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Effect of Cold Plasma Treatment on Storage Quality of Pearl Millet Grain and Flour

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ABSTRACT

In the present study pearl millet (Pennisetum glaucum) PBH1625 variety (whole grain, dehulled grain, and dehulled flour)was subjected to cold plasma exposure at 25kv for 10 mins and 30kv for 10 mins. Subsequently, the samples were packed in low-density polyethylene (LDPE) pouches and metalized polypropylene (MPP) stored for 90 days, and shelf life studies were conducted. The results revealed that cold plasma exposure at 25kv for 10 mins outperformed in controlling lipase and lipoxygenase activity at 30kv for 10 mins. On storage, MPP packaging material outperformed LDPE in controlling moisture, acid value, free fatty acids, peroxide value, water activity, lipase, and lipoxygenase activity in all the samples. The findings collectively indicate that pearl millet whole grain, dehulled grain, and dehulled flour exposed to cold plasma at 25kv for 10 mins followed by packing in MPP have better shelf life and storability up to 90 days.

Keywords: *Cold plasma treatment, Low density polyethylene (LDPE), Metalized polypropylene (MPP), Lipase activity, Lipoxygenase activity.*

INTRODUCTION

Pearl millet is the main source of all the health advantages associated with millet. Growing predominantly in Asia and Africa, pearl millet (*Pennisetum glaucum*), a member of the Poaceae (grass family) family, is a traditional and nutrient-dense crop (Jukanti *et al.*, 2016). It is resistant to insects, diseases high temperatures, and droughts and does not readily succumb to poor soils (Dayakar *et al.*, 2004). After rice, wheat, maize, and sorghum, pearl millet is the fifth most important cereal crop planted worldwide. It is grown in dry and semi-arid locations (Ojediran *et al.*, 2010). In terms of cultivated area, it is the most important variety of millet and helps ensure food security in arid regions of Asia and Africa.

India is the world's largest producer of pearl millet, with 9.8 million hectares of land, accounting for more than 95% of the crop. Because of this, 46% of the grain produced from pearl millet is consumed by humans and the remaining is utilized for feed and fodder (Basavaraj *et al.*, 2010). It has higher carbohydrate (67.5%), protein (14.0%), fat (5.7%), fiber (2.0%), and ash (2.1%) content(Jukanti *et al.,* 2016).

Despite nutritional superiority, the utilization of pearl millet flour is limited to a few specific pockets and regions all around the world due to the poor keeping quality of the flour and the development of off odor during storage. The poor keeping quality of pearl millet flour is due to the oxidative/hydrolytic rancidity caused by enzymes like Lipase and Lipoxygenase(Rani *et al.,* 2018).

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The pearl millet has a high-fat content when compared with other millets. Whole grain when stored for 3 months and dehulled grain on storage for 2 months, leads to the development of off-odors due to an increase in lipase and lipoxygenase enzymes, peroxidase value, and acid value. Hence, proper shelf-life-enhancing treatments are necessary for pearl millet to improve its keeping quality. So, the non-thermal treatment (Cold plasma) is applied applied to enhance the shelf life of the pearl millet (Rathore *et al.,* 2016).

The cold plasma technique was originally applied to enhance the antimicrobial activity in surface engineering, the bio-medical field, and polymer industries. Plasma is ionized gas containing reactive oxygen species (0, 0, 0, and OH), reactive nitrogen species (NO, NO and NO, J, UV, free radicals, and charged particles. Plasma is generated when electrical energy is applied to a gas present between two electrodes (Tavakoli *et al.,* 2022).

The pearl millet has poor keeping quality due to high-fat content and it causes the development of off odors, off flavors, and bitterness with increased oxidative/hydrolytic rancidity caused by enzymatic activity. There are several studies conducted on the shelf life enhancement of pearl millet. However, not many studies are available on the effect of non-thermal treatments on pearl millet storage. With an objective towards a better understanding of cold plasma treatment in enhancing the shelf life of pearl millet grain and flour. A research was designed to study the effect of cold plasma treatment on the quality and storage of pearl millet grain and flour.

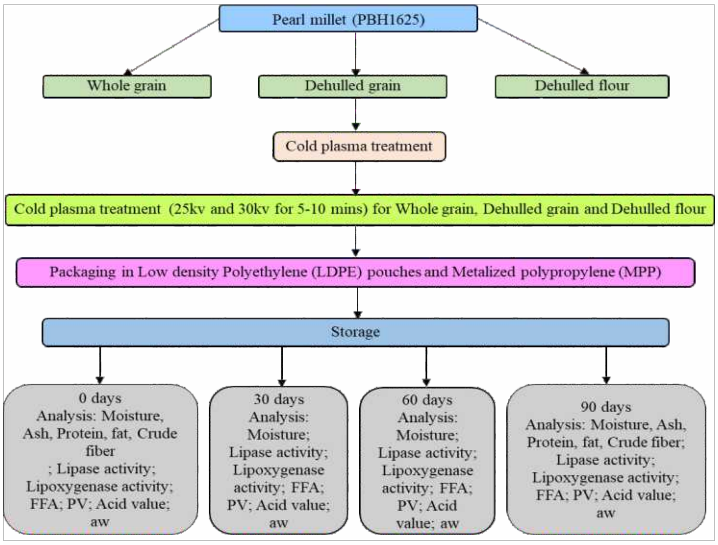
2. MATERIALS AND METHODS

2.1 Raw materials: The Pearl millet (PBH1625) was procured from the Regional Agricultural Research Station (RARS), Palem, Nagarkurnool district, and packaging materials i.e., low-density polyethylene (LDPE) and metalized polypropylene (MPP) from commercial outlets in Hyderabad, Telangana State, India.

The schematic representation of the research study is given in Figure 2.1.

2.2 Preparation of sample for cold plasma treatment: From a 50kg sample of pearl millet (PBH 1625) variety, a homogenized -sub-sample of 3 kgs (2 sets) was subjected to dehulling and pulverizing. After dehulling 3kgs of pearl millet grains, 1.5 kgs of dehulled pearl millet grains were obtained which were used for pulverization. Whole grain, dehulled grain, and dehulled flour of pearl millet (PBH 1625) variety were used for cold plasma treatments as shown in Figure 2.2.

