Available online at www.garmian.edu.krd

Passer Journal of Basic and Applied Sciences

Passer

Passer 7 (Issue 1) (2025) 355-363

Original Article

Response of Brussels sprouts (*Brassica oleracea* var. gemmifera) to different temperatures and NaCl levels on seed germination and growth characteristics

Chinur Hadi Mahmood *

Horticulture Department, College of Agricultural Engineering Sciences, University of Sulaimani, Sulaimaniyah 46001, Kurdistan Region, Iraq.

Received 19 January 2025; revised 30 March 2025;
accepted 19 April 2025; available online 3 June 2025

DOI: 10.24271/psr.2025.500866.1906

ABSTRACT

This study aimed to evaluate the effects of different temperature and salinity levels on the germination and growth characteristics of Brussels sprout seeds. The experiment was conducted in two phases. A completely randomized design (CRD) was used for the germination test under controlled laboratory conditions. For the field experiment, a randomized complete block design (RCBD) with three replicates was implemented on September 1, 2023. The results revealed that the maximum values of Bud Vitamin C (mg) and Bud Vitamin K (g) were recorded at 25 °C across all NaCl concentrations, significantly surpassing the minimum values of 29.333% at 5°C and 150 mM sodium chloride (NaCl) by 0.650mg. The coefficient of variation (CoV%) of germination, the maximum value recorded was 83.940% at 25°C and 150 mM NaCl but the minimum value recorded was 44.130% (at 25°C and 0 mM NaCl). The mean germination time (MGT) was longest at 5°C and smallest at 25°C (3.993 days). The highest marketable yield (ton/ha) was 31.589 ton/ha, and the minimum value was 7.100 ton/ha. The highest germination percentage (GP%) reached its maximum values at 25°C and 0, 50, and 150 mM NaCl. The maximum value for glucosinolates (µmol) was 5.596 µmol at 25°C and 150 mM NaCl, recording its superiority over others by 1.614 µmol at 5ºC and 0 mM NaCl.

Keywords: Brussels sprouts, Temperature, Salinity, Germination, Growth traits.

1 Introduction

Brussels sprouts (*Brassica oleracea* var. gemmifera L.) belong to the Brassicaceae family, which have been extensively studied for their potential to prevent cancer [1]. The Brussels sprout's edible portion consists of the buds, or sprouts, that form beneath each leaf's armpit. Because the leaves arranged along the stalk, the height of the stalk determines how many leaves and buds produced, which determines the yield [2]. Although it is uncommon to use leaves for human consumption in our nation, they can be used as forage along with the stalk because of their high nutritional content. For this reason, it's critical to determine their weight and growth rate. Many plant species rely on their seeds' capacity to sprout at high soil salinity levels for survival and preservation [3,4]. Soil salinity is a worldwide problem which impediment the productivity of several crops. Salinization is the primary factor restricting agricultural yield, particularly in arid and semi-arid regions of the world [5]. It affects many morphological, physiological, and biochemical processes, like seed germination, plant growth, and water and nutrient uptake[6]. All phases of plant growth and development are impeded by salt stress; however, depending on the species, some phases such as germination, seedling, or flowering are the most vulnerable [7]. Seedling establishment will be compromised by exposing the seeds during germination to unfavorable environmental conditions such as salinity and drought stress [8]. For most of the plants, if light and water are obtainable, the temperature of the soil determines the portion of the germinated seeds and the germination rate [9]. According to [10], plant growth is at the most basic level and reduced by salinity stress. Still, the plant species will be different in their salinity admittance, which is not desirable. The significant inhibitory effect of salinity impacts plant growth and development by osmotic inhibition of water availability and increasing the toxic effect of salt ions responsible for colonization [11]. Evaluation of germination is the most important thing and must be evaluated in the correct media to give the best result and have typical quality[12]. This study aims to assess the effects of different temperature and salinity levels on seed germination and growth characteristics of Brussels sprout seeds.

* Corresponding author

E-mail address chnwr.mahmud@univsul.edu.iq (Instructor).

Peer-reviewed under the responsibility of the University of Garmian.

Materials and Methods

This research involves (*Brassica oleracea* var. gemmifera) seeds, whose characteristics are shown in Figure 1. A factorial design in a completely randomized design (CRD) was used for the laboratory and germination experiments, while a completely randomized block design (CRBD) with three replicates was applied in the field. Transplants were planted in the field on September 1, 2023. For this purpose, we applied three temperature levels (5°C in a refrigerator, 15°C and 25°C in controlled rooms) and four NaCl concentrations, as described below:

Table 1: Temperatures and NaCl concentrations (mM) used in this study.

