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Insights into Recent Techniques for Improving Shelf Life and Value Addition in Pearl Millet Flour: A Mini Review on Recent Advances

Suneha Goswami[1]*, Vinutha T[1], Ranjeet R. Kumar[1], Tejveer Singh[1], Ansheef Ali[1], M.C. Meena[1], Sumer Pal Singh[1], Keshram Dulait[2] and C. Tara Satyavathi[3]

[1]*ICAR-Indian Agricultural Research Institute, New Delhi 110012, India*

[2]*Institute of Chemical Technology, Bhubneswar 751 013, India*

[3]*ICAR-Indian Institute of Millets Research, Hyderabad 500 030, India*

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Abstract: Pearl millet is a climate resilient crop, which is nutritionally rich and has numerous health benefits. Despite its nutritional significance, pearl millet is not popular among the consumers and food industries due to poor shelf life and dough quality. To address these problems, researchers have studied various processing technologies like heat treatments (hydrothermal, near infrared rays, microwave, ohmic heating etc.), decortication, malting, germination and fermentation to enhance the shelf life of pearl millet flour. Studies on improving pearl millet dough quality were also reported, wherein vital wheat gluten was reconstituted in pearl millet flour for better dough quality. All these methods and technologies are discussed in this mini review. By adopting these technologies, pearl millet can replace wheat as a sustainable ingredient in many baked preparations and become a new staple food with better nutrition and health.

Key words: Dough quality, pearl millet, rancidity, shelf life, value addition.

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Praveen Kumar
R.N. Kumawat
R.K. Solanki
N.K. Jat

***Correspondence**

Suneha Goswami
suneha08@gmail.com

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In present scenario, climate change, water scarcity, rising food prices, increasing world population, and other socioeconomic effects are predicted to pose a serious threat to agriculture, food and nutritional security globally, particularly for the most vulnerable populations who reside in arid and semi-arid regions. These impacts present a challenge to scientists and nutritionists to investigate the production, processing, and consumption of alternative food sources in order to combat hunger and poverty. Numerous unconventional nutri-grains, such as pearl millet and other millets are vital sources of food on a global scale and play important part in the diet of humans. In terms of numerous nutritional components including iron, zinc, niacin, magnesium, phosphorus, manganese, potassium, and vitamins like vitamin A and vitamin B complex, pearl millet is even more nutrient-dense than rice and wheat (Kumar *et al.*, 2022). They are rich in fibre, important amino acids including methionine, threonine, and tryptophan, and protein. These unconventional grains including pearl millet offer health-promoting effects comparable to or even greater than those of fruits and vegetables due to its superior nutritional quality, which also protects against various non-communicable diseases such as diabetes, heart disease, obesity, blood pressure, and atherosclerosis (Rai *et al.,* 2008; Sharma and Choudhary, 2012; Jukanti *et al.,* 2016). Pearl millet being highly nutritious, several bio-actives derived from this crop can be used in developing nutraceuticals and functional foods. Despite all these advantages, pearl millet is less popular among consumers and occupy a lower position in the human food chain than grains like wheat and rice. The two major limitations associated with pearl millet are i) the rancidity and off-flavour development during storage of seven to ten days ii) poor dough-making quality because of lack of viscoelastic properties, which prevents them from being used to make regular bakery goods and chapattis. These two limitations, hinder the commercialization of pearl millet and its products.

Chemistry behind rancidity development in the pearl millet flour

Despite being extremely nutrient-dense and having a high therapeutic value, rancidity and off flavour during storage limited the pearl millet popularity among the consumer. Keeping quality of pearl millet flour is affected by a number of grain constituents, including lipids, phenolic compounds, sugars, volatile chemicals, free amino acids, short peptides, etc. (Ali *et al.,* 2022a). The flavour of pearl millet flour degrades during storage due to oxidation of fatty acids which results in the production of fatty acid-hydroperoxides and their derivatized aldehydes and ketones (Ali *et al.,* 2022b). Rancidity and the production of off-flavour have an impact on the taste, aroma, quality and nutritional value of flour. There are two important pathways responsible for causing rancidity in pearl millet flour (Goswami *et al.,* 2020) i) enzymatic rancidity and ii) non-enzymatic rancidity associated pathway. Enzymatic rancidity is mainly associated with four enzymes which are responsible for the production of off odour in pearl millet flour. These enzymes are namely lipase, lipoxygenase, peroxidise and poly phenol oxidase.

