare (411.15 kg) were recorded when 6 fruits per plant (F_4) were retained in the pooled analysis.
- The maximum number of seeds per fruit (444.83), highest seed yield per fruit (11.42 g), highest 1000 seed weight (25.60 g), number of filled seeds (348.33), number of unfilled seeds (96.50) were observed when sowing was done on 30th April and 3 fruits per plant were retained (D_2F_1) in the pooled analysis.
- The maximum seed yield per plant (59.89 g), highest seed yield per plot (299.44 g) and highest seed yield per hectare (465.81 kg) were recorded when sowing was done on 30th April and 6 fruits per plant (D_2F_4) were retained in the pooled analysis.

- The lowest seed yield index (14.58) was recorded when sowing was done on 30th April and all fruits per plant (D_2F_5) were retained in the pooled analysis.
- The interaction between sowing dates and fruit load was non-significant in the pooled analysis for both seed fresh weight and seed dry weight, with values ranging from 2.603 g to 2.102 g for fresh weight and 1.629 g to 1.312 g for dry weight.

5.3 Seed quality traits

- The highest seed germination (87.73 %), highest speed of germination (15.92), highest field emergence (68.20 %), highest seedling length (25.70 cm), highest seedling dry weight (13.95 g), highest seedling vigour index - I (2257.06) and highest seedling vigour index - II (1159.33) were recorded when sowing was done on 30th April (D_2) in the pooled analysis from both years.
- The maximum seed germination (82.41 %), highest speed of germination (15.20), highest field emergence (62.50 %), highest seedling length (23.16 cm), highest seedling dry weight (12.94 g), highest seedling vigour index - I (1925.91) and highest seedling vigour index - II (1044.95) were recorded when 3 fruits per plant (F_1) were retained in the pooled analysis.
- The interaction between sowing dates and fruit load was non-significant in the pooled analysis for seed germination, speed of germination and field emergence with values ranging from 90.50 - 69.66 % for seed germination, 16.23 - 13.56 for speed of germination and 68.33 - 50.00 % for field emergence.
- The maximum seedling length (27.49 cm), highest seedling dry weight (14.20 g), highest seedling vigour index - I (2488.66) and highest seedling vigour index - II (1217.33) were observed when sowing was done on 30th April and 3 fruits per plant were retained (D_2F_1) in the pooled analysis.

5.4 Seed physiological assays

- The lowest electrical conductance from seed leachates (55.68 µS cm^{-1} g^{-1}), lowest total soluble sugars in seed leachates (0.638 mg g^{-1}), lowest total soluble proteins in seed leachates (6.02 mg g^{-1}), highest total soluble sugars in seeds (2.720 mg g^{-1}_{dw}) highest total soluble proteins in seeds (155.87 mg g^{-1}_{dw}), highest total starch contents in seeds (118.79 mg g^{-1}_{dw}) and highest oil content in seeds (27.28 %) were recorded when sowing was done on 30th April (D_2) in the pooled analysis from both years.

- The lowest electrical conductance from seed leachates (69.13 µS cm^{-1} g^{-1}), lowest total soluble sugars in seed leachates (0.659 mg g^{-1}), lowest total soluble proteins in seed leachates (6.93 mg g^{-1}), highest total soluble sugars in seeds (2.519 mg g^{-1}_{dw}), highest total soluble proteins in seeds (144.80 mg g^{-1}_{dw}), highest total starch contents in seeds (116.02 mg g^{-1}_{dw}) and highest oil content in seeds (25.58 %) were recorded when 3 fruits per plant (F_1) were retained in the pooled analysis.
- The lowest electrical conductance from seed leachates (50.72 µS cm^{-1} g^{-1}) was observed when sowing was done on 30th April and 4 fruits per plant were retained (D_2F_2) whereas lowest total soluble proteins in seed leachates (5.85 mg g^{-1}) and highest oil content in seeds (27.77 %) were observed when sowing was done on 30th April and 3 fruits per plant were retained (D_2F_1) in the pooled analysis.
- The interaction between sowing dates and fruit load was non-significant in the pooled analysis for total soluble sugars in seed leachates (0.714 - 0.630 mg g^{-1}), total soluble sugars in seeds (2.812 - 2.160 mg g^{-1}_{dw}), total soluble proteins in seeds (159.05 - 121.47 mg g^{-1}_{dw}) and total starch contents in seeds (119.55 - 110.20 mg g^{-1}_{dw}).

5.5 Soil analysis

- The pH values of the soil in pooled analysis were within the range of 7.41 - 7.47 which was in the suitable range for the cultivation of cucumber.
- Electrical conductivity of the soil in pooled analysis ranged from 0.263 - 0.237 dSm^{-1} which was also within suitable limit for the cultivation of cucumber.
- The organic carbon values of the soil in pooled analysis were within the range of 1.29 - 1.35 % which was also in the suitable range for the cultivation of cucumber.
- After the harvest of cucumber crop, the pooled soil analysis revealed maximum availability of N:P:K (295.31:61.77:398.27 kg/ha) in plots where sowing was done on 30th April (D_2).
- The pooled soil analysis revealed maximum availability of N:P:K (298.30:62.32:400.85 kg/ha) in plots where 3 fruits per plant were retained (F_1) after the harvest of cucumber crop.
- The pooled soil analysis revealed maximum availability of N:P:K (300.83:63.84:402.97 kg/ha) in plots where sowing was done on 30th April and 3 fruits per plant were retained (D_2F_1) after the harvest of cucumber crop.

5.6 Incidence (%) of economically important insect-pest /diseases of cucumber

- The lowest incidence of fruit fly (3.79 %) and incidence of powdery mildew (5.56 %) was seen when sowing was done on 15th April (D_2) whereas the effect of date of sowing was non-significant for incidence of downy mildew and the values ranged from 5.60 - 10.4 % in the pooled analysis.
- The effect of fruit load was non-significant for incidence of fruit fly (5.21 - 7.36 %), incidence of powdery mildew (7.36 - 9.17 %) and incidence of downy mildew (7.33 - 9.00 %) in the pooled analysis.
- The interaction between sowing dates and fruit load was non-significant in the pooled analysis for incidence of fruit fly (2.92 - 9.00 %), incidence of powdery mildew (5.00 - 11.6 %) and incidence of downy mildew (4.67 - 11.3 %) in the pooled analysis.

5.7 Economics of the treatments

- In the economic analysis, the treatment T_9 *i.e.* sowing on 30th April with 6 fruits per plant retained (D_2F_4) achieved the highest net returns of ₹ 1471443 per hectare, accompanied by the highest B:C ratio (3.8).

CONCLUSION

The present investigation, titled **"Studies on Influence of Sowing Dates and Fruit Load on Seed Yield and Quality of Cucumber (*Cucumis sativus* L.)"**, revealed significant variations in all plant and fruit characters, seed yield and quality traits, seed physiological assays, soil analysis and incidence of economically important insect-pest/diseases. Additionally, the study demonstrated notable differences in economic returns based on the interaction between sowing dates and fruit load management practices.

The study revealed that sowing on 30th April (D_2) emerged as the optimal date for achieving superior seed yield and quality, as it provided the most conducive agro-climatic conditions for cucumber seed production.

The retaining of 6 fruits per plant (F_4) maximized seed yield, whereas retaining 3 fruits per plant (F_1) enhanced seed quality parameters. The results highlight the potential for tailoring production strategies to align with specific market demands, enabling flexibility in achieving desired outcomes.