2.3 Cold plasma treatment and storage of pearl millet: The cold plasma exposures (25 kv for 10 mins and 30 kv for 10 mins) were given to whole grain, dehulled grain, and dehulled flour of pearl millet, followed by packing in low-density polyethylene (LDPE) pouches and metalized polypropylene (MPP) for storage upto 90 days. The nutritional analysis, chemical composition, and enzymatic activity during storage were carried out at regular intervals i.e., 0, 30, 60, and 90 days (Tavakoli *et al.,* 2022).



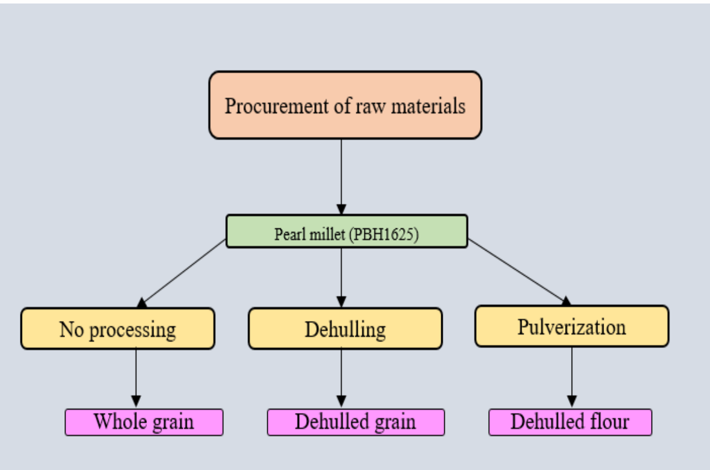


Figure2.1 Schematic representation of research study Figure 2.2 Preparation of sample

2.4 Estimation of nutritional and shelf life parameters: As per AOAC(2005)the moisture, Ash, and Crude fibercontents of the samples were estimated.The fat content of the samples was determined using (AOAC) 1997). Protein was estimated by the Lowry method (Waterborg, 2009). The acid value was estimated according to FSSAI(2021). Free fatty acids were measured according to Pearson (1976).

Peroxide value was estimated according to Sadasivam and Manickam(2018). Water activity was determined according to Abramovic *et al.*(2008). Determination of lipase activity was performed according to the method described by Padmaja *et al.*(2023). Lipoxygenase activity was estimated according to ulousToulouse *et al.*(2018). The data was statistically evaluated by one-way analysis of variance procedure (ANOVA).

3. RESULTS AND DISCUSSION

3.1 Effect of cold plasma treatment on nutritional composition: The proximate analysis such as moisture, ash, protein, fat, and crude fiber were done for control whole grain, dehulled grain, and dehulled flour and cold plasma treated at 30kv and 25kv for 10 minspearl millet whole grain, dehulled and dehulled flour were packed in metalized polypropylene (MPP) and low-density polyethylene (LDPE) at ambient temperature and stored for 90 days.

The moisture content of. The moisture content lowered considerably ($p<0.05$) after cold plasma treatment for all samples, with major drop seen in whole grain (10.268-14.068%), dehulled grain (10.771-13.990%) and flour (10.891-15.958%) samples treated for 10 min at 25kv packed in MPP than control whole grain (10.702-16.687%)was found to be lower than dehulled grain (11.282-17.129%) and flour (11.751-18.071%)packed in MPP. The voltage, and treatment time had a significant effect on moisture content. Because MPP packaging material will not come into contact with oxygen (air) easily, was primarily responsible for the lower increase in moisture during storage. Ajita and Jha (2017) concluded that the product's hygroscopic properties, the storage environment (temperature, relative relative humidity), and the type of packaging material all contributed to the increase in moisture content. The moisture content of control and cold plasma treated samples are summarized in Table 3.1.1.

The fat content of control whole grain (5.793-5.922%) was found to be higher than dehulled grain (5.103-5.283%) and flour (5.067-5.200%) packed in MPP. The fat content lowered considerably ($p<0.05$) after cold plasma treatment for all samples, with a substantial decrease in whole grain (5.107-5.340%), dehulled grain (4.533-5.030%), and flour (4.393-5.054%) samples treated for 10 min at 25kv packed in MPP. There was a significant ($p<0.05$) decrease in fat content in treated samples than control samples. A decrease in lipid content was seen in the early stages of treatment because complex fat aggregates with other components were forming during the early phases of the plasma treatment. The fat content of control and cold plasma treated samples are summarized in Table 3.1.2. Lokeswari*et al.* (2021) showed that during the first phase of the treatment, A1 (2.79/100 g) and B1 (3.15/100 g) showed lower lipid contents. The creation of complicated fat aggregates with other components was the cause of the decrease in the early phases of plasma therapy. An increase in treatment time and voltage for A2 (3.15/100 g), A3 (4.63/100 g), B2 (3.50/100 g), and B3 (4.71/100 g) has resulted in a considerable improvement in the amount of fat extracted. Crude fats break down into their derivatives as a result of the treatment's increased fat content.

The ash content of control whole grain (1.899-1.996%) was found to be higher than dehulled grain (1.518-1.521%) and flour (1.508-1.586%) packed in MPP. The ash content increased significantly ($p<0.05$) after cold plasma treatment for all samples, with a substantial increase in whole grain (2.017-2.020%), dehulled grain (1.578-1.628%), and flour (1.594-1.606%) samples treated for 10 min at 25kv packed in MPP.

While the protein content of the control whole grain (13.073-13.080%) was found to be higher than dehulled grain (13.063-13.068%) and flour (13.063-13.067%) packed in MPP. The ash content increased significantly ($p<0.05$) after cold plasma treatment for all samples, with a substantial increase in whole grain (13.083-13.087%), dehulled grain (13.074-13.083%), and flour (13.058-13.068%) samples treated for 10 min at 25kv packed in MPP. There was a significant ($p<0.05$) increase in ash content in treated samples than control samples. However, an increase in ash content with exposure time is possibly due to the action of plasma reactive species. The ash and protein content of control and cold plasma treated samples are summarized in Fig 3.1.3. Thirumdas *et al.* (2015) revealed that ash concentration decreases as a result of mineral components leaching into the soaking water during treatment. While T1 and T2 showed a drop in ash content of 16.7% and 14.1%, respectively, there was a 19% decrease in ash content in C2 and crude protein increased in T1 by 16.3% and T2 by 17.3%, respectively. On the other hand, a 1.8% increase in the soaked sample was observed in contrast to control C1. Initial stages of plasma processed air bubbling treated samples have reduced ash content because of significant mineral leaching. On the other hand, a rise in ash and protein content overexposure time may be brought on by plasma reactive species.

