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Comparative Study on Physico-chemical, Functional and Flow Properties of Gamma-Irradiated Cassava Flour

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Abstract:
Flour isolated from cassava was modified by gamma-irradiation at different doses of 5, 7.5, and 10 kGy. The physicochemical properties and functional properties of control and irradiated cassava flours are analyzed by the standard methods. After irradiation, some changes were observed in the properties of cassava flour such as Ash, and protein, which were increased while moisture, fat, and amylose were decreased. Swelling, solubility index, oil absorption capacity, and water absorption capacity increased significantly with the dose, while syneresis decreased with the dose. The bulk density, tapped density, foaming capacity, and foaming stability remain unaffected after irradiation. The Carr's Index and Hausner's ratio were high as the standard values therefore according to the result the flowability of the cassava flour was poor. The hunter color *'L'*, *'a'*, and *'b'* values of the native cassava flour sample were found to be non-significantly affected by gamma irradiation. The irradiated cassava flour can be used for complementary food items.
Index Term- Protein, Density, Shrinkage, Moisture, Flour

1. Introduction

The cassava (*Manihot esculenta Crantz*) is cultivated mainly in the tropic and sub-tropic regions of the world, over a wide range of environmental and soil conditions [16]. Cassava is an important energy source as the staple food for more than 500 million people in Africa, Latin America, and Asia. The cassava is an important component in the diets of more than 800 million people around the world (FAO, 2007) and is the third-largest carbohydrate food source within tropical regions, after rice and corn [14]. Cassava tuber contains flour, starch, pomace, and peel which is used to make various good quality bakery products. Nowadays, tapioca flour is gaining momentum as a go-to grain-free and gluten-free flour. In recent years people have been looking at health conscious like weight loss, diabetic issues, etc., and hence those people who avoid gluten-rich products can use cassava flour as a replacement for wheat flour in the baking industry [29]. It is cultivated in about 13 states of India, major production is from the southern states of Kerala and Tamil Nadu. Cassava flour is one of the derivatives from cassava roots whose processing technology is cheaper and easier than cassava starch production besides requiring less consumption of water and energy and producing smaller quantity of byproducts and waste [1]. One of the most popular uses of cassava flour in the world is in the manufacturing of baked products such as bread, cakes, and pastries [47]. It is used as a raw material in the manufacture of processed food, animal feed, and industrial product. It is a mainly starchy raw material and contains no gluten, so it is suitable in case of celiac disease. It is rich in various nutrients, including fibers, vitamins, and minerals, and is widely used in the feed, food, and chemical industries [3]. Cassava is grown in India in an area of 0.23 million hectares with a total production of 6.5 million tonnes. It is cultivated in India in about thirteen states (out of 32 states and union territories) with major production in the South Indian states of Kerala (142,000ha) and Tamil Nadu (65,700 ha) [53]. Cassava flour contains carbohydrates, the body's main energy source. It can replace grain-based flour or a gluten-free flour mix. It is an excellent energy source (80-90% carbohydrate) forming an important source of energy in the human diet worldwide [37]. Cassava flour is highly recommended in the diet of celiac patients with strict adherence to gluten-free food products [12,40]. Cassava flour contains carbohydrates, the body's main energy source. It can replace grain-based flour or a gluten-free flour mix can be achieved with cassava flour. -free flours like coconut or almond. Additionally, cassava flour has a low fat content which makes it a great substitute for wheat flour in baking and other products. it is a valuable product obtained from cassava roots after processing, it is relatively cheap to produce traditionally [8]. The main advantage of this flour cassava flour is that it is a grain-free and nut-free flour and is naturally gluten-free and a great flour to use in baking and cooking therefore people who avoid gluten can use it as a replacement for wheat flour in terms of taste and texture. The main advantage of this flour Cassava flour is that it is a grain-free and nut-free flour and is naturally gluten-free and a great flour to use in baking and cooking therefore people who avoid gluten can use it as a replacement for wheat flour in terms of taste and texture. Cassava flour absorbs more liquid than wheat flour. Tapioca flour/starch is an excellent binding and thickening agent for multiple purposes- baking goods, cooking soups, or making bubble tea. [30] investigated that the fat content of cassava flour was lower, and the ash and starch contents were higher than those of low-gluten wheat flour. The protein content of cassava flour was substantially lower than wheat flour.

2. Material and methods

2.1. Collection of samples

The raw cassava (*Manihot esculenta Crantz*) was procured from the local market of New Delhi (India) and stored at 20^0C until further study. The polyethylene pouches (zipper pouches) of food grade, are purchased from the registered suppliers. All the chemicals used in this study were of analytical grade, procured from Merck India Ltd.

