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Effect of thermal pre-milling treatment on pearl millet and incorporation of psyllium husk in the formulation of vermicelli

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Abstract
Pearl millet is gluten free and nutritious but under-utilized particularly in urban areas because of various factors including limited availability of convenient/ready-to-cook/ready-to-eat pearl millet based food products. In this study, pearl millet grains were subjected to thermal pre-milling treatments like dry-thermal (roasting) and hydro-thermal (boiling) methods. Significant improvement on the functional quality and reduction in anti-nutrients were observed. Psyllium husk is a natural plant based functional food rich in soluble fiber and its incorporation with thermal treated pearl millet flours in different proportions produced desirable characteristic change to the dough in the development of ready-to-cook extruded food product vermicelli. Textural analysis of cooked vermicelli revealed significant improvement in the textural attributes of both the thermal treated vermicelli variations when compared with untreated/raw pearl millet vermicelli. Sensory evaluation of all versions of freshly cooked vermicelli in comparison with standard vermicelli made from refined wheat flour found that, untreated/raw pearl millet vermicelli with lesser (10%) psyllium husk incorporation could only match up with the scores of standard vermicelli, but dry-thermal treated (roasted) vermicelli with the same level of incorporation received a good overall acceptability, scoring more than the standard vermicelli. Above all, a remarkable overall acceptability was observed in hydro-thermally treated (boiled) pearl millet vermicelli with higher level of psyllium husk incorporation (30%), which suggest increased health benefit in this combination. Thus, the findings of the study could be effective in finding a replacement for refined wheat flour and increase the use of pearl millets in every day diet, particularly in gluten free therapeutic diets.

Keywords: pearl millet, roasting, boiling, psyllium husk, gluten free, vermicelli

1. Introduction

Pearl millet commonly known as bajra is one of the sixth important food cereal in the world and India is its largest producer (Kumara *et al*., 2016) [14]. Pearl millets are gluten-free, nutritious and are termed as nutricereal due to its rich source of energy, carbohydrate, protein, fat and ash, besides being a rich source of dietary fiber and minerals. Unfortunately, consumption of pearl millet in India for the past two decades depict a sharp decline both in rural and urban areas while its utilization is growing rapidly as fodder for livestock, poultry and also in alcohol manufacture. According to Amarender *et al*., (2013) [1], only 46 % of annual pearl millet production in India is utilized for food, while 37% is used for cattle feed, 7.7 % for poultry feed, 8.8% in alcohol industry and as low as 0.4 % for seed purpose.

This existing trend of under-utilization of pearl millet, which had also become a lesser known food source particularly in urban areas could be because of economic affluence coupled with fast moving life styles and also limited availability of convenient/ready-to-cook/ready-to-eat pearl millet based food products (Suma *et al*., 2014) [20]. And adding up to the limitation is the low shelf life of milled pearl millet flour and its restriction in bio-accessibility of nutrients which entails that pearl millet grains undergo pre-milling treatment before using it as a food (Sarita and Chauhan, 2017) [19]. Therefore, pre-milling/processing pearl millets before development of convenience food serves as an important driver to increase its utilization on a day-to-day basis.

Epidemiological and clinical studies have demonstrated the pivotal role of natural plant-based functional/nutraceutical foods in human health. A keen interest is expressed among health conscious citizens on search for foods that are not only nutritious but also with nutraceutical properties. This demand is gaining importance now a days and cereals are now employed in preparation of foods that are similar in appearance to conventional foods but with an added advantage of aiding physiological functions with nutritional benefits (Saikia *et al*., 2011) [18].

The plant psyllium, known as Ispaghul *(Plantago ovata)* is native to Iran and India. The husk covering the tiny seeds of psyllium contain glycosides and mucilages which possess gelling property thereby imparting textural changes when incorporated in foods. The soluble fiber in psyllium husk is not broken down as it passes down the gastrointestinal tract and hence has no nutritive value other than as a source of fiber (Karawya, 2003) [11]. Interestingly, the amount of soluble fiber in psyllium is much higher (100gms of psyllium provides 71gms of soluble fiber) and is useful in treating chronic constipation, to restore and maintain intestinal regularity, inflammatory bowel disease, ulcerative colitis, hemorrhoids and anal fissures (Baljit, 2007) [4]. And recently, the nutraceutical role of psyllium husk is well acknowledged in lowering blood cholesterol and blood glucose levels ensuring regularity of its consumption (Chaturvedi *et al*., 2011) [5]. With this background, an attempt was made to process pearl millet by thermal treatments (dry-thermal as roasting and hydro-thermal as boiling method) and incorporate psyllium husk in the formulation of a convenient, ready-to cook, gluten free extruded food product 'vermicelli' and study its textural and sensory characters. This application of novel research could be a huge potential in the development of contemporary pearl millet based extruded food products instead of refined wheat flour and thus revive the usage of pearl millets in our daily diet with an added advantage of psyllium husk for better health promotion and disease prevention.