Treat.	**(C°)Temperature**	NaCl concentrations **(mM)**
T1	5	0
T2		50
T3		100
T4		150
T5	15	0
T6		50
T7		100
T8		150
T9	25	0
T10		50
T11		100
T12		150

To prevent fungal invasion, the seeds were surface-sterilized with 5% sodium hypochlorite (NaOCl) for five minutes, and then they were washed with distilled water. (Abdulrahman & Mahmood, 2021). Twenty seeds from each of the four NaCl treatments were used for each plant type. The seeds were placed in sterile 9 cm Petri dishes pre-saturated with the appropriate salt solution and incubated under different temperature regimes, seeds sprout in a lab setting on filter paper (Whatman No. 2). The number of germinated seeds was counted daily for up to 7 days. Seeds were considered germinated when the radicle emerged. After germination, seeds from each treatment were transplanted into trays containing a 1:1:1 mixture of soil, peat moss, and manure. These trays were placed in a small temporary tunnel covered with polyethylene for 6 weeks to allow growth. After that, the plants were transplanted into a local farmer's field. When buds formed after 90 days of growth, we recorded the growth characteristics.

2. 2. 1 Foundations of Chaotic Systems

Chaotic systems, rooted in the concepts of deterministic nonlinear dynamics, show off behavior that looks random yet is ruled by way of deterministic equations. The basis for understanding chaotic procedures was created by the pioneering studies of mathematicians by Eduard Lorenz and Henri Poincare, which confirmed the existence of extraneous attractions and their sensitivity to initial conditions [15]. Applications of chaos theory can be found in a wide range of disciplines, including physics, biology, economics, security, as well as mathematics.

Figure 1: Package of Brussels sprouts seeds and their properties.

2. 1 Characteristics to be studied

2. 1. 1 Germination Characteristics

After the seed started to germinate, these parameters we calculated:

1. Germination Percentage (GP) (%) [13].
2. Mean Daily Germination (MDG) [14].
3. Mean Germination Time (MGT) [15].
4. Germination Rate Index (GRI) [16].
5. Germination Speed (GS) (day-1) [14].
6. Germination Energy (GE) (72 hours) [17].
7. Time to 50%Germination (T50%) [18].
8. CoV(coefficient of velocity of germination) (%) [19].

2. 1. 2 Growth Characteristics

2. 1. 2. 1 Vegetative parameters

After buds formed, 10 plants we randomly selected in each treatment to determine the following parameters:

1. Leaf Number/plant.
2. Stem Diameter (cm).
3. Plant Dry Matter (%).
4. Leaves Chlorophyll Content (SPAD)
5. Buds Number/plant.
6. Single Buds weight (g).
7. Plant Yield (kg).
8. Marketable Yield (Ton/ha).

2. 1. 2. 2 Bud parameters

After buds formed, 30 buds were selected randomly in each treatment to determine these parameters:

1. Bud Dry Matter (%).
2. Protein (g).
3. Vit. C (mg).
4. Vit. K (µg).
5. Vit A. (µg), (as beta carotene).
6. Iron (mg).
7. Potassium (mg).
8. Calcium (mg).
9. Magnesium (mg).
10. Phosphorous (mg).
11. Glucosinolate (µmol).

2. 2 Statistical analysis

The Factorial CRD for the laboratory part and CRBD in the field we used in this study. The statistical analysis system XL-State (2019) program we used to analyze the data obtained in the research. Significant treatment differences we found at the P≤0.05 level by using the Duncan test.

3 Results

Table (2) shows that the highest germination percentage (GP%) was 100.000%, recorded at 25°C under 0, 50, and 150 mM NaCl concentrations. This treatment significantly exceeded the lowest recorded value of 29.333%, observed at 5°C with 150 mM NaCl. For mean daily germination (MDG), the highest value was 2.777 days at 25°C with 0 mM NaCl, while the lowest value was 0.967 days at 5°C with 0 mM NaCl. The MGT (mean germination time) recorded the maximum value by 4.905 days (at 5°C and 0 mM NaCl). This value suppressed the minimum value by 3.793 days (at 25°C and 0 mM NaCl). The same table shows that the germination rate index (GRI) reached a maximum value of 44.167 at 25°C with 0 mM NaCl, significantly higher than the minimum value of 9.333 observed at 5°C with 0 mM NaCl.

Table 2: Effect of different degrees of temperature and NaCl concentrations on GP%, MDG (Day), MGT (Day), and GRI (Day) of Brussels sprout seeds

Traits	Temp.(ºC)	NaCl concentrations			
		0	50mM	100mM	150mM
GP%	5	33.333 e	31.667 e	36.333 de	29.333 e
	15	93.333 a	83.333 ab	70.000 bc	53.333 cd
	25	100.000 a	100.000 a	96.667 a	100.000 a
MDG (Day)	5	0.967 e	1.637 cd	1.583 cd	1.807 cd
	15	1.917 c	1.803 cd	1.443 d	1.667 cd
	25	2.777 a	2.723 ab	2.337 b	1.443 d
MGT (Day)	5	4.905 a	4.215 bcd	4.091 cd	4.165 cd
	15	4.141 cd	4.210 bcd	4.525 abc	3.993 d
	25	3.793 d	3.876 d	3.934 d	4.652 ab
GRI (Day)	5	9.333 f	20.720 cde	19.777 de	23.387 bcde
	15	30.667 b	26.277 bcd	15.663 ef	16.280 ef
	25	44.167 a	42.390 a	28.443 bc	16.000 ef

For letters a and b, different letters in the same trait significantly alter means (P ≤ 0.05).

