

Oligocarrageenan Foliar Spray Promotes the Growth and Yield of Pechay (*Brassica rapa* ssp. *chinensis*) under Postflooding Stress

Mary Grace Ravidas

Central Mindanao University

Vences Valleser

vcvalleser@cmu.edu.ph

Central Mindanao University

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Abstract

Flooding driven by climate change and poor infrastructure severely compromises the growth and yield of vegetables such as pechay (*Brassica rapa* ssp. *chinensis*). While oligocarrageenan is known to stimulate growth and enhance tolerance to abiotic stress, its curative potential after flooding remains largely unexplored. This study evaluated the effects of flooding and the use of oligocarrageenan as a curative foliar spray on the growth and yield of pechay. Oligocarrageenan concentrations (0, 60, 120, and 240 ppm) were applied as foliar sprays onto 14-day-old pechay plants grown under well-watered and flooding stress conditions. Despite being flooded, pechay plants have high survival rates (86.67–100%). However, flooding caused reductions in shoot and root length and biomass. Oligocarrageenan, as a curative treatment, improved these parameters under the flooding setup, with 240 ppm oligocarrageenan as the most effective concentration. Under well-watered conditions, 120 ppm oligocarrageenan was the optimal concentration. The yield responses provided the most robust evidence of the curative potential of oligocarrageenan; specifically, the foliar spray of 240 ppm oligocarrageenan mitigated flooding stress, resulting in a 769% increase relative to that of the flooded controls at 25 DAT. Flooding stress consistently induces higher TSS accumulation in pechay, although under well-watered conditions, a 60 ppm oligocarrageenan application optimizes the TSS. Temporally, the untreated control plants maintained elevated TSS concentrations at 25 DAT, whereas 60 ppm oligocarrageenan increased the TSS concentration at 35 DAT regardless of the water condition. These findings demonstrate that oligocarrageenan foliar spray improves the growth, yield, and quality of pechay postflooding stress.

1. Introduction

Pechay (*Brassica rapa* L. ssp. *chinensis*) is a nutrient-rich leafy vegetable that contributes to dietary health and food security (Lagon et al., 2022; Gonzaga et al., 2023). It is an important component of Filipino cuisine, featuring “pochero” and “nilaga”. The crop can be grown via container gardening in urban areas and through extensive production in rural areas. Pechay can be harvested as early as 20 days after transplanting, suggesting a year-round production supply and providing continuous income for smallholder farmers.

However, it cannot be denied that pechay is vulnerable to abiotic stresses such as flooding (Gabriel-Galban 2025). Water is essential for crops and serves as a key substrate in photosynthesis. However, excessive water that could be due to heavy and continuous rainfall, poor drainage, or typhoons can carry out severe physiological constraints and result in anoxia or loss of oxygen in the root environment and can compromise nutrient uptake (Fukao et al. 2019; Manghwar et al. 2024). This condition is a persistent reality in the Philippines, which is positioned directly in the typhoon belt. Consequently, farmers face relentless extreme weather (Rivera and Dela Vega 2025) and increasingly unpredictable rains (Hong et al. 2022). Thus, in addition to flood-control infrastructures, technologies that address the adverse impact of flooding in the context of vegetable production are needed.

Biostimulants have emerged as natural interventions to increase plant growth and yield under abiotic stress. Biostimulants differ from fertilizers and plant growth regulators because these compounds do not directly provide nutrients and hormones to plants. Instead, biostimulants stimulate physiological processes (du Jardin 2015), such as improved photosynthetic activity, nitrogen assimilation, and cell division, while activating defense pathways through the synthesis of secondary metabolites (Rouphael and Colla 2020). Biostimulants are less expensive alternatives to synthetic agrochemicals, and their application integrates climate-smart practices into crop management (Lopez-Serrano et al. 2026). Among these, seaweed extract-derived carrageenan (Rupert et al. 2022) represents a particularly notable group. Carrageenan is a long-chain carbohydrate that needs to be broken into shorter oligosaccharide fragments (oligocarrageenan) to become bioactive. Irradiated carrageenan or oligocarrageenan stimulates growth and confers tolerance to abiotic stresses such as drought (Thye et al. 2022; Valleser and Protacio 2024; Vecina et al. 2025). Moreover, it enhances chlorophyll biosynthesis, increases antioxidant enzyme activity, and increases nutrient assimilation efficiency, resulting in yield improvements across diverse crops (Moenne and González 2021).

Despite the stimulatory effects of oligocarrageenan on the growth and yield of crops, most related research has focused on prevention, with the goal of priming plants before stress occurs. The preventive approach assumes that smallholder farmers can predict flood periods and apply treatments in advance. In real scenarios, however, flooding often arises unexpectedly because of prevailing climate change. With this, growers require curative treatments that can be applied to restore plant vigor and recover yield. This embodies a critical knowledge gap, while oligocarrageenan foliar spray has been studied extensively, there is no information about its effectiveness as a curative treatment for postflooding stress in vegetables such as pechay. Testing the efficacy of oligocarrageenan as a curative treatment is essential for developing realistic and practical management strategies that align with the unpredictable nature of climate variability. Thus, this study aimed to evaluate the effects of short-term flooding and demonstrate the efficacy of oligocarrageenan as a curative foliar spray on the growth and yield of pechay.

2. Materials and methods

This study was carried out from September to November 2025 at the Agricultural Experimental Center, Central Mindanao University, Musuan, Maramag, Bukidnon, Philippines. Two experimental setups arranged in a randomized complete block design (RCBD) were conducted with four concentrations of oligocarrageenan serving as treatments (Table 1) and were replicated three times. This resulted in 12 experimental units (eu) per experimental setup. Each eu was composed of 20 plant samples.