The crude fiber content of control and cold plasma treated samples are summarized in Fig 3.1.4. The crude fiber of control whole grain (2.918-2.942%) was found to be higher than dehulled grain (2.455-2.531%) and flour (2.334-2.454%) packed in MPP. The crude fiber decreased significantly ($p<0.05$) after cold plasma treatment for all samples, with a substantial decrease in whole grain (2.658-2.732%), dehulled grain (2.245-2.279%), and flour (2.236-2.248%) samples treated for 10 min at 30kv packed in MPP. There was a significant ($p<0.05$) decrease in crude fiber content in treated samples than control samples. Reduction in crude fiber in samples treated with plasma, potentially as a result of highly active plasma species breaking down complex fibrous structures produced during treatment. Popescu *et al.* (2011) said that the plasma-processed air bubbling treatment increased the crude fiber content, whereas soaking increased it in contrast with C1. According to earlier research, reactive species created during treatment may contribute to the breakdown of fibrous structures.

3.2 Effect of cold plasma treatment on chemical composition: Shelf life studies of millets are a critical facet of food preservation and safety to be considered for storage. The shelf life analysis such as acid value, free fatty acids, peroxide value, and water activity was done for control whole grain, dehulled grain, and control dehulled flour and cold plasma treated pearl millet whole grain, dehulled and dehulled flour were packed in metalized polypropylene (MPP) and low-density polyethylene (LDPE) at ambient temperature and stored for 90 days.

The acid value and FFA of control and cold plasma-treated samples are summarized in Tables 3.2.1 and 3.2.2. The acid value of control whole grain (3.180-20.538mg KOH/100g) was found to be lower than dehulled grain(2.415-23.820mgKOH/100g) and flour (2.381-25.291mgKOH/100g) packed in MPP. The acid value lowered considerably ($p<0.05$) after cold plasma treatment for all samples, with a major drop seen in whole grain (1.675-18.151mgKOH/100g), dehulled grain(1.116-23.162mgKOH/100g)and flour (1.113-23.651mgKOH/100g)samples treated for 10 min at 25kv packed in MPP.

Chavan and Kachare (1994) said that the first decrease in acid levels in the thermally treated samples was caused by the thermal treatment's inhibition of lipase. During storage, the acid values of HHB 67 samples that were not heat treated increased rapidly from 0.23 to 1.00 g.100 g−1 of dry matter and from 0.19 to 0.66 g.100 g−1 of dry matter significantly. This is because enzymatic lipolysis has increased the amount of free fatty acids. The FFA of control whole grain (1.600-10.053%) was found to be lower than dehulled grain(1.214-13.392%) and flour (1.197-14.020%) packed in MPP.

While, the FFA lowered considerably ($p<0.05$) after cold plasma treatment for all samples, with a major drop seen in whole grain (0.842-9.112%), dehulled grain(0.561-11.658%) and flour(0.559-11.909%) samples treated for 10 min at 25kv packed in MPP. There was an increase in acid value in all the control and treated samples among both types of packaging. However, the increase was less observed in treated samples than in control samples. This is due to the high-fat content in whole grain than dehulled grain and flour. Because, the acid value is increased due to an increase in moisture, water activity, and rancidity causing enzymes. Yadav*et al.,* (2012) revealed that, in order of preference, the control samples, treated SBP samples, and SAP samples had a higher rate of increase in FFA. The development of a rancid odor was another indicator of elevated FFA levels. This odor was associated with auto-oxidative degradation, and control samples began to smell after 10 days of storage as a result of rising FFA levels, while SAP and SBP samples didn't begin to smell bad until 45 and 50 days after storage, respectively.

The peroxide value and water activity of control and cold plasma treated samples are summarized in Tables 3.2.1 and 3.2.2. The peroxide value of control whole grain (5.324-18.602 meq/1000g) was found to be lower than dehulled grain(7.727-21.723meq/1000g)and flour (7.727-23.566meq/1000g)packed in MPP. The peroxide value lowered considerably ($p<0.05$) after cold plasma treatment for all samples, with a major drop seen in whole grain (3.100-12.243meq/1000g), dehulled grain(4.613-17.720meq/1000g)and flour (4.726-18.701meq/1000g)samples treated for 10 min at 25kv packed in MPP. Because, peroxide value is increased due to an increase in moisture, water activity, hydrolytic and oxidative rancidity causing enzymes. Yadav *et al.*(2012) concluded that after 30 days of storage, the peroxide value in the control flour raised respectively ($p>0.05$) from 11.23 to 28.96 meq O_2 kg-1fat. When the flour was microwave-treated, its PV was 11.55 meq O_2 kg-1 fat after zero days. After 30 days of storage, it reached 2.48 meq O_2 kg-1 fat and did not differ notably ($p<0.05$) from the control.

While, the water activity of control whole grain (0.350-0.686a_w) was found to be lower than dehulled grain(0.440-0.704a_w)and flour(0.547-0.821a_w)packed in MPP. The water activity value lowered considerably ($p<0.05$) after cold plasma treatment for all samples, with a major drop seen in whole grain (0.173-0.381a_w), dehulled grain(0.193-0.394a_w), and flour(0.203-0.411a_w)samples treated for 10 min at 25kv packed in MPP. There was an increase in water activity in all the control and treated samples among both types of packaging. However, the increase was less observed in treated samples than in control samples. Because, water activity increases with temperature, the free water content in food and little effect on an increase in moisture. Singh*et al*. (2020) explained that in metalized packaging, the water activity of morning cereal improved dramatically ($P\leq0.05$) over a three-month storage period, from 0.17 to 0.40 (an increase of roughly 42%).

As a result, for the course of the 90-day storage period, the water activity of the RTE-BC kept in the Metalized Pouch remained within the allowed range (>0.5).

3.3 Effect of cold plasma treatment on enzymatic activity during storage: The lipase and lipoxygenase enzymes are responsible for the rancidity of pearl millet grain and flour during storage. Because, Pearl millet has a high-fat content, lipase and lipoxygenase activity increase with an increase in moisture, acid value, free fatty acids, and peroxide. The enzymatic analysis was done for control whole grain, dehulled grain, and control dehulled flour, and cold plasma treated pearl millet whole grain, dehulled and dehulled flour were packed in metalized polypropylene (MPP), and low-density polyethylene (LDPE) at ambient temperature and stored for 90 days.