2.2. Processing of cassava flour

The cassava roots were processed into flour. Cassava roots were washed in potable water to remove soil and dirt from their skin and peeled by using a kitchen knife. The peeled roots were washed and cut into chip slices by using a vegetable and fruit slicer after that it was dipped into distilled water for a while then it was dried by using a tray dryer at 65°c for 6 hours. After drying, the dried chips were milled into flour after that it was collected and sieved to obtain fine flour. Then the flour was packed into air-tight low-density polyethylene pouches and stored at room temperature.

2.3. Gamma irradiation treatment

About 500 g of dried cassava flour were packaged in low-density polyethylene bags and the packed sample were subjected to three different doses of gamma irradiation viz, 5, 7.5, and 10 kGy using cobalt-60 as source irradiator at room temperature of 23 ± 2°C with a dose rate of 0.5 kGy/h. The irradiation treatments were performed at the Shri Ram Institute for Industrial Research, New Delhi, India. Un-irradiated starch was taken as control. After irradiation, all samples were stored in a dry and ventilated medium to avoid any humidification before analysis.

2.4. Proximate Analysis:

2.4.1. Moisture content

The moisture content of the sample was determined by the gravimetric method as per the [6] standard method.

2.4.2. Fat, Protein, Fibre

The estimation of fat, protein, and fibre of samples through automatic fat extraction unit, kelplus, and fibra plus (Pelican Equipment, Chennai, India) as described by [53].

2.4.3. Carbohydrate and energy

The carbohydrate content was measured by finding the difference between the main constituents (fat, protein, fibre, ash) from 100% as given by [23].

2.4.4. Amylose

The amylose content of the starch was determined according to the method described by [58].

2.4.5. Color Quest

The color values in terms of L, a, and b of the sample were measured by using a Hunter Color Meter (Shenzhen 3nh Technology Co., Ltd) with illuminant D65 and 100 observers. A higher L* value indicated a brighter or whiter sample. Values of a* and b* indicated the red-green and yellow-blue chromaticity respectively.

2.4.6. Flow properties:

Bulk and Tapped density: BD and TD were calculated as per the methods described by [31,37].
Hausner's ratio: It was calculated from the ratio of the tapped density to the bulk density [4].
The flowability and compressibility of the samples were determined using Carr's index and Hausner's ratio. Carr's index (%) of 5–10, 12–16, 18–21, and 23–28 represent excellent, good, fair, and poor flowability, respectively [7].

2.5. Functional Properties:

2.5.1. Oil and water absorption capacity:

WAC and OAC of the samples (1 g) were carried out as per the methods described by [54].

2.5.2. Foam capacity (FC) and Foam stability (FS):

FC and FS were determined according to the method described by [15]

2.5.3. The least gelation concentration (LGC):
The least gelation concentration (LGC) was determined using the procedure recommended by [15].

2.5.4. Swelling and solubility index:
Water solubility index and swelling power were carried out at 60, 70, 80, and 90 °C with modification of the sample as described by [55].

2.6. Paste clarity:
1g of sample was measured according to the method followed by [49].

2.7. Syneresis:
Syneresis was determined by the modified method as per described by [55].

2.8. Fourier Transform Infrared (FTIR) spectroscopy:
FTIR was performed as per the method described by [36].

3. Result and Discussion:
3.1. Physico-chemical properties of ϒ-irradiated cassava starches
3.1.1. Moisture content:
The moisture content of the flour sample (0 to 10 kGy) is presented in Table 1 which ranged from 9.52 % to 7.37% respectively. This study showed that the highest value was observed for 0 kGy (9.52 %) and the lowest value was found for 10 kGy (7.37 %) followed by 5 kGy (9.31 %) and 7.5 kGy (7.37 %). The same trend was also reported by [4,9] in their studies, indicating the moisture content was increased as the ϒ-irradiated doses increased. The present study revealed that the moisture content of the cassava flour was affected by the increasing doses of radiation from 0 to 10 kGy due to the adsorption and desorption process. The present study showed that low moisture content is suitable for storage without changing any properties of the flour. The fat value decreased with increasing the irradiation doses because due to irradiation the molecular structure was changed to disrupt the double bonds of fatty acids [59].

3.1.2. Fat content:
The fat content for 0, 5, 7.5, and 10 kGy were found to be 0.75 %, 0.71, 0.65 % and 0.53 % respectively. 0 kGy (0.75 %) had the highest value of fat content while least value was found for 10 kGy (0.53 %) similar trend followed by [10]. The present study showed that the fat value decreased with increasing the irradiation doses because the molecular structure was changed due to irradiation disrupting the double bonds of fatty acids. The fat contents indicate stability, if it is higher will lead to rancidity, give undesirable flavour, and be prone to oxidation and there will be the chance to grow the microbes. Therefore, in present study showed that the fat value of samples was low and prolonged storage without rancidity with suitable storage conditions.

