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Article

The Impact of Waxy Wheat Flour, Inulin and Guar Gum on Post-Prandial Glycaemic and Satiety Indices, Sensory Attributes and Shelf Life of Tandoori and Pita Breads

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Abstract: The purpose of this study was to develop two different functional breads (Pita and Tandoori) supplemented with novel functional ingredients: waxy wheat flour (15%), inulin (8%) and guar gum (2%) independently and in combination. The breads were submitted to sensory characteristics, shelf life, glycaemic and satiety indices assessments. Both guar gum and inulin independently and in combination significantly ($p < 0.05$) decreased post-prandial blood glucose and glycemic response of Pita (GI of guar gum bread was 55%, inulin 57%) and Tandoori (GI of guar gum bread was 57% and inulin bread was 60%) compared to the control breads (GI 100%). Moreover, the results of the area under the curve of satiety showed that the addition of functional ingredients increased satiety levels as follows: for Pita, control was 355, a combination of all ingredients was 418, inulin was 451 and guar gum was 452; for Tandoori, control was 329, a combination of all ingredients was 420, inulin was 381 and guar gum was 390. The results showed that all sensory characteristics were improved, and breads were acceptable (all obtained more than five points) when the highest proportions of ingredients were added. Similarly, the shelf life of supplemented Pita and Tandoori breads was improved with the addition of ingredients. Therefore, the functional ingredients such as inulin and guar gum can be used independently and in combination to reduce GI and increase satiety of Pita and Tandoori bread with acceptable quality and shelf life.

Keywords: glycaemic index; satiety index; sensory evaluation; inulin; guar gum; Pita and Tandoori breads



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1. Introduction

The demand for healthier dietary products among the public is rising. Cereal products high in functional ingredients (FI) such as dietary fibres (DF) are of particular interest. This is due to the fact that dietary fibres can have several benefits [1], including reducing risks of cardiovascular diseases, diabetes mellitus and different cancers [2]. Nevertheless, consumers expect acceptable shelf life and reasonable sensory properties, and these characteristics might be affected by the addition of FI. Crumb quality and texture are especially affected by FI additional to breads [3,4].

Several FI are incorporated in cereal products such as breads to improve the nutritional content and sensory characteristics. Different types of fibre also have differing effects on post-prandial blood glucose levels. Insoluble dietary fibres have less of an influence on the glycaemic index (GI), but soluble dietary fibres were found to reduce the glycaemic response and increase satiety [5].

Several studies used FI independently, including inulin (IN) [5] guar gum (GG) [6] and Waxy wheat flour (WWF) [7] in order to impart functional properties. These were

used for different purposes, including improving glycaemic and satiety indices, extending shelf life and improving the sensory characteristics of cereal products such as breads. To the researchers' best knowledge, research has not been performed on the use of these FI independently and/or in combination on Pita and Tandoori breads.

Therefore the aim of this work was to assess the post-prandial glycaemic and satiety indices of Pita and Tandoori breads supplemented with FI; inulin (IN), guar gum (GG) and waxy wheat flour (WWF). A secondary aim was to assess the sensory characteristics and shelf-life of the supplemented breads.

2. Material and Methods

2.1. Experimental Design

Following our previous study [8], Pita and Tandoori breads were supplemented with IN, GG and WWF independently and in combination (Table 1). All the materials were purchased from local markets in Plymouth, UK. Furthermore, after first testing the quality parameters, the highest proportions of the FI were selected independently and in combinations as follows:

Table 1. The proportion of functional ingredients supplemented into Pita and Tandoori breads [8].

Treatments	Proportions of FI		
	WWF (%)	IN (%)	GG (%)
Control	0	0	0
All FI	7.5	4	1
IN	0	8	0
GG	0	0	2
WWF	15	0	0

FI = Functional ingredients, WWF = waxy wheat flour, IN = inulin and GG = guar gum.

2.2. Glycaemic Index Assay of Bread (In Vivo)

On average, nine volunteers from staff and students at the University of Plymouth aged 29 to 50 years participated in each test (Table 2). All gave written informed consent. The exclusion criteria included obesity (BMI > 30 kg/m²), kidney problems, diabetes and allergy to foods. Height was measured using a stadiometer (Seca Ltd., Birmingham, UK), and weight was measured using a Tanita BC-418MA device (Tanita UK Ltd., Yiewsley, Middlesex, UK). BMI was calculated accordingly Weight (kg)/Height (m)².

Table 2. Participant information (*n* = 9).