The lipase and lipoxygenase activity of control and cold plasma-treated samples are summarized in Tables 3.3.1 and 3.3.2. The lipase activity of control whole grain (37.650-49.163Meq/ml) was found to be lower than dehulled grain(28.244-52.339Meq/ml)and flour (27.455-54.823Meq/ml)packed in MPP. The lipase activity lowered respectively (p<0.05) after cold plasma treatment for all samples, with a significant decrease in whole grain (17.352-44.020Meq/ml), dehulled grain(14.190-47.309Meq/ml)and flour(12.581-48.728Meq/ml)samples treated for 10 min at 25kv packed in MPP. Bhargav *et al*. (2021) indicated to decrease in lipolysis in pearl millet genotypes with different seed coat colors like purple, white, and black by deactivating lipases. Microwaves produce uniform heating of the grain and a 26% reduction in lipases in dhanshakti and 4% in WGI-100. The purple Pusa Purple 1 cultivar demonstrated a 23% increase in lipase activity when microwaved. In dhanshakti, decortication resulted in a 6% reduction in lipase activity and nutritional loss. In dhanshakti, vacuum packaging raised lipase activity by 35%, whereas in WGI-100, it increased by 20%. The purple variant displayed a 20% drop in lipase activity. Out of the three types that are not treated, Pusa Purple 1 is the best.

While the lipoxygenase activity of control whole grain(17.147-33.980%) was found to be lower than dehulled grain(15.941-38.941%)and flour (15.732-42.979%)packed in MPP. The lipase activity lowered respectively (p<0.05) after cold plasma treatment for all samples, with a significant decrease in whole grain (8.135-28.426%), dehulled grain(7.524-30.112%), and flour(7.497-33.628%)samples treated for 10 min at 25kv packed in MPP. There was an increase in lipase and lipoxygenase activity in all the control and treated samples among both types of packaging. However, the increase was less observed in treated samples than in control samples. Vinutha*et al.* (2022) examined how these heat treatments affected the hydrolytic and oxidative rancidity processes in flour that had been kept. When hydrothermal (HTh) and thermal near-infrared radiation (thNIR) treated flour was compared to the individual treatments, there was a significant drop in the enzyme activity of lipase (47.8%), lipoxygenase (84.8%), peroxidase (98.1%) and polyphenol oxidase (100%). After 90 days of storage, flour treated with HT-HTh-thNIR showed a decrease in free fatty acid and peroxide concentrations of 67.84% and 66.4%, respectively.

CONCLUSION

Despite having excellent nutritious qualities, pearl millet isn't utilized much because of its short shelf life. Both nutritional and shelf life parameters have changed significantly (p < 0.05) in the cold plasma. On the other hand, it significantly affects lipase and lipoxygenase activities. As a result of the cold plasma treatment's plasma reactive species. In particular, cold plasma packed in MPP at 25 kV for 10 minutes demonstrated superior control over shelf life characteristics compared to 30 kV for 10 minutes in MPP. Lipase and lipoxygenase inhibition rises with exposure duration. In whole grain, dehulled grain, and flour, the nutritional indices such as moisture and fat increased dramatically, while ash, protein, and crude fiber did not vary significantly. After being stored for 90 days, the whole grain, dehulled grain, and flour of pearl millet all had significant changes in their shelf life characteristics, including controlled acid value, free fatty acids, peroxide value, water activity, lipase, and lipoxygenase activity ranges. It has been determined that treating pearl millet with cold plasma can extend its shelf life by up to ninety days. The food industry views cold plasma technology as a promising technology due to its low cost, flexibility in large-scale system application, environmentally benign feed gases, and effective processing. This novel non-thermal technique can be applied by the whole grain processing sectors to improve the features, applications, and quality of new food products.

Table 3.1.1 Moisture content of control and treated pearl millet grain and flour during shelf life study

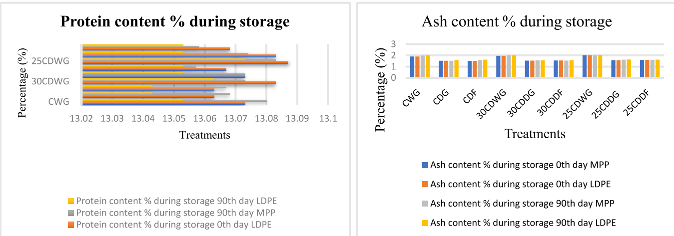
Treatments	Moisturecontent%duringstorage							
	0th day		30th day		60th day		90th day	
	MPP	LDPE	MPP	LDPE	MPP	LDPE	MPP	LDPE
CWG	10.702^{fgh}±0.17	10.702^{fgh}±0.17	12.625^{e}±0.26	13.451^{e}±0.09	14.224^{e}±0.09	15.251^{f}±0.13	16.687^{e}±0.15	17.212^{e}±0.13
CDG	11.282^{cd}±0.10	11.282^{cd}±0.10	13.559^{d}±0.21	14.141^{d}±0.13	15.241^{d}±0.08	16.146^{d}±0.13	17.129^{d}±0.12	18.066^{d}±0.07
CDF	11.751^{b}±0.11	11.751^{b}±0.11	13.972^{c}±0.06	15.061^{c}±0.15	15.990^{c}±0.10	17.372^{c}±0.09	18.071^{c}±0.09	19.082^{c}±0.09
30CDWG	10.346^{ij}±0.10	10.346^{ij}±0.10	10.607^{k}±0.06	10.982^{jk}±0.06	12.903^{h}±0.07	14.920^{g}±0.06	13.910^{h}±0.04	15.946^{h}±0.05
30CDDG	10.947^{ef}±0.05	10.947^{ef}±0.05	11.101^{fg}±0.07	11.610^{g}±0.05	13.370^{i}±0.04	15.242^{f}±0.10	14.591^{g}±0.10	16.484^{g}±0.09
30CDDF	11.054^{de}±0.04	11.054^{de}±0.04	11.153^{f}±0.08	12.133^{f}±0.07	13.975^{f}±0.02	15.912^{e}±0.03	14.988^{f}±0.01	16.991^{f}±0.004
25CDWG	10.268^{ij}±0.05	10.268^{ij}±0.05	10.641^{jk}±0.04	11.002^{jk}±0.03	12.015^{j}±0.04	13.975^{j}±0.01	13.012^{i}±0.03	14.068^{l}±0.09
25CDDG	10.771^{fg}±0.07	10.771^{fg}±0.07	10.843^{hi}±0.08	11.104^{j}±0.07	12.370^{g}±0.11	14.719^{h}±0.12	13.990^{h}±0.005	15.430^{i}±0.10
25CDDF	10.891^{efg}±0.08	10.891^{efg}±0.08	10.981^{fgh}±0.03	11.343^{hi}±0.08	12.969^{h}±0.01	14.946^{g}±0.03	14.001^{h}±0.01	15.958^{h}±0.05
Mean	10.890	10.890	11.720	12.314	13.673	15.387	15.153	16.581
S.Eofmean	0.085	0.085	0.242	0.282	0.243	0.181	0.320	0.273
C.D	0.168	0.168	0.222	0.158	0.128	0.161	0.142	0.147
C.V%	0.898	0.898	1.107	0.752	0.546	0.611	0.550	0.519