3.1.3. Protein content:
The protein content of the samples for 0 to 10 kGy ranged between 1.64 % to 3.14 %. The highest value was observed for 10 kGy (3.14 %) and the lowest value was observed for 0 kGy (1.64 %). The present study revealed that the protein was increased when the irradiation doses were increased similar result was shown in irradiated wheat flour by [9] same trend ascribed by [32]. ϒ-irradiation can disintegrate the non-covalent bonds (hydrogen and disulfide bond) due to the generation of free radicals which may loss of the structural and conformational integrity of protein. Hence it can be used to develop GF foods as a material in the production of biscuits to improve the nutritional value of the products**.**

3.1.4. Fibre content:
The fibre content was increased as the irradiation doses were increased. The fibre content for 0 kGy was found 2.09 %, 2.32 (5 kGy), 2.53 % (7.5 kGy), and 2.84 % (10 kGy). Some researchers have reported that the higher level of fibre tends to lose moisture during drying due to weak water-fiber interaction. When fibre is present along with starch it reveals the limited amount of water available in the food system. The amylose content was found for 0 kGy (17.62 %), 5 kGy (17.91 %), 10 kGy (18.15 %), and 10 kGy (18.53 %) respectively.

3.1.5. Amylose content:
The amylose content is the basis of classifying starches into waxy, semi-waxy, normal/regular, and high-amylose types when amylose content is 0-2%, 3-15% 20-35%, and higher than 40% of the total starch, respectively [38,11]**.** The amylose content is an important aspect of food processing because it affects the gelatinization and retrogradation properties [53]. The present study showed that the amylose content was increased with increasing the irradiation doses. Increasing the amylose content by ϒ-irradiation may define the degradation of the amylopectin structures/branches and also the production of low molecular weight fractions [18]. Similar results are observed for the increased amylose content reported for rice and potato [49]. Therefore, the amylose content must be quantified for food processing and quality [44] also it is responsible for the gelling characteristics of cooked food.

Table 1. Proximate composition of the cassava flour

Parameters	Samples			
	0 kGy	5 kGy	7.5 kGy	10 kGy
Moisture	9.52 ± 0.10^{c}	9.31 ± 0.14^{c}	8.29 ± 0.10^{b}	7.37 ± 0.12^{a}
Ash	2.81 ± 0.00^{a}	2.83 ± 0.01^{b}	2.85 ± 0.00^{c}	2.93 ± 0.01^{d}
Fat	0.75 ± 0.00^{d}	0.71 ± 0.02^{c}	0.65 ± 0.02^{b}	0.53 ± 0.03^{a}
Protein	1.64 ± 0.01	2.28 ± 0.14	2.56 ± 0.02	3.14 ± 0.03
Fibre	2.09 ± 0.01^{a}	2.32 ± 0.01^{b}	2.53 ± 0.01^{c}	2.84 ± 0.02^{d}
pH	5.83 ± 0.04^{d}	5.73 ± 0.03^{c}	5.65 ± 0.04^{b}	5.54 ± 0.01^{a}
Amylose	17.62 ± 0.02^{a}	17.91 ± 0.05^{b}	18.15 ± 0.03^{c}	18.53 ± 0.04^{d}
Carbohydrate	83.16 ± 0.00^{b}	82.51 ± 0.00^{a}	83.20 ± 0.17^{b}	83.17 ± 0.00^{b}
Energy	346.05 ± 0.001^{a}	345.74 ± 0.002^{b}	348.50 ± 0.001^{c}	350.11 ± 0.001^{d}

Means that the rows with different superscripts are significantly different ($p \leq 0.05$).
Values expressed are means ± SD (n=3).

3.1.6. pH:
The pH of the samples from 0 to 10 kGy varied from 4.16 to 3.23. Similar results observed in lotus starch and rice starch have been reported by [28,36]. The present study showed that the pH of the cassava flour gradually decreased as the doses increased. Similar results were observed by other researchers [54]. Due to ϒ-irradiation, the starch molecule could be broken into a carboxylic acid [30]. The present study revealed that the chemical structure of the starch molecule was changed so the pH may be affected.

3.2. Flow properties:
The flow properties of the cassava starch are presented in Table 2.
3.2.1. Bulk density: BD was found 0.421 g/cc (0 kGy), 0.414 g/cc (5 kGy), 0.415 g/cc (7.5 kGy) and 0.0.415 g/cc (10 kGy). The present study showed that there are no significant changes in bulk density with an increase in the doses, which indicates that ϒ-irradiation didn't produce any damage to the polymer. Low bulk density of the flour would be used in the formulation of complementary foods while high bulk density is suitable for use in food preparation has been reported by [41]. The bulk density depends on the initial moisture content and particle size of the sample. Bulk density is an essential quality factor in food industries for making food products [53].

