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RESEARCH PAPER

Effect of processing parameters on the gelation and sensorial characteristics of psyllium husk

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Abstract : Psyllium husk (PH) exerts functional, nutritional and prebiotic properties. However, when dispersed into water it easily forms viscous gel. The PH gel is difficult to swallow due to its sliminess which also reduces its acceptability appearance wise. In the present study, effect of processing treatments involving pre-dispersal grinding, blending, pH and exposure to heat were investigated on the rheological and gel forming properties of PH in water. It was found that pre-dispersal grinding of PH was favourable for its improved dispersion and sensorial characteristics. The pH of dispersion made no difference on the gel properties and with adequate blending treatment for 5 min, an extended heat treatment can also be avoided.

Abbreviations used: DF- Dietary fibre, PH-Psyllium husk, SVR- Sensory viscosity rating

Key Words : Blending, Gel, *Isabgol*, pH, Psyllium husk, Heating, Sliminess, Viscosity

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INTRODUCTION

Psyllium husk (PH, *Isabgol/Ispaghula*) is a rich source of dietary fibre. It comprises 24.05 % soluble and 71.96% insoluble dietary fibres (Singh *et al.,* 2021). According to the Indian Pharmacopoeia (2010), ispaghula husk (*isabgol*) consists of the epidermis and collapsed adjacent layers removed from the dried ripe seeds of *Plantago ovata* Forsk. There is a recent trend for plant-based diets, which are highly correlated with reduced incidences of heart issues (Joshi *et al.*, 2023). Due to its functional, nutritional and prebiotic properties, PH is known to bring various health benefits to human beings (Yadav *et al.,* 2016). Relief in constipation is the one important role that PH plays in maintaining the health of elderly people. India is a big exporter of PH to several countries including Europe, Japan, US and Canada. Plant-based foods are often associated with anti-nutritional factors (Singh and Arora, 2023). However, an intake of about 0.8% PH along with other dietary fibers as a part of diet has been found to not affect adversely the calcium absorption and retention or the true protein digestibility in the weanling rats fed on milk-based diet (Arora and Patel, 2019 and Arora, 2023). The USFDA has approved health claims for β-glucan (0.75 g/serving) and psyllium (1.78 g/serving) in reducing cardiovascular disease risk (Jenkins *et al.*, 2002). As a source of dietary fibre, PH is advocated for fortifying several functional food products and to replace fat in

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several dairy products including milk, *Kheer;* yoghurt and ice cream (Arora and Patel, 2015, 2017 and Perrigue *et al.*, 2009). Pyllium can be used as an emulsifier, stabiliser, and substitute for fat and for wheat flour (Zandonadi *et al.,* 2009). As a health-promoting food ingredient, in place of gelatin or starch-based thickeners, PH can be used in small doses to thicken food products just like carrageenan thickens soups and gravies (Arora, 2022b and Upadhyay *et al.,* 1979). Recently, an intake of 7 g of psyllium fiber daily has been recommended by Shanahan *et al.* (2020) to help control the risk for cardiovascular-related medical costs and for an improved quality of life in adults aged 45 years and above with LDL cholesterol levels of 130 mg/dL.

However, PH easily forms viscous gel which is difficult in swallowing and the slimy appearance of the gel reduces its acceptability. Therefore, in the present study efforts were made to develop PH dispersion with an acceptable drinking/eating quality by analyzing and understanding the effect of varying processing parameters on the gel forming and the organoleptic properties of PH dispersion.

Material and Methods

Psyllium (*Plantago ovata)* husk (PH) of brand 'Sat Isabgol', Palani Group (India) was sourced from local market Karnal. Commercial grade white crystalline sugar was obtained from the Experimental Dairy, National Dairy Research Institute (NDRI), Karnal.

Experimental methods :

For a sweetened dispersion, PH was first dry blended with ground sugar (@ 5.0%) and then added to water.