2. Materials and Methods

Pearl millet grains (*P.glaucum*-Co4 variety) and psyllium husk were obtained from retail market and carefully cleaned up and freed from grain hairs and other foreign materials. Thermal pre-milling treatments were applied to pearl millet grains. Dry-thermal treatment was carried out by roasting pearl millets at 110º C for 60 sec because above this temperature and time, the grains either start puffing or burning (Tiwari *et al*, 2014) [22]. Hydro-thermal treatment was carried out by boiling (1:1 grain is to water) in a pan for 15 min, drained off water and wet grains were spread on a tray and dried at 60ºC for 2hrs (Jalgaonkar *et al*., 2016) [10]. Both the thermally processed pearl millets of this study, a control sample of untreated/raw pearl millets and raw psyllium husk were separately milled into fine flours and used for further purpose of the study.

2.1 Nutrient and Anti-Nutrient Analysis

All versions of pearl millet flour and psyllium husk were analyzed for nutrient and anti-nutrient properties using standard procedures with slight modification to the method of Wani *et al.,* (2013) [24] and AOAC (2005) [2] standard methods.

2.2 Preparation of Vermicelli

The three samples of the study (Untreated Pearl Millet Flour/control sample; UPMF, Roasted Pearl Millet Flour; RMPF and Boiled Pearl Millet Flour; BPMF) were sieved individually and incorporated with Psyllium Husk Flour (PHF) in 3 different percentages as 10% (V1; 90:10), 20% (V2; 80:20) and 30% (V3; 70:30) respectively. All the formulated composite flour mixtures were homogenized and mixed with required salt and water to prepare dough. It was then extruded to make vermicelli strands (UPMV- Untreated Pearl Millet Vermicelli, RPMV- Roasted Pearl Millet Vermicelli and BPMV- Boiled Pearl Millet Vermicelli) which were steamed for few minutes and dried at room temperature for 1Hr and then dried (cabinet drier) at 60ºc for 4 Hrs.

2.3 Texture Analysis

The texture analysis of all the cooked vermicelli variations were studied using TPA (Texture Profile Analysis) method and TA Perten Instrument TVT 6700 texture analyzer were used to measure the textural properties. Each cooked vermicelli samples were placed in the loading cell and double cycle compression was done as per the standard procedure.

2.4 Sensory Evaluation

The freshly cooked vermicelli variations were subjectively evaluated using a nine-point hedonic rating scale for sensory attributes like appearance, flavor, color, texture, taste and over all acceptability by a panel of 25 semi-trained judges on comparison with refined wheat flour vermicelli (V0; RWFV) as the standard.

2.5 Statistical Analysis

The data tabulated and reported is the average of triplicate observations. Statistical analysis of the results were determined with Microsoft Excel 2007 (Microsoft Inc., USA) and Duncan's test was applied to understand the significant differences among mean values.