3.2.2. Tapped density: Tapped density for 0, 5, 7.5, and 10 kGy ranged from 0.71 g/cc, 0.70 g/cc, 0.71 g/cc, and 0.70 g/cc respectively. The low tapped density indicates the non-cohesive properties of the material. Higher tapped density is suitable for the packaging and a greater amount of material is packed within a constant unit volume [33]. In present study showed that the tapped density of the cassava starch was higher than the bulk density this is due to some factors viz size, solid density, geometry, and surface properties of the flour material [35].

3.2.3. Porosity: The porosity of untreated and irradiated cassava starch ranged in between 40.62-41.37 % from 0 to 10 kGy respectively. The present study showed that porosity was decreased as the doses increased. Porosity is a measure of void space present in a material. Porosity is one of the main indicators that determines the quality of bakery products and characterizes their structure, volume, and level of digestibility. The porous structure is the most characteristic of bakery products and determines their quality [45].

3.2.4. Carr's index: C.I. was found for 0 kGy to 10 kGy ranged 40.63 % to 41.35 % respectively. The highest C.I value was observed for 5 kGy (41.94 %) while the lowest value was found for 0 kGy (40.63 %). As per [50], Carr's index and Hausner's ratio are a measure of the flowability and compressibility of a powder respectively. The Carr's percentage indicates the aptitude of a material to diminish in volume while Hausner's index shows the antiparticle friction. The score of Carr's indexes (%) of 5–10, 12–16, 18–21, and 23–28 represent excellent, good, fair, and poor flowability [25] respectively. The values of C.I for samples which were higher than the 15 % which indicates good flowability. It means native and irradiated cassava flour indicates poor flowability.

Table 2. Density and flow properties of the cassava flour

Parameters	Samples			
	0 kGy	5 kGy	7.5 kGy	10 kGy
Bulk density	0.421 ± 0.002^{b}	0.414 ± 0.003^{a}	0.415 ± 0.009^{a}	0.415 ± 0.004^{a}
Tapped density	0.710 ± 0.001^{a}	0.709 ± 0.000^{a}	0.710 ± 0.001^{a}	0.708 ± 0.000^{a}
Porosity (%)	40.62 ± 0.30^{a}	41.59 ± 0.60^{b}	41.52 ± 0.40^{b}	41.37 ± 0.05^{ab}
Carr's index (%)	40.63 ± 0.30^{a}	41.94 ± 0.60^{c}	41.27 ± 0.04^{ab}	41.35 ± 0.05^{bc}
Hausner's ratio	1.685 ± 0.008^{a}	1.712 ± 0.017^{b}	1.710 ± 0.011^{b}	1.705 ± 0.001^{ab}

Means in the rows with different superscripts are significantly different ($p \leq 0.05$), [± SD (n=3)].

3.2.5. Hausner's ratio:

Hausner's ratio of both control and irradiated cassava flour values was found to be higher than 1.25 (values less than 1.25 indicates good flow and greater than 1.25 indicates poor flow, as reported by [50]. So, it can be said that the flowability (flow property) of all the samples was poor.

3.3. Color Quest:

The color values of native and irradiated cassava flour are presented in Table 3. The L* value decreased with increasing the doses of radiation. L* for 0, 5, 7.5, and 10 kGy were found to be 97.53, 97.43, 97.34 and 96.83 respectively. The present study showed that the lightness of the cassava flour is close to whiteness. The* value of the samples was decreased as the doses were increased. The a* value for 0, 5, 7.5, and 10 kGy were found -0.46, -0.31, -0.27, and -0.25 respectively. 7.5 kGy (-0.25) had the highest a* value while 0 kGy (-0.46) had the lowest value. The present study showed that the green color fell as the doses increased, there is a decrement of the greenish color in irradiated samples as compared to 0 kGy. b* value of the samples was increased as the doses increased from 0 kGy to 10 kGy ranging between 92.96 to 96.43 respectively. The present study showed that there was an enhancement of the yellow color when the doses were increased. In present study showed the altering of the color index due to the Maillard reaction formed by the ϒ-irradiation or to cleaved the monosaccharide from the starch polysaccharide [54]. A similar trend was shown by [51]. The Whiteness index indicates the color of starch close to white color. The whiteness score of the samples for 0 to 10 kGy ranged between 92.96 to 96.43 respectively. The highest value of whiteness was found for 10 kGy (96.43), and the lowest value was found for 0 kGy (95.63). The study revealed that the value of whiteness of starch increased with increasing the doses of irradiation. It may suggest that increasing the fibre content decreased the whiteness of cassava starch.

Table 3. Color quest of the cassava flour.