Note: Values are expressed as mean ± standard deviation of three determinations Means within the same column followed by a common letter do not differ significantly at (p ≤ 0.05).

Table3.1.2 Fat content of control and treated pearl millet grain and flour during shelf life study

Treatments	Fatcontent%duringstorage							
	0th day		30th day		60th day		90th day	
	MPP	LDPE	MPP	LDPE	MPP	LDPE	MPP	LDPE
CWG	5.793^{a}±0.19	5.793^{a}±0.19	5.840^{a}±0.15	5.887^{a}±0.10	5.840^{a}±0.13	5.894^{a}±0.10	5.922^{a}±0.09	5.929^{a}±0.08
CDG	5.103^{b}±0.10	5.103^{b}±0.10	5.137^{cd}±0.10	5.197^{e}±0.12	5.137^{cd}±0.09	5.283^{c}±0.13	5.283^{d}±0.10	5.413^{d}±0.14
CDF	5.067^{b}±0.10	5.067^{b}±0.10	5.080^{cde}±0.09	5.130^{ef}±0.06	5.080^{cde}±0.08	5.197^{cde}±0.04	5.200^{de}±0.07	5.320^{de}±0.05
30CDWG	5.210^{b}±0.02	5.210^{b}±0.02	5.430^{b}±0.09	5.623^{bc}±0.26	5.430^{b}±0.09	5.716^{b}±0.23	5.661^{b}±0.12	5.806^{ab}±0.19
30CDDG	4.737^{c}±0.05	4.737^{c}±0.05	5.053^{cde}±0.04	5.034^{ef}±0.02	5.053^{cde}±0.08	5.063^{ef}±0.03	5.063^{ef}±0.13	5.080^{f}±0.04
30CDDF	4.600^{cde}±0.23	4.600^{cde}±0.23	4.930^{efg}±0.22	5.068^{ef}±0.08	4.930^{efg}±0.11	5.077^{ef}±0.05	5.040^{f}±0.07	5.114^{f}±0.05
25CDWG	5.107^{b}±0.04	5.107^{b}±0.04	5.160^{cd}±0.04	5.450^{cd}±0.06	5.167^{cd}±0.02	5.594^{b}±0.10	5.340^{cd}±0.04	5.627^{c}±0.11
25CDDG	4.533^{defg}±0.05	4.533^{defg}±0.05	5.008^{def}±0.01	5.078^{ef}±0.04	5.008^{def}±0.02	5.119^{def}±0.10	5.030^{f}±0.03	5.164^{ef}±0.16
25CDDF	4.393^{fg}±0.15	4.393^{fg}±0.15	5.033^{cdef}±0.03	5.147^{ef}±0.04	5.033^{cdef}±0.04	5.278^{c}±0.02	5.054^{ef}±0.04	5.350^{d}±0.05
Mean	4.858	4.858	5.132	5.276	5.198	5.314	5.247	5.421
S.Eofmean	0.055	0.055	0.038	0.039	0.039	0.039	0.041	0.042
C.D	0.199	0.199	0.187	0.175	0.187	0.152	0.159	0.169
C.V%	2.464	2.464	2.199	1.994	2.199	1.726	1.830	1.875

Note: Values are expressed as mean ± standard deviation of three determinations Means within the same column followed by a common letter do not differ significantly at ($p \leq 0.05$)



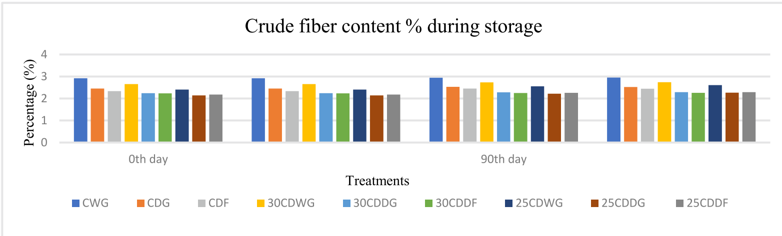


Figure 3.1.3Ash and protein content of control and treated pearl millet grain and flour during shelf life study

Figure 3.1.3 Crude fiber of control and treated pearl millet grain and flour during shelf life study

Table 3.2.1 Acid value of control and treated pearl millet grain and flour during shelf life study