Effect of grinding, blending, pH adjustment and heating :

PH was preheated to 102±2°C either for 30 min or 60 min duration in hot air oven and allowed to cool before grinding into a fine powder either using Cyclotech 1093 sample mill (*Foss Techator*, Sweden) or in an Inalsa grinder at speed '2' for 3 min and sieved through 0.5mm sieve.

Water added with 0.5 per cent pretreated PH was blended by Lee hand blender at speed 'I' for 1.0, 2.5 or 5.0 min and adjusted to pH 4.5 using 1N lactic acid before heating to 63 °C /30 min in a water-bath and cooling to 25 °C.

Sensory responses :

Sensory evaluation of the samples was carried out by a panel of 9 judges from the Dairy Technology Division (NDRI, Karnal). Structured linear scale of 10 cm length with an intensity range of minimum to maximum (100 points) was developed for different attributes like appearance, consistency and flavour (Fig. A). The intensity of a given characteristic was registered by making a vertical linear mark at the appropriate point along the horizontal scale line. The numerical value of the intensity was read out on the scale at the point of the marking by measuring the linear distance from the lower extreme (1 mm being equivalent to 1-point score).

Physical responses :

Instrumental sedimentation was determined by centrifugation method using a Remi centrifuge. A 10 ml sample taken in a 15 ml conical-bottom, plastic centrifuge tube was centrifuged for 5 min at speed '5'. After centrifugation, the supernatant and the gel layer were read directly by viewing against the white light and then the supernatant and the gel layer was carefully decanted to read the volume of the pellet as sedimentation in millilitres.

Water holding capacity (WHC) of PH was determined by the centrifugation method as described by Holloway and Greig (1984). An ultra-high centrifuge (*IEC-B20A*, International Equipment Co., USA) and Freeze-drier/Lyophilizer (*Christ-Alpha 2-4,* Germany) was used for the determination of WHC. Approx. 0.1 g fiber sample taken in each of three tared 10 ml graduated round bottom centrifuge tube, was weighed accurately and added with 10 ml distilled and mixed well to make 1% dispersion. The test tubes transferred to a beaker and covered with a petri plate were held at 25±1°C for 24 h before subjecting to centrifugation in the ultra-high centrifuge (*IEC-B20A*, International Equipment Co., USA) at 12000 rpm (14167.3g) for 60 min. The supernatant was decanted and the pellet was frozen overnight in a deep freezer at -18°C and then freeze-dried in a freeze-drier/lyophilizer (*Christ-Alpha 2-4,* Germany) till a constant weight was reached. The water holding capacity (WHC) of the fiber was calculated (as the weight of water held per gram of dry material) as follows:

Water uptake = Weight of the wet pellet – Weight of the dried pellet

$$\text{WHC, \%} = \frac{\text{Water uptake x 100}}{\text{Wt. of dry pellet}}$$

Lot No.:__________________ Date:________________

Kindly evaluate the given samples by making a vertical linear mark and indicating the sample number along the horizontal linear scale for the respective attribute:

1. Sedimentation

Nil	Slight	Moderate	Heavy	Extremely heavy
(Excellent)	(Fair)	(Poor)	(Very poor)	(Extremely poor)
(100)				(0)

2. Appearance

Highly uniform/smooth	Slightly lumpy/rough	Moderately lumpy/rough	Definitely lumpy/rough	Extremely lumpy/coarse
(Highly acceptable)	(Acceptable)	(Fairly acceptable)	(Hardly acceptable)	(Unacceptable)
(100)				(0)

3. Consistency

Thin fluid	Moderately thick	Definitely thick	Considerably thick	Extremely thick
(Milk-like)	(20% milk conc.)	(Condensed milk)	(Custard-like)	(Gelly-like)
(100)				(0)

4. Mouthfeel

Highly smooth	Slightly slimy/grainy	Moderately slimy/grainy	Definitely slimy/coarse	Extremely slimy/gritty
(Highly acceptable)	(Acceptable)	(Fairly acceptable)	(Hardly acceptable)	(Unacceptable)
(100)				(0)

5. Flavour

No off-flavour	Slight off-flavour	Moderately off-flavour	Definitely off-flavour	Pronounced off-flavour
(Highly acceptable)	(Acceptable)	(Fairly acceptable)	(Hardly acceptable)	(Unacceptable)
(100)				(0)

Sign. / Name: __________________

Fig. A: Sensory evaluation card for pH dispersal

Apparent viscosity was measured using the Viscostar Plus model L viscometer (*Fungilab,* Spain) fitted with an LCP spindle (small sample adapter) at 20 °C. A Thermo Orion 420+ pH meter was used to measure pH.