Parameters	Sample			
	0 kGy	**5 kGy**	**7.5 kGy**	**10 kGy**
L*	97.53±0.017^{a}	97.43±0.030^{b}	97.34±0.030^{c}	96.83±0.025^{d}
a*	-0.46±0.026^{a}	-0.31±0.005^{b}	-0.27±0.020^{c}	-0.25±0.020^{c}
b*	1.57±0.01^{a}	3.96±0.015^{b}	4.04±0.025^{c}	5.25±0.03^{d}
Whiteness	92.96±0.41^{a}	93.66±0.15^{b}	95.63±0.20^{c}	96.43±0.30^{d}

Means in the rows with different superscripts are significantly different ($p \leq 0.05$).
Values expressed are means ± SD (n=3).

3.4. Functional properties of the cassava flour

3.4.1 Water and Oil Absorption Capacity:

WAC and OAC of the native flour as well as irradiated cassava flour are given in Table 4. WAC for 0, 5, 7.5 and 10 kGy were found to be 2.36 g, 2.45 g, 2.46 g, and 2.53 g respectively. WAC deals with the size, shape, proteins, lipids, pH, and salt. It plays a crucial role in the function of protein in various food items like soups, bread, dough, and bakery products. The highest WAC represents the presence of minerals, especially high phosphorus. The WAC increased with increased doses of irradiation due to the degradation of the starch into simple sugars (like glucose, dextrin, etc.) which had a higher affinity for water than starch [55]. The highest WAC was observed for 10 kGy (1.97g) and the lowest value was found for 0 kGy (1.72g). Similar results were shown in ϒ-irradiated lotus starch by [28]. The high WAC is useful in the preparation of soups, and gravies and also to make food items like bread, sausages etc.

The OAC values for 0, 5, 7.5, and 10 kGy were found to be 1.83g, 1.86g, 1.92g, and 2.11g. The present studies showed that the OAC was increased with increased doses. OAC is an important function in food industries for the retention of flavor and improved shelf-life and palatability [10]. It also shows the binding capacity between fat and protein for the manufacturing of food products. When flour is treated with irradiation it may cause the denaturation of protein and disintegrate the physical structure of the amylopectin chain and unfolding of proteins [2]. OAC showed the entrapment of the oil and high affinity of non-polar protein side chains for lipids [46]. Similar results have been reported by [9,10].

3.4.2. Emulsion activity and stability

EA and ES for 0 to 10 kGy ranged between 30.09 % to 53.76 % respectively. Emulsifying activity is defined as the maximum amount of oil that can be emulsified by a fixed amount of the protein, while the stability of the emulsion is defined as the rate of phase separation in water and oil during storage of the emulsion [42]. The EA was increased with increased doses in contrast the ES was gradually decreased with increased doses ranging 68.60 % to 52.08 % for 0 to 10 kGy. The present study showed that the properties of emulsion activity and stability were changed after irradiation. The increment of the emulsion activity and the reduction of the emulsion stability might be due to the disintegration and aggregated protein molecules when the starch was treated with dosage irradiation. Various studies have shown that a good emulsifier acts as a barrier against lipid oxidation. Emulsion properties are an important aspect in the application of food industries like the formulation of agricultural products, use in coating, etc.

3.4.3. Foam capacity and stability

FA and FC for 0, 5, 7.5, and 10 kGy were found at 6.77 %, 7.10 %, 7.93 % and 8.53 % respectively. The FC refers to the surface tension and interfacial area created by whipping the protein. The FC is correlated to the protein, the foam capacity increases when the protein is found to be high. Foaming properties are an important aspect in the food industry and to improve the appearance or to maintain the consistency of food products such as ice cream, cake, etc. In the current study, the FC was increased for 5, 7.5, and 10 kGy as compared to 0 kGy. The foam stability for 0, 5, 7.5, and 10 kGy was found 86.90 %, 86.23 %, 85.30 %, and 84.99 % respectively. The FS was decreased when the doses were increased as compared to 0 kGy. The present study revealed that the FC was increased while FS was decreased for 0, 5, 7.5, and 10 kGy. This depends on the nature of the protein, when flour was treated with the dosage of the radiation the nature of the protein was changed which may have led to a change in the foaming properties. Similar results were shown in irradiated sorghum grains and sesame seeds [5,32].

Table 4. Functional properties of cassava flour

Parameters	Samples			
	0 kGy	5 kGy	7.5 kGy	10 kGy
WAC (g/g)	2.36±0.01^{a}	2.45±0.05^{ab}	2.46±0.04^{ab}	2.53±0.07^{b}
OAC (g/g)	1.83±0.05^{a}	1.86±0.01^{a}	1.92±0.05^{a}	2.11±0.11^{b}
EA (%)	30.09±1.49^{a}	39.58±0.90^{b}	49.50±1.73^{c}	53.76±1.60^{d}
ES (%)	68.60±2.90^{b}	53.60±0.41^{a}	52.82±0.88^{a}	52.08±0.90^{a}
FC (%)	6.77±0.04^{a}	7.93±0.05^{c}	7.10±0.08^{b}	8.53±0.02^{d}
FS (%)	86.90±0.01^{d}	86.23±0.04^{c}	85.30±0.02^{b}	84.99±0.01^{a}
GT (°C)	69.39±0.37^{cd}	69.32±0.22^{c}	69.25±0.18^{b}	69.13±0.10^{a}
LGC (%)	8%	6%	6%	6%

Values expressed are means ± SD (n=3).
Means in the rows with different superscripts are significantly different ($p \leq 0.05$).