Table 1
Water condition and concentrations of oligocarrageenan that served as treatments

Water condition	Oligocarrageenan concentration (ppm)
Well-watered (WW)	0
	60
	120
	240
Flooding stress (FS)	0
	60
	120
	240

The plants in the well-watered setup were regularly irrigated to maintain optimum soil moisture throughout the experimental period. In contrast, the flooding stress experiment involved subjecting 11-day-old transplanted plants to complete submergence for three days to simulate short-term flooding conditions.

2.1. Growth media preparation

Garden soil, commercial compost, and fine sand were thoroughly mixed at a 1:1:1 (v/v) ratio. The growth media was subsequently air-dried and sieved through a sand screen. The growth media were then filled in individual polyethylene bags (15.24 × 25.4 cm).

2.2. Seedling production and transplanting

‘Pavito’ pechay seeds (East–West Seed Philippines) were sourced and purchased from AVC Agricultural Supply, G. Laviña Avenue, Poblacion, Valencia city, Bukidnon, Philippines. The seedling containers made of banana leaves were filled with the recommended growth media. Pechay seeds were then sown in each seedling container. At 7 DAT, thinning was employed, and only one seedling was left per seedling container. Two seedlings at the two-leaf stage were then transplanted into individual polyethylene bags. Transplanting was performed late in the afternoon to minimize heat stress and prevent transplanting shock.

2.3. Flooding stress imposition

A small water pond was constructed. Eleven-day-old transplanted pechay seedlings were subsequently arranged inside the water pond. The pond was then filled gradually with tap water until the seedlings were completely submerged in water. Water was added as necessary to ensure uniform coverage of

water across the submerged seedlings. The water was drained after three days of submergence, and the plants were allowed to recover under nursery conditions.

2.4. Oligocarrageenan foliar treatment

Foliar spraying of oligocarrageenan was subsequently carried out at 14 DAT, which coincided with the start of the stress recovery period in the flooding stress setup and was harmonized with the well-watered control. Various concentrations of oligocarrageenan were applied using a hand-held sprayer. Foliar spraying was conducted late in the afternoon to minimize evaporation losses and maximize absorption efficiency through the leaf surface.

2.5. Data collection

2.5.1. Plant survival

Plant survival was monitored weekly from the application of oligocarrageenan until harvest. The percentage of plant survival was determined using the following equation:

Plant survival (%) =	$\frac{\sum \text{plants alive}}{\text{Number of transplanted seedlings}} \times 100$
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2.5.2. Plant height

Plant height was measured from the ground surface to the tip of the tallest fully expanded leaf using a measuring stick. Measurements commenced at 14 DAT and were gathered at 3-day intervals until harvest.

2.5.3. Number of leaves

The total number of leaves per plant was counted at 3-day intervals beginning at 14 DAT. Only fully expanded and healthy leaves (those with less than 50% senescence or drying) were considered for this parameter.

2.5.4. Leaf width

Leaf width at harvest was determined from the widest portion of three fully expanded leaves per plant.

2.5.5. Root length

Harvested plants were carefully removed from the growth media by submerging polyethylene seedling bags in water. The plants were then washed free of debris. Root length was then measured from the crown to the tip of the longest root.

2.5.6. Fresh biomass

The fresh weights of the shoots and roots were determined at harvest. Harvested plants were washed in tap water and air dried for one hour before being weighed on a calibrated digital balance.

2.5.7. Total soluble solids (TSS)

Leaf juice (10 mL) was extracted from mature pechay leaves at harvest. The TSS content was measured using an Atago handheld refractometer (Atago Co., Ltd.) and is expressed in °Brix.

2.6. Statistical analysis

The gathered data were subjected to combined analysis of variance (ANOVA) using the Statistical Tool for Agricultural Research (STAR). Treatment means were compared using Tukey's honestly significant difference (HSD) test at the 5% level of significance.

3. Results

3.1. Plant survival

The interaction effect between water conditions and oligocarrageenan concentration on the survival of pechay plants was not significant (Table 2). Regardless of the treatment combinations, the survival of the plants was high, ranging from 86.67% to 100%. Interestingly, plants subjected to flooding appeared more vigorously than well-watered controls did at one day post-submergence. However, when floodwater was drained after three days, plants previously subjected to flooding stress displayed visible wilting and senescence of leaves. Despite these symptoms, the flooded plants ultimately survived the stress (Fig. 1), and their survival rates remained comparable to those under well-watered conditions.

Table 2

Survival of pechay plants applied with varying concentrations of oligocarrageenan under different water conditions

Factor	Plant survival (%)
Water condition (WC)	
Well-watered (WW)	99.17
Flooding stress (FS)	90.84
Oligocarrageenan concentration (OCC)	
0 ppm	93.34
60 ppm	95.00
120 ppm	95.00
240 ppm	96.67
WC x OCC	
WW x 0 ppm	100.00
WW x 60 ppm	100.00
WW x 120 ppm	100.00
WW x 240 ppm	96.67
FS x 0 ppm	86.67
FS x 60 ppm	90.00
FS x 120 ppm	90.00
FS x 240 ppm	96.67
<i>p</i> value	
WC	0.0890 ^{ns}
OCC	0.8944 ^{ns}
WC x OCC	0.4696 ^{ns}
cv (%)	7.85
Means within a column followed by the same letter are not significantly different according to Tukey's Honest Significant Difference (HSD) test at the 0.05 probability level.	

3.2. Plant height

The interaction effect between the water condition and oligocarrageenan concentration on the height of the pechay plants was significant at 25 DAT (Table 3). Compared with oligocarrageenan-treated plants, untreated plants in the well-watered setup were consistently shorter by 2–3 cm. The height of the plants exhibited a positive concentration-dependent response under flooding stress, with the greatest increase—a nearly two-fold increase relative to that of the control—achieving at 240 ppm oligocarrageenan.