3. Results and Discussion

3.1 Nutrient Analysis of Pearl Millet Flours

The nutrient analysis of all versions of pearl millet flour (Table 1) revealed the following. The pH concentration reduced in both RPMF and BPMF, which indicated better keeping quality of pearl millet flour. Ash is the rough estimate of non-combustible mineral content and both the thermal processed pearl millets flours showed a decrease when compared with untreated sample, with a marked reduction observed in hydro-thermal processed pearl millet flours which could be due to leaching of soluble inorganic salts while boiling (Habiba, 2002 and Mubarak, 2005) [15], and the reduction in dry-thermal treatment could be due to the destruction of mineral-rich outer bran portion of pearl millet during roasting (Hag *et al*., 2002) [9]. The total titratable acidity ranged from a highest in RPMF to the lowest in BPMF. Moisture plays a pivotal role in the storage life of millet flours and a reduction in moisture content increase the storability of flours. Moisture content was lowest in RPMF (5.46%) followed by UPMF (8.88%) and highest increase was observed in BPMF (12.52%). The lowest moisture content in RPMF was due to drying effect of roasting which was also observed by Komeine *et al*., (2008). Whereas, the highest increase of moisture observed in hydro-thermally treated BPMF was due to increased hygroscopicity of the flour as a result of boiling treatment (Natanga *et al.,* 2008) [16], but nevertheless it was below the maximum moisture content limit (13%) for pearl millet flours intended for human consumption, as recommended by FAO/WHO (2012).

Table 1: Nutrient analysis of pearl millet flours

S:No	Parameters	Untreated Pearl Millet Flour	Roasted Pearl Millet Flour	Boiled Pearl Millet Flour
1.	pH	7.2 ± 0.21	6.9 ± 0.29	6.6 ± 0.31
2.	Ash (g)	3.1 ± 0.11	2.7 ± 0.16	1.1 ± 0.08
3.	Total Titratable Acidity	43.3 ± 2.21	44.6 ± 2.17	32.2 ± 2.14
4.	Moisture (%)	8.88 ± 1.34	5.46 ± 1.13	12.52 ± 2.24
5.	Crude Protein (g)	8.2 ± 2.4	6.9 ± 0.29	7.6 ± 0.34
6.	Carbohydrates (g)	85 ± 2.47	78 ± 2.28	82 ± 2.41
7.	Fat (g)	2.4 ± 1.24	2.3 ± 1.11	1.9 ± 1.01
8.	Energy (Kcals)	394.4 ± 25.14	360.3 ± 21.31	375.5 ± 23.14
9.	Crude Fiber (g)	4.7 ± 1.02	4.3 ± 1.12	5.8 ± 2.24

Regarding proximate compositions (Table 1), crude protein decreased significantly in RPMF also reported by Sarita and Chauhan (2017) [19], which could be attributed to destruction of amino acids by dry heat processing method, and BPMF also showed a slight reduction than UPMF which could be due to degradation of millet proteins during hydro-thermal process. Though millets are a good source of protein, both thermal processing methods decreased their content when compared with the untreated flour. Regarding carbohydrate content, UPMF showed higher values than processed flours and similar observation was also reported by Fasasi, (2009) [8]. Regarding fat content, almost similar values were obtained in UPMF and RPMF, while a lower fat value was observed in BPMF which could be due to inhibition of lipase as a result of hydro-thermal treatment before milling (Nantanga *et al*., 2008) [16]. Regarding energy content, UPMF showed highest value when compared with both the thermal processing methods, and this significant reduction is attributed to the decline in fat, carbohydrate and protein values during thermal treatments. Regarding crude fiber, the apparent decrease in RPMF was due high temperature involved in dry-thermal treatment, while a remarkable increase in hydro-thermal processed BPMF indicated that the increase could be due to the ability of the grain fiber to hold water during boiling treatment, and this increase can play a beneficial role in maintaining good health and in treating diseases.

3.2 Non-nutrient analysis of pearl millet flours

The nutrient availability to human gut is constrained by certain inherent anti-nutritional factors found in pearl millet. This existing limitation use should not deter its consumption because anti-nutrients present in pearl millet can be effectively decreased by various processing methods like roasting and boiling. Reduction in anti-nutrient levels (Table 2) were observed in both the thermal processing methods of this study. Tannins leached out in the hydro-thermal treated BPMF showing marked reduction, also reported by Kumar *et al*., (2018) [13]. Dry-thermal treated RPMF also showed a decline in tannin levels because of High Temperature Short Time (HTST) roasting treatment which reduced anti-nutrients (Nirmala *et al*., 2000) [17]. This desirable reduction of tannins will increase digestibility of proteins, carbohydrates and increase the bioavailability of minerals in pearl millet (Kaushik and Grewal, 2017) [12]. Trypsin inhibitor is also an important anti-nutrient, and when present in the diet causes trypsin drop in the intestine resulting in decreased protein digestibility. Better reduction of trypsin inhibitor activity noted in RPMF could be the effect of heat treatment resulting in its destruction (Jalgaonkar *et al*., 2015), which is important in improving nutritional quality of pearl millets.