No.	Gender	Mean Age (Year)	Mean BMI (kg/m ²)
Total	7 males	35.7 ± 10.7	22.4 ± 7.8
9 volunteers	2 Female		

After overnight fasting of 9–11 h, participants consumed an amount of bread sample containing 50 g of digestible carbohydrate with tea (no sugar and no milk). The meals were finished within 15 min. Finger prick blood samples were taken at 0, 15, 30, 45, 60, 90 and 120 min, and blood glucose readings were taken using a glucometer (Accu Chek Aviva monitor). Each supplemented bread sample was consumed by nine volunteers except the controls that were consumed three times. The area under the curve (AUC) was mathematically calculated using the Food and Agriculture Organization standard method [9]. The GI was calculated following this equation:

$$\text{GI value for the sample (\%)} = \frac{\text{mean AUC for the sample}}{\text{mean AUC for the reference food}} \times 100$$

2.3. Satiety Assessment

The volunteers were asked to document their level of satiety with each blood sampling time from 0 zero time to 120 min on a 7 point system from extremely hungry (1) to extremely satisfied (7). The baseline was considered as zero, and then the S AUC was computed for all the samples and the satiety index was computed by dividing S AUC values by the mean bread S AUC and multiplying by 100.

2.4. Shelf Life Assessment (Staling)

After baking and cooling down the samples, they were placed in impermeable plastic bags and stored at normal room conditions using a temperature data logger monitor.

For Pita breads, springiness and hardness are important as they are used to indicate freshness. Circles of Pita bread were cut 20 mm in diameter from the centre of the bread to assess for hardness, chewiness and springiness at 0, 3, 6, 9 and 12 days using a texture analyser (TA-TX2-Stable Micro System, Godalming, UK) following the test settings: pre-test speed: 1 mm/s; test speed: 1 mm/s; post-test: 1 mm/s; strain 60%. Ten runs for each sample were completed. For Tandoori breads, elasticity and toughness are normally used by consumers to check freshness. Therefore, Tandoori samples were cut into four pieces to assess extensibility and toughness at 0, 3, 6, 9 and 12 days using the following settings: pre-test speed: 2.0 mm/s; test speed: 1 mm/s; post-test speed: 10 mm/s; distance: 60 mm, with a 1-inch radius plastic ball probe (P1/S). Eight replicates for each sample were performed.

2.5. Sensory Evaluation

Tandoori and Pita breads were assessed for sensory characteristics with a double-blind test by a total number of 32 male and untrained female panelists recruited from staff and students of the University of Plymouth, aged between 27 to 50 years old. The experiment protocol was approved by the Faculty Human Ethics committee, University of Plymouth. The samples labeled with three random digit codes were served and assessed on a number of parameters, including texture, chewiness, appearance, elasticity, flavor and overall acceptability utilising a hedonic scale with nine points between strongly liked (9) to strongly disliked (1).

2.6. Statistical Analysis

Data were statistically analysed using Minitab (16.2) software (Minitab Ltd., Coventry, UK). Results were presented as means \pm standard deviation, and analysis of variance (ANOVA) and Tukey's post hoc test were used to find statistical differences.

3. Results

3.1. In Vivo Measurement of the GI of Breads

The results of GI and satiety for Pita and Tandoori breads are shown in Figures 1 and 2 and Table 3, respectively. It can be seen that GI of Pita and Tandoori is slightly different, particularly for the first 30 min. The results also indicate that after this time, the post-prandial blood glucose of breads with FI declined more clearly.

Statistical analysis of data showed that GG and IN independently and in combination significantly ($p < 0.05$) decreased the post-prandial blood glucose of Pita bread by 45% and 43%, respectively (Table 3). Moreover, the combination of all the FI reduced the GI by 37%. The GI was statistically reduced ($p < 0.05$) in GG and IN Tandoori breads (Table 3).

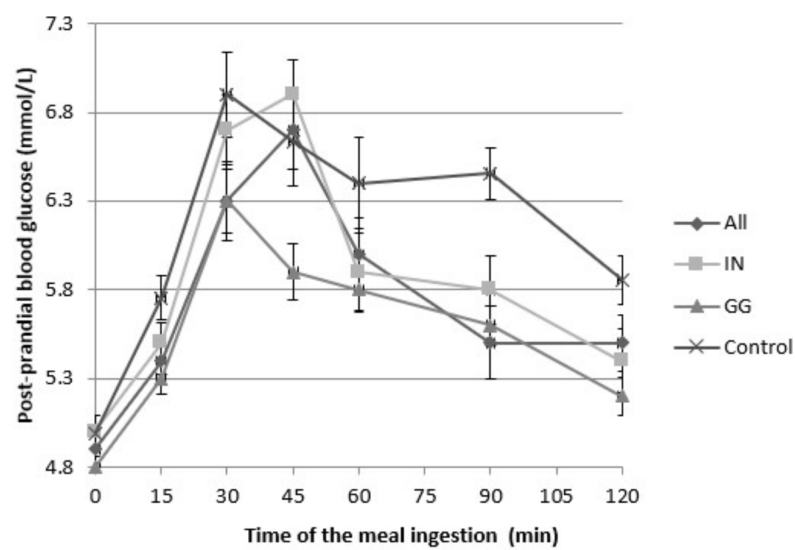


Figure 1. The glycaemic response for Pita breads.