The interaction between 30th April sowing (D_2) and varying fruit load significantly influenced both seed yield and quality. Higher fruit load (F_4 - 6 fruits per plant) optimized seed yield and economic returns, while lower fruit load (F_1 - 3 fruits per plant) improved seed quality traits. This underscores the complementary effects of sowing dates and fruit load on balancing yield and quality in cucumber seed production.

The sowing on 30th April with 6 fruits per plant retained (D_2F_4) resulted in the maximum net returns (₹ 1471443 per hectare) and highest benefit-cost ratio (3.8), establishing it as the most economically viable treatment for large-scale seed production.

Based on the studies conducted over two consecutive years (2022-2023 and 2023-2024), it can be concluded that sowing cucumber seeds of cv. Solan Srijan on 30th April with 3 fruits per plant retained (D_2F_1), is the most effective treatment for achieving high-quality seed production under mid-hill conditions of Himachal Pradesh.

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APPENDIX - I

AGRO-METEROLOGICAL DATA

Mean monthly meteorological data of Dr. YS Parmar University of Horticulture and Forestry, Nauni, Solan (HP) during the research period (April 2022 to September 2022)

Month	Temperature (°C)			Relative Humidity (%)	Rainfall (mm)
	Maximum	Minimum	Mean		
2022					
April 2022	33.20	13.30	23.25	37	1.00
May 2022	32.00	16.10	24.05	52	84.80
June 2022	32.10	17.10	24.60	49	85.60
July 2022	28.50	20.50	24.50	81	195.40
August 2022	29.00	19.90	24.45	78	219.50
September 2022	27.80	17.80	22.80	77	233.50

Mean monthly meteorological data of Dr. YS Parmar University of Horticulture and Forestry, Nauni, Solan (HP) during the research period (April 2023 to September 2023)

Month	Temperature (°C)			Relative Humidity (%)	Rainfall (mm)
	Maximum	Minimum	Mean		
2023					
April 2023	26.60	10.50	18.55	78	130.60
May 2023	27.90	13.20	20.55	78	152.30
June 2023	29.30	17.40	23.35	78	154.00
July 2023	27.50	20.10	23.80	78	660.50
August 2023	29.00	20.10	24.55	78	283.40
September 2023	29.70	18.20	23.95	72	24.2

Source: Meteorological Observatory, Department of Environmental Science, College of Forestry, Dr. YS Parmar University of Horticulture and Forestry, Nauni, Solan (HP)-173 230

APPENDIX – II

Cost of cultivation of cucumber seed production as affected by different treatments

A. Fixed cost			
S. No.	**Particulars**	**Quantity required / ha**	**Cost ₹/ha**
1.	Cost of seeds	4 kg @ ₹ 4000/kg	16000
2.	Ploughing	2 (4 hour/ha @ ₹ 500/hour)	4000
3.	Planking	2 (4 hour/ha @ ₹ 500/hour)	4000
4.	Bed preparation	30 man days @ ₹ 440/ man day	13200
5.	Sowing of seeds	30 man days @ ₹ 440/ man day	13200
6.	Farm yard manure (FYM)	100 q/ha @ ₹ 2.5/kg	25000
7.	Carriage and application of FYM	30 man days @ ₹ 440/ man day	13200
8.	Recommended dose of fertilizers (RDF) i) Urea ii) SSP iii) MOP	100:50:60 NPK kg/ha 312 kg/ha @ ₹ 6/kg 217 kg/ha @ ₹ 12/kg 100 kg/ha @ ₹ 18/kg	 1872 2604 1800
9.	Application of RDF	25 man days @ ₹ 440/ man day	11000
10.	Irrigation	50 man days @ ₹ 440/ man day	22000
11.	Intercultural operations	50 man days @ ₹ 440/ man day	22000
12.	Plant protection (disease and pest management) - Fungicides and pesticides procurement and application		20000
13.	Staking materials - Bamboo poles, suthli, wire, clips etc.		50000
14.	Staking	60 man days @ ₹ 440/ man day	26400
15.	Harvesting	50 man days @ ₹ 440/ man day	22000
16.	Seed extraction, cleaning, drying, packaging and seed storage	70 man days @ ₹ 440/ man day	30800
17.	Miscellaneous expenses		8000
		Total	**307076**
18.	Management + Risk factor @ 10% of working capital		30708
19.	Depreciation + rental value of land + interest on fixed capital		10000
		Grand Total	**347784**

B. Variable cost				
Treatment	**Treatment combinations**	**Treatment details**	**Man days***	**Cost ₹ /ha**
T_1	D_1F_1	15th April sowing date + 3 fruits per plant	70	30800
T_2	D_1F_2	15th April sowing date + 4 fruits per plant	80	35200
T_3	D_1F_3	15th April sowing date + 5 fruits per plant	90	39600
T_4	D_1F_4	15th April sowing date + 6 fruits per plant	100	44000
T_5	D_1F_5	15th April sowing date + all fruits retained (control)	60	26400
T_6	D_2F_1	30th April sowing date + 3 fruits per plant	70	30800
T_7	D_2F_2	30th April sowing date + 4 fruits per plant	80	26400
T_8	D_2F_3	30th April sowing date + 5 fruits per plant	90	39600
T_9	D_2F_4	30th April sowing date + 6 fruits per plant	100	44000
T_{10}	D_2F_5	30th April sowing date + all fruits retained (control)	60	26400
T_{11}	D_3F_1	15th May sowing date + 3 fruits per plant	70	30800
T_{12}	D_3F_2	15th May sowing date + 4 fruits per plant	80	35200
T_{13}	D_3F_3	15th May sowing date + 5 fruits per plant	90	39600
T_{14}	D_3F_4	15th May sowing date + 6 fruits per plant	100	44000
T_{15}	D_3F_5	15th May sowing date + all fruits retained (control)	60	26400
T_{16}	D_4F_1	30th May sowing date + 3 fruits per plant	70	30800
T_{17}	D_4F_2	30th May sowing date + 4 fruits per plant	80	35200
T_{18}	D_4F_3	30th May sowing date + 5 fruits per plant	90	39600
T_{19}	D_4F_4	30th May sowing date + 6 fruits per plant	100	44000
T_{20}	D_4F_5	30th May sowing date + all fruits retained (control)	60	26400
***Man days according to fruit load management**				

Total cost of cultivation for different treatments

C. Total cost			
Treatment	**Treatment combinations**	**Fixed cost (A.) + Variable cost (B.)**	**Total cost**
T_1	D_1F_1	347784 + 30800	378584
T_2	D_1F_2	347784 + 35200	382984
T_3	D_1F_3	347784 + 39600	387384
T_4	D_1F_4	347784 + 44000	391784
T_5	D_1F_5	347784 + 26400	374184
T_6	D_2F_1	347784 + 30800	378584
T_7	D_2F_2	347784 + 26400	374184
T_8	D_2F_3	347784 + 39600	387384
T_9	D_2F_4	347784 + 44000	391784
T_{10}	D_2F_5	347784 + 26400	374184
T_{11}	D_3F_1	347784 + 30800	378584
T_{12}	D_3F_2	347784 + 35200	382984
T_{13}	D_3F_3	347784 + 39600	387384
T_{14}	D_3F_4	347784 + 44000	391784
T_{15}	D_3F_5	347784 + 26400	374184
T_{16}	D_4F_1	347784 +30800	378584
T_{17}	D_4F_2	347784 + 35200	382984
T_{18}	D_4F_3	347784 + 39600	387384
T_{19}	D_4F_4	347784 + 44000	391784
T_{20}	D_4F_5	347784 + 26400	374184