(i) Lipase are enzymes that catalyse the hydrolysis of triacylglycerol (TAG) to diacylglycerols, monoglycerols, glycerol and free fatty acids (FAs). It belongs to the class of serine hydrolases. It has an affinity for short-chain fatty acids, unsaturated fatty acids (oleic, linoleic, linolenic, etc.). In pearl millet lipase enzyme are present in pericarp and aleuron layer of the grain.

(ii) Lipoxygenase is a non-heme, iron containing dioxygenase that catalyzes the oxygenation of poly unsaturated fatty acids containing a cis, cis-l,4-pentadiene moiety to form conjugated diene hydroperoxide. The substrates for the enzymes are 18 carbon fatty acids, linoleic (18:2) and linolenic acids (18:3). The action of lipoxygenase generates very reactive compounds like free radicals, which can react with chlorophylls, carotenoids, ascorbic acid, phenols, α-tocopherol (Vitamin E) cause alteration of organoleptic properties and the colour. In pearl millet lipoxygenase (LOX) catalyzes the oxidation of polyunsaturated fatty acids and esters into the corresponding hydroperoxides.

(iii) Peroxidases are haemoproteins that catalyse the oxidation of a wide variety of substrates, using H_2O_2. Peroxidase enzyme can convert hydroperoxides into aldehyde and ketone. In pearl millet it converts the primary oxidation product of fatty acids i.e., hydro peroxides into secondary oxidation products i.e., aldehyde and ketones, which provide bitterness in teste.

(iv) Poly Phenol Oxidase (PPO) is a tetramer that contains four atoms of copper per molecule, and binding sites for two aromatic compounds and oxygen. The enzyme catalyzes the *o*-hydroxylation of monophenol molecules in which the benzene ring contains a single hydroxyl substituent to *o*-diphenols. Additionally, it has the ability to catalyse the oxidation of o-diphenols into o-quinones. PPO promotes the o-quinones' polymerization, which results in the production of the red, brown, or black pigments (polyphenols) that cause flour to become brown.

The pearl millet flour has relatively high lipid content (3-8%). Lipase enzyme is mainly responsible for lipid hydrolysis and produce free fatty acid (FFA). These FFA serve as substrates for the enzyme lipoxygenase (LOX), which produces the primary oxidative products known as lipid hydroperoxides. The

