Content lists available at Publikasi Polije
International Journal of Technology, Food and Agriculture (TEFA)
journal homepage: https://publikasi.polije.ac.id/index.php/tefa

Article

Effect of Specific Energy Input on Cyanide Reduction in Jack Bean (*Canavalia ensiformis L.*) Flour Treated with High Pulsed Electric Field

Maulidva Suci Rahmawati [1], Budi Hariono [2*]

[1] Agricultural Technology, Politeknik Negeri Jember; maulidvasr@gmail.com
[2] Agricultural Technology, Politeknik Negeri Jember; budi_hariono@polije.ac.id

* Correspondence: budi_hariono@polije.ac.id

Abstract: Jack bean (*Canavalia ensiformis L.*) is a potential source of plant-baes protein; however, its utilization is limited by the presence of cyanogenic compounds that release hydrogen cyanide (HCN), which is toxic. Conventional thermal detoxification methods are effective but may cause nutritional degradation and require extended processing time. High Pulsed Electric Field (HPEF) is a non-thermal technology that induces electroporation. Increasing cell membrane permeability and facilitating the release of intracellular compounds without high-temperature treatment. This study aimed to evaluate the effect of HPEF treatment with varying specific energy inputs on HCN content in jack bean flour and to determine the treatment that achieved the highest HCN reduction. Three treatment were applied: control (P1), HPEF at 30 kV/cm with specific energy 1,3 kJ/kg (P2), and HPEF at 10 kV/cm with specific energy 3,5 kJ/kg (P3). HCN content was determined using the steam distillation method. Data were analyzed using one-way ANOVA followed by the Games-Howell pos-hoc test at a 95% confidence level. Results showed that HPEF treatment significantly reduced HCN content compared to the control ($p<0,05$). HCN levels decreased from 146,90 ppm in P1 to 103,30 ppm in P2 and 88,70 ppm in P3. Although P3 applied lower electric field strength than P2, its higher specific energy input resulted in greater HCN reduction, indicating that specific energy input is a more determinative parameter than electric field strength alone in characterizing HPEF treatment intensity. However, all final HCN levels remained substantially above the permissible food safety threshold of 10 ppm, indicating that HPEF at the parameters applied in this study is not yet sufficient as a standalone detoxification method. These finding suggest that HPEF has potential as a non-thermal pretreatment approach for HCN reduction in jack bean flour, with further optimization of specific energy input required to meet food safety standards.

Keywords: jack bean flour; High Pulsed Electric Field; hydrogen cyanide; specific energy input; electroporation

Citation: M. S. Rahmawati and B. Hariono, "Effect of Specific Energy Input on Cyanide Reduction in Jack Bean (Canavalia ensiformis L.) Flour Treated with High Pulsed Electric Field", *TEFA*, vol. 3, no. 2, pp. 142–151, Jun. 2026.

Received: 20-02-2026
Accepted: 28-06-2026
Published: 28-06-2026

Copyright: © 2026 by the authors. Submitted for possible open access publication under the terms and conditions of the Creative Commons Attribution-ShareAlike 4.0 International License (CC BY SA) license (http://creativecommons.org/licenses/by-sa/4.0/).

1. Introduction

Legumes are widely recognized as an important source of plant-based protein and play a strategic role in food diversification and nutritional security. Jack bean (*Canavalia ensiformis L.*), Jack bean is one of the underutilized legumes with production potential reaching 1–4.5 tons of dry seeds per hectare [1]. This species is known by various local names across Indonesia [2]. One approach to utilizing jack bean is processing it into flour, which can serve as an alternative to wheat flour due to its gluten-free nature and potential an protein-rich ingredient [3]. Nutritionally, jack bean contains 23–27.6% protein, 45.2–56.9% carbohydrates, and 2.3–3.9% fat [2]. It also provides essential amino acids such as isoleucine, leucine, histidine, valine, and threonine [4], along with micronutrients including vitamin B1, iron, copper, phosphorus, potassium, and magnesium [5]. Furthermore, phenolic and flavonoid compounds have been identified in jack bean seeds [6], indicating its potential as a functional food ingredient.

