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Original article

Physicochemical and techno-functional characterization of inulin extracted from chicory roots and Jerusalem artichoke tubers and exploring their ability to replace the fat in cakes

Summer Rashid[1], *Allah Rakha*[1], *Masood Sadiq Butt*[1], *Muhammad Asgher*[2]

[1]National Institute of Food Science and Technology, University of Agriculture, Faisalabad-Pakistan, E-mail: samar.rashid@ymail.com; [2]Department of Biochemistry, University of Agriculture, Faisalabad-Pakistan

Summary. Instant research was an attempt to elucidate the physicochemical characteristics of inulin extracted from chicory roots and Jerusalem artichoke tubers. The extracted inulin was assessed for various physicochemical analysis i.e. viscosity, water absorption index and water solubility index. Moreover, its techno-functional attributes involving water holding capacity, oil holding capacity, swelling capacity and solubility were also determined. Afterwards, extracted inulin from both the sources was used as a fat replacer in cakes. Purposely, eleven types of cakes were prepared by varying the concentration of chicory inulin (T_1 to T_5) and Jerusalem artichoke inulin (T_6 to T_{10}) @ 10%, 20%, 30%, 40% and 50% along with control (T_0). The results of cake batter illustrated that viscosity decreased with increasing concentration of inulin and an inverse relationship was observed between water loss and increased inulin concentration. Results indicated that inulin supplemented designer foods have the potential to serve as fat replacer.

Key words: Chicory roots, Jerusalem artichoke tubers, Inulin, fat replacer, designer foods

Introduction

Inulin occurs naturally as a storage carbohydrate in plants (1). Previously, it was described as a linear molecule having β-(2→1) linkage but in the recent era it has been explored that branching can also be present in inulin molecule to a very little extent *i.e.* 1-2%. The chain length or degree of polymerization (DP) of inulin ranges from 2 to 60 units (2). Its major sources involve wheat, onion, banana, garlic, chicory and Jerusalem artichoke. Among these sources, chicory roots (*Cichorium intybus* L.) and Jerusalem artichoke tubers (*Helianthus tuberosus*) belonging to the family *Asteraceae* have been grown widely for inulin production. About 68% of the total mass of fresh roots and 98% of the dried chicory roots is composed of inulin (3). Jerusalem artichoke tubers are also rich in inulin (7 to 30%) (4) and their chemical composition varies widely with the cultivars, harvesting time, pre- and post-harvest treatments and storage conditions. Commercial inulin can be obtained by either synthesizing from sucrose or by hot water extraction from chicory roots (5).

Dietary interventions have revealed that these fructans specifically affect several functions of gastrointestinal tract such as composition of intestinal microflora, mucosal functions, endocrine activities, mineral absorption and systemic functions (especially lipid homeostasis and immune functions) (6).

For a healthy diet the recommended daily dose of dietary fiber is 25g for the persons consuming 2000 kcal daily and 30g/d for those consuming 2500 kcal. World Health Organization recommends 16-24g/d of non-starch polysaccharides or 27-40g/d of total dietary fiber. However, some studies suggest adverse gastro-intestinal symptoms in most subjects consuming daily doses in excess of 30 g of inulin (Kaur and Gupta, 2002; Kalyani Nair *et al.*, 2010).

Besides remarkable facts regarding the health and nutrition, inulin can also be used in various food products in order to enhance their techno-functional attributes. These can serve as fat substitutes, bulking agents and possess high water retention capacity (7). They exhibit the same texture as induced by fat and this property can be achieved by increasing the degree of polymerization as well as the concentration of inulin. Insoluble inulin fractions possess the property of forming the gel-like texture (8). Native and long chain inulin at the concentration of >25% and >15%, respectively can form a network involving the solid crystalline particles that can confer the gel like characteristics (9). As a result of complete mixing of inulin with water or any other solvent in the presence of shearing action resulting from the shearing devices such as a rotor-stator mixer or a homogenizer, a white creamy structure is formed which can easily replace fat in the foods up to 100%. The resultant system of inulin and water can mimic the fat well to provide the short spreadable texture and fatty mouth feel (10).

Inulin when used as a fat replacer in baked goods contributes less towards viscosity of batter resulting in a large number of air bubbles incorporated during mixing. Accordingly, replacement of fat by inulin can result in batter instability with reduced expansion. Settling of denatured protein and cooling of gelatinized starch at baking temperatures are the possible reasons for crumb firmness (11). However, thermo-mechanics are responsible for the decrease in the crumb hardness. Since, inulin has also high water binding capacity, therefore, its incorporation in baked goods usually results in less weight loss after baking (12).

Keeping in view the nutritional significance of inulin as functional food, the present research was designed to characterize the major aspects of inulin.

Methodology

Procurement of raw materials

Chicory roots and Jerusalem tubers were purchased from the local fields and market, respectively. Chemicals and standards used in research were purchased from reputed companies. Fructan assay kit was purchased from Megazyme International, Ireland.

Extraction process

Extraction of inulin was carried out from chicory roots and Jerusalem artichoke tubers by following the protocol as prescribed by (13) (Figure 1).

Physicochemical properties of inulin

Extracted inulin was subjected to physicochemical analysis such as dry matter (14), inulin content (15), pH, soluble solids (16), viscosity (17, 18) and water solubility index (WSI)/water absorption index (WAI) (19).

Flow diagram for the determination of inulin content has been described in Figure 2.

Techno-functional characteristics of inulin

Extracted inulin was analyzed for techno-functional attributes such as particle size (13), water holding capacity (WHC) (20), oil holding capacity (OHC) (21), solubility (22) and swelling capacity (23).