Table (3) shows the effects of different degrees of temperature and NaCl concentrations on Germination Speed or Rate GS or GR (day^{-1}), GE (72 Hours) %Germination Efficiency, T 50%Time to 50% Germination, and CoV % Coefficient of Variation for Germination of Brussels sprout seeds.For GS or GR (Germination Speed or Rate, day^{-1}) the maximum value was 6.267 (at 25°C and 0 mM NaCl) significantly superior to the minimum value was 1.800 (at 5°C and 0 mM NaCl).For the GE% value (Germination Efficiency at 72 hours), it was 100.000% at 25°C for all NaCl concentrations except 100 mM. This treatment surpassed the minimum value of 46.667%, which was recorded at 5°C and 0 mM NaCl. For time to 50% germination (T50%), the highest value was 5.667 days at 5°C with 0 mM NaCl, while the lowest was 2.667 days at 25°C with 0 mM NaCl. The coefficient of variation for germination (CoV%) reached a maximum of 83.940% at 25°C with 150 mM NaCl, whereas the minimum value was 44.130% at 25°C with 0 mM NaCl. Figure (2) shows that leaf chlorophyll content (SPAD) reached a maximum value of 50.333 at 5°C with 0 mM NaCl, which was notably higher than the value of 32.300 recorded at 15°C with 0 mM NaCl. For the number of buds per plant, the highest value of 65.333 was recorded at 5°C with 0 mM NaCl, while the lowest value of 27.000 was observed at 15°C with 50 mM NaCl. For single bud weight (g), the maximum value was 21.103 g at 5°C with 50 mM NaCl, which significantly surpassed the other treatments. The minimum value of 10.750 g was recorded at 15°C with 50 mM NaCl. The same data on plant yield (kg) indicated a maximum value of 1.264 kg at 5°C with 0 mM NaCl, while the minimum value of 0.284 kg was recorded at 15°C with 50 mM NaCl. The highest marketable yield (ton/ha) was 31.589 ton/ha at 5°C and 0 mM NaCl, while the minimum value, 7.100 ton/ha, was recorded at 15°C and 50 mM NaCl.

Table 3: Effect of different degrees of temperature and NaCl concentrations on GS or GR (day-1), GE (72 Hours) %, T 50%, and CoV % of Brussels sprout seeds.

Traits	Temp.(ºC)	NaCl concentrations			
		0	50mM	100mM	150mM
GS or GR (day^{-1})	5	1.800 f	3.333 cde	3.033 de	3.533 cde
	15	4.800 b	4.133 bcd	2.567 ef	2.467 ef
	25	6.267 a	5.933 a	4.267 bc	2.467 ef
GE (72 Hours) %	5	46.667 d	80.000 ab	70.000 bc	83.333 ab
	15	93.333 a	90.000 ab	70.000 bc	53.333 cd
	25	100.000 a	100.000 a	96.667 a	100.000 a
T 50%	5	5.667 a	4.333 bc	3.833 bcd	4.333 bc
	15	3.333 de	3.333 de	4.667 b	4.667 b
	25	2.667 e	3.500 cde	4.333 bc	4.500 b
CoV%	5	60.477 b-e	79.167 ab	70.793 abcd	74.880 abcd
	15	47.063 e	77.143 abc	58.890 cde	55.833 de
	25	44.130 e	46.510 e	70.000 abcd	83.940 a

For letters a and b, different letters in the same trait significantly alter means ($P \leq 0.05$)

Table 4: Effect of different degrees of temperature and NaCl concentrations on plant Height (cm), leaf number, stem diameter(mm), and Plant dry matter % of Brussels sprouts plants.

Traits	Temp.(ºC)	NaCl concentrations			
		0	50mM	100mM	150mM
Plant height (cm)	5	64.000 a	57.000 ab	51.000 bc	48.000 bc
	15	48.000 bc	55.000 abc	51.333 bc	49.000 bc
	25	48.333 bc	52.000 bc	44.667 c	53.333 abc
Leaf number	5	31.667 b	39.333 ab	45.667 a	38.667 ab
	15	37.333 ab	29.333 b	30.000 b	34.333 b
	25	36.667 ab	28.000 b	36.333 ab	32.000 b
Stem diameter(mm)	5	32.333 c	50.000 ab	48.000 b	51.000 ab
	15	59.667 a	41.000 bc	49.000 ab	44.333 b
	25	44.000 b	43.000 bc	51.000 ab	47.000 b
Dry matter %	5	14.433 a	12.833 a	13.667 a	14.167 a
	15	14.533 a	12.567 a	13.467 a	12.033 a
	25	14.033 a	14.233 a	13.000 a	15.167 a

For letters a and b, different letters in the same trait significantly alter means ($P \leq 0.05$).