Statistical methods :

The sensory evaluation data and gelation data was statistically analyzed for variance (ANOVA) using Excel-2000 Micro software.

Results and Discussion

Various physical processing parameters were investigated with regard to dispersibility of PH in water as a model medium because water as a dispersing medium enabled visual observation of the gel formed by the PH in it. The effect of various pretreatments and processing treatments on the dispersion of PH dispersal in water employed to improve the process of dispersion is discussed below:

PH gelation (0.5%) as influenced by pH, grinding conditions and heat treatment :

PH dispersion in water appeared to show 3 distinct zones namely sediment at the bottom, gel layer rising to the top and a clear liquid in between or at the top. A stable dispersion would mean that the gel layer was spread throughout the bulk without any perceivable sediment. The gel distributions as well as sedimentation of the dispersion as influenced by the pre-dispersal grinding of husk and pH of water were studied by an accelerated process involving centrifugation. Centrifugation of the dispersion resulting in a clear supernatant underlaid with the gel layer and sediment at the bottom could indicate the uniformity of the dispersion in terms of the spread (volume) of the gel layer. Data presented in Table 1 show that ground PH generally gave less sediment as compared to unground PH, the difference being statistically different (P < 0.05, ANOVA) when different blending times were used in the preparation of the dispersion. Further, with the increasing blending time, sedimentation decreased both in neutral as well as in acidic water (pH 4.5). Although minimum sediment appeared in the alkaline dispersions (pH 9.0) and maximum in the neutral dispersion (pH 7.0), the maximum blending time *i.e.*, 5 min yielded nearly similar sedimentation in all cases. With an increase in blending time, the dispersion of psyllium in water improved statistically significantly as indicated by the volume of gel layer (Table 1, ANOVA P < 0.05). Just like the outer portions of cereal grains *i.e.*, the bran, the fibrous portion of PH holds the water and provides several health benefits including relief in constipation (Arora, 2022a). Further, in the case of unground psyllium the acidic dispersion showed slightly smaller gel layer volume (8.4 ml for 5 min blending) as against neutral and alkaline dispersions (9.4 and 9.8 ml, respectively), whereas with ground psyllium both acid and alkaline dispersions showed much smaller gel volume (5.0 and 5.9 ml vs. 9.9 ml for the neutral dispersion). The amount of clear water layer (*i.e.* supernatant) upon centrifugation was inversely related to the gel layer, it being the smallest in the alkaline dispersion of the unground PH and neutral dispersion of ground PH (ANOVA P < 0.05). It thus appeared that although alkalization of water for dispersal of unground PH was desirable unlike acidification, neither alkalization nor acidification enhanced dispersibility of ground psyllium, neutral pH being generally more desirable. This

Table 1: Effect of pre-dispersal grinding of PH (0.5%) on viscosity and gelation with and without acidification/alkalization

Whether ground# or unground	pH of water	Apparent viscosity^		Sedimentation behaviour@								
		Before filtration (mPa.s)	After filtration@@ (mPa.s)	Sediment (ml) Blending## time			Gel layer (ml) Blending## time			Supernatant (ml) Blending## time		
				1.0 min	2.5 min	5.0 min	1.0 min	2.5 min	5.0 min	1.0 min	2.5 min	5.0 min
	Neutral	205.12^^	16.11	0.3	0.2	0.1	7.7	8.8	9.4	2.0	1.0	0.5
Unground	4.5	41.73	12.42	0.15	0.1	0.1	4.85	7.4	8.4	5.0	2.5	1.5
	9.0	151.76^^	28.6	0.1	0.1	0.1	8.9	9.8	9.8	1.0	0.1	0.1
	Neutral	38	32	0.2	0.1	0.05	8.8	9.8	9.9	1.0	0.1	0.1
Ground	4.5	29.48	34.64	0.2	0.1	0.05	4.8	4.9	5.0	5.0	5.0	5.0
	9.0	34.31	30.8	0.1	0.1	0.1	4.9	5.9	5.9	5.0	4.0	4.0
F-Value		0.82 (ns) treatment		2.21 (ns) pH			34.1* (s) pH			26.1* (s) pH		
		3.12 (ns) viscosity		6.73* (s) blending time			9.3* (s) blending time			5.6* (s) blending time		