APPENDIX – III

Analysis of variance table for vine length (cm)

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	23.84		
Factor D	3	86529.76	28843.25	300.74
Error(a)	6	575.43	95.90	
Factor F	4	3500.28	875.07	48.58
Interaction D × F	12	421.72	35.14	1.95
Error(b)	32	576.35	18.01	
Total	59	91627.41		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	220.46		
Factor D	3	136774.30	45591.43	558.97
Error(a)	6	489.38	81.56	
Factor F	4	5898.56	1474.64	42.42
Interaction D × F	12	510.97	42.58	1.22
Error(b)	32	1112.32	34.76	
Total	59	145006.02		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	75.99		
Factor Y	1	1353.46	1353.46	15.36
Factor D	3	211352.03	70450.67	799.84
Interaction Y × D	3	11952.01	3984	45.23
Error(a)	14	1233.13	88.08	
Factor F	4	9150.40	2287.60	86.69
Interaction Y × F	4	248.41	62.10	2.35
Interaction D × F	12	278.41	23.20	0.87
Interaction Y × D × F	12	654.31	54.52	2.06
Error	64	1688.68	26.38	
Total	119	237986.88		

Analysis of variance table for fruit length (cm)

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	28.49		
Factor D	3	484.55	161.52	1108.37
Error(a)	6	0.87	0.14	
Factor F	4	54.00	13.50	75.12
Interaction D × F	12	17.94	1.49	8.32
Error(b)	32	5.75	0.18	
Total	59	591.63		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	8.43		
Factor D	3	435.84	145.28	76.81
Error(a)	6	11.34	1.89	
Factor F	4	44.71	11.17	22.95
Interaction D × F	12	5.31	0.44	0.90
Error(b)	32	15.58	0.48	
Total	59	521.23		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	27.02		
Factor Y	1	39.81	39.81	25.19
Factor D	3	917.92	305.97	193.62
Interaction Y × D	3	2.46	0.82	0.51
Error(a)	14	22.12	1.58	
Factor F	4	98.06	24.51	73.55
Interaction Y × F	4	0.64	0.16	0.48
Interaction D × F	12	17.72	1.47	4.43
Interaction Y × D × F	12	5.54	0.46	1.38
Error	64	21.33	0.33	
Total	119	1152.67		

Analysis of variance table for fruit breadth (cm)

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	0.08		
Factor D	3	4.57	1.52	58.07
Error(a)	6	0.15	0.02	
Factor F	4	0.89	0.22	24.03
Interaction D × F	12	0.52	0.04	4.71
Error(b)	32	0.29	0.00	
Total	59	6.52		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	0.08		
Factor D	3	7.17	2.39	165.78
Error(a)	6	0.08	0.01	
Factor F	4	0.93	0.23	42.28
Interaction D × F	12	0.27	0.02	4.20
Error(b)	32	0.17	0.01	
Total	59	8.73		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	0.12		
Factor Y	1	2.49	2.49	120.63
Factor D	3	11.59	3.86	187.10
Interaction Y × D	3	0.15	0.05	2.54
Error(a)	14	0.28	0.02	
Factor F	4	1.81	0.45	61.25
Interaction Y × F	4	0.01	0.01	0.42
Interaction D × F	12	0.73	0.06	8.33
Interaction Y × D × F	12	0.06	0.01	0.71
Error	64	0.47	0.01	
Total	119	17.75		

Analysis of variance table for fruit weight (g)

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	20.80		
Factor D	3	591270.89	197090.29	164.35
Error(a)	6	7195.27	1199.21	
Factor F	4	60208.85	15052.21	56.24
Interaction D × F	12	17140.20	1428.35	5.33
Error(b)	32	8563.46	267.60	
Total	59	684399.48		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	2974.53		
Factor D	3	1014785.52	338261.84	185.11
Error(a)	6	10963.65	1827.27	
Factor F	4	72371.08	18092.77	92.07
Interaction D × F	12	8137.43	678.12	3.45
Error(b)	32	6287.87	196.49	
Total	59	1115520.1		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	1677.82		
Factor Y	1	23752.68	23752.68	17.07
Factor D	3	1577274.74	525758.25	377.92
Interaction Y × D	3	28793.28	9597.76	6.89
Error(a)	14	19476.43	1391.17	
Factor F	4	132280.62	33070.15	142.51
Interaction Y × F	4	310.94	77.73	0.33
Interaction D × F	12	17355.69	1446.30	6.23
Interaction Y × D × F	12	7910.32	659.19	2.84
Error	64	14851.33	232.05	
Total	119	1823683.89		

Analysis of variance table for total number of seeds per fruit

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	76.23		
Factor D	3	36314.00	12104.66	395.79
Error(a)	6	183.50	30.58	
Factor F	4	2603.43	650.85	49.01
Interaction D × F	12	334.83	27.90	2.10
Error(b)	32	424.93	13.27	
Total	59	39936.93		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	528.40		
Factor D	3	73904.58	24634.86	139.14
Error(a)	6	1062.26	177.04	
Factor F	4	6926	1731.5	68.29
Interaction D × F	12	874.66	72.88	2.87
Error(b)	32	811.33	25.35	
Total	59	84107.25		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	403.61		
Factor Y	1	6409.40	6409.40	62.02
Factor D	3	106832.29	35610.76	344.59
Interaction Y × D	3	3386.29	1128.76	10.92
Error(a)	14	1446.78	103.34	
Factor F	4	8998.21	2249.55	116.45
Interaction Y × F	4	531.21	132.80	6.87
Interaction D × F	12	1043.91	86.99	4.50
Interaction Y × D × F	12	165.58	13.79	0.71
Error	64	1236.26	19.31	
Total	119	130453.59		

Analysis of variance table for seed yield per fruit (g)

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	0.18		
Factor D	3	44.48	14.82	239.57
Error(a)	6	0.37	0.06	
Factor F	4	6.25	1.56	26.64
Interaction D × F	12	2.41	0.20	3.42
Error(b)	32	1.87	0.05	
Total	59	55.58		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	0.47		
Factor D	3	70.12	23.37	150.10
Error(a)	6	0.93	0.15	
Factor F	4	24.01	6.00	338.94
Interaction D × F	12	10.73	0.89	50.51
Error(b)	32	0.56	0.01	
Total	59	106.85		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	0.61		
Factor Y	1	89.16	89.16	918.25
Factor D	3	112.06	37.35	384.66
Interaction Y × D	3	2.54	0.84	8.72
Error(a)	14	1.36	0.09	
Factor F	4	26.48	6.62	173.44
Interaction Y × F	4	3.77	0.94	24.73
Interaction D × F	12	10.64	0.88	23.23
Interaction Y × D × F	12	2.51	0.20	5.47
Error	64	2.44	0.03	
Total	119	251.60		

Analysis of variance table for seed yield per plant (g)