Despite its nutritional value, jack bean contains several antinutritional compounds, including concanavalin A, trypsin inhibitors, tannins, phytic acid, cyanogenic compounds, and hydrogen cyanide (HCN) [7]. Cyanogenic glycosides are capable of releasing HCN through enzymatic or non-enzymatic hydrolysis [8], [9]. In intact plant tissues, cyanogenic glycosides are stored in vacuoles, whereas β-glucosidase is localized in the apo plastic space and cell walls in dicotyledonous plants. Hydroxynitrile lyase accumulates mainly in the cytoplasm and plasma membrane. This compartmentalization prevents HCN formation while the tissue remains intact [9].

When plant tissues are disrupted during processing, cyanogenic glycosides come into contact with β-glucosidase, leading to glycosidic bond cleavage and formation of cyanohydrins, which subsequently decompose such as aldehydes or ketones [10]. Hydrogen cyanide is toxic because it binds to trivalent iron in cytochromes oxidase, thereby inhibiting cellular respiration in humans and animals [8]. The permissible level of HCN in food products is reported to be below 10 ppm [11], whereas raw jack bean seeds contain approximately 52,78 mg/kg (52,78 ppm) HCN [12]. Far exceeding the safety threshold and indicating the necessity of processing interventions prior to consumption.

Conventional detoxification methods such as soaking, boiling, and pressure cooking have been widely applied. Khamidah et al. [13] reported that boiling reduced HCN levels by 89,74%, while pressure cooking achieved a 96,62% reduction. Islami et al. [14] found that untreated jack bean flour contained 50,87 mg/kg HCN, and boiling for one hour reduced the level to 29,95 mg/kg. Although these methods are effective, they present several notable limitations. First, thermal treatments may cause degradation of heat-sensitive nutritional component such as protein, vitamins, and bioactive compounds [15]. Second, soaking and boiling require large volumes of water and extended processing times of up to several days, reducing process efficiency [13]. Third, not all conventional methods achieve sufficient HCN reduction to meet food safety standards; for example, roasting without liquid medium was reported to increase rather than decrease HCN levels [14]. These limitations highlight the need for alternative processing technologies that can effectively reduce HCN content while preserving nutritional quality and improving process efficiency.

High Pulsed Electric Field (HPEF) is a non-thermal food processing technology that applies high-voltage electric pulses for very short durations, ranging from microseconds to milliseconds, with the material placed between two electrodes [15]. The primary mechanism of HPEF is electroporation, which refers to the formation of micropores in the cell membrane when the transmembrane potential exceeds a critical threshold of approximately 0,5-1,5 V, causing reorganization of the lipid bilayer structure [16]. Electroporation is classified into two types: reversible electroporation, in which the formed pores reseal after the electric field is remove without permanent damage, and irreversible electroporation, which occurs at higher filed strengths and pulse durations, causing permanent membrane disruption [16].

In addition to electric field strength, treatment intensity in HPEF processing is significantly influences by specific energy input, which refers to the total electrical energy delivered to the material per unit mass during treatment, expressed in kJ/kg [17]. Specific energy is commonly used as a comprehensive indicator of treatment intensity because it reflects the cumulative energy absorbed by the material and accounts for the combines effects of electric field strength, pulse number, pulse duration, and total exposure time [15]. Increased membrane permeability as a result of electroporation facilitates faster mass transfer, allowing intracellular compounds that were previously confined within the cell to diffuse outward through the newly formed pores [17].

This selection of HPEF parameters in this study was based on preliminary experiments conducted prior to the main trial. Electrode distances of 0,5 cm and 1,5 cm were selected because preliminary testing confirmed that effective electrical conduction occurred at distances below 2 cm, while conduction was not achieved at cm or grater

using the available equipment. Based on the formula E=V/d, with a fixed voltage of 15 kV, these electrode distances yielded electric field strengths of 30 kV/cm and 10 kV/cm, respectively. A pulse number of 4,000 was adopted based on the optimal treatment conditions reported by Giancaterino et al. [18], who demonstrated effective cyanogenic compound reduction in cherry kernels at this pulse number. The specific energy inputs calculated for these treatments were 1,3 kJ/kg at 30 kV/cm and 3,5 kJ/kg at 10 kV/cm, with the difference attributed to the longer total exposure time required to reach 4,000 pulses at the wider electrode distance.