Figure (2) shows that leaf chlorophyll content (SPAD) reached a maximum value of 50.333 at 5°C with 0 mM NaCl, which was notably higher than the value of 32.300 recorded at 15°C with 0 mM NaCl. For the number of buds per plant, the highest value of 65.333 was recorded at 5°C with 0 mM NaCl, while the lowest value of 27.000 was observed at 15°C with 50 mM NaCl. For single bud weight (g), the maximum value was 21.103 g at 5°C with 50 mM NaCl, which significantly surpassed the other treatments. The minimum value of 10.750 g was recorded at 15°C with 50 mM NaCl. The same data on plant yield (kg) indicated a maximum value of 1.264 kg at 5°C with 0 mM NaCl, while the minimum value of 0.284 kg was recorded at 15°C with 50 mM NaCl. The highest marketable yield (ton/ha) was 31.589 ton/ha at 5°C and 0 mM NaCl, while the minimum value, 7.100 ton/ha, was recorded at 15°C and 50 mM NaCl.

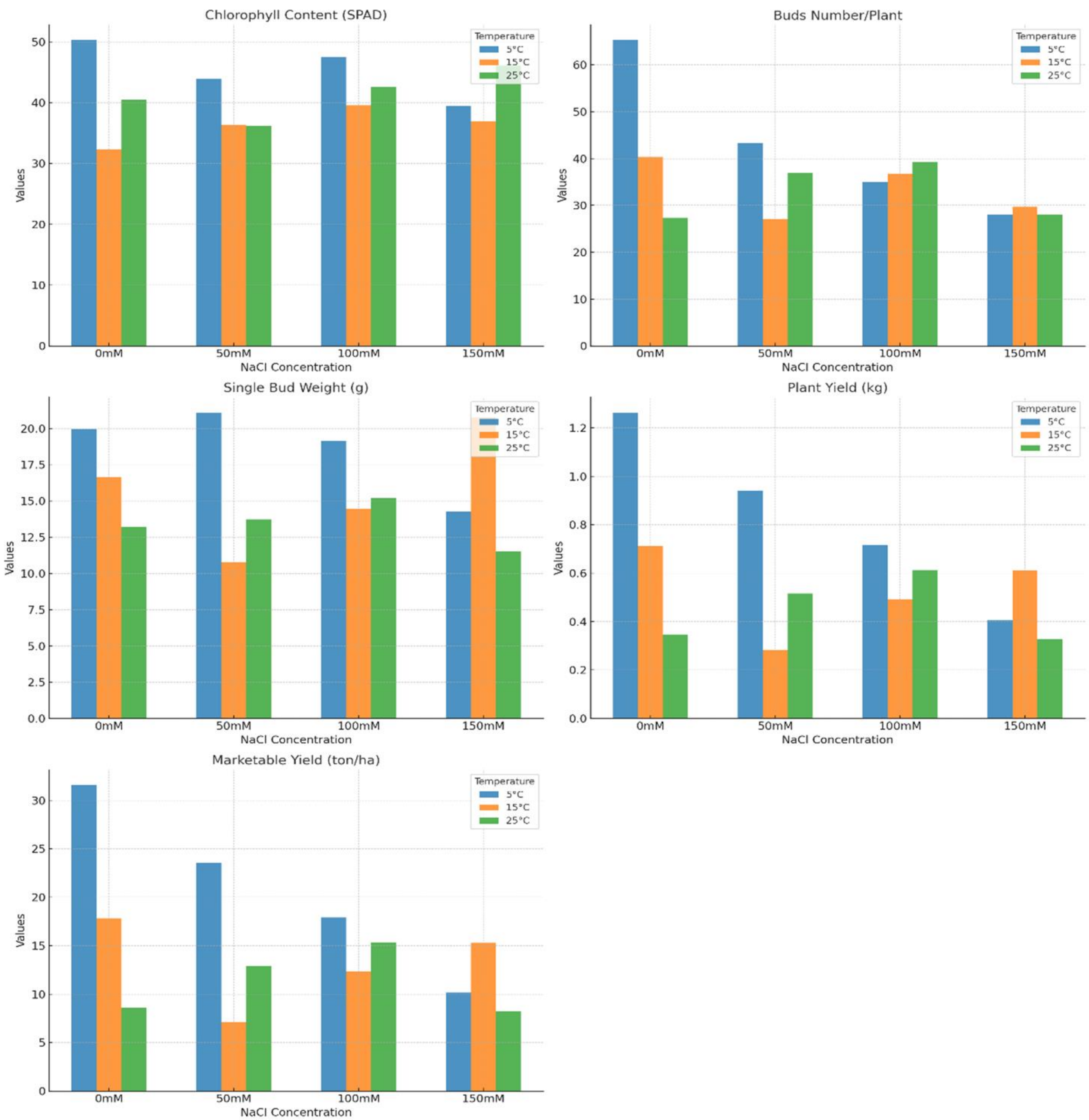

Figure 2: Effect of different degrees of temperature and NaCl concentrations on leaves' chlorophyll content (SPAD), Buds number/plant, single bud weight (g), Plant yield (kg), and Marketable yield(ton/ha) of Brussels sprouts.