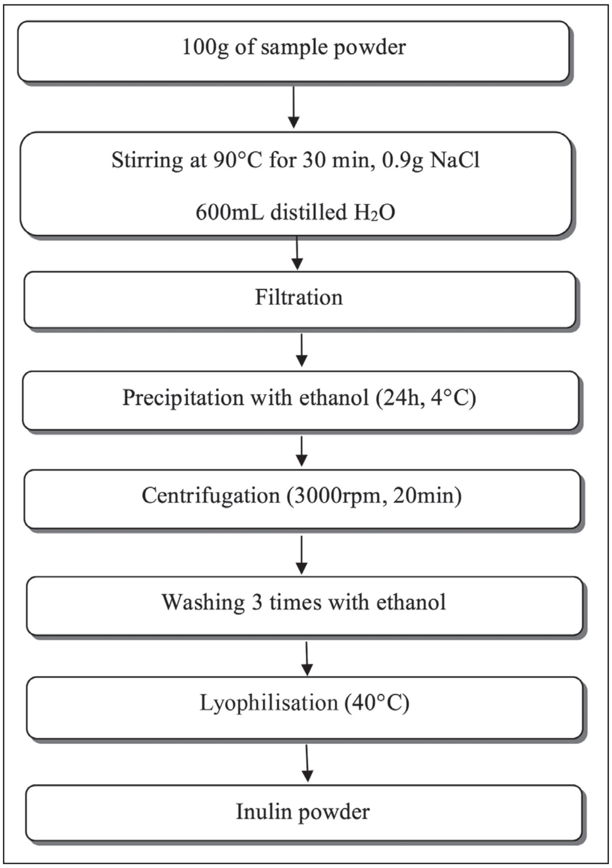

Figure 1. Extraction of inulin [Schematic Diagram]

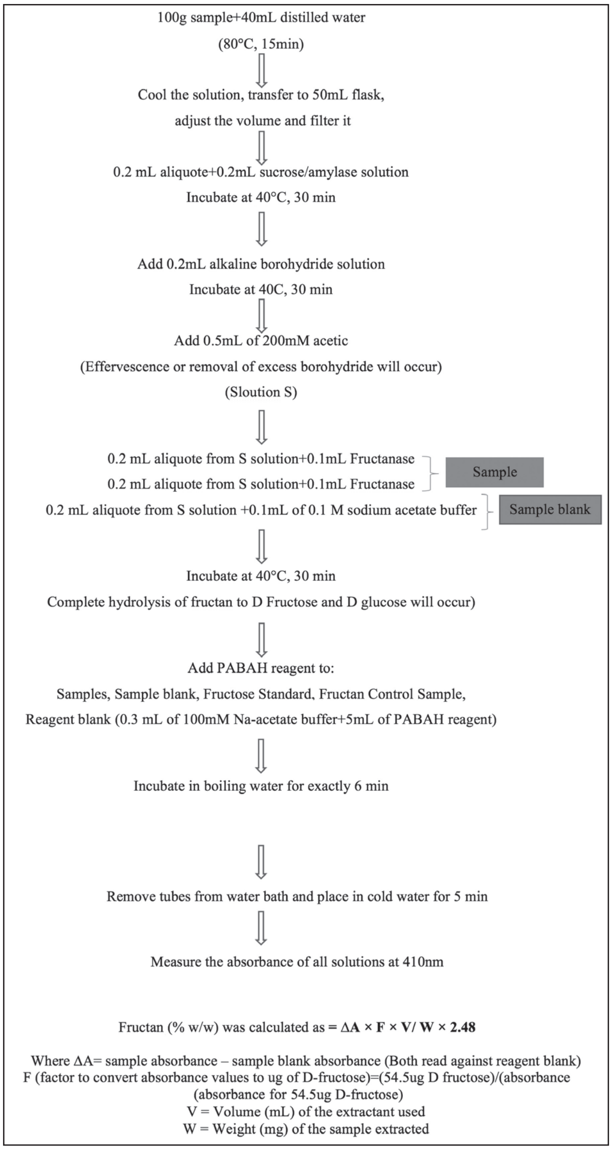

Figure 1. Flow diagram for determination of inulin content

Product development

In product development phase, cakes were prepared by using extracted inulin as fat replacer according to the treatments presented in Table 1.

Product analysis

Physical measurements of cake batters involving batter density (24), pH of batter and apparent viscosity (25) were determined. Besides, cake height (24), cake volume (14), water loss (26) and cake texture (27) was analyzed.

Table 1. Treatment plan for product development

Sources	Treatments	Level of fat replacement (%)
Control	T_0	-
Chicory	T_1	10
	T_2	20
	T_3	30
	T_4	40
	T_5	50
Jerusalem artichoke	T_6	10
	T_7	20
	T_8	30
	T_9	40
	T_{10}	50

Statistical analysis

The collected data were analyzed statistically through completely randomized design (CRD) using Statistix 8.1. Level of significance ($p<0.05$) was estimated by using the analysis of variance technique (ANOVA) with factorial under CRD (28).

Results and discussion

Physicochemical properties of inulin

The results for the physicochemical attributes of extracted inulin i.e. dry matter, inulin content, pH, soluble solids, viscosity, water solubility index and water absorption index indicate that their mean values were 91.72±2.75% (dry matter), 90.95±2.43% (inulin content), 5.48±0.02 (pH), 13.96±0.27°Brix (soluble solids), 1.59±0.02cP (viscosity), 7.95±0.26% (water solubility index) and 4.54±0.19 (water absorption index) for chicory. Likewise, the mean values of physicochemical properties of inulin extracted from Jerusalem artichoke were 94.38±3.82% dry matter, 93.76±3.21% inulin content, 5.58±0.16 pH, 15.61±0.43°Brix soluble solids, 2.22±0.08cP viscosity, 6.43±0.22% water solubility index and 5.10±0.22 water absorption index (Table 2).

The current research findings are in harmony with the work of López-Molina et al. (29) who reported 95% dry matter for chicory and artichoke inulin. Besides, pH values were found to be in the range of 5-7.

Table 2. Physicochemical and techno-functional properties of inulin

Physicochemical Properties	Chicory Inulin	Jerusalem artichoke inulin
DM (%)	91.72±2.75	94.38±3.82
Inulin content (%)	90.95±2.43	93.76±3.21
pH	5.48±0.02	5.58±0.16
Soluble solids (°Brix)	13.96±0.27	15.61±0.43
Viscosity (cp. at 5% sol.)	1.59±0.02	2.22±0.08
Water solubility index (%)	7.95±0.26	6.43±0.22
Water absorption index	4.54±0.19	5.10±0.22
Techno-functional Properties		
Particle size (inches/210 um)	0.08±0.01	0.08±0.01
Water holding capacity (g/g)	1.51±0.02	4.95±1.13
Oil holding capacity (g/g)	0.97±0.02	1.02±0.02
Swelling capacity (mL/g)	0.98±0.02	1.97±0.04
Solubility (g/L)	118.67±3.26	4.62±0.18

Similarly, Panchev et al. (30) evaluated the physicochemical properties of inulin extracted from four different varieties of Jerusalem artichoke i.e. Energina, Verona, Topstar and Spindel. The observed values for dry matter were up to 96%. Besides, pH values for the extracted inulin were reported to be in the range of 6.0-6.4. Moreover, the viscosity of 5% water solution at 25°C ranged from 1.21 to 1.29cP.

