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Effect of Cold Plasma Treatment on Cabbage Seed Germination and Early Development

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Abstract. This study investigated the effect of cold plasma treatment on the germination and early growth of three cabbage (*Brassica oleracea*) varieties (Kalibr-1, Kalibr-2, and Kalibr-3). Seeds were treated with plasma generated at 15 kV, and the exposure duration was controlled by the speed of a rotating belt (P-20, P-30, P-60, P-70, and P-90 which corresponds 3.06, 2.11, 1.04, 0.90 and 0.73 seconds of exposure). Untreated seeds served as the control. Germination performance was evaluated on days 1 and 5, while shoot and root lengths were measured on day 5. The results showed that plasma treatment significantly enhanced seed germination efficiency. The highest effects were observed in the P-30 and P-60 treatments. In particular, in the Kalibr-3 variety, P-30 achieved 100% germination by day 5, while in Kalibr-2 and Kalibr-1, P-60 resulted in 96.7% germination. Plasma treatment also positively influenced morphological parameters, with root length reaching the highest values in Kalibr-2 (5.6 ± 0.9 cm) and Kalibr-3 (6.0 ± 0.7 cm) under the P-60 treatment. However, in some cases (e.g., Kalibr-1 at P-30), a reduction in root length was observed, indicating that excessive plasma exposure may have negative effects. Overall, cold plasma acted as an environmentally friendly biostimulant that improved seed germination and early development.

Keywords: Cold atmospheric plasma; seed germination; germination percentage; shoot length; root length; cabbage varieties (*Brassica oleracea*); plasma exposure times.

I. INTRODUCTION

The global demand for food production is steadily increasing due to population growth and changing dietary patterns [1, 2]. To meet this demand, farmers frequently rely on chemical fertilizers and pesticides [3]. However, excessive use of these agrochemicals has led to serious environmental concerns, including soil degradation, water pollution, and accumulation of harmful residues in crops [4, 5]. These residues not only reduce soil fertility but also pose significant health risks to consumers worldwide. Therefore, there is an urgent need to introduce sustainable and environmentally friendly technologies into modern agriculture.

One promising alternative is cold atmospheric plasma (CAP), which has recently attracted growing attention for its potential applications in agriculture [6, 7]. CAP is the fourth state of matter, generated under high voltage between two electrodes at atmospheric pressure [8]. When seeds are exposed to CAP, numerous beneficial effects have been reported, including surface sterilization, increased water uptake, enhanced germination rates, and stimulation of early growth processes [9, 10]. Moreover, CAP treatment can contribute to reduced water consumption and earlier harvesting of crops. At the physiological level, CAP-irradiated seeds have been shown to upregulate antioxidant enzymes such as catalase, superoxide dismutase, and peroxidase [11, 12], which enhances their resistance against pathogens and abiotic stresses [13, 14]. However, the effectiveness of plasma treatment varies depending on the seed type, device configuration, and exposure duration.

Recent studies also reported that cold plasma pretreatment effectively mitigated the adverse effects of drought stress in rapeseed (*Brassica napus* L.). Plasma-treated seeds showed improved germination, growth, and yield performance under water-limited conditions by enhancing antioxidant enzyme activity and osmotic adjustment [15]. Similarly, DBD plasma treatment of radish (*Raphanus sativus*) seeds using argon gas was found to significantly improve germination percentage, seedling vigor, fresh and dry weight, and carotenoid contents; the positive effects were most evident after 2–3 minutes of treatment owing to accelerated water uptake and increased hydrophilicity of the seed coat [16]. In this context, optimizing plasma treatment parameters for specific crops is of high practical importance. Therefore, the present study aims to investigate the effect of CAP

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treatment on seed germination and early growth of three cabbage (*Brassica oleracea*) varieties, with particular emphasis on determining the favorable exposure conditions.

II. MATERIALS AND METHODS

Seeds of three cabbage (*Brassica oleracea*) varieties—Kalibr-1, Kalibr-2, and Kalibr-3—were selected. The seeds were tested under six plasma treatment variants: Control (no plasma exposure), P-20, P-30, P-60, P-70, and P-90. The numbers in the treatment variants correspond to the rotation speed of the conveyor belt (m/min), which directly determines the plasma exposure time: the higher the speed, the shorter the exposure.