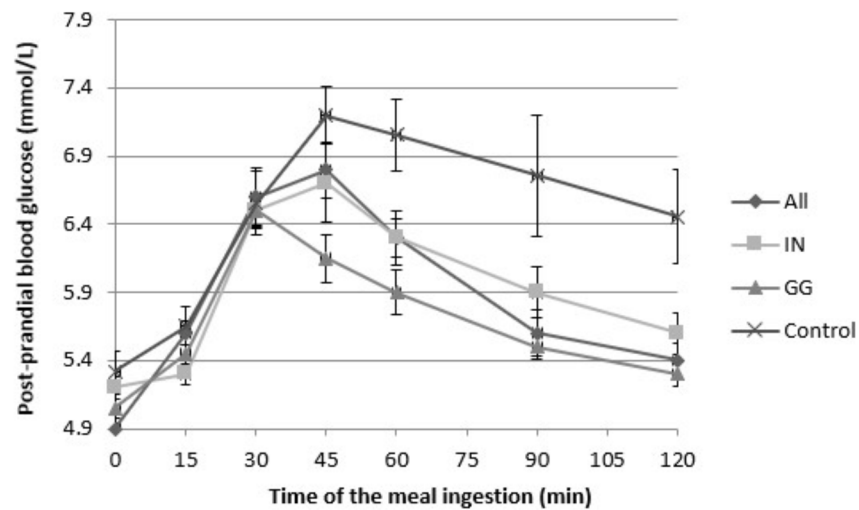


Figure 2. The glycaemic response for Tandoori breads.

Table 3. Area under curve, glycaemic and satiety indices of Pita and Tandoori breads.

Bread Types	Samples	Time of the Meal Ingestion (min)										
		0	15	30	45	60	90	120	G AUC	GI	S AUC	SI
										%		
Pita	Control	5.0	5.8	6.9	6.7	6.6	6.2	5.8	161 + 38 a	100	355 + 110 a	104
	All	4.9	5.4	6.3	6.7	6.0	5.5	5.5	102 + 34 b	63	418 + 110 a	122
	IN	5.0	5.5	6.7	6.9	5.9	5.8	5.4	92 + 27 b	57	451 + 66 a	132
	GG	4.8	5.3	6.3	5.9	5.8	5.6	5.2	89 + 38 b	55	452 + 71 a	132
Tandoori	Control	5.8	5.7	6.6	7.7	6.9	7.5	6.9	162 + 51 a	100	329 + 100 a	96
	All	4.9	5.6	6.6	6.8	6.3	5.6	5.4	120 + 37 a	74	420 + 117 a	123
	IN	5.2	5.3	6.5	6.7	6.3	5.9	5.6	98 + 32 b	60	381 + 86 a	111
	GG	5.5	5.5	6.5	6.2	5.9	5.5	5.3	92. +45 b	57	390 + 56 a	114

G AUC = area under curve (mmol/L min); GI = glycaemic index; SI = satiety index. Same letters mean no statistical differences ($p < 0.05$).

3.2. Satiety Index Test

The statistical analysis of satiety showed that the FI neither independently nor in combinations showed any significant ($p > 0.05$) differences between breads (Table 3).

3.3. Shelf Life: Texture Properties of Breads during Storage Time

Supplemented breads were evaluated throughout the storage time; hardness, chewiness and springiness were tested for Pita bread, and for Tandoori breads, extensibility and toughness were tested (Figures 3–7).

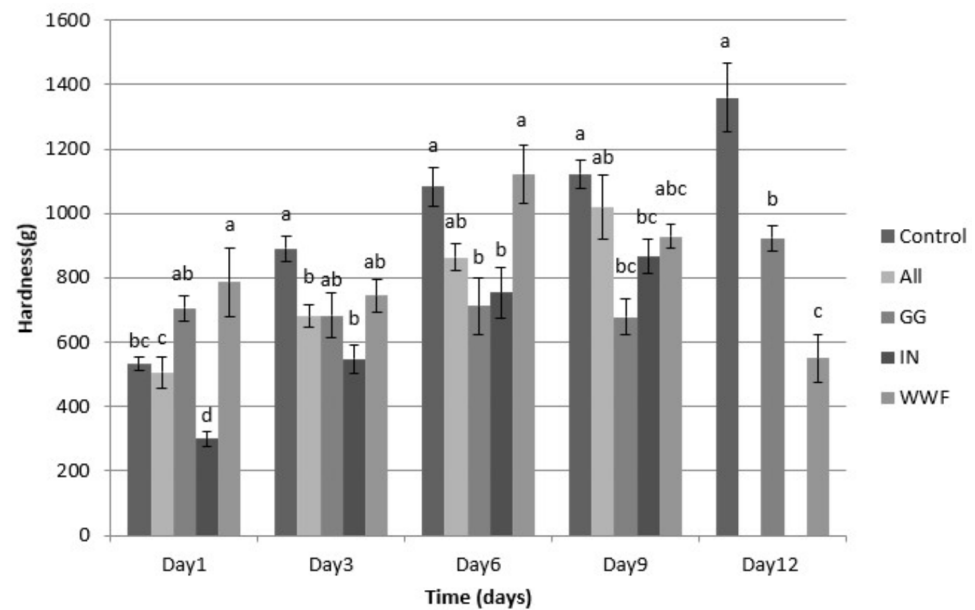


Figure 3. The impact of the added FI on Pita breads hardness(g) over the storage period. Values are mean \pm SEM of 6 replicates; a, b and c letters indicate statistically significant differences ($p < 0.05$) between means.