Giancaterino et al. [18] demonstrated that HPEF treatment as a pretreatment step, followed by waterless incubation, significantly improves the efficiency of cyanogenic compound reduction in cherry kernels. With higher specific energy input resulting in greater HCN reduction. However, to the best of our knowledge, no study has specifically investigated the application of HPEF combined with specific energy as the primary treatment intensity parameter for reducing HCN content in jack bean (*Canavalia ensiformis L.*) flour. Previous studied on jack bean detoxification have focused primarily on conventional thermal and soaking methods, without exploring non-thermal approaches that could preserve nutritional quality. This study therefore addresses a clear research gap by evaluating HPEF as a non-thermal alternative for HCN reduction in jack bean flour, with a specific focus on the role of specific energy input in determining treatment effectiveness.

Therefore, this study aims to evaluate the effect of HPEF treatment with varying specific energy inputs on hydrogen cyanide content in jack bean flour and to determine the treatment conditions that result in the highest HCN reduction.

2. Materials and Methods

*2.1. **Raw** Material Preparation*

Jack bean (*Canavalia ensiformis L.*) was obtained from a plantation located at Masjid Agung Central Java, Semarang, Indonesia. The beans were sorted to remove damaged, pest-infested, or moldy seeds, then washed under running water to eliminate surface contaminants. The cleaned beans were soaked in water at a ratio of 1:4 (w/v), where 200 g of jack beans were immersed in 800 mL of water at 25°C for 1 hour. The soaking process was conducted to increase the water content of the beans and to raise electrical conductivity of material, which is necessary to optimize the effectiveness of the HPEF treatment [18]. After soaking, jack bean coats were manually removed, and the samples were drained and divided into three treatment groups.

2.2. High Pulsed Electric Field Treatment

The peeled jack beans (200 g) were placed in the HPEF treatment chamber filled with water, with a total sample mass of 834 g. The sample was subjected to a laboratory-scale batch HPEF system equipped with a pulse generator module (ZK-PP1K, frequency range 0-150 kHz) and a high-voltage transformer (maximum ± 15 kV). Pulse waveforms were monitored using a digital oscilloscope (GW Instek GDS-2204A) with a high-voltage probe (DC 0-40 kV, AC 0-28 kV, ratio 1000:1).

The variable parameter was electrode distance, which determined the electric field strength applied to the sample. The pulse width for each treatment was measured directly form the oscilloscope 9.094μ at an P2 and 24.33 at and P3. Treatment parameters are summarized in Table 1.

Table 1. Parameters used in this experiment

Treat-ment	Elec-trode distan-ce (cm)	Electric field strength (kV/cm)	W Spe-cific (kJ/kg)	Frequency (Hz)	Vol-tage (V)	Current (A)	Total Exposu-re Time (s)
P1 (Control)	-	-	-	-	-	-	-
P2	0,5	30	1,3	1	15.000	2	197
P3	1,5	10	3,5	1	15.000	2	

The HPEF parameters were calculated to determine the electric field strength and specific energy applied during treatment. These parameters were used as the basic for treatment determination and data interpretation.
The electric field strength was calculated using the following equation [20] :

$$E = \frac{V}{d}$$

Where:
E= electric field strength (kV/cm)
V= applied voltage (V)
d= electrode distance (cm)

based in this calculation, an electrode distance of 0,5 cm yielded an electric field strength of 30 kV/cm, while a distance of 1,5 cm yielded 10 kV/cm.
Specific energy input (kJ/kg) was calculated based on the pulse energy (Wpulse) according to the following equation [18]:

$$Wpulse = U \times I \times \tau$$

Where:
U = Voltage (V)
I = current
τ = pulse width (s)

$$Wspecific = \frac{n \times Wpulse}{m}$$

Where:
n = number of pulse (-)
m = total mass of product in the treatment chamber (kg)

The total HPEF exposure time for each treatment was determined based on the number of pulses and pulse width obtained from oscilloscope measurements. Since both treatments used the same number of pulses (4,000) but different electrode distances, the resulting pulse widths differed between treatments. Specifically, P2 with an electrode distance of 1,5 cm required 401 seconds to reach 4,000 pulses. This difference in exposure time resulted in different specific energy inputs: 1,3 kJ/kg for P2 and 3,5 kJ/kg for P3, despite the lower electric field strength applied in P3. The control treatment (P1) received no HPEF treatment.