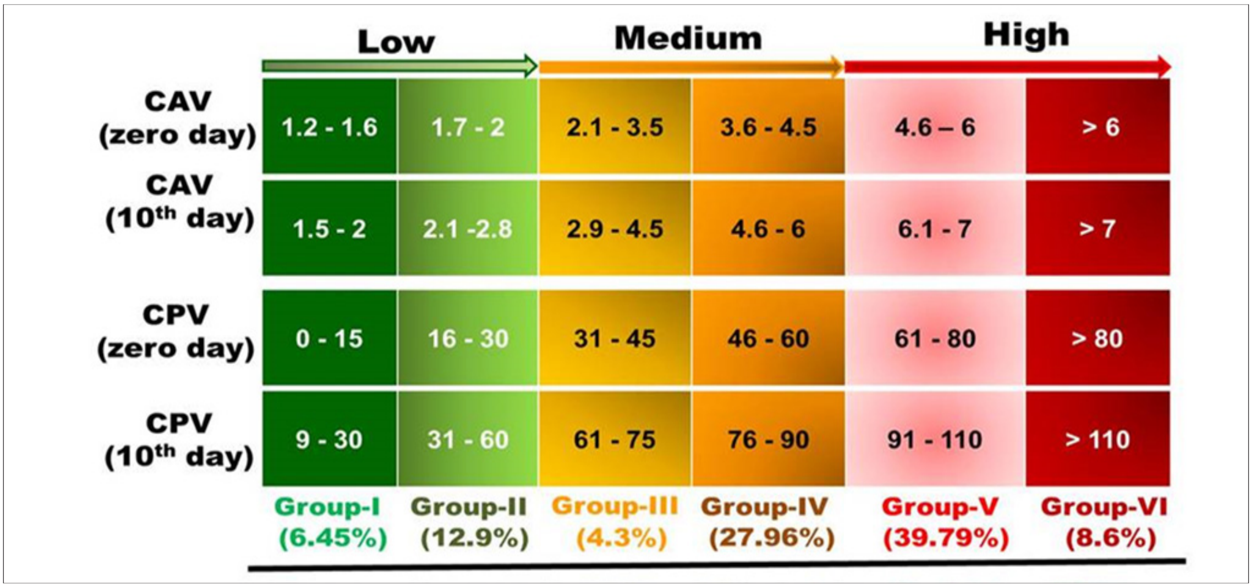

Fig. 1. Rancidity matrix developed (Goswami et al., 2020) to classify pearl millet genotypes into low, medium and high rancid categories and each category is further divided into two classes. CAV is comprehensive acid value; the number of milligrams of potassium hydroxide required to neutralize the free fatty acids present in 1 g of flour, CPV is comprehensive peroxide value: determination of the primary oxidation product i.e. hydroperoxides in the flour.

cellular enzyme machinery, which includes peroxidase (POD) and poly phenol oxidase (PPO), reacts with the lipid hydroperoxides to produce reactive oxygen species (ROS), which further attacks the FFA to produce more lipid hydroperoxides. The hydroperoxides undergo additional non-enzymatic oxidation to create secondary oxidation products such as aldehydes and ketone having pungent taste, which ultimately lead to the rancidity of the flour while it is being stored. Goswami *et al.* (2020), have developed a rancidity matrix to evaluate the rancid behaviours of pearl millet genotypes, which is based on the estimation of primary oxidation products *i.e.,* lipid hydroperoxides on the 10^{th} day after milling of pearl millet grains into flour (Fig. 1). The non-enzymatic rancidity occurs due to moisture, oxygen and light, which convert FFA into lipid free radicals, lipid peroxyl radicals and lipid hydroperoxyl radicals. These highly unstable radicals further converted into aldehyde and ketones and develop bitterness in the taste.

Post-harvest processing for improving the pearl millet flour shelf life

Processing of pearl millet is required to provide edible products that are stable in storage, enhanced nutrition bioavailability and have good sensory properties. So, it is the need of hour to optimize processing methods in order to improve the keeping quality and minimize rancidity in the pearl millet flour. Higher nutritious content and less rancidity may have greater potential to draw both customers and the food industry.

Seed coat of pearl millet comprise of pericarp followed by a single aleurone layer which forms bran. The pericarp is abundant in enzymes like POX and PPO. The aleurone layer of seed contains lipase enzyme, which is responsible for lipid hydrolysis. Besides this, seed coat also serves as a storage area for several bioactive substances such as phenolic compounds, iron, zinc etc. The process of decortication involves detaching of the seed's exterior pericarp layer, as a result, the decorticated grain flour has a lower content of iron, zinc, phenolics, essential amino acids like lysine, tryptophan etc. Other techniques that can be used to inactivate rancidity causing enzymes such as lipases include roasting, acid, and blanching treatment. Emerging technologies can also be used to extend the shelf life of pearl millet flour, including microwave, irradiation, ohmic heating, pulse electric field, and cold plasma treatments etc. (Fig. 2). Heat treatment is generally given at various moisture content levels depending upon the property of samples and it inhibits lipolytic enzymatic activity and helps in reducing the rancidity development (Vinutha *et al.,* 2023). For example, dry heat

