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Current Status and Way Forward

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सत्यमेव जयते

त्रिलोचन महापात्र, पीएच.डी.
एफ एन ए, एफ एन ए एस सी, एफ एन ए ए एस
सचिव एवं महानिदेशक

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FNA, FNASc, FNAAS
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Foreword

Pearl millet is the sixth most important crop globally, and is an important crop for Indian agriculture after rice, wheat, and maize in terms of total cropped area. Pearl millet is capable of growing in some of the most marginal and poor agro-ecologies where other cereals may not give profitable returns. It is often regarded as a climate resilient crop. Pearl millet is a crop of high nutritious value in terms of micronutrient density, starch profile, and protein quality and content. It also yields high biomass which forms nutritious forage, stover and feed. It requires fewer inputs and gives returns within a short span of 70-90 days, making it one of the most preferred crops in dryland agricultural systems, and livelihood support for the poor and marginal farmers.

However, with all these environment, farmer and consumer-friendly traits, pearl millet is not without an "*Achilles heel*". The flour of pearl millet tends to get rancid within few hours to few days after milling at normal room temperature and relative humidity. It develops a mousy odor and off taste which renders it unfit for human consumption and poses serious health risks. It is the single most important constraint to its utilization.

Unfortunately, very little attention has been given to pearl millet flour rancidity in the past, especially on the genetic and genomic fronts. There has been no organized attempt to address this problem. With this background, it gives me immense pleasure and sense of satisfaction to introduce the readers to this book on pearl millet flour keeping quality. This book provides all important information available and research done till date on various physical, biochemical and genetic interventions that are in place or may be attempted to tackle the problem of flour rancidity in pearl millet in our country and elsewhere in the world. This will help the readers appreciate the problem of flour rancidity and encourage public, private and food industry partners to work towards mitigating this major hurdle in popularizing and making pearl millet an economically viable option in dryland agriculture.

I appreciate the efforts of the authors in bringing out this timely publication.

(T. Mohapatra)

Dated: 20.11.2017
Place: New Delhi

Enhancing Demand of Pearl Millet as Health Food – Current Status and Way Forward

Pearl millet [*Pennisetum glaucum* (L.) R. Br.] is the staple food of majority of the poor and small land holders, as well as a source of feed and fodder for livestock in the rainfed regions of the country. Pearl millet excels all other cereals because it is a C4 plant with high photosynthetic efficiency and dry matter production capacity. It requires less inputs, matures in short duration and is considered as nutritious food, feed and fodder. It is usually grown under the most adverse agro-climatic conditions where other crops like sorghum and maize fail to produce economic yields. In India, pearl millet is the third most widely cultivated food crop after rice and wheat. It is grown on 7.128 million ha with an average productivity of 1132 kg/ha during 2015-16 (Directorate of Millet Development, 2017; Project Coordinator Review, 2017). The major pearl millet growing states are Rajasthan, Maharashtra, Gujarat, Uttar Pradesh and Haryana which account for more than 90% of pearl millet acreage in the country. Most of pearl millet in India is grown in rainy (*kharif*) season (June–September). It is also cultivated during the summer season (February–May) in parts of Gujarat, Rajasthan and Uttar Pradesh; and during the post-rainy (*rabi*) season (November–February) at a small scale in Maharashtra and Gujarat.

Pearl millet grain – Composition

The pearl millet grain is small but has a proportionally larger germ than all other cereal grains, except maize (Taylor 2004). The pearl millet grain comprises about 8% pericarp, 17% germ (which is proportionally large) and 75% endosperm (Serna-Saldivar & Rooney 1995). A thin waxy cutin layer covers the surface of the pericarp. Beneath the pericarp, is a thin layer of seed coat, and then a single aleurone layer (one-cell thick). Bran is hard outer layer of cereals which consists of combined aleurone, pericarp and part of germ. Generally the pericarp is thin, single layered with compact aleurone cells, but multilayered pericarp with loosely arranged aleurone cells is not uncommon (Hadimani *et al.* 2001). The colour of pearl millet grain is dependent on endosperm and/or the pericarp colour. The grain colour may be ivory, cream, yellow, grey, deep grey, greyish brown, brown, purple and purplish black (IBPGR/ICRISAT 1993). The most common and generally available colour is slate grey. The pearly-white grains produce creamy white flour that has advantage of competing with other cereal flours.