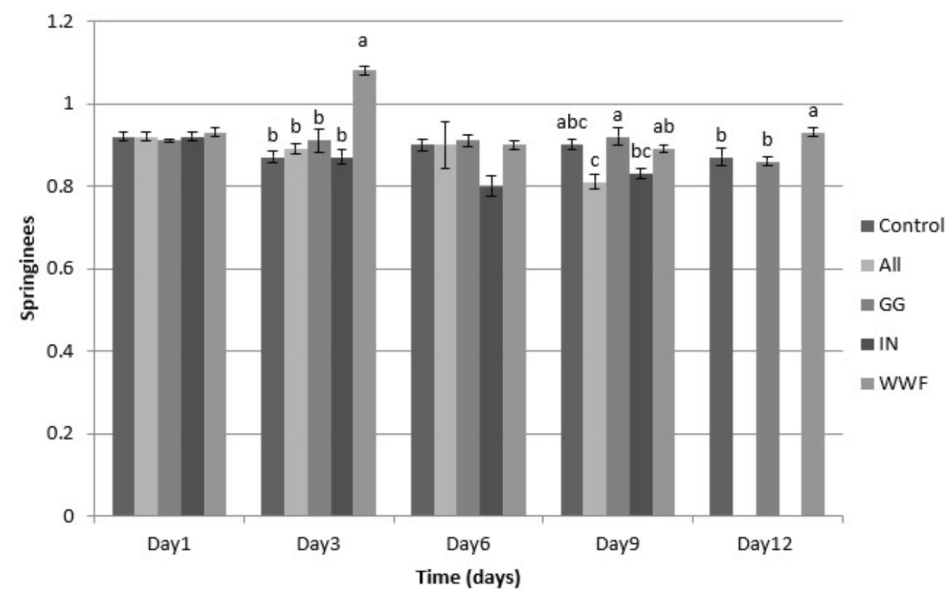


Figure 4. The impact of the added FI on Pita breads springiness. The a, b and c letters at each sampling time indicate statistically significant differences ($p < 0.05$). Values are mean \pm SEM of 6 replicates.

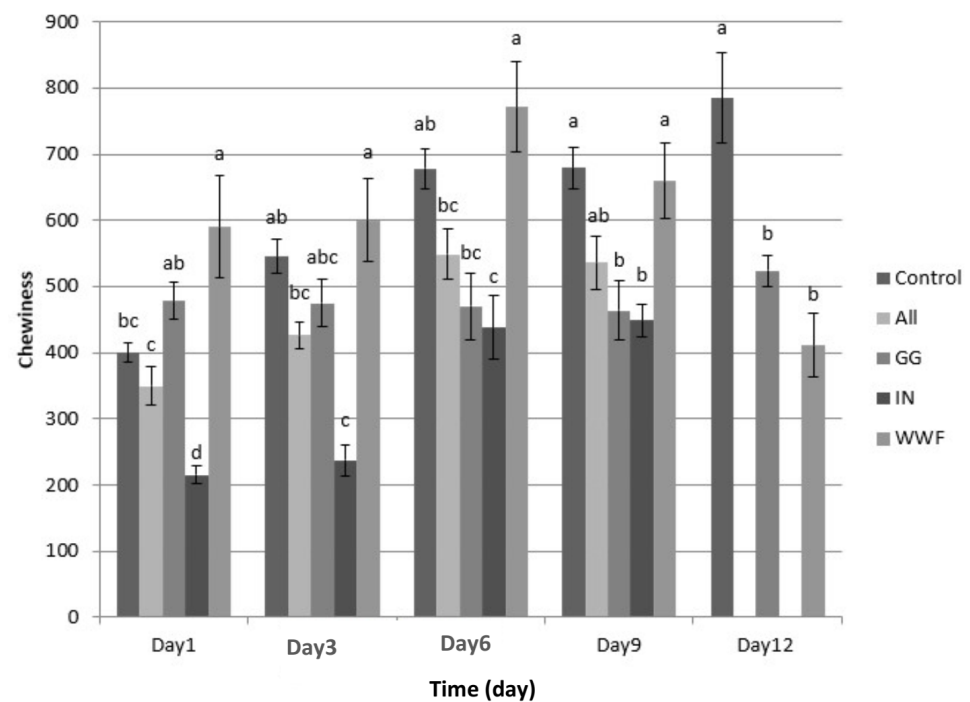


Figure 5. The impact of the added FI on Pita breads Chewiness. The a, b and c letters at each sampling time indicate statistically significant differences ($p < 0.05$). Values are mean \pm SEM of 6 replicates.