3.4.4. Gelatinization temperature and Least gelation concentration

Gelatinization temperature was found 69.39 to 69.13°C for 0 to 10 kGy. The gelatinization temperature was decreased as the dosage was increased. Gelatinization is correlated to the properties of the amylose and amylopectin chains. It deals with the loss of birefringence and crystallinity due to the breakage of the double bond and enhancing the leaching property of the amylopectin due to irradiation [4,21]. It is a process where the starch granules form a suspension in cold water at a lower temperature. When heated before storage at a low temperature the cellulose wall of the starch ruptures and results in swollen bumps into each other and absorbed water. Whereas, the LGC was decreased when the doses were increased for 0 to 10 kGy ranged in between 8 % to 6 %. Lower LGC had the good ability to form the gel which is used in various food items. The gelation properties of cassava starch could enhance their utilization in the food industry which is required for the formation of gel [17].

3.4.5. Swelling power and Solubility index

SP for 0 to 10 kGy ranged between 7.73-10.36 g at 50° C, 8.14-11.32 g at 60° C, 11.12-11.63 g at 70° C, 11.46-12.62 g at 80° C, and 12.95-14.45 at 90° C respectively. Swelling power means to trap the starch and retain the water within the structure, before and during gelatinization [57]. Amylopectin plays a vital role in the swelling. The swelling power of the cassava starch was increased with temperature as well as increased with increased doses from 0 to 10 kGy due to the depolymerization of the amylopectin chain in the starch granules during irradiation and showed degradation of the starch granules chain at higher temperatures with gelatinized the starch and denatured the protein matrix which may prevent the diffusion of water into the matrix of starch [36]. It plays an important role to full fulfilling the requirements of the food industry. It ascribes the classification of the starch from different botanical origins which indicates different swelling powers at different temperatures [15].

It deals with the degradation of the starch which is correlated to amylose and amylopectin. The solubility of the cassava starch was increased with the temperature from 50 to 90 degrees when the irradiate doses were increased ranging from 0 to 10 kGy was 2.54-2.67 % at 50° C, 2.72-2.92 % at 60° C, 2.75-2.91% at 70° C, 4.68-5.42% at 80°C and 4.97-5.61% at 90°C respectively. The highest solubility was observed at 90^0 C for the native and irradiated starches. A similar trend was followed by [18]. Increased the solubility of the starch with the amylose due to the disruption of the starch granules because there is the establishment of H-bond with water when it is released in the solution therefore amylose content was leached out.

Table 5. Swelling power and Solubility index of the cassava flour

Parameters		Irradiation dose (kGy)			
		0	5	7.5	10
Swelling Power (g)	50° C	7.73±0.01ᵃ	8.14±0.00ᵇ	8.67±0.01ᶜ	10.36±0.01ᵈ
	60° C	8.14±0.00ᵃ	8.83±0.01ᵇ	10.86±0.01ᶜ	11.32±32ᵈ
	70° C	11.12±0.01ᵃ	11.26±0.11ᵇ	11.36±0.01ᶜ	11.63±0.01ᵈ
	80° C	11.46±0.01ᵃ	11.52±0.01ᵇ	11.75±0.01ᶜ	12.62±0.01ᵈ
	90° C	12.95±0.01ᵃ	13.41±0.01ᵇ	13.88±0.01ᶜ	14.45±0.00ᵈ
Solubility Index (%)	50° C	2.54±0.01ᵃ	2.60±0.00ᵇ	2.63±0.01ᶜ	2.67±0.00ᵈ
	60° C	2.72±0.01ᵃ	2.82±0.01ᵇ	2.85±0.01ᶜ	2.92±0.01ᵈ
	70° C	2.75±0.11ᵃ	2.83±0.01ᵇ	2.83±0.05ᵇ	2.91±0.01ᶜ
	80° C	4.68±0.01ᵃ	4.77±0.01ᵇ	4.90±0.01ᶜ	5.42±0.01ᵈ
	90° C	4.97±0.00ᵃ	5.02±0.01ᵇ	5.11±0.01ᶜ	5.61±0.01ᵈ

Values expressed are means ± SD (n=3).
Means in the rows with different superscripts are significantly different ($p \leq 0.05$).