Means of triplicates # P < 0.05

#In Inalsa grinder for 3 min at speed '2'

##Lee hand blender, speed '1'

@ Remi centrifuge, speed '5' for 5 min, 10 ml in 15 ml centrifuge tubes

@@ After filtration through double layered muslin cloth

^ LCP spindle; shear rate, 14.68 s^{-1}

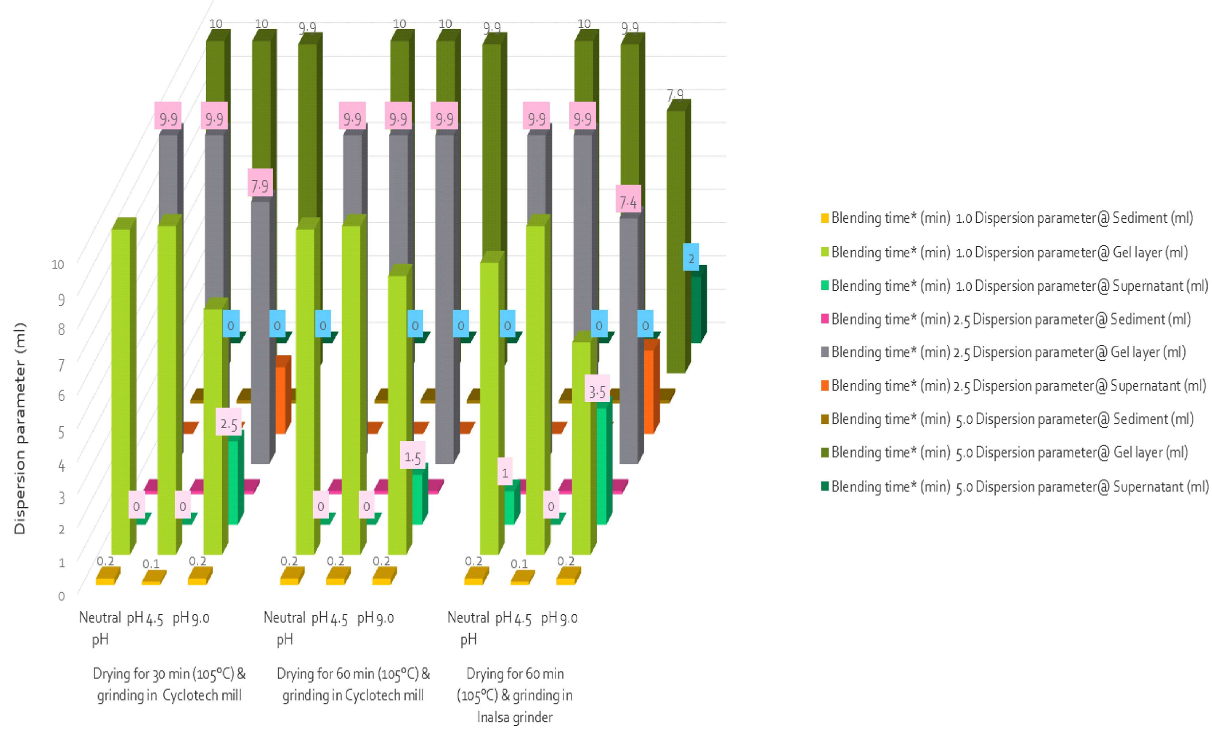
^^ Shear rate, 3.67 s^{-1}

is in agreement with the chemical nature of the psyllium fibre which is essentially a neutral arabinoglycan (Fischer *et al.,* 2004). Farahnaky *et al.* (2010) has also reported reported the PH gels (at 2 and 2.5%) as weak gels and the maximum functional properties of psyllium gum were seen at acidic or neutral pH. Use of PH as a part of dietary-fiber-blend to fortify yoghurt (pH 4.31) resulted in the product with slightly less firmness and more stickiness than the conventional yoghurt as measured using texture analyzer (Arora and Patel, 2015).

Generally, the viscosity of the dispersion is directly related to the gel volume. Table 1 also shows the effect of grinding on the viscosity of the filtrate obtained by passing the PH dispersion through a muslin cloth. It was found to be much smaller (12.4 to 28.6 mPa.s) than the dispersion itself (41.7 to 205.1 mPa.s) in the case of unground psyllium, however, such a difference was not so evident in ground PH which yielded a dispersion with lesser viscosity.