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	2.17		
Factor D	3	918.52	306.17	284.85
Error(a)	6	6.44	1.07	
Factor F	4	3568.72	892.18	343.81
Interaction D × F	12	91.55	7.62	2.94
Error(b)	32	83.03	2.59	
Total	59	4670.46		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	2.74		
Factor D	3	1296.45	432.15	99.96
Error(a)	6	25.93	4.32	
Factor F	4	4207.82	1051.95	782.50
Interaction D × F	12	231.98	19.33	14.38
Error(b)	32	43.01	1.34	
Total	59	5807.96		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	4.36		
Factor Y	1	1731.09	1731.09	735.62
Factor D	3	2177.96	725.98	308.50
Interaction Y × D	3	36.93	12.31	5.23
Error(a)	14	32.94	2.35	
Factor F	4	7725.65	1931.41	980.59
Interaction Y × F	4	50.82	12.70	6.45
Interaction D × F	12	275.20	22.93	11.64
Interaction Y × D × F	12	48.40	4.03	2.04
Error	64	126.05	1.97	
Total	119	12209.44		

Analysis of variance table for seed yield per plot (g)

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	52.91		
Factor D	3	22959.80	7653.26	281.73
Error(a)	6	162.99	27.16	
Factor F	4	89204.46	22301.11	343.82
Interaction D × F	12	2291.95	190.99	2.94
Error(b)	32	2075.60	64.86	
Total	59	116747.72		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	67.87		
Factor D	3	32415.66	10805.22	99.95
Error(a)	6	648.62	108.10	
Factor F	4	105198.63	26299.65	782.13
Interaction D × F	12	5800.89	483.40	14.37
Error(b)	32	1076.01	33.62	
Total	59	145207.69		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	109.48		
Factor Y	1	43279.45	43279.45	736.30
Factor D	3	54452.27	18150.75	308.79
Interaction Y × D	3	922.38	307.46	5.23
Error(a)	14	822.91	58.78	
Factor F	4	193132.68	48283.17	980.48
Interaction Y × F	4	1269.60	317.40	6.44
Interaction D × F	12	6880.91	573.40	11.64
Interaction Y × D × F	12	1212.74	101.06	2.05
Error	64	3151.61	49.24	
Total	119	305234.07		

Analysis of variance table for seed yield per hectare (kg)

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	129.03		
Factor D	3	55557.50	18519.16	282.397
Error(a)	6	393.47	65.57	
Factor F	4	215855.03	53963.75	343.807
Interaction D × F	12	5544.23	462.02	2.944
Error(b)	32	5022.69	156.95	
Total	59	282501.98		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	161.82		
Factor D	3	78433.45	26144.48	99.805
Error(a)	6	1571.73	261.95	
Factor F	4	254556.55	63639.14	781.595
Interaction D × F	12	14038.28	1169.85	14.368
Error(b)	32	2605.50	81.42	
Total	59	351367.37		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	266.58		
Factor Y	1	104723.07	104723.07	736.93
Factor D	3	131758.29	43919.43	309.06
Interaction Y × D	3	2235.40	745.13	5.24
Error(a)	14	1989.48	142.10	
Factor F	4	467340.40	116835.10	980.23
Interaction Y × F	4	3073.92	768.48	6.44
Interaction D × F	12	16648.89	1387.40	11.64
Interaction Y × D × F	12	2930.89	244.24	2.04
Error	64	7628.20	119.19	
Total	119	738595.16		

Analysis of variance table for seed yield index

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	0.23		
Factor D	3	233.01	77.67	33.90
Error(a)	6	13.74	2.29	
Factor F	4	30.06	7.51	11.05
Interaction D × F	12	87.38	7.28	10.71
Error(b)	32	21.75	0.68	
Total	59	386.20		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	16.71		
Factor D	3	1183.70	394.56	37.64
Error(a)	6	62.88	10.48	
Factor F	4	44.90	11.22	15.56
Interaction D × F	12	210.20	17.51	24.28
Error(b)	32	23.08	0.72	
Total	59	1541.49		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	8.04		
Factor Y	1	861.69	861.69	141.04
Factor D	3	1226.26	408.75	66.90
Interaction Y × D	3	190.44	63.48	10.39
Error(a)	14	85.53	6.11	
Factor F	4	72.28	18.07	25.79
Interaction Y × F	4	2.68	0.67	0.95
Interaction D × F	12	264.38	22.03	31.44
Interaction Y × D × F	12	33.20	2.76	3.95
Error	64	44.83	0.70	
Total	119	2789.38		

Analysis of variance table for 1000 seed weight (g)

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	1.51		
Factor D	3	50.93	16.97	61.22
Error(a)	6	1.66	0.27	
Factor F	4	14.51	3.62	9.88
Interaction D × F	12	12.59	1.05	2.85
Error(b)	32	11.74	0.36	
Total	59	92.97		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	0.15		
Factor D	3	15.54	5.18	41.44
Error(a)	6	0.75	0.12	
Factor F	4	47.27	11.81	319.92
Interaction D × F	12	37.83	3.15	85.36
Error(b)	32	1.18	0.03	
Total	59	102.74		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	1.28		
Factor Y	1	382.90	382.90	1912.77
Factor D	3	54.70	18.23	91.09
Interaction Y × D	3	11.78	3.92	19.62
Error(a)	14	2.80	0.20	
Factor F	4	51.82	12.95	64.12
Interaction Y × F	4	9.96	2.49	12.33
Interaction D × F	12	39.58	3.29	16.32
Interaction Y × D × F	12	10.84	0.90	4.47
Error	64	12.93	0.20	
Total	119	578.63		

Analysis of variance table for number of filled seeds

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	1788.03		
Factor D	3	21738.13	7246.04	395.35
Error(a)	6	109.96	18.32	
Factor F	4	1507.83	376.95	41.02
Interaction D × F	12	223.36	18.61	2.02
Error(b)	32	294.00	9.18	
Total	59	25661.33		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	1247.70		
Factor D	3	43992.98	14664.32	71.89
Error(a)	6	1223.76	203.96	
Factor F	4	4033.93	1008.48	49.40
Interaction D × F	12	573.26	47.77	2.34
Error(b)	32	653.20	20.41	
Total	59	51724.85		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	2822.46		
Factor Y	1	6556.40	6556.40	59.33
Factor D	3	63723.29	21241.09	192.22
Interaction Y × D	3	2007.82	669.27	6.05
Error(a)	14	1547.00	110.50	
Factor F	4	5228.38	1307.09	88.31
Interaction Y × F	4	313.38	78.34	5.29
Interaction D × F	12	664.08	55.34	3.73
Interaction Y × D × F	12	132.55	11.04	0.74
Error	64	947.20	14.80	
Total	119	83942.59		

Analysis of variance table for number of unfilled seeds

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	1976.43		
Factor D	3	1860.93	620.31	169.43
Error(a)	6	21.96	3.66	
Factor F	4	151.10	37.77	40.83
Interaction D × F	12	14.90	1.24	1.34
Error(b)	32	29.60	0.92	
Total	59	4054.93		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	3385.90		
Factor D	3	3874.73	1291.57	132.77
Error(a)	6	58.36	9.72	
Factor F	4	403.76	100.94	28.23
Interaction D × F	12	91.43	7.61	2.13
Error(b)	32	114.40	3.57	
Total	59	7928.60		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	5180.31		
Factor Y	1	0.83	0.83	0.04
Factor D	3	5544.30	1848.10	98.62
Interaction Y × D	3	191.36	63.78	3.40
Error(a)	14	262.35	18.73	
Factor F	4	521.61	130.40	57.95
Interaction Y × F	4	33.25	8.31	3.69
Interaction D × F	12	62.78	5.23	2.32
Interaction Y × D × F	12	43.55	3.62	1.61
Error	64	144.00	2.25	
Total	119	11984.36		