Pearl millet grain: A Grain with difference, Nutricereal

Pearl millet is rightly termed as "nutricereal" as it is a good source of energy, carbohydrate, protein, fat, ash, dietary fiber, iron and zinc. Pearl millet is a rich source of energy (361 Kcal/100g) comparable with sorghum (349 Kcal/100g), wheat (346 Kcal/100g), rice (345Kcal/100g) and maize (325Kcal/100g). The carbohydrate content of pearl millet is 67.5 g/100g; with 56 to 65% starch comprising 20 to 22% amylase and 2.6 to 2.8% free sugars mainly sucrose. It is high in fibre (1.2g/100g) and in α amylase activity, when compared with other grains. The protein content of pearl millet is (11.6/100g), comparable to wheat but higher than rice. It is rich in methionine but poor in Sulphur containing amino acids. With low prolamin fraction, pearl millet is gluten free grain and is the only grain that retains its alkaline properties after being cooked which is ideal for people with gluten allergy. Pearl millet is rich in fat content (5 mg/100g) with better fat digestibility as compared to other grains. It is rich in unsaturated fatty acids (75%) with higher content of nutritionally important n-3 fatty acids than other cereal grains. Higher activities of lipases result in rapid release of fatty acids, which limits its shelf life.

Pearl millet is a rich source of vitamins and minerals. Overall mineral content is 2.3 mg/100g constituting potassium, phosphorous, magnesium, iron, zinc, copper and manganese. It is rich in B-vitamins (thiamine, riboflavin and niacin). It has 3 fold higher levels of fat, which are rich in n-

3 fatty acids than wheat. Among micro-nutrients, it is loaded with minerals with relative abundance of Iron and Zinc. Vitamin content of pearl millet is equally good with higher Vitamin A and folic acid compared to wheat (Table1).

Pearl millet has high nutrient content but the nutrient bioavailability is low, inherent to the presence of certain anti-nutritional factors like phytic acid, polyphenol etc. Polyphenol content was found to range from 491 to 765 mg / 100g whereas phytic acid content ranged from 354 to 825.7 mg Protein and starch digestibility of pearl millet is low due to the presence of anti-nutrients in grains. Protein digestibility in pearl millet varieties range from 54.2 to 59.2 per cent. Starch digestibility of pearl millet has been reported to range from 12 to 18.7 mg maltose released/ g by various workers.

Table 1: Comparison in the nutritive value of pearl millet with Wheat and Rice (adapted from Vanisha et al 2011)

Nutrients	**Constituents (per 100g)**		**Pearl Millet**	**Wheat**	**Rice**
Macro nutrients	Carbohydrates	Sugars (g)	67.5	71.2	78.2
		Fiber (g)	1.2	1.2	0.2
	Proteins (g)		11.6	11.8	6.8
	Fats (g)		**5.0**	1.5	0.5
Micro nutrients					
Minerals	Calcium (mg)		42.0	41.0	10.0
	Phosphorous (mg)		296.0	306.0	160.0
	Iron (mg)		**8.0**	5.3	0.7
	Zinc (mg)		**3.1**	2.7	1.4
	Sodium (mg)		10.9	17.1	-
	Magnesium (mg)		137.0	138.0	90.0
Vitamins	Vitamin A (mcg)		**132.0**	64.0	0.0
	Thiamine (mg)		0.3	0.5	0.1
	Riboflavin (mg)		0.3	0.2	0.1
	Niacin (mg)		2.3	5.5	1.9
	Folic acid (mcg)		**45.5**	36.6	8.0

Food products and value-addition:

Processed pearl millet grains, and meals from them, are used to prepare various types of traditional and non-traditional food products. Murty and Kumar (1995) summarized and classified these into 9 major food categories (thick porridge, thin porridge, steam cooked products, fermented breads, unfermented breads, boiled rice-like products, alcoholic beverages, non-alcoholic beverages, and snacks); and they provided the details of their preparations and the various common names in many countries.

Traditional food products:

The simplest and the most common traditional food made from pearl millet are thin porridge (gruel); thick porridge (fermented and unfermented); flat and unfermented bread such as chapatti. Flat, unleavened bread prepared from pearl millet flour enriched with soy flour has been reported to have high protein efficiency ratio, minimal thickness, puffing, and uniform color and texture. Chapati prepared from pearl millet flour produced after the grains had been bleached or acid-treated or heat-treated has been reported to have enhanced overall acceptability as compared to the chapatti prepared from the raw untreated grains (Poonam, 2002). Use of processed flour, in comparison to raw flour, in the product development has been found to reduce anti-nutrients and increase the digestibility (Singh, 2003).