Treatments	Acid value (AV) (mg KOH/100g) during storage							
	0th day		30th day		60th day		90th day	
	MPP	LDPE	MPP	LDPE	MPP	LDPE	MPP	LDPE
CWG	3.180^{a}±0.01	3.180^{a}±0.01	4.363^{g}±0.18	6.429^{g}±0.10	9.714^{b}±0.18	13.733^{d}±0.23	20.538^{g}±0.47	23.208^{g}±0.47
CDG	2.415^{b}±0.32	2.415^{b}±0.32	8.117^{c}±0.17	9.774^{b}±0.26	10.765^{a}±0.18	15.844^{b}±0.15	23.820^{b}±0.29	29.139^{a}±0.12
CDF	2.381^{b}±0.28	2.381^{b}±0.28	8.826^{b}±0.10	9.985^{ab}±0.18	10.975^{a}±0.10	17.330^{a}±0.32	25.291^{a}±0.29	29.507^{a}±0.45
30CDWG	1.671^{c}±0.001	1.671^{c}±0.001	3.160^{h}±0.31	3.642^{i}±0.28	8.644^{d}±0.30	11.971^{g}±0.27	19.239^{h}±0.28	20.989^{h}±0.33
30CDDG	1.276^{def}±0.09	1.276^{def}±0.09	7.116^{e}±0.12	7.353^{f}±0.11	9.237^{c}±0.30	13.682^{d}±0.25	23.820^{b}±0.29	27.037^{bcd}±0.30
30CDDF	1.146^{efg}±0.005	1.146^{efg}±0.005	7.544^{d}±0.27	7.873^{e}±0.09	9.808^{b}±0.30	14.260^{c}±0.27	25.291^{a}±0.29	27.350^{b}±0.33
25CDWG	1.675^{c}±0.005	1.675^{c}±0.005	2.268^{j}±0.06	2.964^{k}±0.16	7.311^{fg}±0.10	11.420^{h}±0.25	18.151^{i}±0.29	20.360^{i}±0.29
25CDDG	1.116^{fg}±0.003	1.116^{fg}±0.003	8.773^{b}±0.09	8.938^{d}±0.04	8.985^{cd}±0.35	12.599^{f}±0.28	23.162^{d}±0.24	26.500^{ef}±0.27
25CDDF	1.113^{fg}±0.003	1.113^{fg}±0.003	9.206^{a}±0.27	9.361^{c}±0.10	9.241^{c}±0.24	13.144^{e}±0.24	23.651^{bc}±0.20	26.886^{bcde}±0.22
Mean	1.774	1.774	6.597	7.368	9.408	13.775	22.551	25.664
S.Eofmean	0.137	0.137	0.488	0.478	0.207	0.346	0.483	0.621
C.D	0.25	0.25	0.341	0.291	0.372	0.445	0.522	0.566
C.V%	8.333	8.333	3.014	2.303	2.310	1.887	1.350	1.287

Note: Values are expressed as mean ± standard deviation of three determinations Means within the same column followed by a common letter do not differ significantly at ($p \leq 0.05$).

Table 3.2.2 Free fatty acids of control and treated pearl millet grain and flour during shelf life study

Treatments	Free fatty acids (FFA) % during storage							
	0th day		30th day		60th day		90th day	
	MPP	LDPE	MPP	LDPE	MPP	LDPE	MPP	LDPE
CWG	1.600^{a}±0.008	1.600^{a}±0.008	3.834^{e}±0.13	5.949^{c}±0.04	6.725^{b}±0.16	10.002^{c}±0.12	10.053^{i}±0.04	14.279^{c}±0.09
CDG	1.214^{b}±0.16	1.214^{b}±0.16	5.863^{b}±0.08	7.872^{b}±0.11	9.949^{a}±0.06	13.138^{b}±0.10	13.392^{b}±0.13	17.388^{b}±0.13
CDF	1.197^{b}±0.14	1.197^{b}±0.14	6.756^{a}±0.20	8.958^{a}±0.05	9.988^{a}±0.08	14.544^{a}±0.06	14.020^{a}±0.10	18.133^{a}±0.11
30CDWG	0.840^{c}±0.001	0.840^{c}±0.001	1.563^{h}±0.14	1.836^{i}±0.14	4.362^{e}±0.15	6.010^{h}±0.14	9.680^{j}±0.14	10.571^{i}±0.16
30CDDG	0.642^{def}±0.05	0.642^{def}±0.05	3.452^{f}±0.08	3.590^{g}±0.01	4.621^{d}±0.15	6.911^{e}±0.13	11.977^{d}±0.14	13.602^{de}±0.15
30CDDF	0.576^{efg}±0.002	0.576^{efg}±0.002	3.801^{e}±0.14	3.952^{f}±0.03	4.916^{c}±0.15	7.182^{d}±0.14	12.218^{c}±0.19	13.622^{d}±0.19
25CDWG	0.842^{c}±0.002	0.842^{c}±0.002	1.132^{i}±0.01	1.239^{k}±0.14	3.790^{g}±0.14	5.750^{i}±0.12	9.112^{l}±0.14	10.213^{j}±0.14
25CDDG	0.561^{fg}±0.001	0.561^{fg}±0.001	4.136^{d}±0.06	4.178^{f}±0.07	4.368^{e}±0.14	6.321^{g}±0.14	11.658^{f}±0.12	13.311^{fgh}±0.14
25CDDF	0.559^{fg}±0.002	0.559^{fg}±0.002	4.603^{c}±0.13	4.752^{e}±0.24	4.655^{d}±0.12	6.596^{f}±0.12	11.909^{de}±0.12	13.354^{fg}±0.14
Mean	0.892	0.892	3.904	4.702	5.930	8.494	11.557	13.8303
S.Eofmean	0.069	0.069	0.333	0.471	0.449	0.609	0.307	0.390
C.D	0.127	0.127	0.213	0.203	0.233	0.213	0.229	0.253
C.V%	8.347	8.347	3.182	2.522	2.299	1.468	1.158	1.065

Note: Values are expressed as mean ± standard deviation of three determinations Means within the same column followed by a common letter do not differ significantly at ($p \leq 0.05$).

Table 3.2.3 Peroxide value of control and treated pearl millet grain and flour during shelf life study