Analysis of variance table for seed fresh weight (g)

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	0.045		
Factor D	3	0.840	0.280	1395.43
Error(a)	6	0.001	0.000	
Factor F	4	0.010	0.002	96.33
Interaction D × F	12	0.000	0.000	0.79
Error(b)	32	0.001	0.000	
Total	59	0.897		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	0.162		
Factor D	3	2.980	0.993	2230.08
Error(a)	6	0.003	0.000	
Factor F	4	0.019	0.005	188.86
Interaction D × F	12	0.000	0.000	1.54
Error(b)	32	0.001	0.000	
Total	59	3.165		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	0.188		
Factor Y	1	0.000	0.000	0.14
Factor D	3	3.492	1.164	742.79
Interaction Y × D	3	0.328	0.109	69.80
Error(a)	14	0.022	0.002	
Factor F	4	0.028	0.007	278.88
Interaction Y × F	4	0.001	0.000	5.70
Interaction D × F	12	0.000	0.000	0.36
Interaction Y × D × F	12	0.001	0.000	1.72
Error	64	0.002	0.000	
Total	119	4.062		

Analysis of variance table for seed dry weight (g)

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	0.016		
Factor D	3	0.302	0.101	1175.69
Error(a)	6	0.001	0.000	
Factor F	4	0.003	0.001	61.09
Interaction D × F	12	0.000	0.000	2.37
Error(b)	32	0.000	0.000	
Total	59	0.323		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	0.068		
Factor D	3	1.259	0.420	2514.93
Error(a)	6	0.001	0.000	
Factor F	4	0.008	0.002	189.88
Interaction D × F	12	0.000	0.000	0.63
Error(b)	32	0.000	0.000	
Total	59	1.337		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	0.075		
Factor Y	1	0.412	0.412	548.17
Factor D	3	1.398	0.466	619.19
Interaction Y × D	3	0.164	0.055	72.54
Error(a)	14	0.011	0.001	
Factor F	4	0.011	0.003	226.92
Interaction Y × F	4	0.001	0.000	10.78
Interaction D × F	12	0.000	0.000	0.91
Interaction Y × D × F	12	0.000	0.000	2.59
Error	64	0.001	0.000	
Total	119	2.072		

Analysis of variance table for seed germination (%)

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	0.03		
Factor D	3	2165.11	721.70	44.44
Error(a)	6	97.43	16.23	
Factor F	4	169.50	42.37	26.83
Interaction D × F	12	11.96	0.99	0.63
Error(b)	32	50.53	1.57	
Total	59	2494.58		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	11.03		
Factor D	3	2017.93	672.64	72.37
Error(a)	6	55.76	9.29	
Factor F	4	157.16	39.29	22.50
Interaction D × F	12	26.56	2.21	1.26
Error(b)	32	55.86	1.74	
Total	59	2324.33		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	5.51		
Factor Y	1	1.87	1.87	0.16
Factor D	3	4150.62	1383.54	122.01
Interaction Y × D	3	32.42	10.80	0.95
Error(a)	14	158.75	11.33	
Factor F	4	324.75	81.18	48.83
Interaction Y × F	4	1.91	0.47	0.28
Interaction D × F	12	17.25	1.43	0.86
Interaction Y × D × F	12	21.28	1.77	1.06
Error	64	106.40	1.66	
Total	119	4820.79		

Analysis of variance table for speed of germination

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	0.12		
Factor D	3	35.75	11.91	886.07
Error(a)	6	0.08	0.01	
Factor F	4	2.60	0.65	45.97
Interaction D × F	12	0.06	0.005	0.38
Error(b)	32	0.45	0.014	
Total	59	39.08		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	0.40		
Factor D	3	33.13	11.04	158.54
Error(a)	6	0.41	0.07	
Factor F	4	2.97	0.74	65.75
Interaction D × F	12	0.11	0.009	0.83
Error(b)	32	0.36	0.011	
Total	59	37.39		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	0.10		
Factor Y	1	0.02	0.02	0.44
Factor D	3	68.84	22.94	347.79
Interaction Y × D	3	0.04	0.014	0.21
Error(a)	14	0.92	0.066	
Factor F	4	5.54	1.387	108.87
Interaction Y × F	4	0.02	0.007	0.53
Interaction D × F	12	0.10	0.008	0.66
Interaction Y × D × F	12	0.08	0.007	0.53
Error	64	0.81	0.013	
Total	119	76.50		

Analysis of variance table for field emergence (%)

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	0.93		
Factor D	3	2002.33	667.44	135.90
Error(a)	6	29.46	4.91	
Factor F	4	93.73	23.43	8.62
Interaction D × F	12	35.33	2.94	1.08
Error(b)	32	86.93	2.71	
Total	59	2248.73		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	8.93		
Factor D	3	1995.20	665.06	114.66
Error(a)	6	34.80	5.80	
Factor F	4	141.06	35.26	39.92
Interaction D × F	12	11.46	0.95	1.08
Error(b)	32	28.26	0.88	
Total	59	2219.73		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	2.40		
Factor Y	1	4.03	4.03	0.78
Factor D	3	3996.36	1332.12	259.98
Interaction Y × D	3	1.16	0.38	0.07
Error(a)	14	71.73	5.12	
Factor F	4	227.00	56.75	31.52
Interaction Y × F	4	7.80	1.95	1.08
Interaction D × F	12	33.80	2.81	1.56
Interaction Y × D × F	12	13.00	1.08	0.60
Error	64	115.20	1.80	
Total	119	4472.50		

Analysis of variance table for seedling length (cm)

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	18.59		
Factor D	3	359.95	119.98	77.60
Error(a)	6	9.27	1.54	
Factor F	4	29.86	7.46	16.94
Interaction D × F	12	4.65	0.38	0.88
Error(b)	32	14.10	0.44	
Total	59	436.45		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	22.15		
Factor D	3	308.17	102.72	140.94
Error(a)	6	4.37	0.72	
Factor F	4	30.13	7.53	94.12
Interaction D × F	12	10.93	0.91	11.38
Error(b)	32	2.56	0.08	
Total	59	378.33		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	40.45		
Factor Y	1	3.61	3.61	3.62
Factor D	3	666.41	222.13	223.05
Interaction Y × D	3	1.72	0.57	0.57
Error(a)	14	13.94	0.99	
Factor F	4	59.51	14.87	57.14
Interaction Y × F	4	0.49	0.12	0.47
Interaction D × F	12	13.16	1.09	4.21
Interaction Y × D × F	12	2.41	0.20	0.77
Error	64	16.66	0.26	
Total	119	818.40		

Analysis of variance table for seedling dry weight (mg)

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	0.26		
Factor D	3	89.79	29.93	232.29
Error(a)	6	0.77	0.12	
Factor F	4	6.65	1.66	105.01
Interaction D × F	12	1.22	0.10	6.43
Error(b)	32	0.50	0.01	
Total	59	99.21		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	1.18		
Factor D	3	92.70	30.90	131.41
Error(a)	6	1.41	0.23	
Factor F	4	5.45	1.36	43.95
Interaction D × F	12	0.91	0.07	2.44
Error(b)	32	0.99	0.03	
Total	59	102.67		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	1.27		
Factor Y	1	0.24	0.24	1.44
Factor D	3	182.39	60.79	361.22
Interaction Y × D	3	0.11	0.03	0.21
Error(a)	14	2.35	0.16	
Factor F	4	12.05	3.01	128.64
Interaction Y × F	4	0.04	0.01	0.51
Interaction D × F	12	1.87	0.15	6.67
Interaction Y × D × F	12	0.25	0.02	0.92
Error	64	1.50	0.02	
Total	119	202.12		