Pearl millet for diabetics:

Recently, millets are receiving increasing spotlight in combating diabetes as a dietary option (Henry and Kaur, 2014; Nambiar and Patwardhan, 2014; Muthamilarasana et al., 2016). Indeed, there are evidences to support that millets have many properties making it a good dietary option for diabetics. For an example, an experiment that has used diabetic mice to test different diets has concluded that added millet protein can increase insulin sensitivities, and reduce blood glucose level as well as triglyceride level (Nishizawa et al., 2009). Pearl millet is a sustainable cereal with superior glycemic control over wheat and rice. Genetic variations present in pearl millet germplasm for traits such as slowly digestible starch (SDS) and resistant starch (RS) known to contribute to low glycemic index (GI) in pearl millet.

Gluten free Pearl millet for celiac disease:

Celiac disease is an immune-mediated enteropathy triggered by the ingestion of gluten in genetically susceptible individuals (Catassi and Fasano 2008). A gluten-free diet primarily affects food consumption from the grain food group. In place of wheat, barley, and rye-based foods, persons adhering to a gluten-free diet must consume foods made from gluten-free grains, including rice, corn, sorghum, millet, amaranth, buckwheat, quinoa, wild rice, and oats (Thompson 2009). In the developed countries, there is a growing demand for gluten-free foods and beverages from people with celiac disease and other intolerances to wheat, barley, or rye. However, since millets are gluten-free, they have considerable potential in foods and beverages that can be suitable for individuals suffering from celiac disease (Taylor and Emmambux 2008; Chandrasekara and Shahidi, 2011c).

High Fat Content and Active Lipases- Flour rancidity: A bottleneck for storage

Despite having a nutrient punch, the full potential of pearl millet flour is limited due to rancidity and off odour during storage. High fat content coupled with highly active lipases causes hydrolysis of pearl millet fats to fatty acids. The typical fat content in pearl millet is about 5.1% on a dry weight basis. Pearl millet fat contains 74% unsaturated fatty acids [oleic (C18:1), linoleic (C18:2) and linolenic (C18:3)]. The remaining fraction is made up of saturated fatty acid residues (palmitic (C16:0) and stearic (C18:0)).The typical fatty acid profile of pearl millet triglycerides is presented in Fig. 1.