Table 2: Non- nutrient analysis of pearl millet flours

S: No	Parameters	Untreated Pearl Millet Flour	Roasted Pearl Millet Flour	Boiled Pearl Millet Flour
1.	Tannin (mg)	0.30 ± 0.01	0.26 ± 0.15	0.28 ± 0.11
2.	Trypsin inhibitor (mg)	0.17 ± 0.02	0.16 ± 0.02	0.13 ± 0.02
3.	Total Phenolic (mg)	58.6 ± 1.14	67.2 ± 2.14	61.2 ± 2.14

Pearl millet is gluten free and has unique phenolic compounds that lend it as a functional food that may impact health positively (Arya *et al*., 2013) [3]. Total phenolic content is a desirable non-nutrient property and this study (Table 2) observed that both the thermal treated samples had increased total phenolic content when compared with untreated sample. Any food sample with high phenolic content can be correlated to high anti-oxidant activity (Thippuswamy and Akilendar, 2005) [21], which extends it as functional food for better health. Millet phenols are reported to have anti-oxidant, anti-mutagenic, anti-oestrogenic, anti-inflammatory, anti-viral effects and platelet aggregation inhibitory activity (Devi *et al*, 2014) [26].

3.3 Fiber composition of psyllium husk flour

The fiber composition of psyllium husk flour (Table 3) revealed that, the total dietary fiber was 1.69g, of which 1.66g was as soluble fiber and 0.03g was as insoluble fiber. Psyllium is utilized mainly for its natural fiber content which is present in the husk of psyllium seeds. The milled seed husk is a white fibrous material and abundant in soluble fiber with hydrophilic gelling property. Upon absorbing water, the mucilaginous gel increases in volume by tenfold or more, imparting thickness and binding activity. This property had led to its increased use in food- processing industry in the production of ice cream and frozen desserts, instant juices, breakfast cereals and in bakery products like biscuits, cakes, breads and muffins with varying functional and health aspects (Zia *et al*., 2005) [25]. And added to this benefit is the significant role of psyllium husk in therapeutic applications (Verma and Mogra., 2015) [23] along with multiple health benefits when consumed in regular diet.

Table 3: Fiber composition of psyllium husk flour

S. No	Parameters	Value
1.	Total dietary fibre (g)	1.69 ± 0.07
2.	Insoluble fibre (g)	0.03 ± 0.02
3.	Soluble fibre (g)	1.66 ± 0.05

3.4 Texture Analysis

Based on the results (Table 4) gathered from texture analysis of cooked pearl millet vermicelli versions, it can be observed that the hardness value of all vermicelli samples were lowest at 10% psyllium husk incorporation (V1) and significantly increased as the incorporation level increased. Regarding cohesiveness, UPMV at 10% incorporation were least cohesive, while hydro-thermally treated BPMV sample at 10% level started with slight increased value but consistently declined as the incorporation level increased. Adhesiveness were lowest in UPMV when compared with the other thermal treated vermicelli samples. Regarding stickiness RPMV was less sticky than the other variations. Thus both the thermal pre-milling treatment of pearl millets had caused desirable changes to the flour characteristics thereby making the dough to yield the extruded food product vermicelli with improved textural attributes.

Table 4: Texture analysis of the formulated pearl millet with psyllium husk vermicelli variations

Variations	Hardness (N)			Cohesiveness (Ratio)			Adhesiveness (J)			Stickiness (N)		
	UPMV	RPMV	BPMV	UPMV	RPMV	BPMV	UPMV	RPMV	BPMV	UPMV	RPMV	BPMV
V1	15.13±0.008	20.28±0.21	24.44±0.02	0.77±0.01	1.14±0.02	0.98±0.015	1324.0±1.0	2284.3±3.41	1412.5±0.66	-1.56±0.01	-2.62±0.31	-1.64±0.08
V2	39.43±0.005	19.24±0.32	31.63±0.16	1.06±0.01	1,10±0.01	0.88±0.03	1328.8±0.57	5373.6±2.47	3999.4±0.32	-1.92±0.01	-5.82±0.20	-1.72±0.14
V3	44.88±0.15	30.16±0.02	33.52±0.04	1.02±0.15	1.25±0.03	0.77±0.02	1960.9±0.05	3611.4±3.12	3605.2±0.12	-2.33±0.015	-4.00±0.04	-4.16±0.02

Note: UPMV: Untreated Pearl Millet Vermicelli; RPMV: Roasted Pearl Millet Vermicelli; BPMV: Boiled Pearl Millet Vermicelli.
V1: Pearl Millet Flour- PMF (90) : Psyllium Husk Flour-PHF (10); V2: PMF (80) : PHF(20); V3 : PMF (70) : PHF (30).