Table 3

Plant height of pechay in response to varying concentrations of oligocarrageenan under different water conditions

Factor	Plant height (cm) at various days after transplanting (DAT)					
	14 DAT	17 DAT	20 DAT	23 DAT	25 DAT	35 DAT
WC						
WW	14.02 ^a	16.97 ^a	21.56 ^a	24.98 ^a	26.29 ^a	27.40 ^a
FS	6.25 ^b	6.95 ^b	10.68 ^b	11.77 ^b	13.63 ^b	19.28 ^b
OCC						
0 ppm	7.41 ^d	9.23 ^c	12.28 ^b	15.54 ^c	16.72 ^c	21.03 ^c
60 ppm	9.79 ^c	11.91 ^b	14.92 ^b	18.06 ^b	19.65 ^b	23.39 ^{ab}
120 ppm	11.23 ^b	12.68 ^b	18.12 ^a	19.24 ^b	21.09 ^b	23.27 ^{bc}
240 ppm	12.12 ^a	14.03 ^a	19.16 ^a	20.64 ^a	22.34 ^a	25.67 ^a
WC x OCC						
WW x 0 ppm	11.42	14.54	18.79	23.12	24.08 ^{bx}	26.31
WW x 60 ppm	13.58	16.53	21.31	24.75	26.24 ^{ax}	27.80
WW x 120 ppm	15.17	17.98	22.71	25.64	27.07 ^{ax}	25.49
WW x 240 ppm	15.93	18.83	23.43	26.39	27.79 ^{ax}	30.00
FS x 0 ppm	3.40	3.91	5.77	7.96	9.35 ^{dy}	15.76
FS x 60 ppm	6.00	7.29	8.52	11.38	13.06 ^{cy}	18.98
FS x 120 ppm	7.29	7.39	13.53	12.84	15.11 ^{by}	21.05
FS x 240 ppm	8.30	9.23	14.89	14.88	17.01 ^{ay}	21.33
<i>p</i> value						
WC	0.0001 ^{**}	0.0000 ^{**}	0.0043 ^{**}	0.0000 ^{**}	0.0000 ^{**}	0.0002 ^{**}
OCC	0.0000 ^{**}	0.0000 ^{**}	0.0018 ^{**}	0.0000 ^{**}	0.0000 ^{**}	0.0072 ^{**}
WC x OCC	0.9225 ^{ns}	0.3399 ^{ns}	0.3106 ^{ns}	0.0569 ^{ns}	0.0295 [*]	0.0679 ^{ns}

Factor	Plant height (cm) at various days after transplanting (DAT)					
	14 DAT	17 DAT	20 DAT	23 DAT	25 DAT	35 DAT
cv (%)	6.33	6.44	15.51	5.55	5.04	7.76
Means within a column followed by the same letter are not significantly different according to Tukey's Honest Significant Difference (HSD) test at the 0.05 probability level.						

Independent of the oligocarrageenan concentration, across growth stages, plants previously subjected to submergence remained stunted and were approximately two-fold shorter than their well-watered counterparts were (Fig. 2 and Fig. 3). Regardless of the water condition, the oligocarrageenan treatment increased the plant height, with the height of the untreated plants being consistently shorter than that of the plants treated with oligocarrageenan. The most pronounced increase was observed at 240 ppm, which resulted in the greatest height increase relative to that of the control across developmental stages (Table 3).

3.3. Leaf production

The interaction effect between water condition and oligocarrageenan concentration on the leaf production of pechay at 14 DAT, 17 DAT, and during the first harvest (25 DAT) was significant (Table 4). Under well-watered conditions, the control plants produced fewer leaves (3.03 at 14 DAT, 4.50 at 17 DAT, and 6.10 at 25 DAT). Oligocarrageenan foliar spray enhanced leaf initiation, with the greatest increase detected at the highest concentration (240 ppm).

Table 4
Leaf production of pechay in response to oligocarrageenan foliar spray under well-watered and postflooding conditions

Factor	Leaf count (number) at various days after transplanting (DAT)					
	14 DAT	17 DAT	20 DAT	23 DAT	25 DAT	35 DAT
WC						
WW	3.51 ^a	5.10 ^a	6.39 ^a	6.83 ^a	7.04 ^a	9.83 ^a
FS	2.02 ^b	2.66 ^b	3.49 ^b	3.60 ^b	4.35 ^b	6.31 ^b
OCC						
0 ppm	2.14	3.02	3.77 ^c	4.21 ^c	4.59	6.82 ^b
60 ppm	2.71	3.78	4.82 ^b	5.09 ^b	5.66	7.74 ^{ab}
120 ppm	3.03	4.12	5.23 ^b	5.65 ^a	5.97	8.82 ^a
240 ppm	3.17	4.59	5.94 ^a	5.92 ^a	6.55	8.90 ^a
WC x OCC						
WW x 0 ppm	3.03 ^{cx}	4.50 ^{cx}	5.37	5.87	6.10 ^{bx}	7.83
WW x 60 ppm	3.50 ^{bx}	4.90 ^{bx}	6.40	6.93	7.03 ^{ax}	9.36
WW x 120 ppm	3.70 ^{abx}	5.23 ^{bx}	6.90	7.20	7.47 ^{ax}	11.22
WW x 240 ppm	3.80 ^{ax}	5.73 ^{ax}	6.90	7.32	7.55 ^{ax}	10.89
FS x 0 ppm	1.24 ^{cy}	1.53 ^{cy}	2.18	2.55	3.08 ^{cy}	5.80
FS x 60 ppm	1.92 ^{by}	2.66 ^{by}	3.24	3.24	4.30 ^{by}	6.12
FS x 120 ppm	2.37 ^{ay}	3.00 ^{by}	3.57	4.09	4.47 ^{by}	6.42
FS x 240 ppm	2.53 ^{ay}	3.44 ^{ay}	4.98	4.53	5.55 ^{ay}	6.92
<i>p</i> value						
WC	0.0000 ^{**}	0.0013 ^{**}	0.0003 ^{**}	0.0000 ^{**}	0.0002 ^{**}	0.0055 ^{**}
OCC	0.0000 ^{**}	0.0000 ^{**}	0.0000 ^{**}	0.0000 ^{**}	0.0000 ^{**}	0.0081 ^{**}
WC x OCC	0.0134 [*]	0.0401 [*]	0.0670 ^{ns}	0.1847 ^{ns}	0.0492 [*]	0.1372 ^{ns}