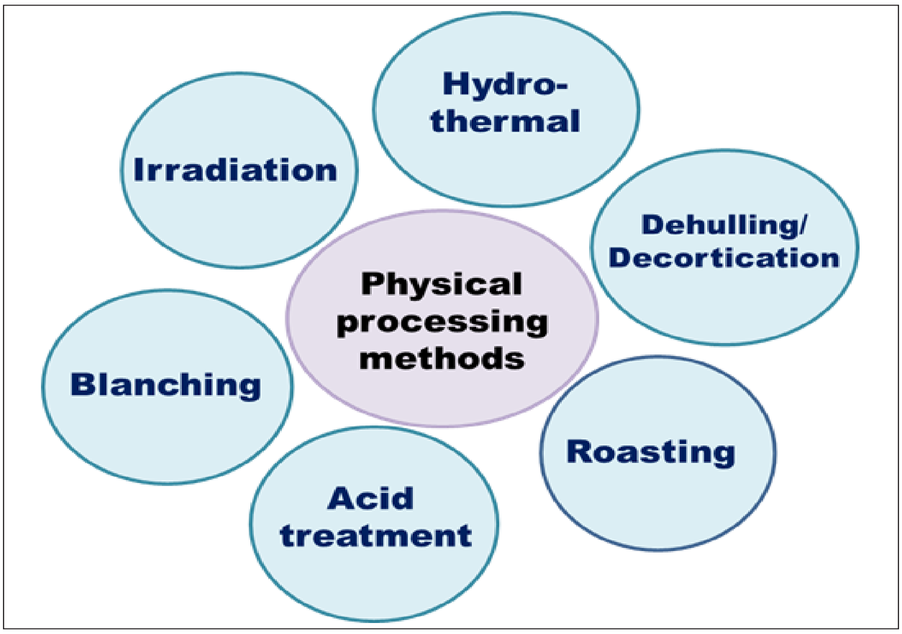

Fig. 2. Different physical processing methods for enhancing the shelf life of pearl millet flour.

treatment is most commonly given through oven heating (60-100°C). Irradiation thermal treatment can be given through gamma rays (0.1 to 1 KGy), infrared rays (light wavelength ranging between 780 nm to 1mm) and microwave heating (~2450 MHz). The ohmic heating instrument is equipped with titanium electrodes and enclosed on a Teflon tee. Samples are placed between the electrodes with an alternating current of 50 Hz with three different levels of electrical field strengths (EFS) (75, 150, and 225 V/m). A 1.5 KW capacity dielectric heater operating at 13.56 MHz can be used.

Malting is another potential processing method, which increases the availability of free amino acids, the *in vitro* digestibility of protein (14 to 26%) and starch (86 to 112%), as well as the bio-accessibility of minerals like iron and zinc (Archana *et al.,* 2001). Another alternative for pearl millet's processability is fermentation and enzymatic hydrolysis, which not only aids in food preservation but also offers a wide range of flavours and better nutritional characteristics. Vinutha *et al.* (2022) have developed a combined thermal treatments of hydro treatment-hydrothermal-near infrared rays (HT-HTh-thNIR) (Fig. 3) and reported the effectiveness of combined thermal treatment of HT-HTh-thNIR in reducing rancidity and preserving the functional properties of the stored flour upto 90 days. Hydrothermal treatment is a process of heat moisture treatment (HMT) given at elevated pressure that inactivate enzymes and impart changes in physico-chemical, nutritional and functional properties such as pasting properties, swelling properties, starch structural changes, and starch/protein digestibility. They examined how these thermal treatments affected the biochemical processes of hydrolytic and oxidative rancidity and found that HT-HTh-thNIR treated flour had significantly lower lipase (47.8%), lipoxygenase (84.8%), peroxidase (98.1%), and polyphenol oxidase (100%) enzyme activities than the individual treatments.

Post-harvest processing for improving the dough quality and value addition

Another important area of research for value addition of pearl millet flour is improving its dough quality that can benefits stakeholders involved in the processing of pearl millet flour and its subsequent application in the bakery and food industry. A report (Anonymous, 2022) stated a process to regenerate vital wheat gluten (VWG) viscoelasticity property in bajra flour, producing "Soft Bajra Atta" that has superior dough quality and is just as good as wheat dough. The impact of gluten reconstitution in pearl millet (PM-g) flour dough as well as how these doughs responded when made using the onset of gelatinization procedure (OGP), and were evaluated for Mixolab characteristics. The product developed by gluten reconstitution