3.5. Light transmittance:

The percentage of the light transmittance of the flour gel (samples) at refrigerated temperature (4^0 C) is shown in Table 6. Transmittance is the fraction of incident light at a specified wavelength that passes through a sample. The transmittance value was decreased for 0, 5, 7.5, and 10 kGy ranging between 75.36-50.37 %, 75.86-51.52%, 76.24-52.86%, and 80.16-53.26 % respectively during 0 days to 5 days. The transmittance value was increased as the dosage increased for 0, 5, 7.5, and 10kGy ranging between 75.36 to 80.16 %, 59.16 to 62.76 %, 61.96 to 62.95 %, 53.11-54.42 and 50.37-53.26 during day 1 to day 5. The result revealed that the light transmittance was significantly decreased during the storage period at refrigeration temperature for 5 days due to the retrogradation (re-association of the amylose chains) of the starch and the presence of high amylose and phospholipids [20,48] but increased the transmittance value as the doses were increased from 0 to 10 kGy due to the disintegration of the starch granules. A similar trend was observed in ϒ-irradiated lotus starch, wheat starch, and Indian beans [9,28,56]. The present study suggested that cassava flour could be used in the processing of jam, jellies confectionaries food items. Transparent gels can be used as carriers of active ingredients composed of oils, surfactants, vitamins, sunscreen agents, and antioxidants in the formulation of multifunctional cosmetic gels [19].

Table 6. Transmittance of the cassava flour

Parameters	Samples			
Transmittance (%)	0 kGy	5 kGy	7.5 kGy	10 kGy
Day-1	75.36±0.01ᵃ	75.86±0.01ᵇ	76.24±0.02ᶜ	80.16±0.01ᵈ
Day-2	59.16±0.01ᵃ	59.76±0.18ᵇ	61.12±0.02ᶜ	62.76±0.02ᵈ
Day-3	61.96±0.02ᵃ	62.02±0.02ᵇ	62.65±0.04ᶜ	62.95±0.04ᵈ
Day-4	53.11±0.00ᵃ	53.37±0.00ᵇ	53.96±0.02ᶜ	54.42±0.01ᵈ
Day-5	50.37±0.00ᵃ	51.52±0.01ᵇ	52.86±0.00ᶜ	53.26±0.04ᵈ
Syneresis (g/g)				
0 h	4.12±0.04ᵈ	3.84±0.01ᶜ	3.56±0.02ᵇ	3.11±0.04ᵃ
24 h	37.29±0.30ᵈ	35.37±0.25ᶜ	32.74±0.18ᵇ	30.96±0.23ᵃ
48 h	45.89±0.46ᶜ	43.08±0.12ᵇ	42.67±0.20ᵇ	40.68±0.14ᵃ
72 h	46.85±0.09ᵈ	45.72±0.17ᶜ	44.90±0.25ᵇ	43.09±0.56ᵃ
96 h	47.46±0.02ᵈ	46.94±0.33ᶜ	45.13±0.11ᵇ	43.45±0.32ᵃ
120 h	56.14±0.03ᶜ	48.30±0.02ᵇ	45.45±0.08ᵃ	45.03±0.84ᵃ

Values expressed are means ± SD (n=3).
Means in the rows with different superscripts are significantly different ($p \leq 0.05$).