Analysis of variance table for seedling vigour index – I

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	119271.63		
Factor D	3	6379727.86	2126575.95	117.56
Error(a)	6	108535.43	18089.23	
Factor F	4	520908.73	130227.18	39.86
Interaction D × F	12	38334.46	3194.53	0.97
Error(b)	32	104529.60	3266.55	
Total	59	7271307.73		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	179382.70		
Factor D	3	5979843.78	1993281.26	108.76
Error(a)	6	109960.76	18326.79	
Factor F	4	547984.66	136996.16	82.17
Interaction D × F	12	162695.46	13557.95	8.13
Error(b)	32	53347.86	1667.12	
Total	59	7033215.25		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	295572.46		
Factor Y	1	32637.00	32637.00	2.06
Factor D	3	12327510.75	4109170.25	259.63
Interaction Y × D	3	32060.89	10686.96	0.67
Error(a)	14	221578.06	15827.00	
Factor F	4	1066723.61	266680.90	108.10
Interaction Y × F	4	2169.78	542.44	0.22
Interaction D × F	12	158903.11	13241.92	5.36
Interaction Y × D × F	12	42126.81	3510.56	1.42
Error	64	157877.46	2466.83	
Total	119	14337159.99		

Analysis of variance table for seedling vigour index – II

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	6203.43		
Factor D	3	1507806.40	502602.13	53.12
Error(a)	6	56769.90	9461.65	
Factor F	4	38222.56	9555.64	11.52
Interaction D × F	12	74744.10	6228.67	7.51
Error(b)	32	26527.33	828.97	
Total	59	1710273.73		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	18287.03		
Factor D	3	1355037.93	451679.31	63.07
Error(a)	6	42963.36	7160.56	
Factor F	4	38862.43	9715.60	8.46
Interaction D × F	12	148145.56	12345.46	10.76
Error(b)	32	36715.60	1147.36	
Total	59	1640011.93		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	22883.81		
Factor Y	1	6134.70	6134.70	0.84
Factor D	3	2845810.96	948603.65	131.04
Interaction Y × D	3	17033.36	5677.78	0.78
Error(a)	14	101339.91	7238.56	
Factor F	4	70852.70	17713.17	17.92
Interaction Y × F	4	6232.30	1558.07	1.57
Interaction D × F	12	196533.03	16377.75	16.57
Interaction Y × D × F	12	26356.63	2196.38	2.22
Error	64	63242.93	988.17	
Total	119	3356420.36		

Analysis of variance table for electrical conductance (µS cm^{-1} g^{-1}) from seed leachates

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	313.04		
Factor D	3	11168.85	3722.95	360.44
Error(a)	6	61.97	10.32	
Factor F	4	843.52	210.88	52.55
Interaction D × F	12	93.38	7.78	1.93
Error(b)	32	128.39	4.01	
Total	59	12609.16		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	161.41		
Factor D	3	13908.79	4636.26	367.63
Error(a)	6	75.66	12.61	
Factor F	4	997.58	249.39	135.03
Interaction D × F	12	79.60	6.63	3.59
Error(b)	32	59.10	1.84	
Total	59	15282.17		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	111.09		
Factor Y	1	813.92	813.92	22.74
Factor D	3	24920.01	8306.67	232.12
Interaction Y × D	3	157.63	52.54	1.46
Error(a)	14	501.00	35.78	
Factor F	4	1827.85	456.96	155.97
Interaction Y × F	4	13.25	3.31	1.13
Interaction D × F	12	91.02	7.58	2.58
Interaction Y × D × F	12	81.96	6.83	2.33
Error	64	187.49	2.93	
Total	119	28705.26		

Analysis of variance table for total soluble sugars in seed leachates (mg g^{-1})

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	0.126		
Factor D	3	0.030	0.010	17.87
Error(a)	6	0.003	0.001	
Factor F	4	0.003	0.001	2.44
Interaction D × F	12	0.003	0.000	0.69
Error(b)	32	0.010	0.000	
Total	59	0.175		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	0.083		
Factor D	3	0.032	0.011	70.21
Error(a)	6	0.001	0.000	
Factor F	4	0.001	0.000	1.18
Interaction D × F	12	0.003	0.000	1.07
Error(b)	32	0.008	0.000	
Total	59	0.128		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	0.188		
Factor Y	1	0.143	0.143	80.14
Factor D	3	0.060	0.020	11.26
Interaction Y × D	3	0.001	0.000	0.28
Error(a)	14	0.025	0.002	
Factor F	4	0.004	0.001	3.44
Interaction Y × F	4	0.000	0.000	0.29
Interaction D × F	12	0.003	0.000	0.91
Interaction Y × D × F	12	0.003	0.000	0.82
Error	64	0.018	0.000	
Total	119	0.445		

Analysis of variance table for total soluble proteins in seed leachates (mg g^{-1})

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	0.31		
Factor D	3	47.05	15.68	173.55
Error(a)	6	0.54	0.09	
Factor F	4	2.18	0.54	46.56
Interaction D × F	12	0.23	0.01	1.63
Error(b)	32	0.37	0.01	
Total	59	50.71		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	0.50		
Factor D	3	46.95	15.65	181.84
Error(a)	6	0.51	0.08	
Factor F	4	1.92	0.48	15.40
Interaction D × F	12	0.90	0.07	2.41
Error(b)	32	1.00	0.03	
Total	59	51.80		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	0.08		
Factor Y	1	0.75	0.75	5.88
Factor D	3	93.64	31.21	242.86
Interaction Y × D	3	0.35	0.12	0.93
Error(a)	14	1.79	0.12	
Factor F	4	4.03	1.00	46.88
Interaction Y × F	4	0.08	0.02	0.94
Interaction D × F	12	0.87	0.07	3.38
Interaction Y × D × F	12	0.26	0.02	1.01
Error	64	1.37	0.02	
Total	119	103.27		

Analysis of variance table for total soluble sugars in seed (mg g^{-1}_{dw})

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	0.16		
Factor D	3	1.97	0.65	184.54
Error(a)	6	0.02	0.04	
Factor F	4	0.15	0.03	22.71
Interaction D × F	12	0.04	0.00	1.97
Error(b)	32	0.05	0.00	
Total	59	2.40		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	0.37		
Factor D	3	2.04	0.68	219.90
Error(a)	6	0.01	0.00	
Factor F	4	0.15	0.03	19.98
Interaction D × F	12	0.01	0.00	0.64
Error(b)	32	0.06	0.02	
Total	59	2.66		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	0.43		
Factor Y	1	0.27	0.275	28.55
Factor D	3	3.99	1.333	138.20
Interaction Y × D	3	0.01	0.005	0.53
Error(a)	14	0.13	0.010	
Factor F	4	0.30	0.077	42.21
Interaction Y × F	4	0.01	0.001	0.35
Interaction D × F	12	0.02	0.002	1.14
Interaction Y × D × F	12	0.03	0.003	1.40
Error	64	0.11	0.002	
Total	119	5.34		

Analysis of variance table for total soluble proteins in seed (mg g^{-1} $_{dw}$)