Plasma was generated at 15 kV in an open-type, two-electrode generator operating at atmospheric pressure. The gap between electrodes was 10 mm, and a belt 5 mm in thickness passed between them. The belt speed was adjusted according to the experimental variants, resulting in exposure times ranging from 0.73 s (90 m/min) to 3.06 s (20 m/min) (Table I).

TABLE I: Conveyor belt speed and corresponding plasma exposure time applied to seeds.

Groups	Control	P-20	P-30	P-60	P-70	P-90
Speed, m/min	0	20	30	60	70	90
Time, s	0	3.06	2.11	1.04	0.90	0.73

After plasma treatment, 30 seeds from each variant were placed into Petri dishes and supplied with 5 mL of distilled water. The dishes were kept closed at room temperature. Germination was evaluated 1 and 5 days after treatment by counting the number of germinated seeds and calculating germination percentage. On day 5, five seedlings were randomly selected from each Petri dish, and shoot and root lengths were measured.

III. RESULTS

Plasma treatment had a significant effect on the germination speed, overall germination percentage, and morphological development parameters of cabbage seeds.

In the Kalibr-1 variety, on day 1 the highest germination percentages were observed in P-60 (90%) and P-70 (83.3%), considerably higher than the control (56.7%). By day 5, P-60 reached 96.7%, showing the maximum efficiency (Table II). These changes are visible in Figure 1.

TABLE II: Germination performance of Kalibr-1 seeds at days 1 and 5.

Groups	Control	P-20	P-30	P-60	P-70	P-90
Germinated seeds on day 1	17	12	18	27	25	18
Germination percentage on day 1 (%)	56.7	40.0	60.0	90.0	83.3	60.0
Germinated seeds on day 5	18	19	26	29	25	23
Germination percentage on day 5 (%)	60.0	63.3	86.7	96.7	83.3	76.7

In the Kalibr-2 variety, on day 1 the highest percentages were recorded in P-90 (80%) and P-70 (76.7%). By day 5, P-60 reached 96.7%, while the control reached only 66.7% (Table III). As shown in Figure 2, the P-60 treatment ensured faster germination and stronger seedling development.

TABLE III: Germination performance of Kalibr-2 seeds at days 1 and 5.

Groups	Control	P-20	P-30	P-60	P-70	P-90
Germinated seeds on day 1	8	18	20	18	23	24
Germination percentage on day 1 (%)	26.7	60.0	66.7	60.0	76.7	80.0
Germinated seeds on day 5	20	21	22	29	20	26
Germination percentage on day 5 (%)	66.7	70.0	73.3	96.7	66.7	86.7

In the Kalibr-3 variety, P-30 and P-60 achieved 93.3% germination on day 1, nearly twice the control (50%). By day 5, P-30 showed 100% germination (Table IV). This result is clearly visible in Figure 3, where almost all seeds germinated under the P-30 and P-60 treatments.

TABLE IV: Germination performance of Kalibr-3 seeds at days 1 and 5.

Groups	Control	P-20	P-30	P-60	P-70	P-90
Germinated seeds on day 1	15	15	28	28	21	22
Germination percentage on day 1 (%)	50.0	50.0	93.3	93.3	70.0	73.3
Germinated seeds on day 5	23	22	30	28	24	24
Germination percentage on day 5 (%)	76.7	73.3	100.0	93.3	80.0	80.0

Shoot length increased with plasma treatment in all varieties: Kalibr-1 had the highest value in P-70 (3.7 ± 0.7 cm); Kalibr-2 showed higher values in P-30 and P-70 (3.2–3.4 cm); Kalibr-3 was maximal in P-30 (3.5 ± 0.5 cm) (Table V). The differences in root length were even more pronounced: in Kalibr-2 and Kalibr-3, P-60 yielded 5.6 ± 0.9 cm and 6.0 ± 0.7 cm, respectively, clearly exceeding the controls; in Kalibr-1, P-90 (5.2 ± 0.6 cm) slightly exceeded the control (Table VI). See Figures 4–6.