3.5 Sensory Evaluation

The sensory evaluation (Table 5) of freshly cooked vermicelli made from untreated/raw pearl millet flour incorporated with psyllium husk (UPMV) in three different proportions (10%, 20% and 30%), in comparison with the standard refined wheat flour vermicelli (RWFV: V0) revealed that, appearance and flavor preference were highest in the formulated V1 and V2 vermicelli, which also scored more than the standard sample (V0). Regarding colour, V3 sample scored the highest preference and regarding texture V1 scored similar preference as that of the standard vermicelli (V0). Regarding taste, standard vermicelli (V0) was preferred most, followed by V3 sample. Overall acceptability revealed that only V1 with lesser (10%) psyllium husk incorporation, could matched up to the score same that of the standard vermicelli (V0), and as the incorporation level of psyllium husk increased in V2 and V3 samples, its acceptability declined respectively. However, the overall acceptability scores of all the untreated pearl millet vermicelli samples ranged between 8.30 and 8.10 in a 9 point hedonic scale, which implied a good preference level.

Table 5: Sensory evaluation of untreated/ raw pearl millet with psyllium husk vermicelli

Variation	Appearance	Flavour	Colour	Texture	Taste	Overall acceptability
V_1	8.00±0.66^{abcde}	8.20±0.78^{bcde}	7.70±0.82^{abcde}	8.10±0.73^{cdf}	7.90±0.87^{abd}	8.30±0.67^{bce}
V_2	8.00±0.47^{abcde}	8.00±0.81^{abc}	7.60±0.69^{abc}	8.00±0.66^{abe}	7.90±0.73^{abc}	8.10±0.56^{ab}
V_3	7.50±0.70^{abcd}	7.80±0.78^{abcde}	7.90±0.87^{defg}	8.00±0.94^{cdef}	8.10±0.56^{cdef}	8.20±0.63^{cde}
V0	7.60±0.84^{bcde}	7.70±0.67^{cde}	7.80±0.91^{abcde}	8.10±0.99^{cdef}	8.20±0.63^{abc}	8.30±0.67^{cde}

Note: Untreated/Raw Pearl Millet Flour (UPMF); Psyllium Husk Flour (PHF); Refined Wheat Flour (RWF).
V1: UPMF(90) : PHF(10) ; V2: UPMF(80) : PHF(20) ; V3: UPMF(70) : PHF(30) ; V0: RWF (100).

Regarding roasted pearl millet vermicelli incorporated with psyllium husk (RPMV), sensory evaluation found that (Table 6), the appearance scores were highest in V1 sample, while all the other samples including the standard sample scored lesser but with similar scores. Regarding flavor, both V1 and V3 samples scored highest, and regarding colour, V1 sample topped the other vermicelli samples. Regarding texture, only V1 matched with the standard V0 sample, while the other formulations scored a decline. Regarding taste, standard vermicelli (V0) was preferred the most, but closely followed by V1 and V3 samples. Overall acceptability of the dry-thermally treated (roasted) pearl millet vermicelli revealed that, V1 sample with 10% incorporation of psyllium husk received highest preference than the standard vermicelli (V0) made from whole wheat flour, while the other formulations could not match up with the standard vermicelli.