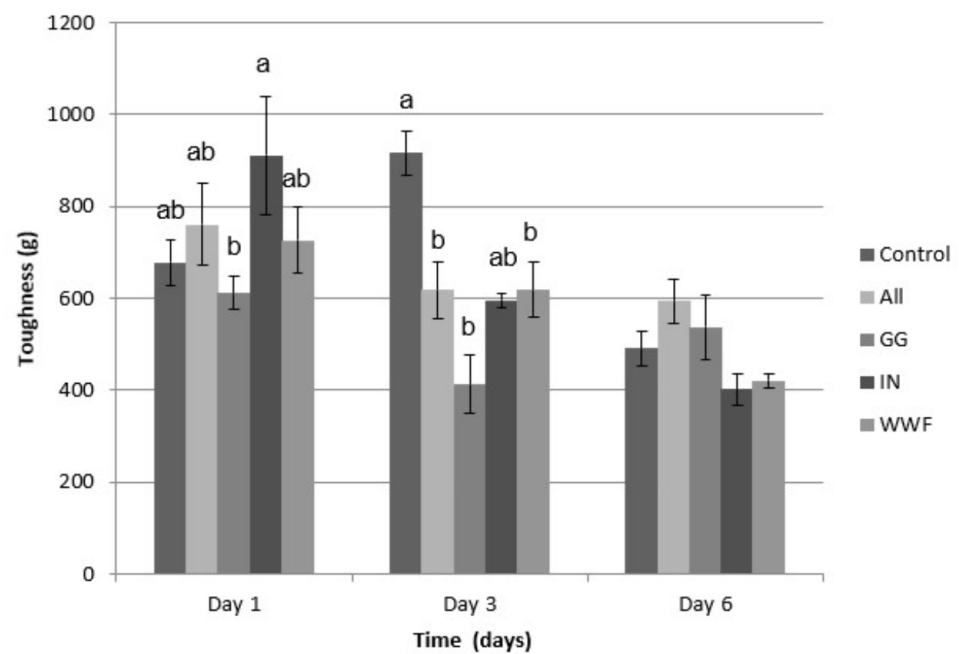


Figure 6. The impact of the added FI on Tandoori breads toughness. The a and b letters at each sampling time indicate statistically significant differences ($p < 0.05$). Values are mean \pm SEM of 6 replicates.

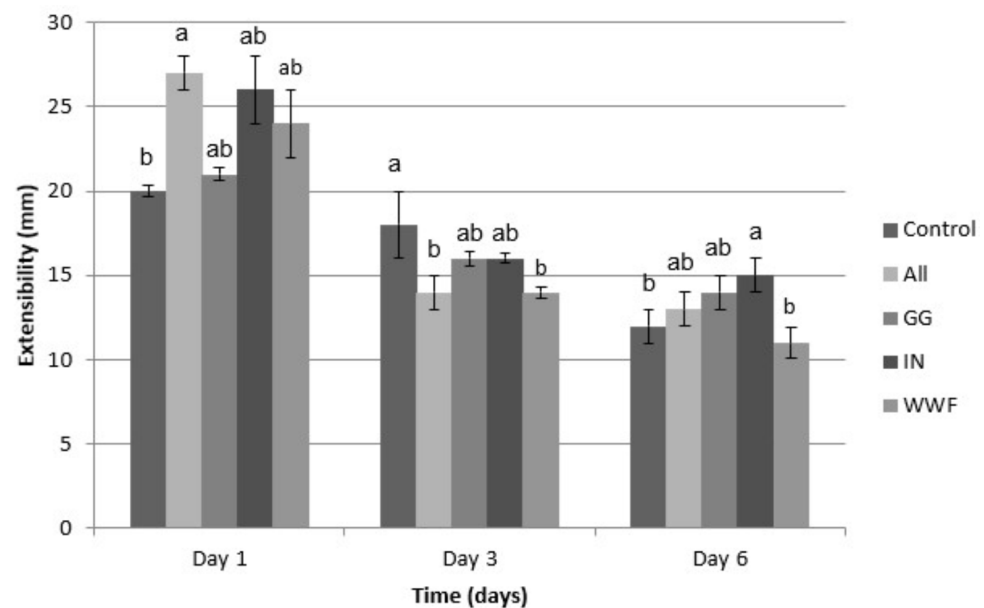


Figure 7. The impact of the added FI on Tandoori breads extensibility (mm). The a and b letters at each sampling time indicate statistically significant differences ($p < 0.05$). Values are mean \pm SEM of 6 samples.