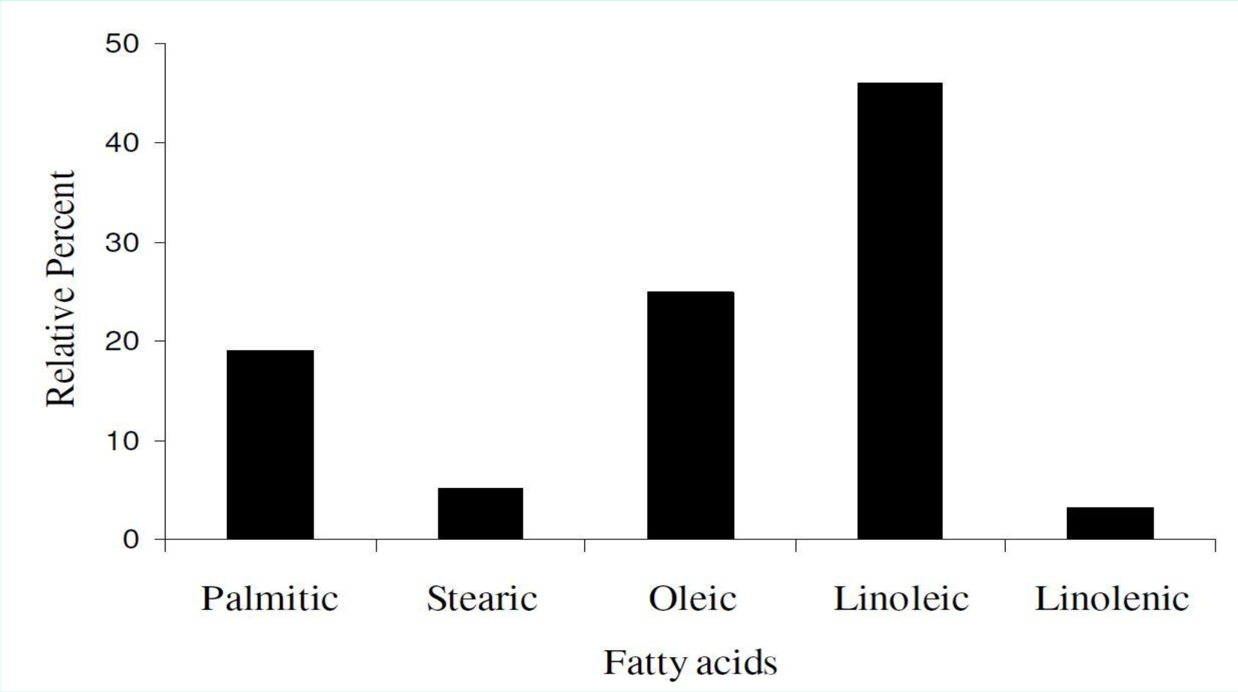

Fig 1: Typical fatty acid composition of pearl millet triglycerides (adapted from Rooney, 1978 and Nantanga, 2006)

Lipase (triacylglycerol acylhydrolase, E.C.3.1.1.3) enzyme, is concentrated in the pericarp, aleurone layer and germ and accounts for the stepwise hydrolysis of the triacylglycerol into diacylglycerol, monoacylglycerol, glycerol and free fatty acids. Since unsaturated fatty acids are in abundance, they get oxidised in presence of moisture and oxygen, resulting in undesired characteristics. It has been reported that pearl millet lipase shows relatively higher activity than that of most other cereal grains (Galliard, 1999).

Thus, the highly unsaturated nature of pearl millet fat coupled with the presence of the hydrolytic enzyme lipase causes rapid deterioration in the fat quality of pearl millet flour. Pearl millet is also reported to contain oxidative enzymes such as Peroxidases (Reddy *et al*, 1986) and "enzymatic browning" catalyzing enzymes such as Polyphenol oxidase (PPO), both of which play an important role in deterioration of pearl millet flour quality, immediately after milling of the grains, resulting in rancidity of the flour. Hence when pearl millet is milled into flour under conditions of moderately high moisture and oxygen exposure, chemical changes manifest themselves as off odors and/or off-taste of the flour or in products made from the flour.

Oxidative rancidity results in hydroperoxides (chain reaction through autoxidation) and subsequently generation of off-odour causing volatile secondary metabolites (aldehydes, ketones, acids, polymers etc.). Enzymatic rancidity results in free fatty acids by the action of Lipase and further generation of bitter and mousy odour causing phenolic aglycones, by the action of Peroxidase on C-glycosyl flavones (Eskin and Przybylski, 2001). Bitter compounds are also formed due to enzymatic browning by the action of Polyphenol oxidase (PPO). The schematic representation of the mechanism of onset of rancidity is presented in Fig 2.

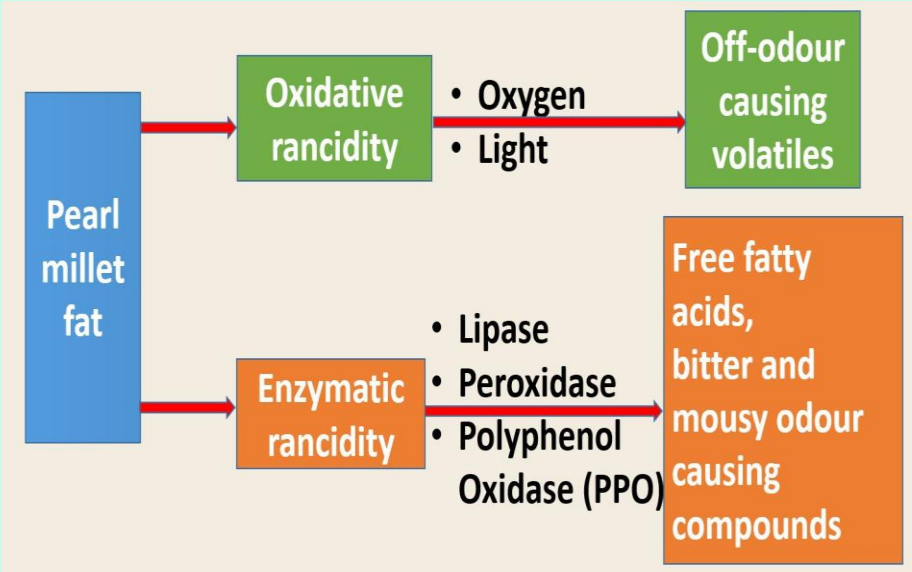

Fig. 2: Schematic representation of the rancidity mechanism (adapted from Datta Mazumdar et.al., 2016)