Factor	Leaf count (number) at various days after transplanting (DAT)					
	14 DAT	17 DAT	20 DAT	23 DAT	25 DAT	35 DAT
cv (%)	4.55	5.80	9.24	6.39	5.47	11.94
Means within a column followed by the same letter are not significantly different according to Tukey's Honest Significant Difference (HSD) test at the 0.05 probability level.						

Regardless of the oligocarrageenan concentration, water conditions influence pechay leaf development. The leaf production of previously submerged pechay plants was lower than that of their well-watered counterparts. The decreases were approximately 1–2 leaves at 14 DAT, 2–3 leaves at 17–20 DAT, and 3–4 leaves at 23–35 DAT (Table 4).

The individual effects of oligocarrageenan concentration were significant at later growth stages (20 DAT, 23 DAT, and 35 DAT). Compared with oligocarrageenan-treated plants, untreated plants had fewer leaves, with the 240 ppm concentration producing the highest leaf counts across these growth stages (Table 4).

3.4. Leaf width

The interaction effect between the water condition and oligocarrageenan concentration had no significant effect on the width of the leaves of pechay at harvest (Table 5). However, the individual effects of both factors on the width of the pechay leaves were significant. Flooding reduced the leaf expansion of the pechay plants. Compared with that of the well-watered plants, the leaf width of the flooded plants decreased nearly three-fold at 25 DAT and approximately two-fold at 35 DAT.

Table 5

Leaf width of pechay in response to oligocarrageenan foliar spray under well-watered and postflooding conditions

Factor	Leaf width (cm)	
	25 DAT	35 DAT
Water condition (WC)		
Well-watered (WW)	14.32 ^a	14.18 ^a
Flooding stress (FS)	5.54 ^b	8.48 ^b
Oligocarrageenan concentration (OCC)		
0 ppm	8.10 ^c	9.83 ^c
60 ppm	9.67 ^b	10.71 ^{bc}
120 ppm	10.38 ^b	12.20 ^{ab}
240 ppm	11.57 ^a	12.57 ^a
WC x OCC		
WW x 0 ppm	12.63	12.54
WW x 60 ppm	13.95	14.28
WW x 120 ppm	14.69	14.72
WW x 240 ppm	15.99	15.17
FS x 0 ppm	3.56	7.12
FS x 60 ppm	5.39	7.14
FS x 120 ppm	6.08	9.68
FS x 240 ppm	7.16	9.97
<i>p</i> value		
WC	0.0000 ^{**}	0.0000 ^{**}
OCC	0.0000 ^{**}	0.0146 [*]
WC x OCC	0.8978 ^{ns}	0.5347 ^{ns}
cv (%)	6.52	12.00
Means within a column followed by the same letter are not significantly different according to Tukey's Honest Significant Difference (HSD) test at the 0.05 probability level.		

Regardless of the water conditions, oligocarrageenan had a positive influence on the leaf width. The leaf widths of the untreated pechay at 25 DAT and 35 DAT were 8.10 and 9.83 cm, respectively. Compared with the control treatment, the foliar application of oligocarrageenan enhanced leaf expansion, with 240 ppm resulting in the most pronounced increase (3 cm).

3.5. Root length

A significant interaction effect between water conditions and oligocarrageenan concentration on root length was observed at 35 DAT (Table 6). The root length under well-watered conditions varied across oligocarrageenan concentrations, with 60 ppm oligocarrageenan-treated pechay plants displaying longer roots than both the untreated plants and those treated with 240 ppm oligocarrageenan. Under flooding stress, the roots of the untreated plants were shorter, whereas oligocarrageenan treatment increased elongation under poststress conditions. The greatest increase in roots was achieved at a concentration of 240 ppm, which was ≥ 15 cm greater than that of the control.

The independent influence of water conditions on root elongation was also significant at 25 DAT and 35 DAT. Compared with plants receiving optimum irrigation, flooded plants developed shorter roots (Fig. 3), with reductions of ≥ 13 cm and ≥ 18 cm at 25 and 35 DAT, respectively.

Regardless of the water condition, the effects of oligocarrageenan on root length were also significant at 25 DAT. Compared with oligocarrageenan-treated plants, untreated plants had shorter roots. Compared with the untreated control, the foliage spray of oligocarrageenan at concentrations of 60 ppm, 120 ppm, and 240 ppm increased root elongation by ≥ 8 cm, ≥ 10 cm, and ≥ 7 cm, respectively (Table 6).

Table 6

Root length of pechay in response to varying concentrations of oligocarrageenan applied as foliar spray under well-watered and postflooding conditions

Factor	Root length (cm)	
	25 DAT	35 DAT
WC		
WW	35.78 ^a	39.14 ^a
FS	12.11 ^b	21.29 ^b
OCC		
0 ppm	18.91 ^b	23.69 ^b
60 ppm	23.37 ^b	32.00 ^a
120 ppm	23.90 ^{ab}	33.96 ^a
240 ppm	29.60 ^a	31.22 ^a
WC x OCC		
WW x 0 ppm	29.34	36.08 ^{bx}
WW x 60 ppm	35.71	42.56 ^{ax}
WW x 120 ppm	35.05	41.85 ^{abx}
WW x 240 ppm	43.03	36.08 ^{bx}
FS x 0 ppm	8.48	11.30 ^{cy}
FS x 60 ppm	11.03	21.43 ^{by}
FS x 120 ppm	12.76	26.06 ^{aby}
FS x 240 ppm	16.18	26.36 ^{ay}
<i>p</i> value		
WC	0.0025 ^{**}	0.0026 ^{**}
OCC	0.0162 ^{**}	0.0013 ^{**}
WC x OCC	0.7113 ^{ns}	0.0069 ^{**}
cv (%)	19.79	11.57

Factor	Root length (cm)	
	25 DAT	35 DAT
Means within a column followed by the same letter are not significantly different according to Tukey's Honest Significant Difference (HSD) test at the 0.05 probability level.		