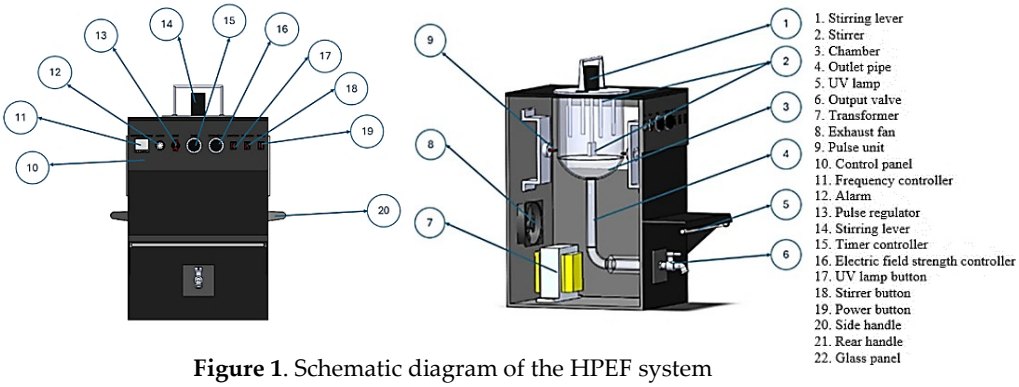


Figure 1. Schematic diagram of the HPEF system

2.3. Incubation Process After HPEF treatment

After HPEF treatment, the jack beans were immediately drained and tightly wrapped in aluminum foil. The wrapped samples were then placed in an incubator set at 40 C and 50% relative humidity for 12 hours.

The incubation conditions were selected based on the following scientific rationale. The temperature of 40 C was chosen to maintain, optimal enzymatic activity of β-glucosidase, which is responsible for hydrolyzing cyanogenic glycosides into cyanohydrins and subsequently HCN. This temperature range has been reported to support enzymatic hydrolysis activity without causing thermal inactivation of the enzyme [18]. The relative humidity of 50% was maintained to provide sufficient moisture for enzymatic reactions to proceed without the addition of water as a liquid medium, thereby preventing the dissolution and loss of water-soluble nutritional components such as proteins and minerals. The waterless incubation approach was adopted to allow HCN formed during hydrolysis to volatilize and diffuse out of the material matrix, as demonstrated by Giancaterino et al. [18]. Who reported that HPEF pretreatment followed by waterless incubation effectively accelerated cyanogenic compound reduction in cherry kernels. The duration of 12 hours was selected based on the same reference, which indicated that this incubation period was sufficient to achieve significant HCN reduction after HPEF pretreatment.

2.4. Freeze Drying Process

After incubation, the jack beans were placed in plastic bags and frozen at −80 °C for 18 hours. The frozen samples were then subjected to freeze drying (Christ Alpha 3-4 LSC basic, condenser temperature -105°C) for 72 hours at 0.5 mbar pressure, or until moisture content reached <10%. Freeze drying operates based on sublimation, in which ice is directly converted into vapor without passing trough the liquid phase, thereby preserving the structural and nutritional integrity of the sample [19].

2.5. Sample Preparation

The freeze-dried samples were removed and placed in a desiccator containing silica gel for 30 minutes to gradually equilibrate to room temperature and prevent moisture reabsorption. The samples were then ground using a grinder at 15,000–30,000 rpm in small batches of approximately 50 g per batch to prevent overheating. Which could cause HCN volatilization and alteration of sample characteristic. The resulting flour was sieved using an 80mesh sieve (opening size < 1mm) to obtain a uniform pasticle size. The jack bean flour was stored in sealed plastic bags prior to analysis.

2.6. Determination of Hydrogen Cyanide (HCN) Content

HCN analysis was performed according to AOAC (2005) [20] using the steam distillation method. A total of 20 g of finely ground sample was weighed and mixed with 100 mL of distilled water in an Erlenmeyer flask and allowed to stand for 2 hours.

Subsequently, an additional 10 ml of distilled water was added and steam distillation was performed. The distillate was collected in an Erlenmeyer flask containing 20 mL of 0.02 N $AgNO_3$ and 1 mL HNO_3. Distillation was continued until 150 mL of distillate was collected. The distillate was filtered using a Gooch crucible, and any precipitate formed was washed with running water. Excess $AgNO_3$ in the distillate was titrated using potassium thiocyanate (KSCN) with ferric indicator until a red color was obtained.