Pearl millet flour, can only be stored for short periods because it quickly gets rancid and develops an unpleasant odour. This adds to the drudgery of women in the household as traditionally pearl millet is hand pounded into flour, in an amount that is just enough for a few days of household use. The problem of rancidity also constraints the commercialization of pearl millet flour in the form of packaged shelf-stable pearl millet flour or use of pearl millet flour as an ingredient in the food processing industry. Hence, research needs to be carried out to understand the variability in the rancidity profile existing among lines in pearl millet germplasm collections, identify lines having low susceptibility to rancidity and explore the pre-processing, processing and post-processing options of using these low rancidity profile lines to obtain shelf-stable pearl millet flour. The ultimate aim is to reduce drudgery of women and further promote the commercialization and usage of this Nutricereal.

Past efforts addressing rancidity in Pearl millet:

The review of literature on status on research for addressing rancidity in pearl millet clearly show that the problem of rancidity in pearl millet needs to be addressed immediately through a holistic approach. It shall involve a combination of appropriate pre-processing and post-processing treatments both traditional (decortication or pearling to remove the oil rich germ, defatting of pearl millet flour using solvents, inactivation of enzymes responsible for hydrolytic rancidity, lowering the pH to inactivate enzymes, use of antioxidants to retard auto-oxidation of triglycerides, use of heat energy such as boiling-water blanching, dry heat application etc. to the flour, fermentation and malting, use of different packaging material, use of in package desiccants and oxygen scavengers etc.) and new, such as microwave treatment. Identification and use of low rancid pearl millet varieties and hybrids, and innovative packaging solutions along with the appropriate pre-processing treatments need to be explored as part of identifying the most suitable method (s) for tackling rancidity in pearl millet flours and in value-added product prepared from pearl millet. In the long run based on the data obtained for low rancidity susceptible pearl millet lines conventional breeding as well as molecular breeding approaches may be considered to overcome the problem of rancidity in pearl millet.

Table 2. Techniques/Methods used to overcome the problem of rancidity.

Name of Technique/ Method	Conditions / Treatments to grains	Tempera -ture/ Time	Uses/Effect on nutritional components/ Functional properties present in flour	References
Decortication	Wet/Dry	Ambient	Enzymes, fat, fibre, vitamins, phytate, micronutrients and phenolics are lost.	Traditional house hold method. Varriano-Marston and Hoseney, 1983; Abdelrahman et. al. 1983; Jain and Bal, 1997; Nantanga, 2006
Dry Heat	Heating Oven	100^{O}C, 2 hrs	Enzymes are inactivated. Antioxidants, vitamins may be reduced.	Pruthi (1981); Kapoor and Kapoor, (1990); Patel and Parameswaran, (1992); Chavan and Kachare (1994); Kadlag et al. (1995); Arora et al. (2002)
Use of different packaging material	Cotton and polyethylene bags for storage		Fat acidity increased rapidly in cotton bags compared to Polyethylene bags	Kaced et. al. (1984)
	gunny sacks, earthen pots, tin		Flour became rancid on days 6,7,8 and 10, and	Chaudhary and Kapoor (1984)

	cans and polythene bags		inedible on days 11, 12, 13 and 14 respectively	
Defatting of the flour	defatted pearl millet flour using n-hexane		Fat acidity and peroxide values (PV) did not change during one-month storage	Kapoor and Kapoor (1990)
Hygroscopic material in storage	lump of rock salt	Used for storage in earthern pots	unsuccessful in retarding triglyceride deterioration as the fat acidity level and peroxide values were almost the same for untreated and rock salted preserved flours.	Kapoor and Kapoor, (1990).
Blanching	Boiling water	98^{O}C, 30-120 Sec	Enzymes are inactivated. Phenolics are reduced. Minerals, antioxidants, vitamins may be reduced.	Chavan and Kachare, (1994); Kadlag et al. (1995); Palade et al, 1996
Use of antioxidants	BHA, BHT and ascorbic acid	Product Specific concentrati ons	No encouraging results	Kapoor and Kapoor (1990)
	BHA, BHT, Citric acid, TBHQ) tocopherols and a range of phenolics		inhibit the radical propagation stages in the triglyceride oxidation process	Eskin and Przybylski, (2001)
Germination and Malting	Incubator/ Oven	30 ^{O}C for Germinatio	Improves digestibility.	Akinola et al. (2017)

		n and 50^{O}C for 48 hrs for drying	Functional properties of flour are changed.	
Acid treatment	Diluted HCl, Acetic acid, Fumaric acid, tamarind	Ambient	Bleaching of colour. Improves digestibilty and colour of flour.	(Hadimani and Malleshi 1993)
Toasting and Boiling	-	-	Enzymes are inactivated. Non-enzymatic oxidative rancidity not controlled.	Natanga et al. (2008)
Storage at low temperature	Refrigerator	10^{O}C	Development of rancidity in slowed down. Amino acid profile is not affected.	Mohamed et al. (2011)
Microwave	Tempered grains to be treated at 18% moisture	100 sec	Enzymes are inactivated.	Yadav et al. (2012)