It is evident from the present study that pre-dispersal grinding of PH generally resulted in a better dispersion. The pre-grinding heating of PH and the degree of grinding as determined by the grinder used could influence the dispersion behaviour. Fig. 1 indicates that sediment (0.1 -0.2 ml) was not perceivably influenced by the drying conditions for any of the blending times studied. The gel-layer volume was slightly smaller, especially in the alkaline dispersion, when Inalsa grinder was used than when the Cyclotech mill was employed. The drying time did not make any difference when psyllium was ground in the Cyclotech mill except in the alkaline dispersion blended for 1 or 2.5 min. The effect of pH of water on the dispersion behaviour of psyllium was similar to that observed above (*vide* Table 1), alkaline pH showing generally poor dispersion although this effect was much less in the dispersion of psyllium ground in the Cyclotech mill. It was thus evident that when psyllium was ground effectively into a fine particle size (<0.5 mm) before dispersion in water and the dispersion was blended effectively (for 5 min), the pH of water made practically no difference on the dispersion.

The 5 min blending of ground psyllium in water



Means from triplicate
* Lee hand blender, speed 'I'
@ Upon centrifugation (10ml dispersion) in a 15ml centrifuge tube (speed '5') for 5 min

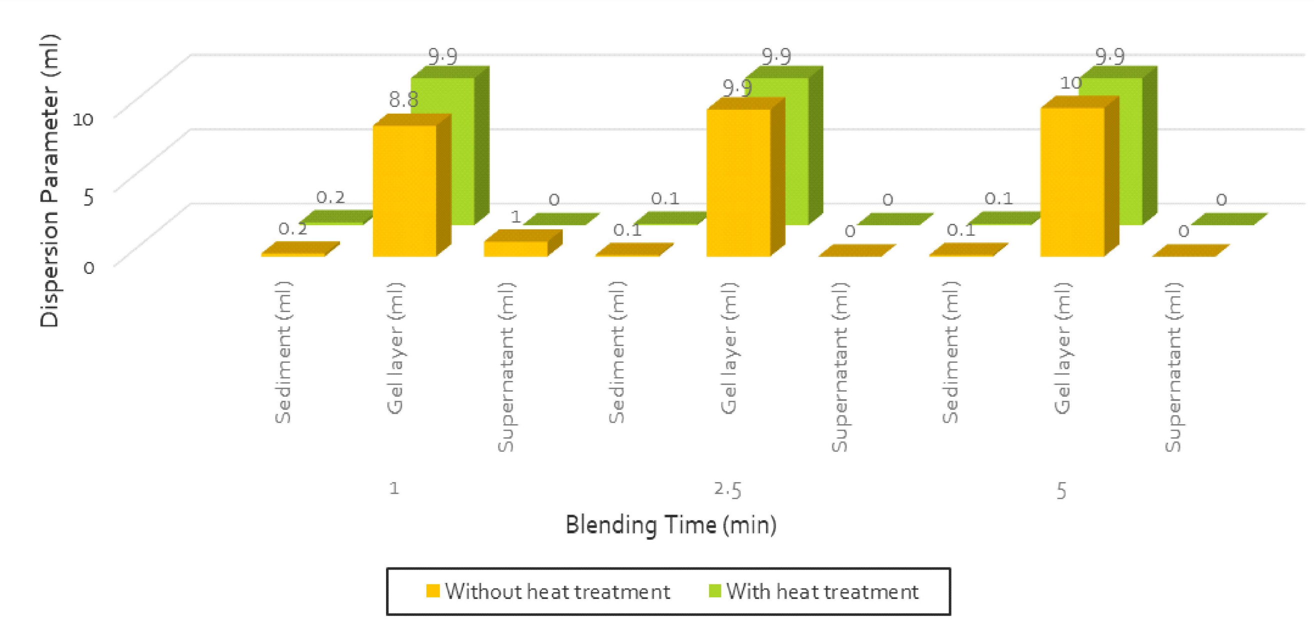
Fig. 1 : Effect of drying conditions for pre- dispersal grinding and blending time on dispersion of pH (0.05%) at different pH values at 25°C