The equivalency factor used was: 1 mL $AgNO_3$ = 0.54 mg HCN

The cyanide content was calculated using the following formula:

$$HCN\ (ppm) = \frac{(mL\ titration\ (blank - sampel)}{(mL\ blank\ titration)} \times 20 \times \frac{N.AgNO_3}{0{,}02} \times 0.54 \times 50$$

2.7. Statistical Analysis

All experiments were conducted in duplicate(n=2). Data were expressed as mean ± standard deviation. It is acknowledged that the use of duplicate measurements represents a limitation of this study in terms of statistical power; however, this was due to the constraints of the available HPEF equipment and the complexity of the experimental procedure. Statistical analysis was performed using one-way analysis of variance (ANOVA) prior to ANOVA, the assumptions of fata normality and variance homogeneity were tested. When the ANOVA result was significant and variance homogeneity was met, Tukey post hoc test was applied to determine significant differences between treatments. When variance homogeneity was not met, the Games-Howell post hoc test was used an alternative that does not require homogeneity of variance. Differences were considered statistically significant at p<0,05.

3. Results and Discussion

3.1. Subsection

HCN content analysis was conducted using a steam distillation method followed by titration, and the HCN values were expressed in ppm (mg/kg). The results of HCN analysis in jack bean flour after HPEF treatment are presented in Table 2 and figure 2.

Table 2. Results of analysis of HCN content of jack bean flour

Treatment	HCN (ppm)
P1 (Control)	146.90±0.01^{c}
P2 (30 kV/cm)	103.30±0.05^{b}
P3 (10 kV/cm)	88.70±0.06^{a}

Description: Different superscript letters indicate significant differences between treatment 9p<0,05). P1 (control), P2 (electric field strength 30 kV/cm), P3 (electric field strength 10 kV/cm)
Source: Primary Data (2026)

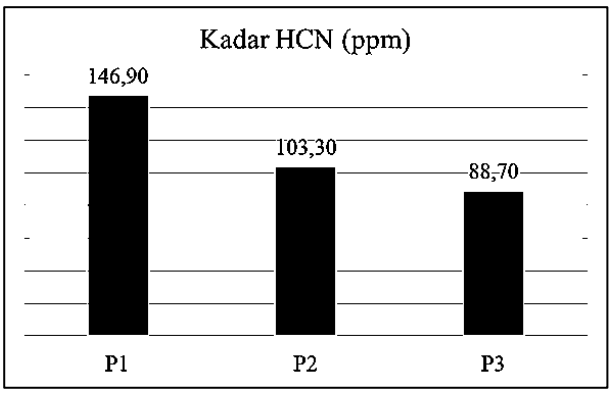


Figure 2. Bar Chart of HCN content analysis
Source: Primary Data (2026)

Based on the results shown in Table 2 and Figure 2, one-way ANOVA showed that HPEF treatment had a significant effect on HCN content (P<0,05). The Games-Howell post hoc-test confirmed that all treatments were significantly different from each other (p<0,05). The highest HCN content was observed in P1 (control) at 146,90 ±0.01 ppm, while the lowest was obtained in P3 at 88,70±0.06 ppm. HCN reduction of 29,69% and 39,60% were achieved in P2 and P3, respectively, compared to the control.

Despite these reductions, it is important to note that the HCN levels in all treatments, including P3 (88,70 ppm), remained substantially above the permissible food safety threshold of 10 ppm [11]. This indicates that while HPEF treatment at the parameters applied in this study was effective in reducing HCN content, further optimization of treatment parameters-particularly specific energy input-is required to achieve HCN levels that meet food safety standards for direct consumption.

3.2. Role of Specific Energy Input in HCN Reduction

A key observation in this study is that P3, which had a lower electric field strength (10 kV/cm) than P2 (30 kV/cm), achieved greater HCN reduction. This result can be explained by differences in specific energy input between the two treatments. As shown in Table 1, P3 had a higher specific energy input of 3,5 kJ/kg compared to P2 at 1,3 kJ/kg. the higher specific energy in P3 was due to the longer total exposure time required to reach 4.000 pulses at the wider electrode distance (P3 vs P2), as pulse width increases with electrode distance.

Specific energy input is recognized as a comprehensive indicator of HPEF treatment intensity because it reflects the cumulative electrical energy absorbed by the material, accounting for the combined effect of electric field strength, pulse width, pulse number, and total exposure time [17]. S. Töpfl [21] reported that higher specific energy input leads to more intensive electroporation of the cell membrane, resulting in greater membrane permeability and more effective release of intracellular compounds. This principle directly explains the greater HCN reduction observed in P3 compared to P2 in this study.