Current status in addressing rancidity:

Varsha and Narayanan, (2017) studied the effect of different pre-processing options on the rancidity and overall quality of pearl millet flours such as HDPE packaging and refrigeration, combination of fermentation and malting (Akinola et. al., 2017), and evaluating the best storage conditions to enhance the keeping quality of flour of four different pearl millet varieties, with respect to effect of storage containers and temperature on biochemical quality parameters, including monitoring of the marker Malondialdehyde used for determination of the extent of lipid peroxidation in pearl millet flours (Bhatt et. al., 2017). However, one area which is observed to have very limited research is in terms of understanding the variability in rancidity profile of different pearl millet varieties and hybrids.

Recently, Datta Mazumdar et. al., 2016 as part of ICRISAT's involvement in the CGIAR Research Program on Dry land Cereals carried out a study to evaluate suitability of popular Indian commercial varieties/hybrids for obtaining shelf-stable pearl millet flour. 56 commercial pearl millet lines (40 hybrids grown in India, 4 OPVs, and 12 hybrid parents) were profiled for peroxide and acid values (AV) of fat extracted from their flours. Two parameters indicating rancidity namely acid value (AV indicates enzymatic rancidity) and peroxide value (PV indicates oxidative rancidity) were monitored during the study. Flour from each variety/hybrid were stored under three storage conditions – Refrigerated (4°C), room temperature (25°C) and accelerated (35°C, 70%RH) and the acid and peroxide values of their extracted fat measured at regular intervals.

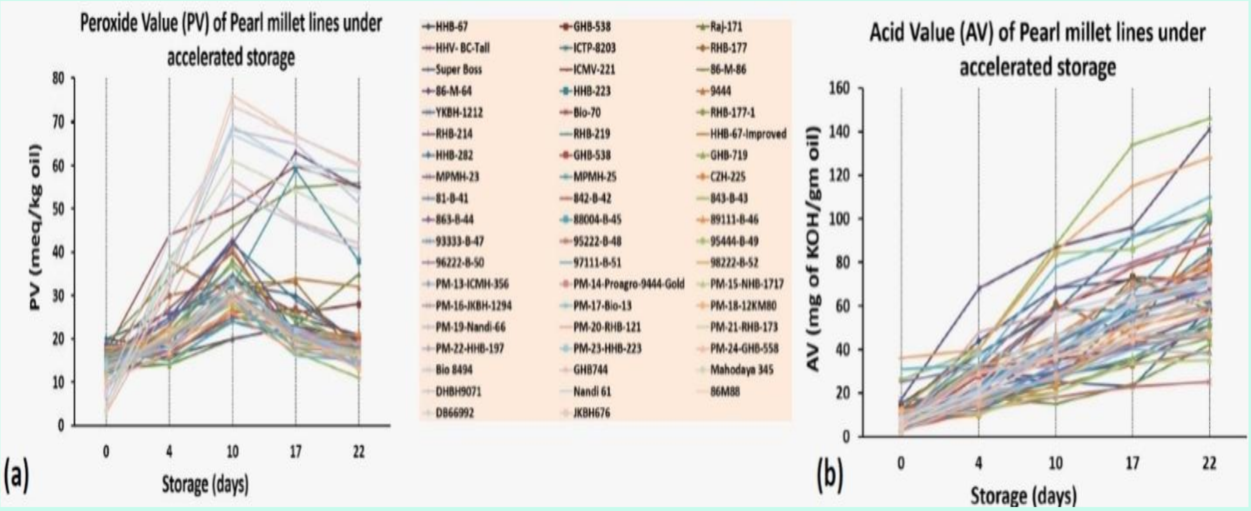

Fig. 3: Differential rate of onset of a) oxidative rancidity (PV) and b) enzymatic rancidity (AV) in pearl millet varieties/hybrids (adapted from Datta Mazumdar et.al., 2016).