The viscosity of soluble fiber is mainly determined by its structural configuration and molecular weight. It has been demonstrated that polysaccharides with high molecular weight are capable of providing high viscosity. Similar trend has been suggested for polysaccharides with rigid conformations than those with flexible configurations (31). In addition, it has been observed that the development of inulin gel involves a dynamic process by which inulin in amorphous state after coming in contact with water results in nucleation and crystallization process (32). Heating temperature and time are among the important factors which can greatly influence the functionality of inulin to form the gel. It has been suggested that temperatures above 80°C can completely inhibit the gel development of inulin-water dispersions (33).

Water solubility index is expressed as the percentage of dry matter recovered after the evaporation of supernatant. It often increases with the intensity and severity of thermal treatment. In contrast, water absorption index is the measure of swelling power of molecules and is determined by the weight of gel obtained per g of dry sample (34).

In our research, the recorded variation between the inulin in terms of viscosity (1.52±0.02 chicory inulin, 2.22±0.08 Jerusalem artichoke inulin) was may be due to molecular weight differences as DP of both the inulin varies widely. The DP of Jerusalem artichoke inulin lies in the range of 2–50 with 94% of the molecules having DP<40, whereas, DP of chicory inulin varies from 2-65 with 83% of the molecules having DP<40. Hence, it can be observed that besides average DP, the relative distribution of long and short DP is also an important consideration. Besides, the gel forming nature of Jerusalem artichoke inulin can be the possible reason of this increased viscosity as compared to chicory inulin. Furthermore, the difference between water solubility index and water absorption index of both the inulin (chicory, Jerusalem artichoke) might be linked with the presence of varying proportion of degraded molecules as they can absorb more water at room temperature. In addition, particle size may also be the possible reason in contributing towards these variations.

Techno-functional attributes of inulin

Techno-functional attributes (Table 2) of inulin depicted that extracted inulin contributed well towards the functional properties. It can be seen that the recorded values for water holding capacity, oil holding capacity, swelling capacity and solubility of chicory inulin were 1.51±0.02g/g, 0.97±0.02g/g, 0.98±0.02mL/g and 118.67±3.26g/L, respectively. Likewise, recorded values for the mentioned traits in Jerusalem artichoke inulin were 4.95±1.13g/g (water holding capacity), 1.02±0.02g/g (oil holding capacity), 1.97±0.04mL/g (swelling capacity) and 4.62±0.18g/L (solubility).

Water holding capacity is usually defined as the amount of retained water which either remains held/fixed or absorbed by the particles after acquiring the state of equilibrium. High water holding capacity is directly related with the presence of hydrophilic regions in the structure (33). Hydroxyl groups present on the molecular chains are the major contributors towards the hydrophilic property. These hydroxyl groups can hydrate polymers due to their ability to interact with water molecules through hydrogen bonding. As water holding capacity is mainly determined by the particle size and porosity of matrix, therefore, hydration rate can be increased by small reductions in particle size. But the limitation behind this strategy is the conflicting opinion regarding the processing treatments for the fibers obtained from different sources.

The mechanism of oil holding capacity is mainly due to the physical entrapment of oil by capillary attraction. Moreover, fat absorption is affected by the hydrophobic nature of proteins. Therefore, oil holding capacity of the samples can vary depending on the extent of polar side chains of amino acids present on the surface of protein molecules. Furthermore, the oil holding capacity is also related to the particle size, overall charge density and hydrophilic nature of the individual particles (35, 36).

Various findings have revealed the characteristics of inulin involving its fat replacing functionality, hydration or water holding properties and its oil holding mechanism. Inulin has been commercialized as a fat replacer as it can exert the fat mimicking properties in food products without affecting the taste and texture while reducing the energy content of food (37, 38). Besides, the presence of β (2→1) linkage among the fructose residues of inulin resists its hydrolysis by human intestinal enzymes enabling its use as low calorie fat replacer. Average degree of polymerization (DP) of inulin is very important to describe its functional attributes involving solubility. This generally works well but can also mislead potentially owing to fact that it only explains the average size but the actual size distribution cannot be determined by this characteristic. Inulin consists of a mixture of different polymers which can vary in their chain length and its properties are highly dependent on the size distribution of the mixture. It is notable to mention that inulins containing the same degree of polymerization can behave differently in terms of their characteristics. Inulin fractions with high DP are more stable in nature, exhibit less solubility and provide firm gels when come in contact with water. Besides, these possess high glass transition temperatures when amorphous and high melting temperatures in crystalline state (39). Perhaps, the large variations in solubility of chicory and Jerusalem artichoke inulin i.e. 118.67±3.26g/L and 4.62±0.18, respectively can be attributed to variable size and molecular weight distribution.

Although inulin exhibits poor solubility especially in case of high molecular weight fractions but this property shows an increase with the rise in temperature for all types of inulin (31). Commercial chicory inulin can exhibit the greater solubility up to the range of (122.98±1.27 g/L). Small particle size and occurrence of more hydrophilic regions/spaces may be the major reason of inulin solubility to such an extent. Due to its solubility, it becomes easier to utilize it in different food items (like dairy, bakery and beverages) without affecting their rheological and sensory attributes (40).

In our current study, the recorded differences between water and oil holding capacities of chicory and artichoke inulin are supposed to be governed by the particle size, shape, hydrophilic and hydrophobic interactions. Besides, these properties may also depend on the presence of carbohydrates, lipids and amino acid residues on the surface indicating that nonpolar amino acid residues and polar groups are usually not hydrated from the interior.

Higher swelling property is mainly the function of increased surface area and low density. Therefore, the rate of hydration is also considered to be linked with physical structure of particles which can be manipulated through processing. Various studies have supported our research work by providing the similar findings as described above.

Physical measurements of cake batters

Batter density

Batter density usually defined as mass per unit volume is one of most important parameter in determining the overall structure of the product. It can be seen from the data regarding the batter density that significant variations were recorded for this trait among the treatments when compared with control (Table 3), however; non-significant differences were observed for the interaction between chicory (T_1-T_5) and artichoke inulin (T_6-T_{10}). In addition, significant differences were recorded for the treatments prepared by chicory inulin. Furthermore, artichoke inulin also behaved significantly in influencing the batter density among the treatments.