This finding in consistent with Giancaterino et al [18], who demonstrated that increasing specific energy form 10 kJ/kg to 50 kJ/kg in PEF treatment of cherry kernels resulted in progressively greater HCN reduction, with 50 kJ/kg achieving up to 72% reduction compared to the untreated control. Although the specific energy values used in the present study (1,3 and 3,5 kJ/kg) were considerably lower than those in Giancaterino et al [18], the same directional relationship between specific energy and HCN reduction was observed: higher specific energy input corresponded to greater HCN reduction. The lower specific energy in this study explains why the HCN reduction achieved (39,60% at most) was lower than that reposted by Giancaterino et al [18], and why the final HCN level did not reach the food safety threshold of 10 ppm.

Furthermore, Góngora-Nieto et al. [22], stated that increasing voltage and energy input enhances the electric field intensity, thereby increasing the extent of electroporation on cell membranes, Rahmah et al. [23], also confirmed that higher specific energy input in PEF treatment promotes more extensive pore formation in the cell membrane, increasing permeability and accelerating intracellular mass transfer. These findings collectively support the observation that, despite its lower electric field strength, P3 achieved greater HCN reduction than P2 due to its higher specific energy input.

3.3. Mechanism of HCN Reduction

The reduction of HCN content in jack bean flour following HPEF treatment in associated with electroporation-induced changes in cell membrane permeability. In intact plant tissues, cyanogenic glycosides are stored in vacuoles, physically separated from with β-glucosidase, which is localized in the apo plastic space [9]. This compartmentalization prevents spontaneous HCN formation. When HPEF is applied,

the resulting electric field causes micropore formation in the cell membrane through electroporation [16], allowing with β-glucosidase to come into contact with cyanogenic glycosides. This contact triggers hydrolysis of the glycosidic bond, forming cyanohydrins, which subsequently decompose into HCN and carbonyl compounds such as aldehyde or ketones [10].

Following HPEF treatment, the samples were incubated at 40°C and 50% relative humidity for 12 hours without the addition of water. This waterless incubation approach allowed HCN formed during enzymatic hydrolysis to volatilize and diffuse out of the food matrix, as demonstrated by Giancaterino et al [18]. The absence of liquid medium during incubation also prevented the dissolution and loss of water-soluble nutritional components, which is an advantage over conventional soaking methods. The initial soaking step (1 hour in water at 25°C) prior the HPEF treatment also contributed to reducing the initial HCN level by facilitating leaching of HCN into the soaking water, while simultaneously increasing the electrical conductivity of the material to enhance HPEF treatment effectiveness [18].

3.4. Comparison with Conventional Methods

To contextualize the results, table 3 present a comparison of HCN reduction achieved in this study with results reported for other methods applied to materials containing cyanogenic compounds.

Table 3. Comparison of HCN Content Reduction with Previous Studies.

Treatment/Product	HCN (ppm)	Final HCN (ppm)	Reduction	Source
P1 (control)	-	146,90±0,01	-	This study
P2	146,90	103,30±0,05	29,69%	This study
P3	146,90	88,70±0,06	39,60%	This study
Jack bean soaking in water (3 hours)	134,25	41,42	69,14%	Sakinah et al.[24]
PEF + incubation	301,70	84,60	71,96%	Giancaterino et al. [18]

Based on Table 3. The HCN reduction achieved by HPEF treatment in this study 929,69-39,60%) was lower compared to soaking in water for 3 hours as reposted by Sakinah et al. which achieved a 69,14% reduction. This difference is attributable to two main factors. First, soaking in water as a liquid medium allows HCN, which is water-soluble, to leach directly into the soaking water and be discarded, providing a more direct removal pathway. Second, Sakinah et al. [24] applied soaking for 3 hours compared to only 1 hour of pre-soaking in this study, resulting in a longer contact time with the liquid medium. However, prolonged soaking carries the risk of losing water-soluble nutritional components such as proteins and minerals [26], which is a limitation not encountered with the HPEF approach used in this study.