TABLE V: Shoot length of cabbage varieties (cm, mean $\pm$ SD).

Groups	Control	P-20	P-30	P-60	P-70	P-90
Kalibr-1	2.8 ± 0.9	3.4 ± 0.8	3.4 ± 0.7	3.3 ± 0.6	3.7 ± 0.7	3.2 ± 0.6
Kalibr-2	2.8 ± 0.7	2.9 ± 0.7	3.2 ± 0.3	3.2 ± 0.4	3.4 ± 0.6	3.4 ± 0.7
Kalibr-3	2.7 ± 0.4	2.9 ± 0.4	3.5 ± 0.5	3.0 ± 0.3	3.2 ± 0.6	3.1 ± 0.6

TABLE VI: Root length of cabbage varieties (cm, mean $\pm$ SD).

Groups	Control	P-20	P-30	P-60	P-70	P-90
Kalibr-1	5.0 ± 0.3	4.9 ± 0.4	3.1 ± 0.4	4.2 ± 0.6	4.2 ± 0.9	5.2 ± 0.6
Kalibr-2	3.3 ± 0.7	5.2 ± 0.5	4.7 ± 0.7	5.6 ± 0.9	3.8 ± 0.7	4.6 ± 0.7
Kalibr-3	4.7 ± 0.8	4.8 ± 0.9	5.0 ± 0.7	6.0 ± 0.7	3.7 ± 0.8	4.7 ± 0.8

IV. DISCUSSION

The results obtained showed that plasma treatment had a significant effect on the percentage of germination and the morphological development of cabbage seeds. In all varieties, short-duration plasma exposure (particularly P-30 and P-60) ensured faster and higher germination. For example, in Kalibr-3, P-30 achieved 100% germination by day 5, while in Kalibr-2 and Kalibr-1, P-60 reached 96.7% (Tables II–IV). These findings indicate that plasma can modify the seed surface, improve water uptake, and accelerate metabolic processes.

Morphological parameters also responded positively: in Kalibr-2 and Kalibr-3, P-60 resulted in root lengths of 5.6 ± 0.9 cm and 6.0 ± 0.7 cm, respectively, significantly higher than controls (Table VI). These results agree with previous reports showing improved germination speed and efficiency after plasma treatment [17] and high germination efficiency using dielectric barrier discharge plasma [18]. Mechanically, increased hydrophilicity of the seed coat promotes faster imbibition [19], while plasma-enhanced ion exchange at the surface facilitates nutrient uptake [20]. Genotype-specific responses can also occur; for example, in our study, the reduction of root length in Kalibr-1 at P-30 likely reflects excessive exposure.

V. CONCLUSION

Cold atmospheric plasma (CAP) treatment effectively improved germination and early growth in three varieties of cabbage. The best performances were recorded in P-30 and P-60, with Kalibr-3 reaching 100% germination by day 5 and Kalibr-1/2 reaching 96.7%. The length of the shoot and root generally increased (Kalibr-2: 5.6 ± 0.9 cm; Kalibr-3: 6.0 ± 0.7 cm under P-60). However, excessive exposure may negatively affect some traits; thus, identifying optimal durations is essential. Further field trials are recommended to assess the yield under real conditions.