Means regarding the batter density (Table 3) depicted that the maximum value was recorded in T_5 (1.19±0.02g/cm^3) followed by T_4 (1.15±0.04g/cm^3) and T_{10} (1.14±0.03g/cm^3). However, minimum values for this characteristic were observed in T_6 (1.03±0.02 g/cm^3), T_0 (1.04±0.02 g/cm^3) and T_7 (1.06±0.03g/cm^3).

Batter density is considered an important factor since it has major contribution in determining the final dosing and properties of cakes (volume, texture) Majzoobi et al. (24). Batter density is inversely related to the quantity of air bubbles incorporated in the batter (41, 42).

This gradual increase in batter density was might be due to the fact that increasing concentration of chicory inulin results in increased portion of dry matter content due to which number of spaces are reduced leading towards the less porous consistency. In current illustrations, more pronounced effect was noticed in case of chicory inulin as compared to Jerusalem artichoke inulin because the gelling nature of artichoke inulin contributes well in exhibiting the fat like attributes.

Batter pH

It has been expounded from the Table 3 that the pH values of batter differed significantly with respect to the treatments. Highly significant differences were also observed for pH values in case of interaction between chicory and artichoke inulin. Moreover, treatments prepared by the incorporation of chicory inulin also behaved significantly whilst the effect of artichoke inulin was found to be non-significant.

Current explorations regarding the means of batter pH have depicted a decline in pH value (Table 3). Maximum value for pH was recorded for T_0 (8.24±0.22), whereas, minimum value of pH was observed for T_5 (7.33±0.12).

Physicochemical and rheological attributes of cake batters prepared with or without the addition of Jerusalem artichoke powder (JAP) were studied by Celik et al. (43). In that study, slight reduction in pH value was also observed in cake batters prepared by the incorporation of JAP ($P>0.05$).

Reduction in pH values was owing to the fact that fiber possess the unique property of acting as buffer, hence, can contribute towards lowering of pH. More reduction in pH values was observed in the treatments prepared by chicory inulin when its concentration was increased from 10% to 50% to replace the fat content. pH values highly depend on rising agent (baking powder) as well, used to develop the cakes.

Batter viscosity

Viscosity of batter plays key role in determining the overall porosity and volume of cakes. In current study, a substantial reduction in viscosity was observed when inulin content was increased from 10% to 50% to replace that fat content. It was illustrated from the

Table 3. Means for batter density, pH and viscosity

Sources	Treatments	Density (g/cm^3)	pH	Viscosity (cP)
Control	T_0	1.04±0.02^c	8.24±0.22^a	11324.64±226.92^a
Chicory inulin	T_1	1.07±0.02^{bc}	8.14±0.18^a	10723.34±338.08^{ab}
	T_2	1.09±0.02^b	7.86±0.24^{ab}	10175.23±256.29^b
	T_3	1.11±0.02^b	7.58±0.17^{bc}	9797.80±292.87^{bc}
	T_4	1.15±0.04^{ab}	7.39±0.15^c	9464.60±206.31^c
	T_5	1.19±0.02^a	7.33±0.12^c	6311.13±124.23^d
Artichoke inulin	T_6	1.03±0.02^c	7.81±0.22^{ab}	10966.14±278.86^a
	T_7	1.06±0.03^{bc}	7.70±0.11^b	10561.12±306.72^{ab}
	T_8	1.10±0.02^b	7.67±0.18^b	10155.00±199.90^b
	T_9	1.12±0.02^b	7.54±0.21^{bc}	9898.24±194.84^{bc}
	T_{10}	1.14±0.03^{ab}	7.68±0.25^b	9392.36±204.88^c

Means sharing the same letter are not significantly different. Where, T_0 = Control; T_1 = 10% Chicory inulin; T_2 = 20% Chicory inulin; T_3 = 30% Chicory inulin; T_4 = 40% Chicory inulin; T_5 = 50% Chicory inulin; T_6 = 10% Jerusalem artichoke inulin; T_7 = 20% Jerusalem artichoke inulin; T_8 = 30% Jerusalem artichoke inulin; T_9 = 40% Jerusalem artichoke inulin; T_{10} = 50% Jerusalem artichoke inulin statistical splitting that treatments exerted significant effects on batter viscosity in comparison to control (Table 3). It was also depicted that the chicory inulin (T_1-T_5) caused significant variations among the treatment in terms of influencing the viscosity of batter, whereas, artichoke inulin (T_6-T_{10}) exerted non-significant effects. Besides, their interaction also remained non-significant in affecting the batter viscosity.

Means regarding the viscosity of batter (Table 3) showed that the higher values for this parameter were attained in T_0 (control), T_6 (10% Jerusalem artichoke inulin) and T_1 (10% chicory inulin) as 11324.64±226.92, 10966.14±278.86 and 10723.34±338.08cP, respectively. Whilst for the treatments T_{10} (50% Jerusalem artichoke inulin) and T_5 (50% chicory inulin), relatively low viscosity of 9392.36±204.88 and 6311.13±124.23cP, respectively was observed.

The present findings are in accordance with the research illustrations of Rodríguez-García et al. (44) who checked the effect of various levels of fat (sunflower oil) replacement (0%, 35%, 50%, 70% and 100%) with inulin on physicochemical attributes of cakes. They studied the microstructure and witnessed that substitution of oil with inulin resulted in low batter viscosity with heterogeneous bubble size distribution. The cake batter viscosity is among the main factors controlling the final volume of cakes. In their study, batters prepared with 0 % fat replacement had significantly higher apparent viscosity values (11173.33mPa.s) ($P<0.05$) than batters with 50 % of fat replacement (5648.89mPa.s). Moreover, they concluded that inulin requires more aqueous medium for its dispersion due to its high water binding capacity. Reduction in viscosity results in increased size of air bubbles. Less aerated structure is obtained in the absence of oil owing to the reason that oil acts as an interface and hence can stabilize the air bubbles. The high viscosity aids in incorporation and retention of more air bubbles and provides more stability to the cakes (45).