was found to be more effective than smaller blending times (Fig. 2). When the predispersion was heated at 75°C/60 min before blending and compared with the dispersion without heat treatment, it was found that the heat treatment was slightly better, as indicated by the gel volume, when 1 min blending was carried out but it made no impact on the dispersion behaviour when blending was carried out for 2.5 min or more. Ren *et al*. (2020) also suggested that heat treatment does not influence water mobility in husk powder dispersions and found no significant rheological difference before and after heating on the PH dispersion using frequency sweep test. It could be thus concluded that with adequate blending treatment, extended heat treatment of the predispersion was not necessary.

Sensory properties of PH dissolved in water :

In the present study, PH yielded highly viscous solutions (0.5 %) or non-flowable gels (1.00-1.50 %). Sensory viscosity rating (SVR) of PH dispersed in water can be seen from Table 2, a lower value of SVR indicating higher viscosity. Soluble fibres mainly the gums like PH impart viscosity to the aqueous solutions (Ladjevardi, *et al*., 2015). PH forms a gel-like dispersion (Ren *et al*., 2020). The pure psyllium gum shows true gel formation, which is weaker gel at 2.0 and 2.5% but is a stronger gel at 3.0% concentration as revealed from the microstructure obtained by SEM images (Farahnaky *et al.* 2010). Fennema (1996) described slimy material as one that is thick, coats the mouth and is difficult to swallow. Slimy solutions are less pseudoplastic and give long flow (Fennema, 1996).

The grinding and blending treatment improved the sensorial characteristics (P<0.05%, ANOVA). At 0.5% level in water sweetened with 5% canesugar, significant difference between sensory score between dispersions with and without treatment were observed [*F value 11.83 is > F Critical 6.61 and P (0.018) < alpha (0.05)]. After the treatment of grinding and blending, PH (0.5%) resulted in an appreciably less thickening (consistency score SVR, 44) of the dispersion with better appearance (score, 32), less slimy mouthfeel (score, 68) and desirable coarse texture (score, 86) and flavour than PH dispersion (0.5%) without any grinding or blending treatment [*F value (11.83) > F Critical (6.61) and P (0.018) < alpha (0.05)]. PH is rich in polysaccharides with the plenty of OH-groups and contains various kinds of phytochemicals such as alkaloids, flavonoids, tannins, etc. (Patel *et al.,* 2016; Singh *et al.,* 2021) and shows shear-thinning behaviour *i.e.,* it shows decrease in viscosity with increase



^ Dried for 30 min (at 102°C) and ground in a Cyclotech mill

* Hand blender, speed 'I

@ Upon centrifugation (10ml dispersion) in a 15 ml centrifuge tube (speed '5') for 5 min

Fig. 3: Effect of pre- blending heat treatment (75°C/60 min) and blending time on dispersion of ground pH^ (0.05%) in water

Table 2 : Sensory evaluation of PH dispersed in water at different concentrations