3.6. Shoot biomass

The shoot biomass of pechay was not significantly influenced by the interaction between water condition and oligocarrageenan concentration at 25 DAT or 35 DAT (Table 7). Nevertheless, the individual effects of water condition and oligocarrageenan concentration were highly significant. Compared with well-watered plants, flooded plants were reduced by approximately 16-fold and 6-fold at 25 and 35 DAT, respectively.

Regardless of the water condition, the untreated plants had lighter shoots at 25 DAT and 35 DAT. Foliar spraying of oligocarrageenan improved shoot biomass, with the 240 ppm concentration achieving the greatest increase (≥ 17 g per plant) at 25 DAT compared with that of the control. At 35 DAT, compared with the untreated plants, the oligocarrageenan-treated plants had greater shoot weight (Table 7).

Table 7

Shoot and root weights of pechay in response to varying oligocarrageenan concentrations applied under well-watered and postflooding conditions

Factor	Shoot and root weights at 25 DAT and 35 DAT			
	Shoot weight (g)		Root weight (g)	
25 DAT	35 DAT	25 DAT	35 DAT	
WC				
WW	66.49 ^a	127.23 ^a	18.01 ^a	30.47 ^a
FS	4.51 ^b	20.44 ^b	0.77 ^b	7.60 ^b
OCC				
0 ppm	26.95 ^c	58.59 ^b	7.12	10.32 ^b
60 ppm	32.56 ^{bc}	74.89 ^a	8.88	19.60 ^a
120 ppm	38.12 ^{ab}	83.37 ^a	11.49	24.36 ^a
240 ppm	44.38 ^a	78.49 ^a	10.08	21.87 ^a
WC x OCC				
WW x 0 ppm	52.89	105.58	14.06	18.50
WW x 60 ppm	62.39	130.16	17.39	31.10
WW x 120 ppm	70.61	145.64	22.17	39.73
WW x 240 ppm	80.06	127.52	18.44	32.57
FS x 0 ppm	1.00	11.60	0.19	2.13
FS x 60 ppm	2.72	19.62	0.36	8.10
FS x 120 ppm	5.63	21.10	0.81	8.99
FS x 240 ppm	8.69	29.45	1.72	11.17
<i>p</i> value				
WC	0.0007 ^{**}	0.0005 ^{**}	0.0357 [*]	0.0023 ^{**}
OCC	0.0285 [*]	0.0139 ^{**}	0.2077 ^{ns}	0.0057 ^{**}
WC x OCC	0.2512 ^{ns}	0.1296 ^{ns}	0.3430 ^{ns}	0.2312 ^{ns}
cv (%)	22.83	15.08	36.40	29.87

Factor	Shoot and root weights at 25 DAT and 35 DAT			
	Shoot weight (g)		Root weight (g)	
25 DAT	35 DAT	25 DAT	35 DAT	
Means within a column followed by the same letter are not significantly different according to Tukey's Honest Significant Difference (HSD) test at the 0.05 probability level.				

3.7. Root biomass

The root biomass of pechay was not influenced by the interaction between water condition and oligocarrageenan concentration (Table 7). However, the individual effects of water condition and oligocarrageenan concentration on root biomass were highly significant. Compared with the control treatment, the flooding stress treatment resulted in lower root biomass, with decreases of 23-fold and 4-fold at 25 and 35 DAT, respectively.

Regardless of the water condition, the untreated plants produced lighter roots at 35 DAT. The oligocarrageenan foliar spray increased the root weight of the pechay plants.

3.8. Yield response

The yield response (Table 8) reflects the economic yield of pechay as influenced by oligocarrageenan under well-watered and flooding stress conditions. Interestingly, compared with well-watered plants, pechay plants subjected to flooding stress were more responsive to oligocarrageenan foliar spray.

Table 8
Yield response of pechay in response to oligocarrageenan foliar spray under well-watered and postflooding conditions

Water condition	Oligocarrageenan concentration (ppm)	Yield response (%)	
		25 DAT	35 DAT
Well-watered	0	–	–
	60	17.96	24.58
	120	33.50	40.06
	240	53.37	21.94
Flooding stress	0	–	–
	60	172.00	69.14
	120	463.00	81.90
	240	769.00	153.90

At 25 DAT, under well-watered conditions, the greatest yield response relative to that of the control (53.37%) was detected in plants treated with 240 ppm oligocarrageenan. At 35 DAT, however, the highest

yield response (40.06%) was attained at 120 ppm.

Under flooding stress, the yield response increased in response to oligocarrageenan treatment, particularly at 240 ppm. At 25 DAT, compared with the control plants, the oligocarrageenan-treated plants had an astonishing yield response of 769%. Although the yield response decreased by 35 DAT, compared with the control treatment, the 240-ppm treatment resulted in a substantial increase of 153.90%.

3.9. Total soluble solids

The total soluble solids (TSS) content of pechay juice was significantly influenced by the interaction between the water condition and oligocarrageenan concentration at 25 DAT and 35 DAT (Table 9). The variation in TSS at 25 DAT was evident only under flooding stress, where the highest TSS value (6 °Brix) was recorded in the untreated control, while oligocarrageenan-treated plants exhibited lower TSS. In contrast, under well-watered conditions, TSS remained uniform at 3 °Brix across oligocarrageenan concentrations. At 35 DAT, under well-watered conditions, the lowest TSS (2.8 °Brix) was recorded in the control. In contrast, compared with the untreated control, the 60 ppm oligocarrageenan foliar spray increased the TSS by approximately 2 °Brix. Under flooding stress, however, the untreated plants again produced the greatest amount of TSS (6.2 °Brix).