Compared to the PEF treatment on cherry kernels reported by Giancaterino et al. [18], the HCN reduction in this study was also lower. This difference is primarily explained by the substantially higher specific energy used by Giancaterino et al. [18] at 50 kJ/kg compared to a maximum of 3.5 kJ/kg in this study. Additionally, differences in material type, initial moisture content, and cellular structure between cherry kernels and jack bean seeds contribute to variations in treatment effectiveness. These comparisons suggest that increasing the specific energy input through optimization of HPEF parameters such as pulse number and exposure duration has potential to improve HCN reduction effectiveness in future studies.

4. Conclusions

High Pulsed Electric Field (HPEF) treatment significantly reduced hydrogen cyanide (HCN) content in jack bean (*Canavalia ensiformis L.*) flour compared to the untreated control ($p<0,05$). The control sample exhibited the highest HCN level 146,90 ppm, while P2 and P3 achieved reductions of 29,69% and 39,60%, resulting in final HCN levels of 103,30 ppm and 88,70 ppm, respectively.

However, it must be emphasized that all final HCN levels, including the lowest value observed in P3 (88,70 ppm), remained substantially above the permissible food safety threshold of 10 ppm. This indicates that HPEF treatment at the parameters applied in this study is not yet sufficient as a standalone detoxification method for jack bean flour intended for direct consumption. Additional detoxification steps, such as soaking in water, boiling, or combined processing approaches, would still be required to bring HCN levels within the safe limit.

The results demonstrate that HCN reduction was not determined solely bye electric field strength, but was more closely associated with specific energy input. Although P3 applied a lower electric field (10 kV/cm) than P2 (30 kV/cm), its higher specific energy input (3,5 kJ/kg vs 1,3 kJ/kg), resulting from a longer total exposure time 401s vs 197 s), led to greater HCN reduction. This finding highlights specific energy input as a key parameter in characterizing HPEF treatment intensity and its effectiveness in releasing cyanogenic compounds from the food matrix through electroporation-induced increases in cell membrane permeability.

From a practical standpoint, HPEF shows potential as a non-thermal pretreatment step that can reduce HCN content while preserving the nutritional quality of jack bean flour, particularly degraded under the applied treatment conditions. This advantage over conventional thermal methods, which risk nutritional losses, positions HPEF as a promising component in a combined processing strategy for jack bean detoxification.

For future research, it is recommended to investigate higher specific energy inputs through optimization of parameter such as pulse number, pulse duration, and total exposure time, in order to achieve greater HCN reduction. Studies combining HPEF pretreatment with subsequent soaking or mild thermal processing should also be explored to determine whether synergistic effects can bring HCN levels within the food safety threshold while minimizing nutritional losses. Additionally, scale-up feasibility and economic analysis of HPEF application for jack bean flour production should be addressed to support practical implementation.

Funding: this research received no external funding.

References

[1] N. T. L. Putro, J. H. Arisasmita, and I. Srianta, "Kajian kadar HCN dan karakteristik pati pada tepung koro pedang (*Canavalia ensiformis*) berdasarkan waktu perendaman biji dalam air panas dan larutan natrium bikarbonat ($NaHCO_3$). 2015. *J. Teknol. Pangan Dan Gizi*.

[2] D. S. Pramita, Pengaruh teknik pemanasan terhadap kadar asam fitat dan aktivitas antioksidan koro benguk (mucuna pruriens), koro glinding (phaseolus lunatus), dan koro pedang *(canavalia ensiformis)*. 2008. digilib.uns.ac.id,.

[3] R. A. Fadri, Y. Muchrida, I. Roza, and S. Syahrul. Inovasi Tepung Labu Kuning, Tepung Ubi Ungu dan Kacang Koro dalam Pengolahan Cake dan Roti Sebagai Makanan Tambahan Stunting. repository.ppnp.ac.id, 2022.

[4] D. Gustiningsih and D. Andrayani. Potensi Koro Pedang (*Canafalia ensiformis*) dan Saga Pohon (*Adhenanthera povonina*) Sebagai Alternatif Subtitusi Bahan Baku Tempe. 2011. Bogor Agricultural University, Institut Pertanian Bogor,.

[5] I. Susanti, N. C. Siregar, and D. Supriatna. Potensi kacang koro pedang (Canavila ensiformis DC) sebagai sumber protein produk pangan. 2013. *Indones. J. Ind. Res*.