Batter properties of gluten-free layer cakes in the presence of different fibers (oat-guar, oat-inulin, oat and inulin) were also studied by Gularte et al. (46). According to their findings, decreased batter density of inulin compared to other fibers indicate that inulin incorporates the air during mixing. They explained that batter density is determined by the particle size distribution and concentration of fibers. Furthermore, they also described that except inulin, all the fibers resulted in increased batter viscosity. The batter viscosity is of prime importance in retaining the air bubbles during baking process. It has been stated that air incorporation ability must be taken into account as low volume cakes result from the batters of low consistency (47, 48), increased consistency is related to the limited expansion of batter (46, 41).

Similar trend was obtained in our research indicating the reduction in viscosity with increased concentration of inulin content. More viscosity values observed for artichoke inulin were perhaps due to its ability to bind more water, thereby, the amount of free water was lowered and batter flow ability was reduced.

Physical measurements of cakes

Cake height

Cake height presented in Table 4 revealed significant differences between the treatments under study and control. These experimental measures also illustrated that the interaction between chicory and artichoke inulin as well as the treatments prepared by encountering the chicory inulin (T_1-T_5) exerted significant variations for cake height.

It is noticeable from the means (Table 4) that the maximum cake height recorded was 7.43±0.22, 7.35±0.28 and 7.25±0.26 in T_0 (control), T_6 (10% Jerusalem artichoke inulin) and T_7 (20% Jerusalem artichoke inulin), respectively. However, the lowest cake heights i.e. 6.24±0.22 and 6.31±0.16 were recorded in T_5 (50% chicory inulin) and T_{10} (50% Jerusalem artichoke inulin).

The results of our research in terms of cake height are in corroboration with those presented by Rodríguez-García et al. (12). They concluded that control cakes showed the highest height when compared to the cakes having fat replaced with inulin i.e. 12.18cm for control, 10.62cm at 35% replacement, 10.63cm at 50% replacement, 10.42cm at 70% replacement and 9.07cm at 100% replacement. According to them, final volume of cake was highly governed by the air retained during baking in addition to the amount of initial air incorporation. The control batter resulted in the development of higher cakes having controlled structure indicating the better gas retention capacity. Instead, decreased expansion was observed in the cakes prepared by fat replacement representing the batter instability during baking. In our findings, increased height of cakes prepared by the artichoke inulin was possibly the function of their increased batter consistency that aids in the entrapment and retention of more air bubbles and prevents their loss from the surface during baking leading towards their full expansion. On the other hand, batters prepared by chicory inulin were of low viscosity which might result in large but broader bubble size distribution as they coalesce and increase in size resulting in flaccid cakes after cooling as also explained during microscopic examination and image analysis of the batters performed by Rodríguez-García et al. (12). They showed more controlled and uniform increase in the size of bubbles with 0% fat replacement. On the other hand, 50% replacement of fat occluded more number of smaller bubbles. They described that the batter without fat replacement contained lesser air bubbles during mixing stage, but it retained more air bubbles during the process of baking. Moreover, the reduced apparent viscosity was linked with migration of air bubbles and rate of disproportionation leading towards decreased stability of air bubbles.

Cake volume

Mean squares for the cake volume revealed the significant differences for all the treatment combinations of inulin used as fat replacer in cakes (Table 4). Reduction in cake volume was observed with increasing concentration of inulin. It was narrated that treatments exerted significant effects when compared with control. Besides, significant variations were recorded for chicory inulin, artichoke inulin as well as for their interaction in influencing the cake volume.

Means depicting volume of cakes (Table 4) revealed that the maximum value for the trait was noticed in T_0 (539.53±18.46) trailed by T_6 (537.34±12.05) and T_7 (525.47±11.86). However, the lowest value for the volume was reported by T_5 (412.22±13.08) lead by T_4 (441.34±17.29) and T_{10} (453.16±11.27).

Volume is most important quality attributes of cake as it has great influence on consumer's acceptance and depends on the type and amount of shortening used. Shortening imparts different functions in bakery products including, appearance, flavor, mouthfeel and texture. It helps in incorporation of air which improves the final air cell structure and expansion of cakes. Therefore, cakes with low fat become flat and exhibit low volume index (49). The results of current research are supported by the work of Rodríguez-García et al. (12) who showed that cakes with 0% fat replacement had significantly smaller and higher percentage of cells than the cakes prepared with 50% fat replacement with inulin. Moreover, control batter showed a more constant and narrow bubble size distribution as well as controlled baking expansion. Thus, the final cake showed a high number of small cells within the crumb. On contrary, microbaking of the cakes with 50% fat replacement exhibited considerable expansion of the bubbles but the resulting crumb had bigger and fewer cells distributed in an irregular manner within the crumb.

Our research illustrations are also in coherence with Gularte et al. (46), they used the blends of various fibers (oat-guar gum, oat-inulin, oat, inulin) to explicate their effects on batter and gluten-free layer cake attributes. They investigated that highest cake volume was observed with oat-inulin blend whereas; inulin containing cakes showed the highest collapse after baking. In case of oat-inulin blend, it was described that oat fiber confers some strength to the structure and hence counteracts the collapse after baking. They observed that inspite of collapse, inulin containing cakes showed the volume near to control but the developed structure was not strong enough to hold this expansion after cooling. In another research conducted by Gómez et al. (41), it was narrated that the volume can vary depending upon the formula and type of fiber used. They were of the opinion that batter viscosity plays a major role in retaining the air incorporated during mixing as well as the air bubbles produced by baking powder during baking process. They also suggested that a small rise in batter viscosity can result in improved gas retention and increased cake volume (50).

Hence, it can be inferred from these research investigations that the cake's volume can vary depending upon the batter properties (viscosity, distribution of air bubbles) which play a key role in its transformation from aerated fluid emulsion to porous cake structure. The rise in the volume of Jerusalem artichoke inulin containing cakes might be the result of increased consistency and uniform distribution of air bubbles

Table 4. Means for cake height, volume, water loss and hardness

Sources	Treatments	Cake Height (cm)	Volume (cm^3)	Water Loss (%)	Hardness (N)
Control	T_0	7.43±0.22^a	539.53±18.46^a	19.97±0.57	7.38±0.23^a
Chicory inulin	T_1	6.64±0.14^{bc}	519.72±15.19^{ab}	19.80±0.64	7.33±0.19^a
	T_2	6.60±0.26^{bc}	503.24±21.50^b	19.56±0.52	7.31±0.26^{ab}
	T_3	6.56±0.18^{bc}	487.33±20.71^b	19.21±0.48	7.28±0.20^{ab}
	T_4	6.36±0.19^c	441.34±17.29^c	19.02±0.42	7.24±0.17^b
	T_5	6.24±0.22^c	412.22±13.08^d	18.84±0.53	7.22±0.28^b
Artichoke inulin	T_6	7.35±0.28^a	537.34±12.05^a	19.47±0.38	7.34±0.33^a
	T_7	7.25±0.26^a	525.47±11.86^{ab}	19.21±0.46	7.30±0.22^{ab}
	T_8	7.12±0.24^{ab}	512.17±14.16^{ab}	18.86±0.44	7.27±0.18^{ab}
	T_9	6.73±0.22^b	476.37±16.53^{bc}	18.65±0.52	7.23±0.25^b
	T_{10}	6.31±0.16^c	453.16±11.27^c	18.46±0.48	7.20±0.27^c