Table 9

Total soluble solids (TSS) of pechay extracts in response to oligocarrageenan foliar spray under well-watered and postflooding conditions

Factor	TSS (°Brix)	
	25 DAT	35 DAT
Water condition (WC)		
Well-watered (WW)	3.00 ^b	3.50 ^b
Flooding stress (FS)	5.08 ^a	5.52 ^a
Oligocarrageenan concentration (OCC)		
0 ppm	4.50 ^a	4.50 ^b
60 ppm	4.16 ^b	5.16 ^a
120 ppm	3.50 ^d	3.90 ^c
240 ppm	4.00 ^c	4.46 ^b
WC x OCC		
WW x 0 ppm	3.00 ^a	2.80 ^c
WW x 60 ppm	3.00 ^a	4.80 ^a
WW x 120 ppm	3.00 ^a	3.00 ^c
WW x 240 ppm	3.00 ^a	3.40 ^b
FS x 0 ppm	6.00 ^a	6.20 ^a
FS x 60 ppm	5.33 ^b	5.53 ^b
FS x 120 ppm	4.00 ^d	4.80 ^c
FS x 240 ppm	5.00 ^c	5.53 ^b
<i>p</i> value		
WC	0.0000 ^{**}	0.0000 ^{**}
OCC	0.0000 ^{**}	0.0000 ^{**}
WC x OCC	0.0000 ^{**}	0.0000 ^{**}
cv (%)	1.00	3.18

Factor	TSS (°Brix)	
	25 DAT	35 DAT
Means within a column followed by the same letter are not significantly different according to Tukey's Honest Significant Difference (HSD) test at the 0.05 probability level.		

Regardless of the oligocarrageenan concentration, the water condition influenced the TSS of the pechay extracts (Table 9). Under well-watered conditions, the TSS values were relatively low, registering 3 °Brix at 25 DAT and 3.5 °Brix at 35 DAT. In contrast, plants subjected to flooding stress consistently accumulated more TSS, with 2 °Brix higher than their well-watered counterparts at both harvest rounds.

Regardless of the water condition, the oligocarrageenan concentration influenced the TSS of pechay. At 25 DAT, the extracts of the control plants had the highest TSS (4.5 °Brix), whereas at 35 DAT, the highest TSS (5.16 °Brix) was attained with 60 ppm oligocarrageenan (Table 9).

4. Discussion

During the past year, the Philippines experienced several flood events because of typhoons and scandalous inadequate flood control infrastructure. Flooding events can occur anytime, threatening the livelihoods of smallholder vegetable growers. Unlike most vegetable crops, pechay can survive under short-term flooding (Vega et al. 2025). When plants are submerged in water, their photosynthetic efficiency decreases as chloroplast function is inhibited, and the closure of stomata restricts gas exchange, thereby impairing carbohydrate assimilation and cell division and culminating in stunted growth, yield reduction and plant mortality (Mielke and Schaffer 2010; Haque et al. 2011; Martinez-Alcantara et al. 2012; Aslam et al. 2023; Gabriel-Galban, 2025). Thus, adaptive strategies that not only sustain survival but also restore growth and productivity in vegetable crops after flooding stress are essential. One promising strategy is the application of biostimulants. Biostimulants are becoming popular, as these substances are eco-friendly and less expensive alternatives to synthetic fertilizers and pesticides. Biostimulants are known to increase plant resilience under climate-induced stress (Mandal et al. 2023; Arinaitwe et al. 2025). Among the biostimulants, carrageenan-derived oligocarrageenan from seaweed extracts stimulates plant growth and confers tolerance to abiotic stresses such as drought (Franzoni et al. 2022). Reports on the effects of oligocarrageenan as a curative treatment on the growth and yield of pechay plants after flooding stress are lacking. Hence, this study was conducted.

The high survival rates associated with pechay postflooding stress affirm the tolerance of crops to short-term flooding stress through morphological, physiological, and biochemical adjustments (Fukao et al. 2019; Manghwar et al. 2024; Vega et al. 2025). One visible morphological coping mechanism of plants under submergence stress is stem elongation, which functions as an escape strategy to restore contact with the aerial environment (Jackson 2008). These findings elucidate that compared with plants receiving the optimum amount of water, submerged plants appeared taller and more vigorous one day post-flooding. However, when the water was drained after three days of submergence, plants previously

submerged in water wilted, probably because of massive efflux of water. Moreover, anoxia during submergence alters respiration and carbohydrate metabolism, resulting in energy deficits that become evident once metabolic demand resumes after aerobic conditions (Mielke and Schaffer 2010).

The flooded plants in this study ultimately survived, and their survival rates remained comparable to those of well-watered plants. However, the growth performance of the surviving plants was inferior to that of the plants under well-watered conditions. Foliar spraying of oligocarrageenan reversed this situation, promoting elongation after treatment postflooding. Under flooding stress, plant height increased in a concentration-dependent manner, with 240 ppm resulting in a nearly twofold increase compared with that of the untreated plants. These results highlight the role of oligocarrageenan in promoting resilience under stress. Even under well-watered conditions, oligocarrageenan treatment increased the height of pechay plants, highlighting the growth-promoting effects of oligocarrageenan under nonstress conditions. These findings suggest that oligocarrageenan plausibly enhanced cell expansion and modulated the expression of genes involved in hormone signaling, such as those involved in gibberellin and auxin signaling (Contreras et al. 2026), thereby alleviating stress-induced stem elongation. Height measurements in this study commenced three days post-submergence, when the detrimental effects on plant morphology were already evident; thus, only post-stress recovery rather than immediate stress responses was captured. Nonetheless, oligocarrageenan improved the plant height across water conditions, with 240 ppm being the most effective concentration for poststress recovery.