Treatments	Peroxide value (PV) (meq/1000g) during storage							
	0th day		30th day		60th day		90th day	
	MPP	LDPE	MPP	LDPE	MPP	LDPE	MPP	LDPE
CWG	5.324^{bc}±0.19	5.324^{bc}±0.19	8.870^{c}±0.11	12.702^{c}±0.26	13.561^{c}±0.37	17.564^{c}±0.37	18.602^{d}±0.32	22.715^{g}±0.26
CDG	7.727^{a}±0.11	7.727^{a}±0.11	13.797^{b}±0.27	17.521^{b}±0.44	16.731^{b}±0.26	20.558^{b}±0.38	21.723^{b}±0.23	24.707^{c}±0.27
CDF	7.727^{a}±0.11	7.727^{a}±0.11	15.762^{a}±0.26	19.479^{a}±0.18	17.552^{a}±0.10	22.346^{a}±0.09	23.566^{a}±0.35	27.537^{a}±0.35
30CDWG	4.684^{d}±0.17	4.684^{d}±0.17	4.735^{h}±0.25	5.702^{i}±0.26	7.227^{j}±0.24	10.230^{f}±0.25	13.268^{h}±0.27	16.715^{j}±0.26
30CDDG	5.084^{c}±0.16	5.084^{c}±0.16	6.130^{g}±0.30	7.188^{g}±0.26	9.731^{e}±0.26	11.225^{d}±0.24	18.723^{d}±0.23	23.707^{e}±0.27
30CDDF	5.226^{c}±0.15	5.226^{c}±0.15	6.762^{f}±0.26	8.178^{ef}±0.26	10.219^{d}±0.25	11.569^{d}±0.35	20.233^{c}±0.25	25.204^{b}±0.26
25CDWG	3.100^{g}±0.08	3.100^{g}±0.08	3.771^{i}±0.26	5.733^{hi}±0.25	6.237^{l}±0.25	9.728^{g}±0.24	12.243^{i}±0.24	15.715^{k}±0.25
25CDDG	4.613^{d}±0.21	4.613^{d}±0.21	6.029^{g}±0.08	6.901^{g}±0.39	9.226^{f}±0.24	10.228^{f}±0.24	17.720^{e}±0.23	22.744^{g}±0.22
25CDDF	4.726^{d}±0.14	4.726^{d}±0.14	6.293^{g}±0.26	7.758^{f}±0.25	9.232^{f}±0.24	10.723^{e}±0.26	18.701^{d}±0.26	24.227^{d}±0.24
Mean	5.356	5.356	8.016	10.129	11.079	13.796	18.308	22.585
S.Eofmean	0.277	0.277	0.760	0.962	0.739	0.916	0.674	0.722
C.D	0.269	0.269	0.413	0.508	0.444	0.489	0.467	0.466
C.V%	2.929	2.929	3.010	2.929	2.340	2.067	1.490	1.203

Note: Values are expressed as mean ± standard deviation of three determinations Means within the same column followed by a common letter do not differ significantly at ($p \le 0.05$).

Table 3.2.4 Water activity of control and treated pearl millet grain and flour during shelf life study

Treatments	Water activity (a_w) during storage							
	0th day		30th day		60th day		90th day	
	MPP	LDPE	MPP	LDPE	MPP	LDPE	MPP	LDPE
CWG	0.350^{c}±0.01	0.350^{c}±0.01	0.413^{c}±0.007	0.524^{c}±0.001	0.519^{c}±0.002	0.634^{c}±0.005	0.686^{c}±0.002	0.706^{c}±0.002
CDG	0.440^{b}±0.04	0.440^{b}±0.04	0.514^{b}±0.001	0.635^{b}±0.001	0.625^{b}±0.002	0.746^{b}±0.001	0.704^{b}±0.002	0.823^{b}±0.002
CDF	0.547^{a}±0.03	0.547^{a}±0.03	0.625^{a}±0.001	0.741^{a}±0.001	0.737^{a}±0.002	0.851^{a}±0.002	0.821^{a}±0.002	0.999^{a}±0.008
30CDWG	0.187^{ef}±0.005	0.187^{ef}±0.005	0.209^{f}±0.001	0.224^{f}±0.001	0.219^{f}±0.002	0.234^{fg}±0.005	0.386^{h}±0.002	0.406^{hi}±0.002
30CDDG	0.203^{de}±0.005	0.203^{de}±0.005	0.214±0.001	0.235^{e}±0.001	0.225^{e}±0.002	0.246^{e}±0.001	0.404^{f}±0.002	0.423^{f}±0.002
30CDDF	0.213^{d}±0.005	0.213^{d}±0.005	0.225^{d}±0.001	0.241^{d}±0.001	0.237^{d}±0.002	0.251^{d}±0.002	0.421^{d}±0.002	0.444^{d}±0.002
25CDWG	0.173^{fg}±0.005	0.173^{fg}±0.005	0.193^{h}±0.001	0.210^{i}±0.001	0.211^{g}±0.002	0.221^{hi}±0.002	0.381^{i}±0.002	0.404^{i}±0.002
25CDDG	0.193^{def}±0.005	0.193^{def}±0.005	0.208^{f}±0.001	0.218^{g}±0.001	0.218^{f}±0.002	0.231^{g}±0.002	0.394^{g}±0.002	0.421^{f}±0.002
25CDDF	0.203^{de}±0.005	0.203^{de}±0.005	0.216^{e}±0.001	0.241^{d}±0.001	0.229^{e}±0.002	0.237^{f}±0.002	0.411^{e}±0.002	0.431^{e}±0.002
Mean	0.278	0.278	0.313	0.363	0.357	0.405	0.512	0.561
S.Eofmean	0.025	0.025	0.030	0.038	0.038	0.048	0.032	0.041
C.D	0.034	0.034	0.004	0.002	0.003	0.005	0.003	0.005
C.V%	7.204	7.204	0.827	0.331	0.616	0.752	0.438	0.592

Note: Values are expressed as mean ± standard deviation of three determinations Means within the same column followed by a common letter do not differ significantly at ($p \le 0.05$).

Table 4.19 Lipase activity of control and treated pearl millet grain and flour during shelf life study