WWF significantly ($p < 0.05$) increased hardness and chewiness in Pita bread on the first day of storage, but IN significantly ($p < 0.05$) decreased them compared to the control (Figure 3). On the third day, only IN significantly ($p < 0.05$) decreased chewiness and hardness, and other FI had no effect. Furthermore, springiness was significantly ($p < 0.05$) reduced with WWF addition (Figure 4).

On the sixth day, data showed that IN significantly reduced ($p < 0.05$) both chewiness and hardness (Figure 5). Furthermore, hardness and the other characteristics of GG bread showed no significant differences.

On the ninth day of storage, only GG and IN significantly ($p < 0.05$) decreased chewiness and hardness. On the twelfth day, some microbial growth was noticed using a microscope on the surface of breads with all the combinations and IN. Therefore, they were terminated and eliminated from the study. However, their textures were still acceptable. The observations of day 12 showed that WWF and GG significantly decreased hardness and chewiness compared to Pita control.

On the first day of Tandoori bread storage, no significant differences were seen in the comparison to control except for the chewiness of bread with all FI. On the third day, WWF, GG and a combination of all the ingredients significantly reduced ($p < 0.05$) toughness (Figure 6).

Furthermore, bread supplemented with WWF and combinations of all FI reduced extensibility (Figure 7). On the sixth day, negligible alterations were documented. After the sixth day of storage, mold growth was seen, and breads were not considered and removed from the experiment. It is obvious that substituting flour with FI, particularly IN, GG and all in combination, could decrease chewiness and hardness to a reasonable extent.

The data from the sensory assessment indicated that all samples of both breads recorded above five points (five considered successful points). Furthermore, the data analysis of Pita bread showed that there were no significant differences between the Pita breads for texture, appearance and elasticity (Figure 8). In contrast, the flavour of bread with IN obtained 7.3, which was statistically higher ($p < 0.05$) than WWF bread (5.5), GG bread (5.7) and bread control (5.6). Similarly, overall acceptability and chewiness of bread with IN scored 7.3 and 7.1, respectively, followed by bread with all the combinations with 6.6 and 6.8, GG 6.1 and 6.0, WWF 5.7 and 5.7 and the control 5.7 and 5.6, respectively. In both attributes, only IN was statistically different from WWF and the control. It is

worth mentioning that all the breads containing FI obtained five or above; thus, they were considered acceptable.

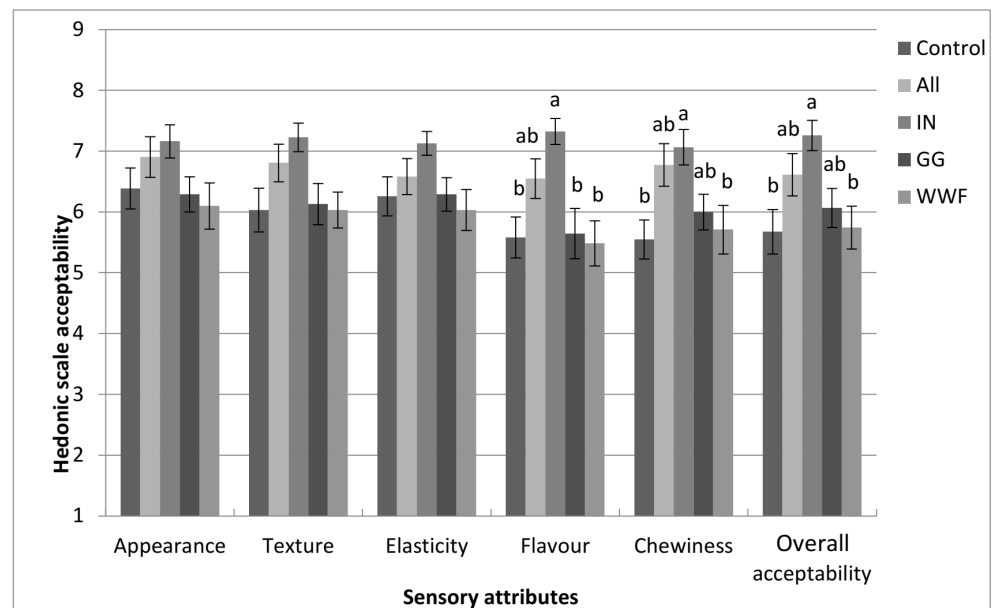


Figure 8. Acceptability of sensory characteristics of Pita breads, from 1 (strongly dislike) to 9 strongly like, ($n = 31$, mean scores \pm S.E.M). The a and b letters within formulation treatments indicate statistically significant differences ($p < 0.05$).

For Tandoori breads, in terms of chewiness, texture, appearance and elasticity, no significant differences ($p < 0.05$) were seen (Figure 9). Whereas for flavour and overall acceptability, bread with all the combinations scored highest with 7.3 and 7.2, followed by GG bread (6.3 and 6.6), the control bread (6.3 and 6.4), IN bread (6.0 and 6.2) and WWF (6.0 and 6.2).