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	9.37		
Factor D	3	7983.06	2661.02	354.02
Error(a)	6	45.09	7.51	
Factor F	4	451.52	112.88	110.34
Interaction D × F	12	18.36	1.53	1.49
Error(b)	32	32.73	1.02	
Total	59	8540.16		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	1.93		
Factor D	3	7686.32	2562.10	683.76
Error(a)	6	22.48	3.74	
Factor F	4	479.11	119.77	138.10
Interaction D × F	12	26.47	2.20	2.54
Error(b)	32	27.75	0.86	
Total	59	8244.07		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	7.19		
Factor Y	1	53.68	53.68	10.48
Factor D	3	15630.49	5210.16	1017.50
Interaction Y × D	3	38.89	12.96	2.53
Error(a)	14	71.68	5.12	
Factor F	4	929.20	232.30	245.77
Interaction Y × F	4	1.43	0.35	0.38
Interaction D × F	12	12.72	1.06	1.12
Interaction Y × D × F	12	32.10	2.67	2.83
Error	64	60.49	0.94	
Total	119	16837.92		

Analysis of variance table for total starch contents in seed (mg g^{-1}_{dw})

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	5.82		
Factor D	3	482.36	160.78	1360.66
Error(a)	6	0.70	0.11	
Factor F	4	33.96	8.49	83.65
Interaction D × F	12	1.33	0.11	1.09
Error(b)	32	3.24	0.10	
Total	59	527.44		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	0.16		
Factor D	3	507.20	169.06	1951.62
Error(a)	6	0.52	0.08	
Factor F	4	31.69	7.92	106.65
Interaction D × F	12	1.22	0.10	1.37
Error(b)	32	2.37	0.07	
Total	59	543.19		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	5.10		
Factor Y	1	3.02	3.02	20.06
Factor D	3	989.96	329.98	2189.17
Interaction Y × D	3	0.16	0.05	0.36
Error(a)	14	2.11	0.15	
Factor F	4	66.30	16.57	188.58
Interaction Y × F	4	0.42	0.10	1.19
Interaction D × F	12	0.87	0.07	0.82
Interaction Y × D × F	12	1.46	0.12	1.38
Error	64	5.62	0.08	
Total	119	1073.88		

Analysis of variance table for oil content in seeds (%)

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	1.05		
Factor D	3	112.40	37.46	3808.67
Error(a)	6	0.05	0.01	
Factor F	4	6.99	1.75	164.16
Interaction D × F	12	0.16	0.01	1.25
Error(b)	32	0.34	0.01	
Total	59	121.02		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	0.14		
Factor D	3	278.21	92.73	639.27
Error(a)	6	0.87	0.14	
Factor F	4	15.22	3.80	110.96
Interaction D × F	12	0.56	0.04	1.37
Error(b)	32	1.09	0.03	
Total	59	296.11		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	5.10		
Factor Y	1	3.02	3.02	20.06
Factor D	3	989.96	329.98	2189.17
Interaction Y × D	3	0.16	0.05	0.36
Error(a)	14	2.11	0.15	
Factor F	4	66.30	16.57	188.58
Interaction Y × F	4	0.42	0.10	1.19
Interaction D × F	12	0.87	0.07	0.82
Interaction Y × D × F	12	1.46	0.12	1.38
Error	64	5.62	0.08	
Total	119	1073.88		

Analysis of variance table for soil pH

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	0.000		
Factor D	3	0.008	0.003	4.59
Error(a)	6	0.003	0.001	
Factor F	4	0.003	0.001	0.88
Interaction D × F	12	0.015	0.001	1.37
Error(b)	32	0.029	0.001	
Total	59	0.059		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	0.001		
Factor D	3	0.001	0.000	0.46
Error(a)	6	0.004	0.001	
Factor F	4	0.003	0.001	1.31
Interaction D × F	12	0.008	0.001	1.20
Error(b)	32	0.018	0.001	
Total	59	0.035		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	0.000		
Factor Y	1	0.225	0.225	344.95
Factor D	3	0.003	0.001	1.34
Interaction Y × D	3	0.007	0.002	3.45
Error(a)	14	0.009	0.001	
Factor F	4	0.000	0.000	0.01
Interaction Y × F	4	0.007	0.002	2.25
Interaction D × F	12	0.015	0.001	1.65
Interaction Y × D × F	12	0.008	0.001	0.91
Error	64	0.047	0.001	
Total	119	0.319		

Analysis of variance table for EC (dSm^{-1})

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	0.007		
Factor D	3	0.003	0.001	3.04
Error(a)	6	0.002	0.000	
Factor F	4	0.000	0.000	0.63
Interaction D × F	12	0.003	0.000	2.74
Error(b)	32	0.002	0.000	
Total	59	0.018		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	0.005		
Factor D	3	0.001	0.000	1.66
Error(a)	6	0.002	0.000	
Factor F	4	0.002	0.000	4.39
Interaction D × F	12	0.002	0.000	1.83
Error(b)	32	0.003	0.000	
Total	59	0.014		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	0.007		
Factor Y	1	0.000	0.000	0.64
Factor D	3	0.001	0.000	0.42
Interaction Y × D	3	0.004	0.001	1.91
Error(a)	14	0.009	0.001	
Factor F	4	0.001	0.000	4.11
Interaction Y × F	4	0.000	0.000	1.13
Interaction D × F	12	0.002	0.000	2.47
Interaction Y × D × F	12	0.002	0.000	2.04
Error	64	0.005	0.000	
Total	119	0.032		

Analysis of variance table for organic carbon (%)

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	0.003		
Factor D	3	0.008	0.003	0.40
Error(a)	6	0.041	0.007	
Factor F	4	0.001	0.000	0.13
Interaction D × F	12	0.013	0.001	0.62
Error(b)	32	0.055	0.002	
Total	59	0.120		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	0.006		
Factor D	3	0.005	0.002	0.16
Error(a)	6	0.061	0.010	
Factor F	4	0.001	0.000	0.11
Interaction D × F	12	0.013	0.001	0.71
Error(b)	32	0.048	0.001	
Total	59	0.134		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	0.002		
Factor Y	1	0.000	0.000	0.03
Factor D	3	0.008	0.003	0.35
Interaction Y × D	3	0.005	0.002	0.21
Error(a)	14	0.109	0.008	
Factor F	4	0.001	0.000	0.12
Interaction Y × F	4	0.001	0.000	0.12
Interaction D × F	12	0.018	0.001	0.93
Interaction Y × D × F	12	0.008	0.001	0.40
Error	64	0.102	0.002	
Total	119	0.254		

Analysis of variance table for available N (kg/ha)

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	120.26		
Factor D	3	14.90	4.96	1.73
Error(a)	6	17.23	2.87	
Factor F	4	164.82	41.20	23.77
Interaction D × F	12	33.37	2.78	1.60
Error(b)	32	55.46	1.73	
Total	59	406.05		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	41.10		
Factor D	3	451.09	150.36	46.53
Error(a)	6	19.38	3.23	
Factor F	4	1536.78	384.19	141.06
Interaction D × F	12	143.61	11.96	4.39
Error(b)	32	87.15	2.72	
Total	59	2279.13		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	8.79		
Factor Y	1	4753.43	4753.43	351.75
Factor D	3	270.02	90.00	6.66
Interaction Y × D	3	193.69	64.56	4.77
Error(a)	14	189.18	13.51	
Factor F	4	1295.34	323.83	145.32
Interaction Y × F	4	403.96	100.99	45.32
Interaction D × F	12	107.92	8.99	4.03
Interaction Y × D × F	12	71.35	5.94	2.66
Error	64	142.61	2.22	
Total	119	7436.33		