The study clearly established the existence of diversity in the rancidity profile among the select varieties/hybrids of pearl millet studied. There was wide variability observed in the overall rancidity profiles (Fig. 3). Peroxide value was found to increase up to 10th /17th day and then decreased gradually (Fig. 3a). Acid value showed a continuous increase over the study period (Fig. 3b). 13 pearl millet varieties/hybrids least susceptible to rancidity were identified (Fig. 4). The study shows that pearl millet varieties/hybrids that are least susceptible to rancidity can be promoted for use in production of self-stable pearl millet flour in conjunction with appropriate pre-treatment, processing and packaging technologies. This proof of concept study needs to be further validated with pearl millet varieties/hybrids grown over different seasons.

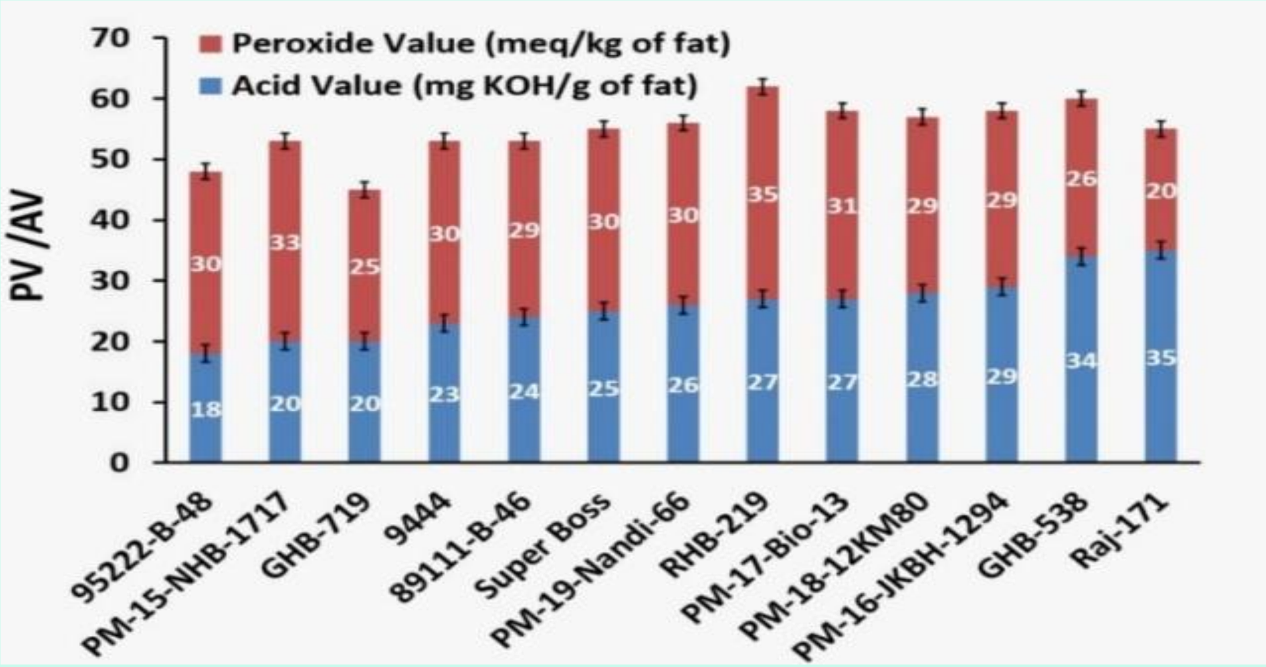

Fig.4: PV and AV (10th day) values of pearl millet varieties/hybrids howing least susceptibility towards rancidity. (adapted from Datta Mazumdar et.al., 2016).

The review of literature on status on research for addressing rancidity in pearl millet clearly show that the problem of rancidity in pearl millet needs to be addressed immediately through a holistic approach. Screening genotypes with biochemical and molecular markers for low lipase activity helps in developing hybrids and post harvest processing of pearl millet using different methods to down regulate or denature lipases is another approach.

Dark / grey colour of the pearl millet:

Inspite of good nutrition profile and several advantages utilization of pearl millet is low due to major constraints, like rapid development of rancidity or bitterness in the flour after milling, presence of various anti-nutrients like phytate and polyphenol and typical grey colour of the pearl millet. The flour when used in making preparations imparts dark colour to the product which in general consumer acceptance is poor. Work is underway in ICAR-IARI, New Delhi, CCSHAU, Hisar and ICRISAT to develop cream/ white coloured pearl millet genotypes.

Fig 5. The typical grey colour of the pearl millet and its products due to polyphenolic pigment present in peripheral area of grains restricts its efficient use in food industry.