Data in table 5 showed that bud dry matter (%) reached a maximum value of 12.490% at 5°C and 0 mM NaCl, which significantly surpassed the other treatments. The minimum average was 7.280% at 25°C and 50 mM NaCl. For bud protein (g) content, data represented that the maximum average was 3.990 g (at 25°C and 0 mM NaCl) while the minimum value was 2.407 g (at 25°C and 100 mM NaCl). According to the results, the highest content in Bud Vitamin C (mg) recorded was 116.743 mg (at 25°C and 100 mM NaCl), but the minimum value of 80.470 mg (at 15°C and 150 mM NaCl). Data revealed Bud Vitamin K (µg) content showed that the maximum average was 195.147 µg (at 5°C and 0 mM NaCl), while the minimum recorded was 175.487 µg (at 15°C and 50mM NaCl). Bud Vitamin A (µg) (as Beta-Carotene) According to the values obtained from the research, the maximum average was 49.303 µg (at 5°C and 0 mM NaCl) which significantly bypassed the other treatments and gave 38.020 µg (at 15°C and 50mM NaCl).

Table 5: Effect of different degrees of temperature and NaCl concentrations on Bud Dry matter %, Buds protein (g), Bud vit. C (mg), Bud vit. K(µg), and Bud vit. A(µg) (as beta-carotene) of Brussels sprout buds.

Traits	Temp.(ºC)	NaCl concentrations			
		0	50mM	100mM	150mM
Dry matter %	5	12.490 a	10.423 a	8.067 a	11.883 a
	15	7.347 a	7.763 a	9.893 a	8.377 a
	25	10.223 a	7.280 a	11.870 a	12.330 a
Protein (g)	5	3.670 ab	2.590 cd	2.913 bcd	3.400 abc
	15	3.533 ab	3.550 ab	3.483 abc	3.617 ab
	25	3.990 a	3.433 abc	2.407 d	3.337 abc
Vit.C (mg)	5	115.620 ab	104.367 abc	93.627 bcd	96.530 abcd
	15	99.113 abcd	106.670 abc	95.290 abcd	80.470 d
	25	98.823 abcd	96.363 abcd	116.743 a	88.077 cd
Vit.K(µg)	5	195.147 a	181.957 a	188.213 a	185.173 a
	15	193.770 a	175.487 a	181.573 a	176.817 a
	25	175.630 a	180.503 a	182.350 a	181.890 a
vit A(µg) (as beta-carotene)	5	49.303 a	48.607 ab	42.260 abc	43.693 abc
	15	49.140 a	38.020 c	42.280 abc	39.453 bc
	25	38.717 c	41.677 abc	43.800 abc	45.683 abc

For letters a and b, different letters in the same trait significantly alter means ($P \leq 0.05$).

Table (6) represents the effect of different degrees of temperature and NaCl concentrations on Bud Iron (mg), Bud potassium (mg), Bud Calcium (mg), Bud Magnesium(mg), Bud Phosphorus(mg), and Bud Glucosinolates (µmol) of Brussels sprout buds.

Table 6: Effect of different degrees of temperature and NaCl concentrations on Bud Iron(mg), Bud potassium (mg), Bud Calcium (mg), Bud Magnesium(mg), Bud Phosphorus(mg), and Bud Glucosinolates (µmol) of Brussels sprout buds.

Traits	Temp.(ºC)	NaCl concentrations			
		0	50mM	100mM	150mM
Iron(mg)	5	0.711 b	0.855 b	0.947 b	0.954 a
	15	0.949 b	0.668 b	0.789 b	0.828 b
	25	0.880 b	0.716 b	0.650 b	0.829 b
Potassium (mg)	5	456.667 a	393.667 ab	435.667 ab	373.333 ab
	15	439.000 ab	428.000 ab	390.667 ab	427.000 ab
	25	407.667 ab	328.667 b	417.333 ab	396.333 ab
Calcium(mg)	5	38.047 a	36.263 ab	30.787 abc	23.183 c
	15	29.473 abc	32.493 abc	33.523 abc	29.613 abc
	25	33.987 ab	32.703 abc	32.553 abc	26.350 bc
Magnesium(mg)	5	23.187 ab	24.400 a	17.823 cd	23.003 abc
	15	23.327 ab	19.092 bcd	17.937 cd	22.810 abc
	25	18.373 bcd	16.997 d	18.347 bcd	22.663 abc
Phosphorus(mg)	5	55.143 b	61.853 ab	59.330 ab	57.850 ab
	15	63.437 ab	68.197 a	68.510 a	60.023 ab
	25	57.777 ab	65.507 ab	55.890 b	58.713 ab
Glucosinolates (µmol)	5	1.614 e	4.147 abcd	2.737 cde	2.311 de
	15	4.672 abc	3.626 abcd	3.711 abcd	4.932 ab
	25	2.750 cde	5.115 ab	3.129 bcde	5.596 a

For letters a and b, different letters in the same trait significantly alter means ($P \leq 0.05$).