In practical assessments, compared with plant height, leaf dynamics are more important in leafy vegetables such as pechay. Our results revealed that flooding stress caused a reduction of 1–4 leaves across growth stages in pechay. In addition to the effects of anoxia on assimilate allocation (Renziehausen et al. 2025), submergence stress caused mortality of initial leaf counts at 14 DAT (three days post-submergence). Interestingly, submerged pechay plants produced new leaves during recovery, suggesting a tolerance of meristematic activity, resulting in increased plant survival under stress. The production of new leaves postsubmergence was further enhanced by oligocarrageenan foliar spray at 240 ppm. The stimulatory effects of oligocarrageenan on the growth hormone synthesis needed during the stress recovery period (Castro et al. 2011; Laporte et al. 2025) probably occurred as well during this experiment.

Compared with the well-watered controls, the flooding treatment not only reduced the leaf counts but also reduced the degree of leaf expansion threefold. Regardless of the water condition, the 240 ppm oligocarrageenan foliar spray resulted in the greatest increase in leaf width, complementing the increase in leaf number and collectively strengthening canopy development under both stress and non-stress conditions (Abad et al. 2018). Wide leaves improve light interception and photosynthetic efficiency (Lusk et al. 2019; Murchie and Burgess 2022), which are critical for biomass accumulation and yield recovery.

The economic parts of pechay are the shoots. However, root elongation provides critical insights into below-ground adaptation. In this study, short-term flooding caused a significant reduction in root length. An oligocarrageenan foliar spray at 240 ppm resulted in submerged plants producing the longest roots

during harvest. Under well-watered conditions, however, 60 ppm was the most effective concentration, suggesting concentration-dependent responses. These results imply that oligocarrageenan stimulates root elongation, which is an essential trait that increases nutrient acquisition and tolerance under stress (Mandal et al. 2023). In practical terms, stronger root systems confer better anchorage, improved nutrient uptake, and greater tolerance to subsequent stresses such as drought or nutrient deficiency (Liu et al. 2023; Karla et al. 2024). Under submergence stress, root elongation is generally not considered an adaptive mechanism, as roots are typically stunted because of oxygen deprivation. The results of this study are therefore noteworthy, as post-submergence plants treated with 240 ppm oligocarrageenan developed longer roots than did the untreated controls did. This suggests that oligocarrageenan stimulates recovery growth in both above-ground and below-ground organs of pechay previously subjected to submergence stress.

Heavier fresh biomass of pechay implies higher yields and incomes for farmers. In this study, compared with their well-watered counterparts, plants under flooding stress experienced 16-fold and 6-fold decreases at 25 and 35 DAT, respectively. However, compared with the control, oligocarrageenan increased the biomass, particularly at 240 ppm, which resulted in increases of ≥ 17 g per plant. This stimulatory effect suggests improved nutrient assimilation and modulation of stress-responsive pathways (Hossain et al. 2024). Root biomass followed a similar trend, with flooding suppressing accumulation but oligocarrageenan enhancing root weight at later stages. The complementary effects on shoot and root biomass emphasize the ability of oligocarrageenan to increase whole-plant productivity.

The yield response provides insight into the effectiveness of biostimulant application (Li et al. 2022). Oligocarrageenan caused a positive yield response of pechay under both water conditions. However, under flooding stress, the yield response was extraordinary, particularly at 240 ppm. At 25 DAT, compared with the control plants, the 240 ppm oligocarrageenan-treated plants experienced a 769% increase. Although the magnitude of the response decreased by 35 DAT, the 240-ppm treatment resulted in a substantial increase of 153.90%. For farmers, these results are highly significant. Greater yield response under stress conditions directly translates into economic resilience, ensuring that production remains profitable even in flood-prone environments. This means that the application of oligocarrageenan is a practical tool for safeguarding yields against unpredictable flooding events (Arinaitwe et al. 2025).

Finally, quality attributes measured as total soluble solids (TSS) revealed complex metabolic responses. The TSS content is higher in fruits under water-limiting conditions (Bai et al. 2023). Currently, there is no literature reporting that submergence stress can increase TSS levels. In this study, however, flooding resulted in higher TSS values. This result could be due to concentration effects from reduced biomass or altered carbohydrate metabolism (Osorio et al. 2014; Barbosa et al. 2023) under anoxic conditions. Oligocarrageenan moderated these imbalances, probably enhancing carbohydrate accumulation under nonstress conditions while reducing stress-induced excesses. The most favorable TSS response was observed at 60 ppm, suggesting that oligocarrageenan can improve juice quality under favorable

conditions while stabilizing metabolic responses under stress. For farmers and consumers, improved TSS values translate into better pechay taste and nutritional quality. This adds value to the crop, making it more competitive in local markets. By moderating stress-induced imbalances, oligocarrageenan ensures that quality is maintained even under adverse conditions, thereby supporting both farmer profitability and consumer satisfaction.

5. Conclusion and recommendation

This study demonstrates that while pechay is inherently resilient to short-term flooding, its growth, yield, and quality are significantly compromised without intervention. Foliar application of oligocarrageenan effectively mitigated submergence-induced damage, enhanced vegetative growth, increased root length, and increased biomass accumulation and yield. The most pronounced effects were consistently observed at 240 ppm, whereas the 60 ppm concentration resulted in an increase in total soluble solids.

For practical application, oligocarrageenan foliar spray should be integrated into production systems for vegetable farmers in flood-prone areas, particularly at concentrations of approximately 240 ppm, for growth and yield recovery.