[6] T. Widiantara, Y. Taufik, and R. M. Ghaffar. Pemanfaatan Komoditas Lokal Melalui Pembuatan Produk Mie Berbasis Tepung Kacang Koro Pedang (*Canavalia ensiformis*) Termodifikasi Secara Fermentasi Spontan. 2021. *Food Technol. J.*

[7] R. Ahirwar and P. Nahar. Development of an aptamer-affinity chromatography for efficient single step purification of Concanavalin A from Canavalia ensiformis. 2015. *J. Chromatogr. B*.

[8] D. Hartanti and A. N. Cahyani. Plant cyanogenic glycosides: an overview. 2020. *Farmasains J. Farm. dan Ilmu*.

[9] J. C. Vetter, C; Ligabue-Braun, R. *Plant cyanogenic glycosides. Plant toxins Toxinology*. Dordrecht, 2017. Springer,

[10] P. M. Dewick. The acetate pathway: fatty acids and polyketides. *Medicinal natural products: A*. John Wiley &Sons Publ 2001. Chichester.
[11] A. T. Forkum, A. E. Wung, M. T. Kelese, and C. M. Ndum. Safety of cassava and cassava-based products: a systematic review. 2025. *Sec Nutr. Sustain. Diet*, doi: 10.3389/fsufs.2025.1497609.
[12] N. A. M. Ramli, Y. H. Chen, and Z. M. Zin. Effect of soaking time and fermentation on the nutrient and antinutrients composition of *Canavalia ensiformis* (Kacang Koro). *IOP Sci. Home Access. Help IOP Conf. Ser. Earth Environ. Sci.* doi: 10.1088/1755-1315/756/1/012033. 2021.
[13] A. Khamidah, E. Ginting, I. Ambarsari, and S. S. Antarlina. Physicochemical, anti-nutritional, and sensory characteristics of jack bean (*Canavalia ensiformis* L.) and velvet bean (*Mucuna pruriens*) tempe pretreated with with different detoxification methods. 2025. *Applied Food Research*. Elsevier.
[14] R. Islami, E. Prangdimurti, T. Muhandri, and D. R. Adawiyah. Efek berbagai pretreatment koro pedang kupas terhadap kadar HCN, proksimat dan karakteristik fisik tepung koro pedang (*Canavalia ensiformis*). 2023.
[15] F. J. Barba, O. Parniakov, S. A. Pereira, and A. Wiktor. Current applications and new opportunities for the use of pulsed electric fields in food science and industry. 2015. *Food Res.*
[16] G. Ghoshal. Comprehensive review on pulsed electric field in food preservation: Gaps in current studies for potential future research. 2023. *Heliyon*. cell.com.
[17] W. Su, Q. Wang, J. Li, Z. Qiu, and Y. Qiu. Effects of pulsed electric field technology on the nutritional value and biological function of plant food. 2024. *Front. Sustain. Food*. doi: 10.3389/fsufs.2024.1385533.
[18] M. Giancaterino, T. Fauster, and A. Krottenthaler. Effect of pulsed electric field pre-treatment on the debittering process of cherry kernels. 2023. *Innovative Food Science and Emerging*. Elsevier.
[19] S. Maharani. Stabilitas antosianin nasi merah instan akibat pengaruh varietas beras merah (*Oryza nivara*. L) dan teknik pemasakan menggunakan metode pengeringan beku (freeze drying). 2020. *Pasundan Food Technol. J.*
[20] Association of Official Agricultural Chemists. Official Methods of Analysis. Dumas method (990.03)." AOAC international 2005. Washington DC.
[21] S. Toepfl, V. Heinz, and D. Knorr. Applications Of Pulsed Electric Fields Technology. 2010. *Pulsed Electr. Fields Technol.*
[22] M. M. Góngora-Nieto, P. D. Pedrow, B. G. Swanson. Energy analysis of liquid whole egg pasteurized by pulsed electric fields. 2003. *J. Food*.
[23] N. L. Rahmah. Aplikasi perlakuan pendahuluan Pulsed Electric Field (PEF) pada ekstraksi tanin biji pinang (*Areca catechu*) (kajian frekuensi dan waktu PEF). 2019. *J. Teknol. Ind. Pertanian*.
[24] R. G. Sakinah, W. Hermana, and N. Nahrowi. Jack Bean (*Canavalia ensiformis*) Meal Inclusion and Lactic Acid Bacteria Supplementation on the Performance of IPB D1 Chickens. 2024. *J. Ilmu Nutr. Dan Teknol. Pakan*.