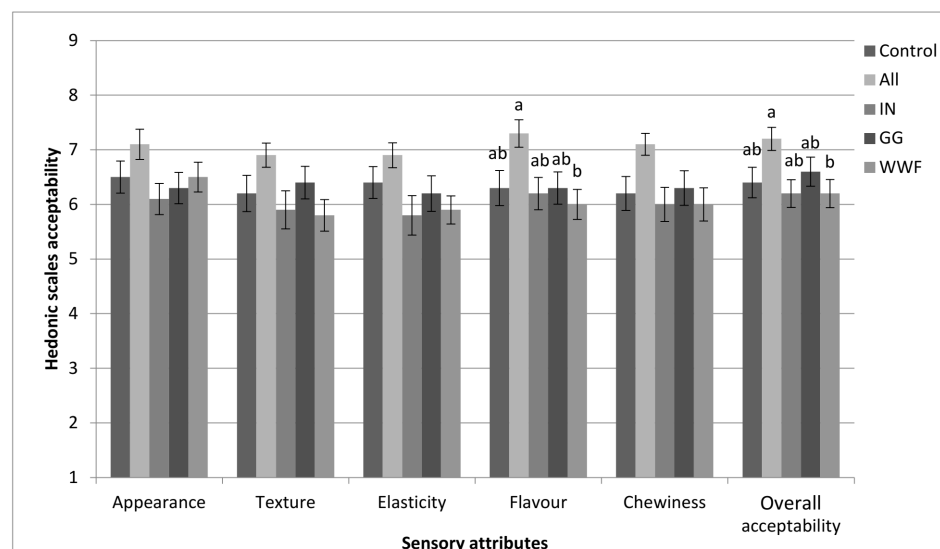


Figure 9. Sensory characteristics of Tandoori breads, from 1 (strongly dislike) to 9 strongly like ($n = 33$, mean scores \pm S.E.M). The a and b letters at within formulation treatments indicate statistically significant differences ($p < 0.05$).

4. Discussion

4.1. *In Vivo* Measurement of the GI of Breads

From the above results, it can be summarised that IN and GG may be utilised to decrease the post-prandial blood glucose response and decrease the GI of breads. Furthermore, it is clear that the AUCs for Pita breads are lower than Tandoori breads. This might refer to the same results as presented in the microstructure of the bread [8]. It could be attributed to the starch granules of Tandoori bread being more gelatinised and easier for digestive enzymes to hydrolyse and digest and thus increase GI. Moreover, the GI for the combination of all FI also was expected to be similar to the control breads. This is due to the fact that the bread's microstructure reported in our previous work showed similarity in terms of the microstructure of control and bread with all the FI.

A number of previous studies on the GI of loaf bread with added FI were reported that are in agreement with our results. In a study to find the effect of DFs such as GG on the post-prandial serum glucose, it was found that GG addition significantly reduced GI [10], and GG reduced the GI by 10%. Moreover, it was found that GG decreased post-prandial blood glucose after a meal was served to four volunteers and blood glucose reduced from $114 \pm \text{mg/dL}$ to $86 \pm 3 \text{ mg/dL}$ [11]. In addition, in a study on supplementation of spaghetti with GG, it was summarised that GG significantly reduced hydrolysis of starch and thus decreased GI [12].

Regarding IN, a number of previous studies have also found that IN can decrease post-prandial blood glucose concentrations. Adding IN to pasta showed that IN significantly slowed down the amount of digested sugar from pasta [5]. Furthermore, a study on the performance of two different types of IN in their degree of crystallisation on the structure and texture of the pasta was conducted, and it was revealed that IN seemed capable of modifying the digestibility of starch, which could consequently reduce the GI. The effect was ascribed to the formation of DFs and protein matrix that acts as a physical barrier and traps the digestive enzyme, and stops them from attaching to starch granules [12]. Moreover, the addition of up to 15% of IN to pasta modified the microstructure of starch in comparison to control, which subsequently changed the digestion of starch. It was found that a reverse relationship between the increase in IN and the number of gelatinised starch granules was seen. This was attributed to the IN stronger affinity to compete with starch granules for moisture, and the starch granules were less hydrolysed and thus less available for digestive enzymes [13].

A few proposed mechanisms are suggested by which FIs modify and reduce the GI curve of food products [14]. Firstly, DF is able to prolong the digestion route of polysaccharides in the stomach. Secondly, gastrointestinal movement changes, prolong transit time and delays digestion. Thirdly, DFs restrict amylase activity to hydrolyse starch granules as they cover the starch granules and extend the distance between granules and digestive enzymes. Finally, DFs form a thick physical barrier that narrows the transfusion of digested saccharides and bloodstream through the small intestine [10,14,15]. Additionally, DFs are fermented by natural microflora in the gut, and short fatty acids are produced [16].