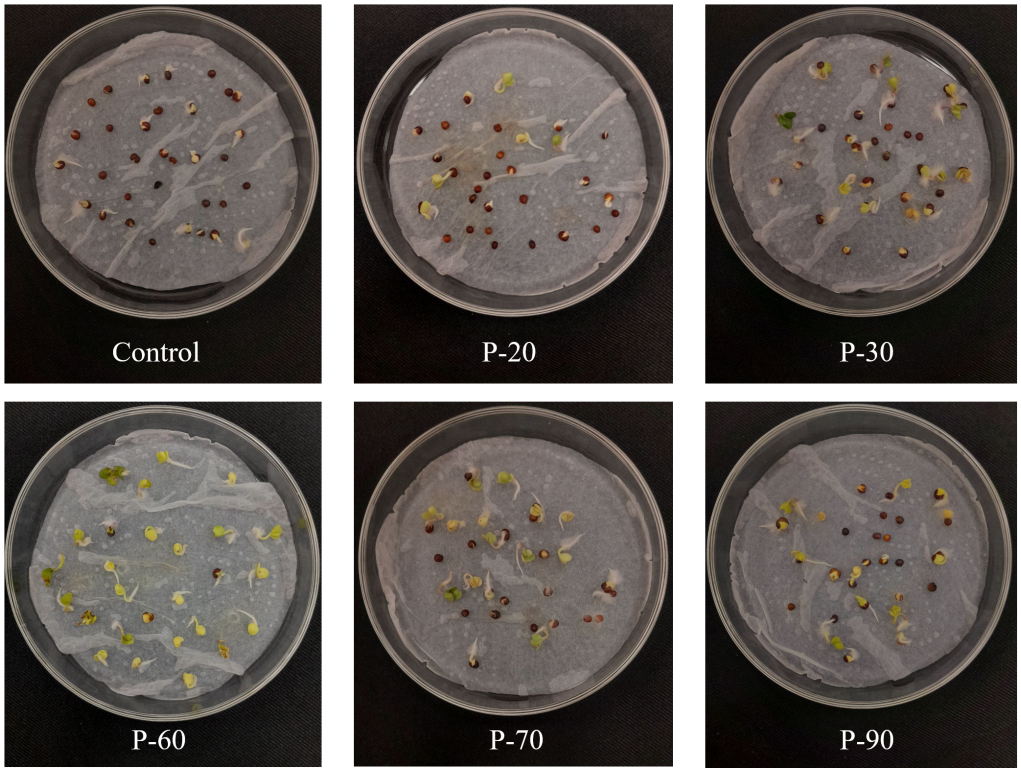


FIG. 1: Appearance of Kalibr-1 seeds after 1 day under control and different plasma treatments.

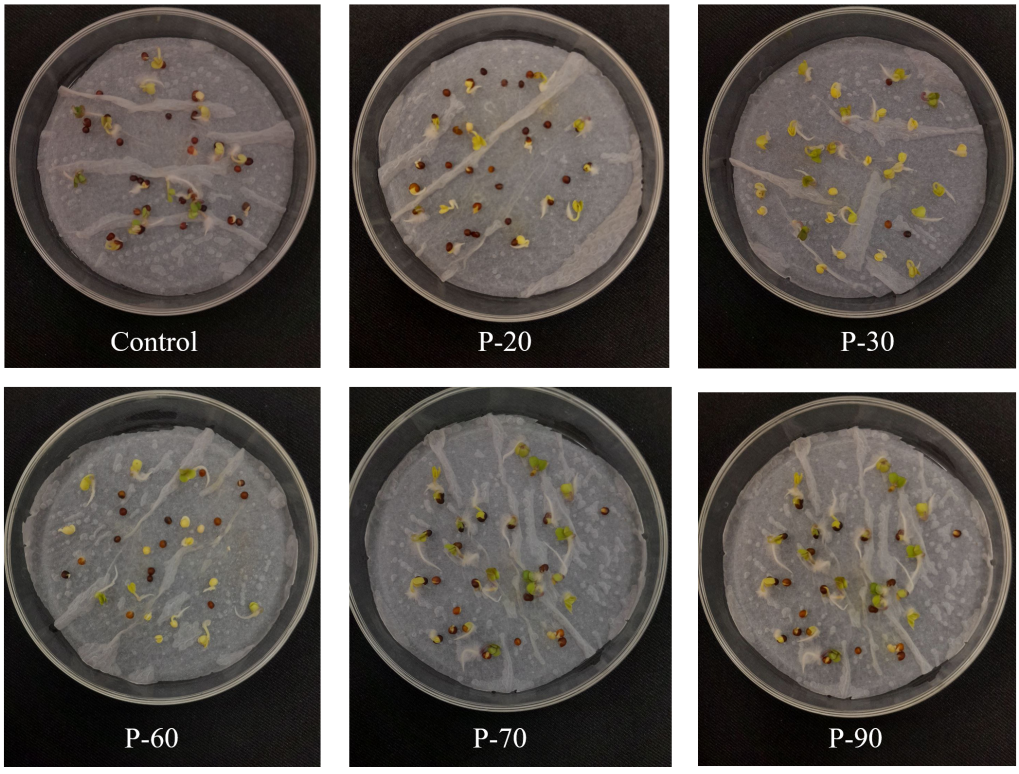


FIG. 2: Appearance of Kalibr-2 seeds after 1 day under control and different plasma treatments.