Table 6: Sensory evaluation of roasted pearl millet with psyllium husk vermicelli

Variation	Appearance	Flavour	Colour	Texture	Taste	Overall acceptability
V_1	8.10±0.73 ^{de}	8.10±0.73^{ef}	8.20±0.78^{efg}	8.40±0.96^{fg}	8.10±0.73^{ef}	8.60±0.51^{cde}
V_2	7.70±0.94^{abcde}	7.80±0.63^{abcde}	7.30±0.94^{cde}	7.50±1.08^{cdef}	7.80±0.91^{bcd}	7.70±0.94^{bcde}
V_3	7.70±0.94^{abcde}	8.10±0.56^{bcde}	7.60±1.07^{cde}	7.90±0.99^{bcd}	8.00±0.94^{abc}	7.90±0.99^{bcde}
V0	7.70±0.82^{e}	7.90±0.73^{e}	7.80±0.91^{g}	8.40±0.69^{g}	8.30±0.67^{f}	8.40±0.69^{e}

Note: Roasted Pearl Millet Flour (RPMF); Psyllium Husk Flour-PHF; Refined Wheat Flour (RWF).
V1: RPMF(90) : PHF(10) ; V2: RPMF(80) : PHF(20) ; V3: RPMF(70) : PHF(30) ; V0 : RWF (100).

Regarding boiled pearl millet vermicelli incorporated with psyllium husk (BPMV), sensory evaluation revealed that (Table 7), appearance scores was highest in the formulated V3 sample followed by V2 which scored same as that of the standard V0 sample. Regarding flavor, V3 sample scored the same as the standard V0 sample but the other two formulations received a slight decline, yet with similar scores. Regarding colour, V3 topped the preference followed by V1 sample, while V2 and V0 scored the least with similar scores. Regarding texture, V3 sample scored the highest, followed by V1 sample. Regarding taste, both V3 and V1 variations scored the highest, while V2 received similar score same as that of the standard sample. Overall acceptability of the hydro-thermally treated (boiled) pearl millet vermicelli revealed that, V3 sample with 30% incorporation of psyllium husk received a remarkable preference score than all the other samples including the standard vermicelli, followed by V1 sample scoring more than the standard vermicelli.

Table 7: Sensory evaluation of boiled pearl millet with psyllium husk vermicelli

Variation	Appearance	Flavour	Colour	Texture	Taste	Overall acceptability
V_1	$7.60{\pm}0.84^{e}$	$7.70{\pm}0.67^{ef}$	$7.80{\pm}0.91^{fg}$	$8.00{\pm}0.94^{fg}$	$8.10{\pm}0.56^{def}$	$8.20{\pm}0.63^{cde}$
V_2	$7.80{\pm}0.78^{bcd}$	$7.70{\pm}0.82^{bcde}$	$7.50{\pm}0.70^{cdefg}$	$7.60{\pm}0.847^{cd}$	$7.90{\pm}0.73^{ab}$	$8.00{\pm}0.66^{bcd}$
V_3	$8.00{\pm}0.81^{e}$	$7.90{\pm}0.73^{cde}$	$8.20{\pm}0.78^{defg}$	$8.10{\pm}1.19^{def}$	$8.10{\pm}0.73^{ab}$	$8.60{\pm}0.51^{cde}$
V0	$7.80{\pm}0.78^{a}$	$7.90{\pm}0.87^{a}$	$7.50{\pm}0.70^{a}$	$7.80{\pm}0.91^{a}$	$7.90{\pm}0.73^{a}$	$8.00{\pm}0.66^{a}$

Note: Boiled Pearl Millet Flour (BPMF); Psyllium Husk Flour (PHF); Refined Wheat Flour (RWF).
V1: RPMF(90) : PHF(10) ; V2: RPMF(80) : PHF(20) ; V3: RPMF(70) : PHF(30) ; V0 : RWF (100).

4. Conclusion

From the present study it can concluded that thermal pre-milling treatments (roasting and boiling) enhanced the functional attributes of pearl millets and significantly lowered the anti-nutrients namely tannin and trypsin inhibitor activity thereby improving the bioavailability of pearl millet nutrients. In the absence of gluten as in pearl millet, incorporation of psyllium husk, a natural plant based dietary fiber which is rich in soluble fiber along with other health benefits served as a potential ingredient in the development of extruded food product vermicelli. The combination of thermal pre-milling treatments of pearl millets along with incorporation of psyllium husk produced desirable characteristic changes thereby making extrusion easier and the formulated vermicelli acceptable with good textural and sensory properties, even outstanding the standard vermicelli made from refined wheat flour. Therefore, the formulated vermicelli could be effective in finding a replacement for refined wheat flour in production of ready-to-cook extruded food product like vermicelli and increase the use of pearl millet in every day diet with huge potential of desirable health benefits, particularly in gluten free therapeutic diets.

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