4.2. *Satiety Index* Test

We expected to find an increase in satiety with the added FI, but our results did not reach statistical significance. Food products that produce high satiety can help with energy intake regulation and consequently the management of weight. This is due to imparting a satiation sensation, which reduces the amount of energy consumed at the following meals. There are a number of studies on the impact of FI, including DFs, on the SI of food products.

It is suggested that the addition of DF can modify and improve gut hormone excretion and induce satiety. Previous researchers studied the impact of some DF on satiety response. Adding 2.5% DF for semi-solid and solid foods improved satiety response [17]. In a previous review on the relationship of DFs and appetite, it was stated that high-level addition of both GG and IN improved satiety response and decreased intake of energy [18].

The impact of DF on satiety levels have been linked to a number of mechanisms, including that DF are less energy-dense, take longer time to chew and digest [19], make a physical barrier and imparts a satiety sensation, they are fermented and produce short-chain fatty acids such as propionate, butyrate and acetate, which modify gastrointestinal mobility and induce secretion of satiety hormones, including cholecystokinin glucagon-like peptide-1 and ghrelin [19,20]. However, in this case, the number of fibers and time might not be enough to increase satiety significantly.

4.3. Shelf Life: Texture Properties of Bread during Storage Time

Possible alterations mainly in texture can happen to bread during storage time. This change in texture is ascribed to a phenomenon called staling. It is the time between baking and consuming when the sensory properties of the end product are changed. Bread texture is undesirably changed as elasticity and hardness increase product become chewier [21].

The major reason for staling is related to the distribution of moisture and starch retrogradation within the bread protein and starch matrix. The starch of wheat is composed of straight and branched chains. Therefore, throughout baking, granules of starch uptake water and the linear chains immigrate from the starch granules to form the early structure of products. On the other hand, the branched chains need time to form. Over time, these chains are brought closer to harden the crumb; moreover, water might transport surface crust and evaporate [22]. The product becomes harder over time, and this is the start of staling.

It can be expected that breads become harder over time. This clearly refers to the physio-chemical alteration and staling. Another expected trend was the FI influence on the breads' starch and protein. It is clearly seen that the addition of FI retarded the staling rate and molecules starch re-integration. Moreover, it is clear that FI demonstrated different impacts in retarding starch gelatinisation. In a study on the effect of GG on stored chapatti at ambient temperature, it was stated that GG reduced extensibility and the tear force of the chapatti [23]. This outcome is in agreement with this finding, as GG reduces both extensibility force and toughness.

It was previously documented that GG has anti-staling properties that reduce the rate of starch retrogradation [24]. The anti-staling role of GG was attributed to its capability to better regulate moisture distribution within the bread starch-gluten matrix [25]. IN also seem retarded staling rate. It was reported that IN is supplemented in different cereal products to prolong shelf life [12].

WWF also showed the capability to prolong shelf life. This is possibly a result of the capability of branched amylopectin to induce water uptake and decrease the amylopectin retrogradation enthalpy causing the postponement of staling [26].

The impact of FI on the Tandoori storage time is less effective. This could be ascribed to a number of factors. Firstly, the crumbs of Tandoori bread were thinner in comparison to Pita, and fewer changes were observed. Secondly, it needs more water, and most of the starches were hydrolysed and released, which limits the impact of the FI on starch molecules re-organization. Finally, the moisture in the bread evaporates quicker due to thin crumbs, and there is less water to keep moisture and retard starch retrogradation.

4.4. Sensory Assessment of Breads

It is worth recalling that IN can provide a peculiar smell and taste to end products, and this makes it appropriate to be utilised as a fat replacer in food products [27]. Thus, this made some dietary fibres such as IN suitable to be incorporated into cereal products to improve sensory characteristics. Other FI also improved the sensory attributes of the bread. This could be due to the fact that the FI has similar physical properties, including color, taste and particle size, to flour.

5. Conclusions

The glycemic index results showed that both guar gum and inulin (but not WWF for Pita and Tandoori breads), independently and in combination, significantly decreased postprandial blood glucose and GI. It can be suggested from the results above that only guar gum and inulin independently and in combinations can be utilised to develop functional breads with acceptable sensory characteristics and quality and a reasonable glycemic index.

Author Contributions: Conceptualization, Y.G., G.R. and V.K.; methodology, Y.G.; software, Y.G.; validation, Y.G., G.R. and V.K.; formal analysis, Y.G., G.R. and V.K.; investigation, Y.G.; resources, Y.G.; data curation, G.R. and V.K.; writing—original draft preparation, Y.G.; writing—review and editing, G.R. and V.K.; visualization, Y.G.; supervision, G.R. and V.K.; project administration, G.R. and V.K.; funding acquisition, Y.G. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the University Of Plymouth, Faculty of Science and Technology, Human Ethics Committee, protocol code FREIC-Galali and date of approval is 8 May 2013.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to ethical issues.

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Conflicts of Interest: The author declares that there is no conflict of interest.

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