Means sharing the same letter in a row are not significantly different. Where, T_0 = Control; T_1 = 10% Chicory inulin; T_2 = 20% Chicory inulin; T_3 = 30% Chicory inulin; T_4 = 40% Chicory inulin; T_5 = 50% Chicory inulin; T_6 = 10% Jerusalem artichoke inulin; T_7 = 20% Jerusalem artichoke inulin; T_8 = 30% Jerusalem artichoke inulin; T_9 = 40% Jerusalem artichoke inulin; T_{10} = 50% Jerusalem artichoke inulin

of their respective batters allowing them to expand up to their full potential. Whilst, reduction in volume in chicory inulin containing cakes in comparison to artichoke inulin was the indication of batter instability resulting from less viscosity of batter and irregular distribution of bubbles as suggested by various studies discussed above.

Water loss

Data regarding water loss depicted non-significant variations with respect to treatments (Table 4). Water loss seemed to decrease as the concentration of inulin was increased due its water binding capacity and this reduction was more obvious in cakes prepared with Jerusalem artichoke inulin representing its greater ability to bind water as compared to chicory inulin.

It can be followed from the means (Table 4) indicating the water loss that the values for this trait in T_0, T_1 and T_2 were 19.97±0.57, 19.80±0.64 and 19.56±0.52%, respectively. Furthermore, the recorded values for the respective parameter were 18.46±0.48 and 18.65±0.52% for T_{10} (50% Jerusalem artichoke inulin) and T_9 (40% Jerusalem artichoke inulin), respectively.

The findings of (12, 44) also revealed the reduction in water loss when level of fat replacement was increased from 0% to 100% with inulin. They concluded that inulin as a soluble fiber could bind more water than oil thereby, helped to retain more moisture content during baking. It has been illustrated that gas is produced during baking process along with increased vapor pressure when liquid expands as a result of heat penetration in cake batter (51). Water loss (bake loss) is the major concern for the structural transformation of cakes as well as is associated with decreased shelf life of products. In addition, it has been stated that sufficient amount of initial water content can increase the volume through swelling of vapors during baking leading to a moist texture.

Hence, it can be inferred from the results that less water loss in Jerusalem artichoke containing treatments was possibly the function of its greater water binding ability than chicory inulin.

Cake hardness

Significant effects of fat substitution by inulin were revealed on cake hardness for all the treatments when compared with control (Table 4). The statistical splitting further revealed the non-significant effect for the interaction between chicory inulin and artichoke inulin. However, significant variations were observed among the treatments of chicory inulin and artichoke inulin.

Regarding hardness, substantial reduction was observed indicating that addition of inulin led to the development of softer cakes. Means regarding cake hardness for various treatments (Table 4) revealed that cake hardness decreased from 7.33±0.19 to 7.22±0.28 when concentration of chicory inulin was increased from 10% (T_1) to 50% (T_5) to replace the fat. Similar trend was observed in cakes produced with Jerusalem artichoke inulin when its concentration was increased from 10% to 50% to replace the fat and the observed values were 7.34±0.33 and 7.20±0.27, respectively. For this parameter T_0 showed the maximum hardness of 7.38±0.23.

The observed reduction in hardness was probably related to the presence of more initial aqueous component for inulin dispersion and its water binding ability which ultimately results in the development of softer cakes. The cakes prepared by Jerusalem artichoke inulin were comparatively softer than those prepared with chicory inulin.

Texture is mainly determined by many factors such as baking time, baking temperature, formulation and amount of water absorbed (46). In a research conducted by Rodríguez-García et al. (44) to check the effect of fat replacement with inulin on the texture of cakes, narrow bubble size distribution was observed at no or low level of fat replacement with significantly softer cakes. On the other hand, large differences in bubble size distribution per unit area were observed in full fat replacement cakes resulting in relatively harder crumb. Reported values of hardness in their study were 8.8, 8.48, 8.91, 7.6 and 14.91 Newton for 0%, 35%, 50%, 70%, and 100% fat replacement, respectively. It was also observed by Alava et al. (52) that the cakes had softer texture when the batter contained homogeneous distribution of bubbles, whereas, broad distribution of bubbles lead to the harder texture. In other studies, it has been known that oil substitution by inulin reduce the number of crumb cells besides diminishing the cake height (53, 54).

Besides, De Man and Weegels (55) reported the softer bread crumb along with extended shelf life with the incorporation of Jerusalem artichoke flour and inulin. It has been envisaged from various studies that hardness is a function of intermolecular interactions among ingredients (46, 56).

Conclusion

Conclusively, it has been observed that chicory roots and Jerusalem artichoke tubers are good sources of health promoting ingredient i.e. inulin. Inulin holds unique technological and functional characteristics, hence, can be incorporated in various food products (bakery and dairy products). Inulin as dietary fibre can be tailored to develop various therapeutic and functional food recipes. Its fat replacing functionality can be utilized to formulate low calorie foods without imparting any deleterious effects on consumer's health. In the instant investigation, inulin proved very effective in imparting the fat replacing functionality in the cakes. Best treatments were referred as T_3 (30% chicory inulin) and T_8 (30% Jerusalem artichoke inulin) by the panelists from both the sources. It was observed that Jerusalem artichoke inulin exhibited better viscosity, oil holding capacity and swelling capacity in comparison to chicory inulin. Additionally, better results were obtained for Jerusalem artichoke inulin in terms of water loss, cake height and volume when compared with their corresponding treatments for chicory inulin. Although both the inulin (chicory, Jerusalem artichoke inulin) exhibited the fat replacing functionality, however, Jerusalem artichoke inulin lead the chicory inulin for this attribute in the underlying research. It is of notable worth to mention that with increasing concentration of inulin, organoleptic attributes are affected and has been described by various scientific studies. In current investigations, cakes prepared by using high levels of inulin as fat replacer exhibited somewhat bitter taste. Hence, it is recommended that before selecting the inulin level, consumer preference must be evaluated by sensory evaluation. However, purification of inulin can prove helpful in masking this bitter effect of taste at high levels of inulin. As the inulin can be extracted from the indigenous sources by the means of simple solvent extraction without using the extensive chemicals and equipments, hence owing to this fact, it cannot lead towards extensive burden in terms of cost. On the other hand it can be preferably used as a prebiotic component beyond exerting its fat replacing functionality. Besides, its benefits associated with lowering hyperglycemia, hypercholesterolemia and colorectal cancer as well as increasing the growth of bifidobacteria can easily justify the increase of cost if it happens in further extensive study.