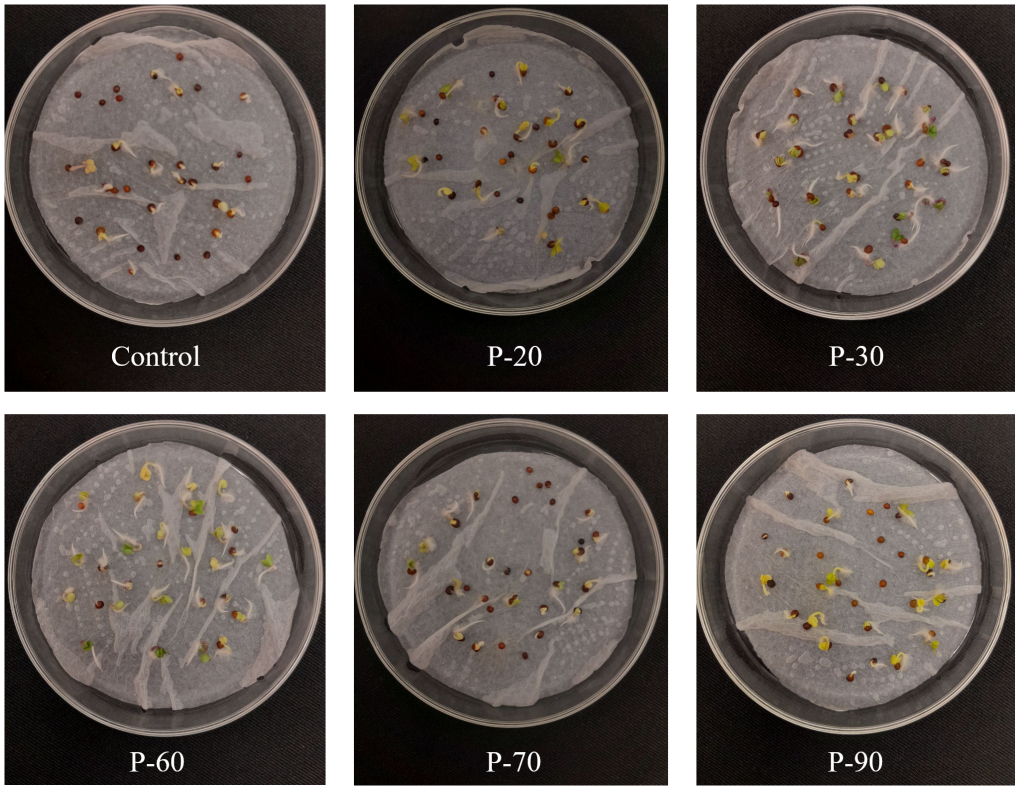


FIG. 3: Appearance of Kalibr-3 seeds after 1 day under control and different plasma treatments.