Declarations

6. Acknowledgment

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7. Author Contributions

Mary Grace Ravidas conducted the study, data collection, data analysis, and interpretation of the results. She prepared all the tables and figures and drafted the manuscript.

Vences C. Valleser supervised the implementation of the research, edited the manuscript draft, and approved the final draft.

8. Conflict of Interest

The authors declare that there are no conflicts of interest in this work.

9. Funding

This study received no external funding.

10. Data availability

Available with restricted access:

The data that support the findings of this study are available from the Department of Horticulture, College of Agriculture, Central Mindanao University, Philippines, but restrictions apply to the availability of these data, which were used under licence for the current study and so are not publicly available. The data are, however, available upon request and with the permission of the Department of Horticulture, College of Agriculture, Central Mindanao University.

11. Competing Interests

The author declares that there are no competing interests.

12. Clinical Trial Number

Not applicable.

13. Dual Publication

The authors confirm that this manuscript has not been published elsewhere and is not under consideration by another journal.

14. Declarations

Ethical Approval

The plant materials used in this study were grown from commercially available seeds (East-West Seed Philippines) purchased from the AVC Agricultural Supply, Valencia City, Bukidnon, Philippines. No wild or protected plant species were collected. The use of plant materials complied with relevant institutional, national, and international guidelines and legislation for the use of plant resources. As the materials were commercially sourced and not collected from natural habitats or protected areas, no specific permits or ethical approval was needed.

Permissions to collect the plants/plant parts

This is not applicable in this study. The 'Pavito' pechay seeds used in the experiments are commercially available from the East–West Seed Philippines and were purchased from the lead author at the AVC Agricultural Supply, Valencia City, Bukidnon, Philippines.

Consent to Participate

This is not applicable in this study. The 'Pavito' pechay seeds used in the experiments are commercially available from the East–West Seed Philippines and were purchased from the lead author at the AVC Agricultural Supply, Valencia City, Bukidnon, Philippines.

Consent to Publish

The authors have read and approved the manuscript and consent to its publication.

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Figures



Figure 1

Morphological appearance of 20-day-old pechay plants under flooding stress compared with well-watered controls. Surviving plants under flooding stress maintain viability but exhibited reduced vigor relative to well-watered counterparts



Figure 2

Growth performance of 25-day-old transplanted pechay under varying oligocarrageenan concentrations (0, 60, 120, 240 ppm) applied in well-watered and postflooding conditions (flood-stressed plants highlighted in yellow box).

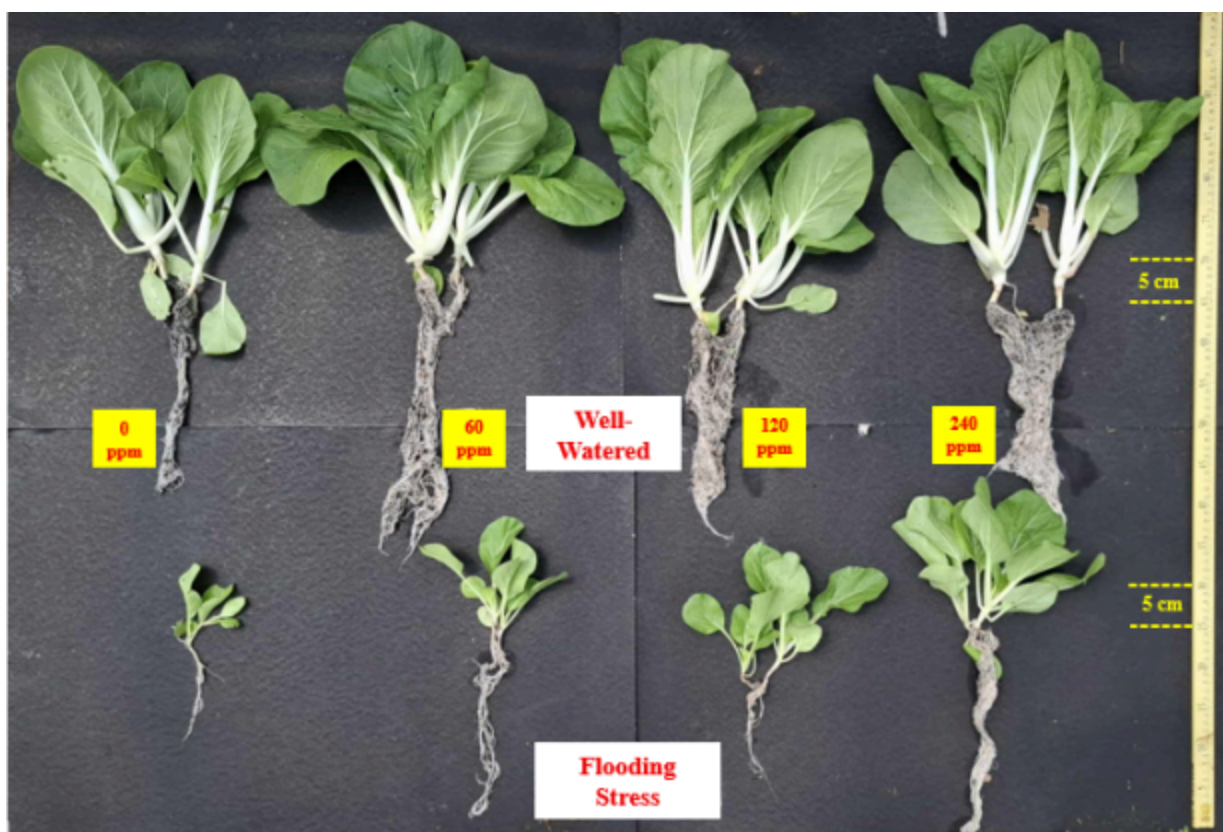


Figure 3

Pechay plants at 25 DAT in response to varying concentrations of oligocarrageenan under well-watered and flooding stress