4 Discussion

Seed germination doesn't happen in isolation. It is influenced by environmental factors such as temperature, moisture, light, and the type of growing medium. In our study, we observed that seed varieties showed varying responses to temperature changes, indicating genotype-specific sensitivity to thermal conditions. This matches what [20,21] found: seed response to temperature isn't uniform and often depends on the plant's origin. These variations aren't random—they're likely adaptations. A plant's success or failure in a specific environment can depend on whether its germination behavior fits local conditions. [22] also noted that each species or cultivar has its temperature threshold for ideal germination. In our study, most seeds showed optimal performance at 25°C, indicating that this temperature is favorable for the germination and growth of these vegetable varieties.

We also saw how salinity can interfere with germination. It does this in two ways. First, higher salinity raises the osmotic pressure, which makes it harder for seeds to absorb water—something they need to start growing. Second, too much salt, especially sodium (Na^+) and chloride (Cl^-) creates toxicity that damages the seeds. [23] pointed out these effects as key reasons high salinity can suppress germination. Combined, osmotic stress and ion toxicity can significantly hinder seed germination and early development under saline conditions.

The maximum germination percentage (GP%) was recorded at 25°C across all NaCl concentrations, significantly surpassing the minimum value of 29.333% at 5°C and 150 mM NaCl. This aligns with findings that moderate temperatures (15-25°C) optimize germination in Brassica species, while extreme temperatures and high salinity can inhibit it [24]. The germination speed (GS) was highest at 25°C (6.267 day^{-1}) and lowest at 5°C (1.800 day^{-1}), reflecting the inhibitory effect of low temperatures on metabolic processes [25]. Germination efficiency (GE%) reached 100% at 25°C, except at 150 mM NaCl, while it dropped to 46.667% at 5°C, indicating that both temperature and salinity play critical roles in germination success [26]. The time to 50% germination (T50%) was longest at 5°C (5.667 days) and shortest at 25°C (2.667 days), consistent with the trend observed in MGT[15]. The coefficient of variation (CoV%) for germination was highest at 25°C and 150 mM NaCl (83.940%), suggesting that high salinity increases variability in germination under optimal temperatures [27]. The mean daily germination (MDG) peaked at 2.777 at 25°C and 0 mM NaCl, indicating that optimal conditions enhance germination speed [28]. (Bradford, 2002). The mean germination time (MGT) was longest at 5°C (4.905 days) and shortest at 25°C (3.793 days), consistent with studies showing that lower temperatures delay germination [29]. The germination rate index (GRI) also peaked at 25°C (44.167), further emphasizing the importance of optimal temperature for rapid and uniform germination [20, 21].In the present study, the results showed a decrease in germination traits as salinity levels increased. This finding is supported by [30], who reported that the germination speed and efficiency of the studied plant species were significantly reduced under saline conditions compared to the control. However, [31] noted that low concentrations of salt had minimal adverse effects on seed germination, indicating the species' tolerance to mild salinity stress.

Plant height was most significant at 5°C and 0 mM NaCl (64.000 cm), while the minimum we observed at 25°C and 100 mM NaCl (44.667 cm). This suggests that cooler temperatures may promote elongation, but high salinity can inhibit growth [32]. Leaf number peaked at 5°C and 100 mM NaCl (45.667), indicating that moderate salinity can stimulate leaf development under cooler conditions [33]. Stem diameter was thickest at 15°C and 0 mM NaCl (59.667 mm), while the thinnest was at 5°C and 0 mM NaCl (32.333 mm), highlighting the complex interaction between temperature and salinity on plant structure [34].

Chlorophyll content was highest at 5°C and 0 mM NaCl (50.333 SPAD), while the lowest was at 15°C and 0 mM NaCl (32.300 SPAD), suggesting that cooler temperatures enhance photosynthetic efficiency [35]. Bud number and weight were maximized at 5°C and 0 mM NaCl (65.333 buds and 21.103 g, respectively), indicating that cooler temperatures favor bud development [36]. Plant yield and marketable yield were also highest at 5°C and 0 mM NaCl (1.264 kg and 31.589 ton/ha, respectively), further supporting the benefits of cooler temperatures for productivity [37].