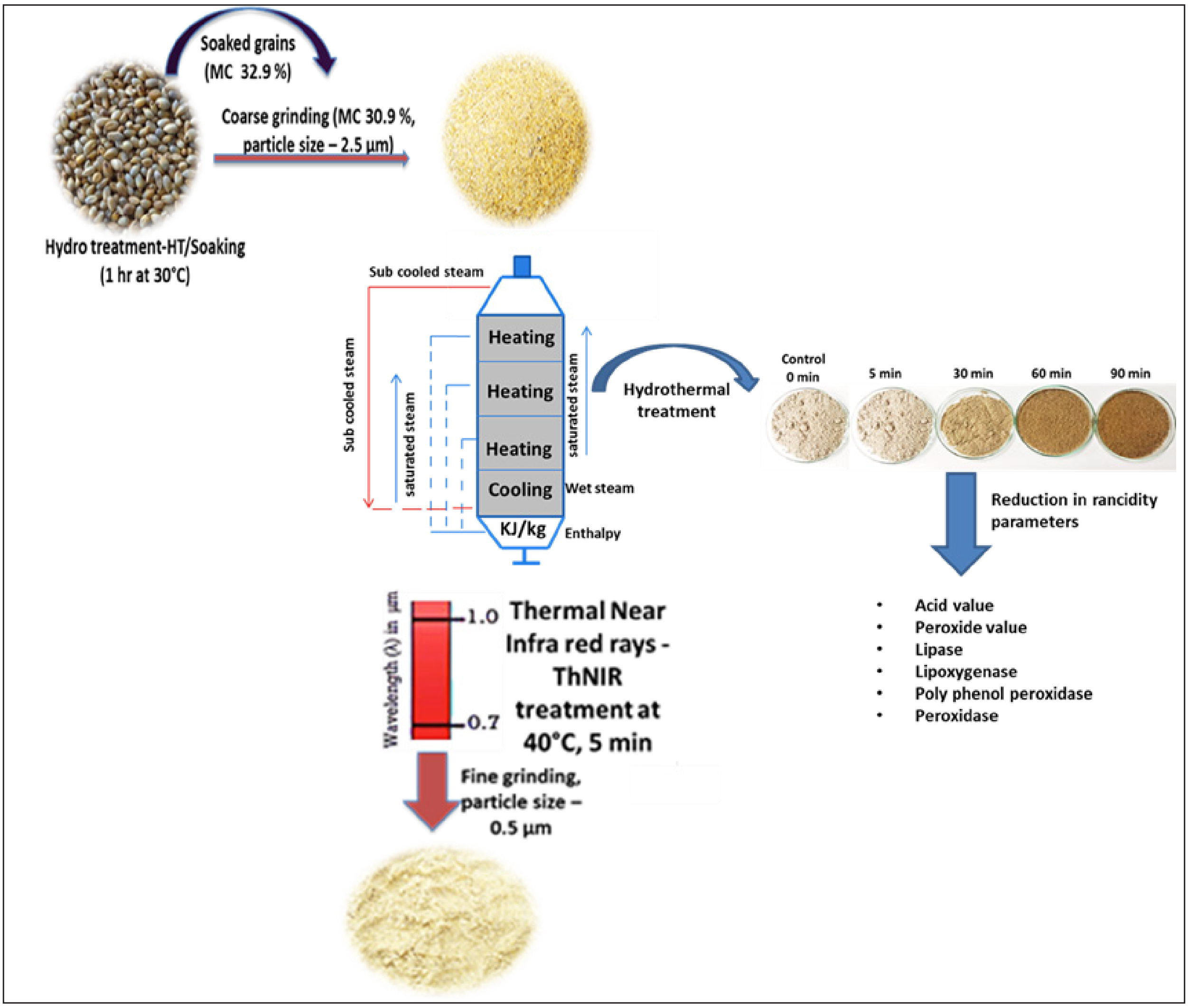

Fig. 3. Three step treatment of soaking, hydrothermal (HTh) and near infrared (NIR) rays. Initially, grains were soaked (Moisture Content (MC) - 32.9%) for 1 h and wet milled to a coarse particle size of 2.5 µm (MC - 30.9%) and subjected to HTh treatment of 5 min at 100°C (MC - 23.7%) followed by thNIR treatment for 5 min to bring down the MC < 14%. These treated samples were finely ground to a particle size 0.5 µm for all the biochemical and physico-chemical and structural analysis.

called a "Soft Bajra Atta" has the potential to replace wheat as a sustainable ingredient in many baked preparations and become a new staple food with better nutrition and health. But since the millions of people have gluten allergy, developing "Soft Bajra Atta" with improved dough quality without gluten reconstitution will require significant effort in the future.

Conflict of interest

The authors declare that they have no conflict of interest.

Acknowledgments

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