Treatments	Lipase activity (LA)(Meq/ml) during storage							
	0th day		30th day		60th day		90th day	
	MPP	LDPE	MPP	LDPE	MPP	LDPE	MPP	LDPE
CWG	37.650^{a}±0.09	37.650^{a}±0.09	40.621^{c}±0.09	43.821^{c}±0.10	43.414^{c}±0.14	46.866^{e}±0.08	49.163^{e}±0.13	58.452^{e}±0.10
CDG	28.244^{b}±0.08	28.244^{b}±0.08	42.832^{b}±0.07	45.148^{b}±0.15	45.607^{b}±0.13	48.213^{c}±0.13	52.339^{d}±0.11	62.610^{b}±0.15
CDF	27.455^{c}±0.11	27.455^{c}±0.11	44.321^{a}±0.12	46.540^{a}±0.07	48.016^{a}±0.20	50.626^{a}±0.11	54.823^{a}±0.13	65.305^{a}±0.16
30CDWG	18.907^{d}±0.06	18.907^{d}±0.06	23.621^{g}±0.09	29.821^{g}±0.10	31.414^{h}±0.14	43.866^{g}±0.08	47.163^{gh}±0.13	56.452^{h}±0.10
30CDDG	15.717^{f}±0.12	15.717^{f}±0.12	26.832^{e}±0.07	33.148^{e}±0.15	34.607^{e}±0.13	47.213^{d}±0.13	50.339^{b}±0.11	59.610^{d}±0.15
30CDDF	14.164^{g}±0.14	14.164^{g}±0.14	28.321^{d}±0.12	34.540^{d}±0.07	36.146^{d}±0.20	48.626^{b}±0.11	51.823^{c}±0.13	61.305^{c}±0.16
25CDWG	17.352^{e}±0.09	17.352^{e}±0.09	20.492^{i}±0.11	26.716^{i}±0.10	28.255^{j}±0.10	40.860^{i}±0.09	44.020^{j}±0.05	53.540^{j}±0.12
25CDDG	14.190^{g}±0.13	14.190^{g}±0.13	23.642^{g}±0.09	29.825^{g}±0.11	31.437^{h}±0.13	43.962^{g}±0.02	47.309^{g}±0.14	56.629^{h}±0.12
25CDDF	12.581^{h}±0.10	12.581^{h}±0.10	25.178^{f}±0.15	31.406^{f}±0.13	32.92^{fg}±0.04	45.503^{f}±0.13	48.728^{f}±0.12	57.971^{g}±0.02
Mean	20.695	20.695	30.651	35.662	36.868	46.192	49.522	59.096
S.Eofmean	1.574	1.574	1.712	1.385	1.304	0.549	0.597	0.659
C.D	0.187	0.187	0.186	0.201	0.224	0.189	0.212	0.220
C.V%	0.529	0.529	0.355	0.330	0.355	0.239	0.250	0.218

Note: Values are expressed as mean ± standard deviation of three determinations Means within the same column followed by a common letter do not differ significantly at ($p \le 0.05$).

Table 4.20 Lipoxygenase activity of control and treated pearl millet grain and flour during shelf life study

Treatments	Lipoxygenase activity (LOX) % during storage							
	0th day		30th day		60th day		90th day	
	MPP	LDPE	MPP	LDPE	MPP	LDPE	MPP	LDPE
CWG	$17.147^{a}\pm0.06$	$17.147^{a}\pm0.06$	$19.527^{c}\pm0.08$	$21.346^{c}\pm0.19$	$22.816^{d}\pm0.09$	$27.627^{d}\pm0.08$	$33.980^{cd}\pm0.01$	$37.579^{f}\pm0.13$
CDG	$15.941^{b}\pm0.04$	$15.941^{b}\pm0.04$	$21.822^{b}\pm0.09$	$24.861^{b}\pm0.10$	$24.706^{b}\pm0.11$	$30.763^{b}\pm0.20$	$38.941^{b}\pm0.04$	$43.847^{b}\pm0.09$
CDF	$15.732^{b}\pm0.09$	$15.732^{b}\pm0.09$	$23.310^{a}\pm0.12$	$27.941^{a}\pm0.04$	$26.247^{a}\pm0.21$	$32.893^{a}\pm0.05$	$42.979^{a}\pm0.03$	$48.815^{a}\pm0.12$
30CDWG	$8.615^{c}\pm0.09$	$8.615^{c}\pm0.09$	$14.527^{fg}\pm0.08$	$16.346^{h}\pm0.19$	$20.816^{f}\pm0.09$	$24.627^{h}\pm0.08$	$28.980^{i}\pm0.01$	$34.579^{j}\pm0.13$
30CDDG	$7.707^{ef}\pm0.27$	$7.707^{ef}\pm0.27$	$14.822^{e}\pm0.09$	$17.861^{de}\pm0.10$	$22.706^{d}\pm0.11$	$25.709^{e}\pm0.10$	$30.941^{f}\pm0.04$	$36.847^{g}\pm0.09$
30CDDF	$7.783^{e}\pm0.13$	$7.783^{e}\pm0.13$	$15.310^{d}\pm0.12$	$17.941^{d}\pm0.04$	$23.442^{c}\pm0.12$	$27.893^{c}\pm0.05$	$34.030^{c}\pm0.05$	$40.815^{c}\pm0.12$
25CDWG	$8.135^{d}\pm0.19$	$8.135^{d}\pm0.19$	$13.953^{h}\pm0.03$	$16.153^{hi}\pm0.12$	$20.138^{g}\pm0.12$	$23.733^{j}\pm0.08$	$28.426^{j}\pm0.12$	$34.232^{k}\pm0.13$
25CDDG	$7.524^{f}\pm0.17$	$7.524^{f}\pm0.17$	$14.797^{e}\pm0.11$	$17.653^{fg}\pm0.12$	$22.354^{e}\pm0.14$	$24.883^{g}\pm0.07$	$30.112^{h}\pm0.15$	$36.448^{h}\pm0.11$
25CDDF	$7.497^{f}\pm0.11$	$7.497^{f}\pm0.11$	$14.896^{e}\pm0.07$	$17.806^{def}\pm0.09$	$23.319^{c}\pm0.16$	$27.713^{cd}\pm0.09$	$33.628^{e}\pm0.10$	$40.534^{d}\pm0.14$
Mean	10.675	10.675	16.996	19.767	22.949	27.315	33.526	39.299
S.Eofmean	0.782	0.782	0.659	0.760	0.341	0.555	0.874	0.877
C.D	0.256	0.256	0.165	0.215	0.233	0.179	0.328	0.212
C.V%	1.398	1.398	0.568	0.635	0.594	0.383	0.571	0.315

Note: Values are expressed as mean ± standard deviation of three determinations Means within the same column followed by a common letter do not differ significantly at ($p \leq 0.05$).

CWG-Control whole grain; CDG-Control dehulled grain; CDF-Control dehulled flour; 30CDWG-Cold plasma treated whole grain at 30kv for 10min; 30CDDG-Cold plasma treated dehulled grain at 30kv for 10min; 30CDDF-Cold plasma treated dehulled flour at 30kv for 10min; 25CDWG-Cold plasma treated whole grain at 25kv for 10min; 25CDDG-Cold plasma treated dehulled grain at 25kv for 10min; 25CDDF-Cold plasma treated dehulled flour at 25kv for 10min; LDPE-Low density polyethylene; MPP-Metalized polypropylene.

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