Bud dry matter was highest at 5°C and 0 mM NaCl (12.490%), while the lowest was at 25°C and 50mM NaCl (7.280%), indicating that cooler temperatures enhance dry matter accumulation [38]. Protein content peaked at 25°C and 0 mM NaCl (3.990 g), while vitamin C was highest at 25°C and 100 mM NaCl (116.743 mg), suggesting that moderate salinity can enhance specific nutrients under optimal temperatures [39]. (Hanson *et al*., 2006). Glucosinolate content we maximized at 25°C and 150 mM NaCl (5.596 µmol), consistent with studies showing that salinity can stimulate the production of these bioactive compounds [40].

Conclusion

The results show that both temperature and NaCl concentration have a significant impact on the germination rate, plant growth, and nutritional composition of Brussels sprouts. Optimal temperatures (15-25°C) generally enhance germination and growth, while cooler temperatures (5°C) favor certain morphological and nutritional traits. High salinity (150 mM NaCl) can inhibit germination and growth but may enhance specific nutrients like glucosinolates. The low temperature (5°C) we used during seed storage, not during growth. Cold storage helps preserve seed quality, delay aging, and enhance germination performance when the seeds are later planted. That gives the plants a stronger start, which can lead to better overall growth and productivity.

Our recommendation: store your seeds at 5°C before planting. This helps maintain seed quality and supports better germination. When it's time to grow the plants, aim for around 25°C. That temperature range encourages good growth, enzyme function, and overall plant strength. There's no contradiction between the two—each serves a different purpose. Using both, one for storage and one for growth, can help you get the most out of your seeds.

References

[1] Pena, M., Guzman, A., Martinez, R., Mesas, C., Prados, J., Porres, J. M. & Melguizo, C. Preventive effects of Brassicaceae family for colon cancer prevention: A focus on in vitro studies. *Biomed Pharmacother* **151**, 113145, doi:10.1016/j.biopha.2022.113145 (2022).

[2] Gopalakrishnan, T. R. Vegetable crops. *New India Publishing*, No. 4 (2007).

[3] Ibrahim, C. O. & Mahmood, C. H. Response of tomato (*Lycopersicum esculentum* L.) to imbibing seeds by GA_3, and foliar spraying by boron and α-tocopherol. *J Duhok Univ* **25**, 211–228 (2022).

[4] Bojović, B., Đelić, G., Topuzović, M. & Stanković, M. Effects of NaCl on seed germination in some species from families Brassicaceae and Solanaceae. *Kragujevac J Sci* **32**, 83–87 (2010).

[5] Ahmed, S. Effect of soil salinity on the yield and yield components of mungbean. *Pak J Bot* **4**, 263–268 (2009).

[6] Willenborg, C. J., Gulden, R. H., Johnson, E. N. & Shirtliffe, S. J. Germination characteristics of polymer-coated canola (*Brassica napus* L.) seeds subjected to moisture stress at different temperatures. *Agron J* **96**, 786–791 (2004).

[7] Khoshsokan, F., Babalar, M., Chaghazardi, H. R. & Fatahimoghasam, M. R. Effect of salinity and drought stress on germination indices of two *Thymus* species. *Cercet Agron Moldova* **1**, 27–35 (2012).

[8] Albuquerque, F. M. C. D. & Carvalho, N. M. D. Effect of type of environmental stress on the emergence of sunflower (*Helianthus annuus* L.), soybean (*Glycine max* (L.) Merril) and maize (*Zea mays* L.) seeds with different levels of vigor. *Seed Sci Technol* **31**, 465–467 (2003).

[9] Abdulrahman, N. M. & Mahmood, C. H. Impact of seed soaking by salicylic acid, biozyme application, and covering on okra (*Abelmoschus esculentus* L.) germination and yield. *Euphrates J Agric Sci* **13**, 136–155 (2021).

[10] Ibrahim, C. O. Effect of seed soaking in GA_3 and foliar spraying of boric acid and α-tocopherol on growth, fruit quantity and quality and seed yield of tomato. Thesis, MSc. (2023).

[11] Hakim, M. A., Juraimi, A. S., Begum, M., Hanafi, M. M., Ismail, M. R. & Selamat, A. Effect of salt stress on germination and early seedling growth of rice (*Oryza sativa* L.). *Afr J Biotechnol* **9**, 1911–1918 (2009).

[12] Venudevan, B., Srimathi, P., Natarajan, N. & Vijayakumar, R. M. Standardization of germination media for the endangered medicinal tree, bael (*Aegle marmelos*). *Afr J Agric Res* **8**, 3172–3176 (2013).

[13] ISTA. International rules for seed testing. *Seed Sci Technol* **21**, 288 pp. (1999).

[14] Czabator, F. J. Germination value: An index combining speed and completeness of pine seed germination. *Forest Sci* **8**, 386–395 (1962).

[15] Ellis, R. H. & Roberts, E. H. The quantification of ageing and survival in orthodox seeds. *Seed Sci Technol* **9**, 373–409 (1981).

[16] Azizi, M., Chehrazi, M. & Zahedi, S. M. Effects of salinity stress on germination and early growth of sweet William (*Dianthus barbatus*). *Asian J Agric Sci* **3**, 453–458 (2011).