Analysis of variance table for available P (kg/ha)

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	0.36		
Factor D	3	5.89	1.96	4.64
Error(a)	6	2.53	0.42	
Factor F	4	33.72	8.43	15.07
Interaction D × F	12	13.53	1.12	2.01
Error(b)	32	17.89	0.55	
Total	59	73.94		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	1.80		
Factor D	3	23.87	7.96	43.88
Error(a)	6	1.08	0.18	
Factor F	4	114.65	28.66	103.49
Interaction D × F	12	17.10	1.42	5.14
Error(b)	32	8.86	0.27	
Total	59	167.39		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	1.92		
Factor Y	1	712.72	712.72	2578.54
Factor D	3	22.21	7.40	26.79
Interaction Y × D	3	7.68	2.56	9.26
Error(a)	14	3.87	0.27	
Factor F	4	134.62	33.65	80.49
Interaction Y × F	4	13.87	3.47	8.29
Interaction D × F	12	19.78	1.64	3.94
Interaction Y × D × F	12	10.72	0.89	2.13
Error	64	26.75	0.41	
Total	119	954.19		

Analysis of variance table for available K (kg/ha)

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	50.03		
Factor D	3	115.52	38.50	3.39
Error(a)	6	68.06	11.34	
Factor F	4	735.17	183.79	24.17
Interaction D × F	12	154.80	12.90	1.69
Error(b)	32	243.25	7.60	
Total	59	1366.85		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	14.36		
Factor D	3	178.40	59.46	49.49
Error(a)	6	7.21	1.20	
Factor F	4	1252.78	313.19	163.43
Interaction D × F	12	249.51	20.79	10.85
Error(b)	32	61.32	1.91	
Total	59	1763.59		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	41.33		
Factor Y	1	5706.67	5706.67	812.43
Factor D	3	274.79	91.59	13.04
Interaction Y × D	3	19.13	6.37	0.90
Error(a)	14	98.33	7.02	
Factor F	4	1914.68	478.67	100.58
Interaction Y × F	4	73.27	18.31	3.84
Interaction D × F	12	347.56	28.96	6.08
Interaction Y × D × F	12	56.74	4.72	0.99
Error	64	304.57	4.75	
Total	119	8837.12		

Department of Vegetable Science
Dr. Yashwant Singh Parmar University of Horticulture and Forestry
(Nauni) Solan (HP) 173 230 India

Title of Thesis	:	**"Studies on Influence of Sowing Dates and Fruit Load on Seed Yield and Quality of Cucumber (*Cucumis sativus* L.)"**
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Admission Number	:	H-2021-49-D
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Major Advisor	:	Dr. Kuldeep Singh Thakur

ABSTRACT

The investigation, titled "Studies on Influence of Sowing Dates and Fruit Load on Seed Yield and Quality of Cucumber (*Cucumis sativus* L.)," was conducted at the Experimental Farm and Laboratory of the Department of Vegetable Science, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, HP, over two consecutive years (2022-2023 and 2023-2024). The research aimed to optimize sowing dates and fruit load to enhance seed yield and quality of cucumber cv. Solan Srijan. The experiment employed a split-plot design with 20 treatment combinations, including four sowing dates (15th April, 30th April, 15th May and 30th May) and five fruit loads (3, 4, 5, 6 fruits per plant and all fruits per plant as control), replicated three times. Data on plant and fruit characteristics, seed yield and quality parameters, seed physiological assays, soil analysis, pest and disease incidence and economic returns revealed significant variations across treatments. The plant growth and fruit characteristics were significantly influenced by sowing dates and fruit loads. The sowing on 30th April and retaining 3 fruits per plant (D_2F_1) consistently recorded the maximum vine length, fruit length, fruit breadth and fruit weight. The seed yield attributes varied across treatments, with the maximum total number of seeds per fruit, seed yield per fruit, 1000 seed weight, number of filled and unfilled seeds seed fresh and dry weight recorded with sowing on 30th April and retaining 3 fruits per plant (D_2F_1) whereas the maximum seed yield per plant, seed yield per plot and seed yield per hectare were recorded with sowing on 30th April and retaining 6 fruits per plant (D_2F_4). The seed yield index was recorded best with sowing on 30th April and retaining all fruits per plant (D_2F_5). The seed quality traits were markedly improved with 30th April sowing and retaining 3 fruits per plant (D_2F_1). This treatment resulted in superior germination percentage, speed of germination, field emergence, seedling vigour indices (I and II), seedling length and seedling dry weight, indicating strong seedling establishment potential. Seed physiological assays demonstrated optimal results with 30th April sowing and 3 fruits per plant (D_2F_1), showing the minimum electrical conductivity of seed leachates, minimum soluble proteins and sugars in seed leachates and maximum total soluble sugars, proteins, starch contents and oil content in seeds. The soil analysis revealed that the soil health (pH, EC and organic carbon) remained within optimal ranges across all treatments, with maximum available N:P:K when sowing was done on 30th April and 3 fruits per plant were retained (D_2F_1). Pest and disease incidence was minimal across treatments when sowing was done on 30th April (D_2). The economic analysis identified sowing on 30th April with 6 fruits per plant (D_2F_4) retained as the most profitable treatment, achieving the highest net returns and benefit-cost ratio. Over the two consecutive years (2022-2023 and 2023-2024), sowing seeds of cucumber cv. Solan Srijan on 30th April with 3 fruits per plant retained (D_2F_1) was identified as the best treatment for quality seed production in mid-hill conditions of Himachal Pradesh.

Signature of Student
Name: Anamika Walia
Dated: 19.04.2025

Signature of Major Advisor
Name: Dr. Kuldeep Singh Thakur
Dated: 19.04.25

19.04.2025
Head of the Department

BRIEF BIO-DATA

Name	:	**Anamika Walia (अनामिका वालिया)**
Father's name	:	Sh. Manoj Kumar Walia (श्री मनोज कुमार वालिया)
Mother's name	:	Smt. Seema Walia (श्रीमति सीमा वालिया)
Date of birth	:	02.03.1996
Gender	:	Female
Aadhar No.	:	7893 0982 0038
E-mail address	:	anamikawalia72@gmail.com
Permanent Address	:	Village - Nalsar and P.O. - Rajgarh (Baggi), Tehsil - Balh, District - Mandi, Himachal Pradesh, India - 175 027

Academic Qualifications

Examination Passed	Year	School / College	University/Board	Marks (% / CGPA)	Division
Matriculation	2012	St. Mary's School, Sundernagar	Central Board of Secondary Education, New Delhi	9.0/10	First
10 + 2 (Medical)	2014	St. Mary's School, Sundernagar	Central Board of Secondary Education, New Delhi	86.80 %	First
B Sc (Hons) Horticulture	2018	College of Horticulture	Dr Y S Parmar University of Horticulture and Forestry, Nauni, Solan (HP)	8.33/10	First
M Sc (Horticulture) Vegetable Science	2021	Faculty of Post-Gradute Studies	Sher-e-Kashmir University of Agricultural Sciences and Technology, Main Campus Chatha, Jammu (J&K)	7.80/10	First

Title of Thesis in M Sc	:	**Studies on Alternative Sources in *In-vitro* Culture of Potato (*Solanum tuberosum* L.)**
Scolarship/ Stipend/ Fellowship, any other financial assistance received during the study period	:	University Stipend
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(Anamika Walia)