References

1. Wichienchot S, Thammarutwasik P, Jongjareonrak A, et al. Extraction and analysis of prebiotics from selected plants from southern Thailand. Sonklanakarin J. Sci. Technol. 2011; 33: 517.
2. Alexiou H, Franck A. Prebiotic inulin-type fructans: nutritional benefits beyond dietary fibre source. Nutr. Bull. 2008; 33: 227-233.
3. Bais HP, and Ravishankar GA. Cichorium intybus L–cultivation, processing, utility, value addition and biotechnology, with an emphasis on current status and future prospects. J. Sci. Food Agric. 2001; 81: 467-484.
4. Lachman J. Kays SJ, Nottingham SF. Biology and Chemistry of Jerusalem Artichoke Helianthus tuberosus L. Biologia Plantarum. 2008; 52: 492-492.
5. Saengkanuk A, Nuchadomrong S, Jogloy S, Patanothai A, Srijaranai S. A simplified spectrophotometric method for the determination of inulin in Jerusalem artichoke (Helianthus tuberosus L.) tubers. Eur. Food Res. Technol. 2011; 233: 609-616.
6. Meyer D, Stasse-Wolthuis M. The bifidogenic effect of inulin and oligofructose and its consequences for gut health. Eur. J. Clin. Nutr. 2009; 63: 1277-1289.
7. O'brien C, Mueller A, Scannell A, Arendt E. Evaluation of the effects of fat replacers on the quality of wheat bread. J. Food Eng. 2003; 56:265-267.
8. KimY, Faqih M, Wang S. Factors affecting gel formation of inulin. Carbohydr. Polym. 2001; 46: 135-145.
9. Franck A, De Leenheer L. Inulin. 2005. Biopolymers online.
10. Barclay T, Ginic-Markovic M, Cooper P, Petrovsky N. Inulin-a versatile polysaccharide with multiple pharmaceutical and food chemical uses. J. Excipients Food Chem. 2010; 1: 27-50.
1. Kalyani Nair, K., S. Kharb and D. Thompkinson. 2010. Inulin dietary fiber with functional and health attributes—a review. Food Rev. Int. 26: 189-203.
11. Kocer D, Hicsasmaz Z, Bayindirli A, Katnas S. Bubble and pore formation of the high-ratio cake formulation with polydextrose as a sugar-and fat-replacer. J. Food Eng. 2007; 78: 953-964.
12. Rodríguez-García J, Salvador A, Hernando I. Replacing fat and sugar with inulin in cakes: bubble size distribution, physical and sensory properties. Food Bioprocess Technol. 2014; 7: 964-974.
13. Bouaziz MA., Rassaoui R, Besbes S. Chemical composition, functional properties, and effect of inulin from Tunisian Agave americana L. leaves on textural qualities of pectin gel. 2014. J. Chem. 2014; 2014: 1-11.
14. AACC. 2000. Approved Methods of the American Association of Cereal Chemists, 10th Ed. American Association of Cereal Chemists, Inc. St. Paul, MN. USA.
15. Mccleary BV, Murphy A, Mugford DC. Measurement of total fructan in foods by enzymatic/spectrophotometric method: collaborative study. J. AOAC Int. 2000; 83: 356-364.
16. Van Waes C, Baert J, Carlier L, Van Bockstaele E. A rapid determination of the total sugar content and the average inulin chain length in roots of chicory (Cichorium intybus L). J. Sci. Food Agric. 1998; 76: 107-110.
17. Kim M. The water-soluble extract of chicory reduces cholesterol uptake in gut-perfused rats. Nutr. Res. 2000; 20:1017-1026.
18. Dunn S, Datta A, Kallis S, Law E, Myers CE. Whelan K. Validation of a food frequency questionnaire to measure intakes of inulin and oligofructose. Eur. J. Clin. Nutr. 2011; 65: 402-408.
19. Ding QB, Ainsworth P, Plunkett A, Tucker G, Marson H. The effect of extrusion conditions on the functional and physical properties of wheat-based expanded snacks. J. Food Eng. 2006; 73: 142-148.
20. Bchir B, Rabetafika HN, Paquot M, Blecker C. Effect of pear, apple and date fibres from cooked fruit by-products on dough performance and bread quality. Food Bioprocess Technol. 2014; 7: 1114-1127.
21. Moure A, Sineiro J, Domi´Nguez H. Extraction and functionality of membrane-concentrated protein from defatted Rosa rubiginosa seeds. Food Chem. 2001; 74: 327-339.
22. Ronkart, SN, Paquot M, Deroanne C, Fougnies C, Besbes S, Blecker CS. Development of gelling properties of inulin by microfluidization. Food hydrocolloids. 2010; 24: 318-324.
23. Guillon F, Champ MJ. Carbohydrate fractions of legumes: uses in human nutrition and potential for health. Brit. J. Nutr. 2002; 88: 293-306.
24. Majzoobi M, Habibi M, Hedayati S, Ghiasi F, Farahnaky A. Effects of Commercial Oat Fiber on Characteristics of Batter and Sponge Cake. J. Agric. Sci. Technol. 2015; 17: 99-107.
25. Rodriguez-Garcia J, Puig A, Salvador A, Hernando I. Functionality of Several Cake Ingredients: A Comprehensive Approach. Czech J. Food Sci. 2013; 31: 355-360.
26. Sumnu G, Sahin S, Sevimli M. Microwave, infrared and infrared-microwave combination baking of cakes. J. Food Eng. 2005; 71: 150-155.
27. Sanz T, Salvador A, Baixauli R, Fiszman S. Evaluation of four types of resistant starch in muffins. II. Effects in texture, colour and consumer response. Eur. Food Res. Technol. 2009; 229:197-204.
28. Steel RG, Jh Dickey D. Principles and procedures of statistics a biometrical approach, WCB/McGraw-Hill. 1997.
29. López-Molina D, Navarro-Martínez MD, Rojas-Melgarejo F, Hiner AN, Chazarra S, Rodríguez-López JN. Molecular properties and prebiotic effect of inulin obtained from artichoke (Cynara scolymus L.). Phytochem. 2005; 66: 1476-1484.
30. Panchev I, Delchev N, Kovacheva D, Slavov A. Physicochemical characteristics of inulins obtained from Jerusalem artichoke (Helianthus tuberosus L.). Eur. Food Res. Technol. 2011; 233:889-896.
31. Glibowski P. Effect of thermal and mechanical factors on rheological properties of high performance inulin gels and spreads. J. Food Eng. 2010; 99:106-113.