[17] Zhang, T., Fan, S., Xiang, Y., Zhang, S., Wang, J. & Sun, Q. Non-destructive analysis of germination percentage, germination energy and simple vigour index on wheat seeds during storage by Vis/NIR and SWIR hyperspectral imaging. *Spectrochim Acta A Mol Biomol Spectrosc* **239**, 118488, doi:10.1016/j.saa.2020.118488 (2020).

[18] Khan, A., Imran, A. M., Aiman, K., Hasina, G., Habib, A. & Said, W. Impact of fertilizer priming on seed germination behavior and vigor of maize. *Pure Appl Biol* **5**, 744–751, doi:10.19045/bspab.2016.50093 (2016).

[19] Moghadam, P. A. & Alaei, Y. Evaluation of important germination traits of soybean genotypes through factor analysis in osmotic drought stress conditions. *Bull Environ Pharmacol Life Sci* **3**, 5–8 (2014).

[20] Mahmood, C. H. Response of some vegetables belongs to Solanaceae family to different temperature and NaCl levels on seed germination and growth characteristics. *Tikrit J Agric Sci* **17**, 11–27 (2017).

[21] Ranal, M. A. & Santana, D. G. How and why to measure the germination process? *Rev Bras Bot* **29**, 1–11 (2006).

[22] Atak, M. D., Kaya, G., Kaya, Y. & Cikili, C. Y. Effects of NaCl on the germination, seedling growth and water uptake of triticale. *Turk J Agric For* **30**, 39–47 (2006).

[23] Rajabi, R. & Postini, K. Effect of NaCl on thirty cultivars of bread wheat seed germination. *Agric Sci J* **27**(1), 29–45 (2005).

[24] Almansouri, M., Kinet, J. M. & Lutts, S. Effect of salt and osmotic stresses on germination in durum wheat (*Triticum durum* Desf.). *Plant Soil* **231**, 243–254 (2001).

[25] Garcia-Huidobro, J., Monteith, J. L. & Squire, G. R. Time, temperature and germination of pearl millet (*Pennisetum typhoides* S. & H.). *J Exp Bot* **33**, 288–296 (1982).

[26] Khan, M. A. & Ungar, I. A. The effect of salinity and temperature on the germination of polymorphic seeds and growth of *Atriplex triangularis* Wild. *Am J Bot* **71**, 481–489 (1984).

[27] Alvarado, V. & Bradford, K. J. A hydrothermal time model explains the cardinal temperatures for seed germination. *Plant Cell Environ* **25**, 1061–1069 (2002).

[28] Bradford, K. J. Applications of hydrothermal time to quantifying and modeling seed germination and dormancy. *Weed Sci* **50**, 248–260 (2002).

[29] Bewley, J. D. & Black, M. *Seeds: Physiology of Development and Germination*. Plenum Press (1994).

[30] Sarker, A., Hossain, M. D. I. & Abul Kashem, M. D. Salinity (NaCl) tolerance of four vegetable crops during germination and early seedling growth. *Int J Latest Res Sci Technol* **3**, 91–95 (2014).

[31] Mazur, Z. & Radziemska, M. Effect of sodium chloride salinization on the seed germination of selected vegetable plants. *Sci Rev Eng Environ Sci* **62**, 444–453 (2013).

[32] Munns, R. & Tester, M. Mechanisms of salinity tolerance. *Annu Rev Plant Biol* **59**, 651–681 (2008).

[33] Ashraf, M. & Harris, P. J. C. Potential biochemical indicators of salinity tolerance in plants. *Plant Sci* **166**, 3–16 (2004).

[34] Taiz, L. & Zeiger, E. *Plant Physiology*. Sinauer Associates (2010).

[35] Maxwell, K. & Johnson, G. N. Chlorophyll fluorescence—a practical guide. *J Exp Bot* **51**, 659–668 (2000).

[36] Kopsell, D. A. & Kopsell, D. E. Accumulation and bioavailability of dietary carotenoids in vegetable crops. *Trends Plant Sci* **11**, 499–507 (2006).

[37] Salisbury, F. B. & Ross, C. W. *Plant Physiology*. Wadsworth Publishing Company (1992).

[38] Marschner, H. *Marschner's Mineral Nutrition of Higher Plants*. Academic Press (2012).

[39] Hanson, P. M., Yang, R. Y., Wu, J., Chen, J. T., Ledesma, D. R., Tsou, S. C. S. & Lee, T. C. Variation for antioxidant activity and antioxidants in tomato. *J Am Soc Hortic Sci* **131**, 704–711 (2006).

[40] Cartea, M. E., Velasco, P., Obregón, S., Padilla, G. & de Haro, A. Seasonal variation in glucosinolate content in *Brassica oleracea* crops grown in northwestern Spain. *Phytochemistry* **69**, 403–410 (2011).