Way forward in enhancing demand of Pearl millet

The main constraint in enhancing the demand for Pearl millet has been the problem of rancidity in pearl millet flour as well as in value added products prepared using pearl millet flour. Thus, as discussed in the earlier sections appropriate research and development, leveraging on the past and ongoing research activities, towards tackling the issue of rancidity in pearl millet flour is the most important intervention required for ensuring a sustainable demand for pearl millet.

In addition, focus on creating demand pull for pearl millet through an integrated value chain approach by linking the farmers to the markets need to be undertaken. Farm gate level pearl millet processing units equipped with primary and secondary processing machinery for directly processing the farmers produce, as per market demand shall result in additional income for the farmers, thus motivating them to grow pearl millet. These include equipment for destoning, sorting and grading, dehulling, roasting, pulverizing, shifting, flaking and packaging. The processing units may be run by Farmer Producer Organizations (FPOs) or women self-help groups involving the local farming communities especially the rural youth and women. Appropriate capacity building and leveraging of ICT technologies also needs to be encouraged. The effectiveness of these processing units needs to be demonstrated through pilot projects involving the establishment of processing facilities to be run by the local communities in a sustainable manner. The model proposed by the Agribusiness and Innovation Platform of ICRISAT for enhancing demand for dryland crops including pearl millet and ultimately resulting in enhanced income of the small holder farmers is presented in Fig. 6.

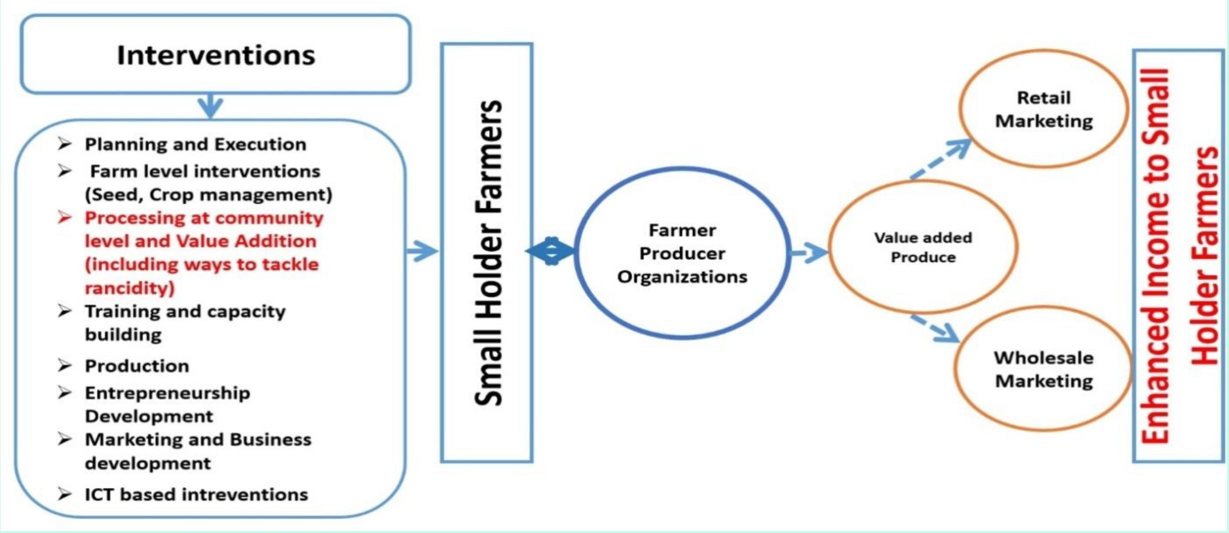

Fig.6: Model proposed by the Agribusiness and Innovation Platform (AIP) of ICRISAT for enhancing demand for pearl millet and enhancing income of the small holder farmers.

Creating demand pull for pearl millet is also linked to identification of market/consumer demand and further making available to the consumers scientifically validated value added food products. Thus, profiling and identification of pearl millet varieties with specific nutritional, nutraceutical and consumer preferred traits as well as development, validation and commercialization of new innovative pearl millet based value added food products is required. In addition, promoting enterprises linked to these innovations needs to be undertaken and these enterprises need to be provided business incubation support in order to ensure their sustainability. Awareness and communication campaigns directed towards creating awareness on the health benefits of pearl millet and pearl millet based value added products through print, electronic and social media also needs to be undertaken in order to create a demand sustainable demand for pearl millet.

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