32. Alvarez-Sabatel S, De Marañón IM, Arboleya J.C. Impact of high pressure homogenisation (HPH) on inulin gelling properties, stability and development during storage. Food Hydrocoll. 2015; 44: 333-344.
33. Cui S, Nie S. Roberts K. Functional properties of dietary fibre. Biotechnol. 2011; 4: 517-525.
34. Charunuch C, Limsangouan N, Prasert W, Butsuwan P. Optimization of extrusion conditions for functional ready-to-eat breakfast cereal. Food Sci. Technol. Res. 2011; 17: 415-422.
35. Yaich H, Garna H, Besbes S, Paquot M, Blecker C, Attia H. Chemical composition and functional properties of Ulva lactuca seaweed collected in Tunisia. Food Chem. 2011; 128: 895-901.
36. Wong K, Cheung PC. Nutritional evaluation of some subtropical red and green seaweeds: Part I—proximate composition, amino acid profiles and some physico-chemical properties. Food Chem. 2000; 71: 475-482.
37. Devereux, H, Jones G, Mccormack L, Hunter W. Consumer acceptability of low fat foods containing inulin and oligofructose. J. Food Sci. 2003; 68:1850-1854.
38. Franck A. Technological functionality of inulin and oligofructose. Brit. J. Nutr. 2002; 87: S287-S291.
39. Mensink MA, Frijlink HW, Van Der Voort Maarschalk K, Hinrichs WL. Inulin, a flexible oligosaccharide I: review of its physicochemical characteristics. Carbohydr. Polym. 2015; 130: 405-419.
40. Mudannayake DC, Wimalasiri K, Silva KF, Ajlouni S. Comparison of Properties of New Sources of Partially Purified Inulin to Those of Commercially Pure Chicory Inulin. J. Food Sci. 2015; 80: C950-C960.
41. Gómez M, Moraleja A, Oliete B, Ruiz E, Caballero PA. Effect of fibre size on the quality of fibre-enriched layer cakes. LWT-Food Sci. Technol. 2010; 43:33-38.
42. Ronda F, Oliete B, Gómez M, Caballero PA, Pando V. Rheological study of layer cake batters made with soybean protein isolate and different starch sources. J. Food Eng. 2011; 102: 272-277.
43. Celik I, Isik F, Gursoy O, Yilmaz Y. Use of Jerusalem artichoke (Helianthus tuberosus) tubers as a natural source of inulin in cakes. J. Food Process. Pres. 2013; 37: 483-488.
44. Rodríguez-García, J, Puig A, Salvador A, Hernando I. Optimization of a sponge cake formulation with inulin as fat replacer: structure, physicochemical, and sensory properties. J. Food Sci. 2012; 77: C189-C197.
45. Lee S, Inglett G, Carriere C. Effect of nutrim oat bran and flaxseed on rheological properties of cakes. Cereal Chem. 2004; 81: 637-642.
46. Gularte MA, De La Hera E, Gómez M, Rosell CM. Effect of different fibers on batter and gluten-free layer cake properties. LWT-Food Sci. Technol. 2012; 48: 209-214.
47. Lee S, Kim S, Inglett GE. Effect of shortening replacement with oatrim on the physical and rheological properties of cakes. Cereal Chem. 2005; 82: 120-124.
48. Lakshminarayan SM, Rathinam V, Krishnarau L. Effect of maltodextrin and emulsifiers on the viscosity of cake batter and on the quality of cakes. J. Sci. Food Agric. 2006; 86: 706-712.
49. Kalinga D, Mishra VK. Rheological and physical properties of low fat cakes produced by addition of cereal β-glucan concentrates. J. Food Process. Pres. 2009; 33: 384-400.
50. Kaur, N. and A.K. Gupta. 2002. Applications of inulin and oligofructose in health and nutrition. J. Biosci. 27: 703-714.
51. Gómez M, Oliete B, Rosell CM, Pando V, Fernández E. Studies on cake quality made of wheat–chickpea flour blends. LWT-Food Sci. Technol. 2008; 41: 1701-1709.
52. Kim JH, Lee HJ, Lee HS, Lim EJ, Imm JY, Suh HJ. Physical and sensory characteristics of fibre-enriched sponge cakes made with Opuntia humifusa. LWT-Food Sci. Technol. 2012; 47: 478-484.
53. Alava J, Whitworth M, Sahi S, Catterall P. Fat emulsifiers and their functionality in cake batters: image analysis of the batter bubble distribution. Bubbles in food. 1999; 273-282.
54. Grigelmo-Miguel N, Carreras-Boladeras E, Martin-Belloso O. Influence of the addition of peach dietary fiber in composition, physical properties and acceptability of reduced-fat muffins. Food Sci. Technol. Int. 2001; 7: 425-431.
55. Zahn S, Pepke F, Rohm H. Effect of inulin as a fat replacer on texture and sensory properties of muffins. Int. J.Food Sci. Technol. 2010; 45: 2531-2537.
56. De Man M, Weegels P. High fibre bread and bread improver compositions. Google Patents. 2004.
57. Gomez M, Ronda F, Caballero PA, Blanco CA, Rosell CM. Functionality of different hydrocolloids on the quality and shelf-life of yellow layer cakes. Food Hydrocoll. 2007; 21: 167-173.

Correspondence:
Summer Rashid PhD Scholar
National Institute of Food Science & Technology
University of Agriculture, Faisalabad
Email: samar.rashid@ymail.com