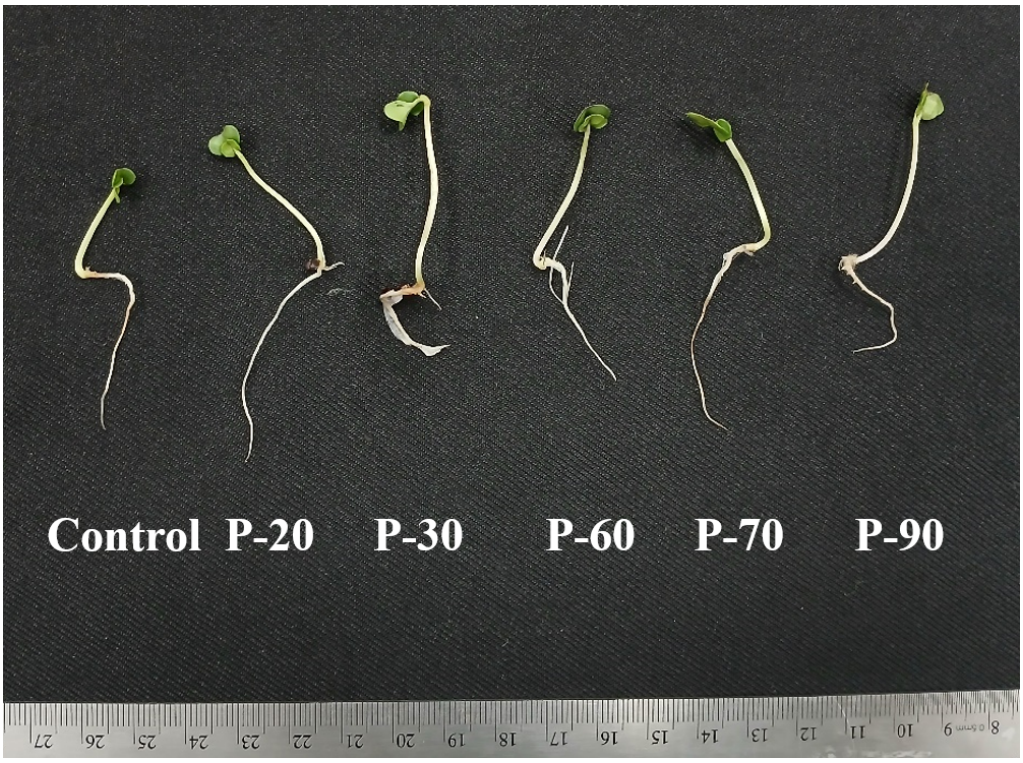


FIG. 4: Shoot and root lengths of seedlings grown from control and plasma-treated seeds of the Kalibr-1 variety.

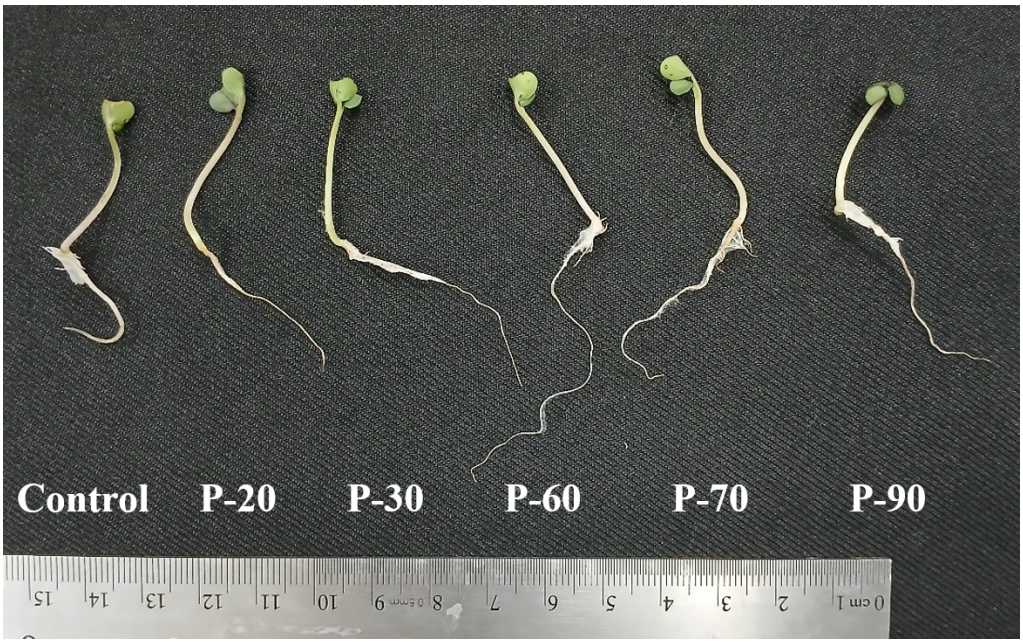


FIG. 5: Shoot and root lengths of seedlings grown from control and plasma-treated seeds of the Kalibr-2 variety.



FIG. 6: Shoot and root lengths of seedlings grown from control and plasma-treated seeds of the Kalibr-3 variety.

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