Conc. (%)	Consistency (SVR)	Mean sensory score[# #]				
		Appearance	Sedimentation	Mouthfeel		Flavour
				Slimi-ness	Coarse-ness	
1.50	0	Turbid, whitish, translucent solution; on stirring: air incorporation but flowable: 1.25 and 1.5 % were non-redispersible gel				
1.25	0					
1.00	3					
0.50[$*]	24	20	43	46	80	82
0.50[#*]	44	32	51	68	86	83
*F value (11.83) > F Critical (6.61) and P (0.018) < alpha (0.05), hence significant difference between sensory score for 0.5 % PH dispersions with and without treatment						
0.25[$*]	79	58	86	70	92	88
0.25[#*]	96	62	95	77	98	90
*F value (12.27) > F Critical (6.61) and P (0.017) < alpha (0.05), hence significant difference between sensory score for 0.25 % PH dispersions with and without treatment						

Means of triplicates
[#] Dried at 105°C/30min, ground in the Cyclotech grinder and after dispersing in water blended in hand blender (5 min at speed 'I') and pasteurized at 63 °C /30 min and cooled to 25 °C
[# #]vide Fig. 1
[$] No grinding and no blending (PH added 'as such' whole)

in shear-rate (Arora *et al.,* 2016). This is a typical characteristic of non-newtonian fluids, wherein due to increase in shear rate the disentanglement of chains of molecules take place resulting in reduced viscosity. The sensory scores obtained after the treatment of grinding and blending for 0.25 % PH dispersion were significantly better with that of 0.5 % PH dispersions [*F value (10.62) > F Critical (6.61) and P (0.022) < alpha (0.05)]. Increase in concentration, leads to denser gel formation (Farahnaky *et al.,* 2010) which may be the reason for difficulty in swallowing and slimy mouthfeel at higher concentrations of PH. An increase in viscosity of *kheer* with the increase in the concentration of PH in dietary fiber blends were observed by Arora and Patel (2017). Due to water absorption, an increase in the viscosity of the cake batter has resulted with the increase in the psyllium content (from 2.5 % to 15%) (Beikzadeh *et al.*, 2016). In one of the studies, it was found that the PH-supplemented doughs have significantly higher storage modulus and lower loss tangent values than control samples relating to more elastic and solid-like characteristics (Peressini *et al.*, 2020). The USFDA has approved health claims for psyllium (1.78 g/serving) in reducing cardiovascular disease risk (Jenkins *et al.*, 2002). In the present study, PH dispersion of 0.5% was examined for improved dispersibility in terms of sediment, gel layer and supernatant formed. However, a 240 ml serve with 0.5% PH prepared using the above processing methods will provide only 1.2 g of PH.

Water holding capacity :

The physiological function of DF is often related to Water holding capacity (WHC) of PH. The dispersion of PH (preheated at 102°C/30min, ground in Cyclotech grinder, @1.0% by wt.) showed high WHC of 61.36 g/g (range: 56.2 – 64.7) which could be related to its gel-forming characteristic. The -OH groups and –OH of alcohols dominates in PH as detected by the Fourier Transform Infra Red Spectroscopy stretching vibrations at 3447 and 3207 cm^{-1}, respectively are quite hydrophillic in nature and shall be responsible for such a high WHC of PH (Farahnaky *et al.,* 2010).

Conclusion :

PH which comprises both the soluble and insoluble dietary fibres has been the most widely acknowledged fibre ingredient with proven dietary benefits. Sensorially, its dispersion into water has acceptable colour and taste but poses difficultly during eating and the slimy appearance reduces its acceptability further. Pre-dispersal grinding and blending of PH (both at 0.5 % and 0.25 %) showed statistically improved dispersion and better sensorial quality requiring lesser heat treatment. The pH of dispersion made no difference on the gel properties. In future, there is a need to further investigate the possibilities of developing PH dispersion having at least 0.75% concentration so that a serve of 240 ml can provide 1.8 g PH with the health claim for reduction in cardiovascular disease risk.

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