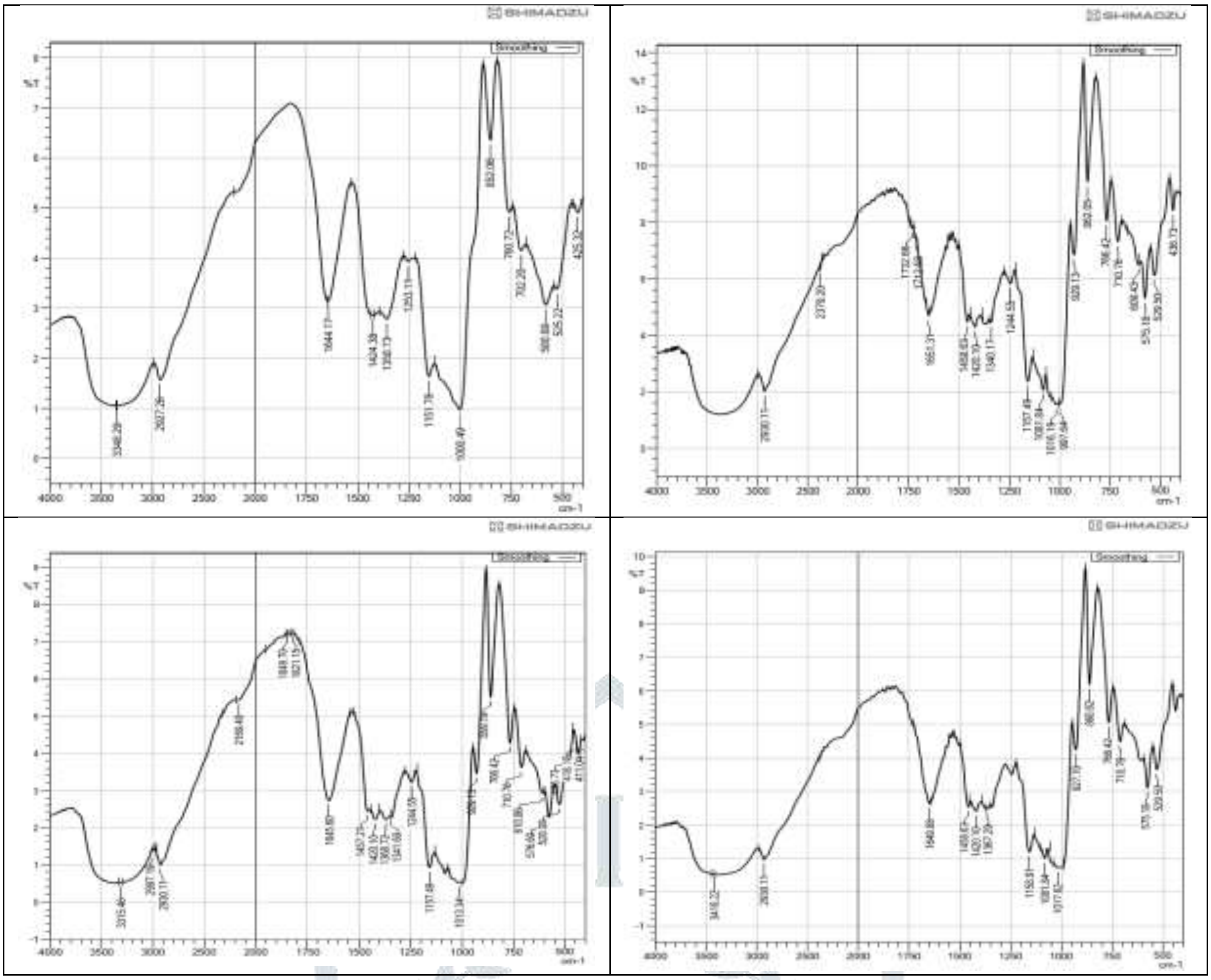

Fig. 1: FTIR spectra of control and irradiated cassava flour (Doses: 0, 5, 7.5, 10 kGy)

3.6. Syneresis:

The highest value of syneresis in the samples was found at 120 h during storage at lower temperatures shown in Table 6. The syneresis value was increased with storage but decreased with an increase in the dosage for 0 to 10 kGy. The syneresis was increased for 0, 5, 7.5, and 10 kGy ranged 4.12-56.14 %, 3.84-48.30 %, 3.56-45.45 %, and 3.11-45.03 % during the storage period (0 to 120 h). The highest value was found to be 4.12-56.14 % (10 kGy) and the minimum value was found for 0 kGy (3.11-45.03 %) during storage. Syneresis is the physical phenomenon in which water is expelled and released from the starch gel [34]. Syneresis occurs due to the re-crystallization of the amylose in the granules of starch at low temperatures in a loss of water from the gel structure. Similar results for syneresis were reported for irradiated lotus starch, potato, and buckwheat starch, horse chestnut [28,54,55]. The increase in syneresis during storage could be attributed to the interaction of leached amylose chains which results in the release of water [54] while decreasing as the dosage increases due to the weak interaction of H-bond between amylose and amylopectin chain and forms simple sugar which have higher tendency for water.

3.7. FTIR

The samples were analyzed by FTIR to confirm the breakdown of glycosidic bonds and the decrease of the short-range crystalline order (double helices). Extreme broadband at 3400 cm^{-1} was ascribed to N-H stretching vibrations are presented in Figure 1. The bands at 2900 cm^{-1} were ascribed to C-C stretching vibration. Small peaks at 1600 cm^{-1}, 1650 cm$^{-1,}$ and 1550 cm^{-1} were ascribed to amide representing C=O stretch in proteins and amide II peak representing N-H bending in proteins respectively, that indicate inter and intra-molecular H-bonding and also ascribed to C-H stretching associated with the ring methane h atoms. The peak below 900 cm^{-1} (fingerprinting region) with the major band at 500 cm^{-1}, 550 cm^{-1}, 600 cm^{-1}, 650 cm$^{-1,}$ and 750 cm^{-1} represent the pyranose ring in the glucose unit of starches [9,54] The band at 1349 cm^{-1} was ascribed to O-C-H, C-C-H and C-O-H.

Conclusion

The ϒ-irradiated cassava flour product would be recommended in prospect those people suffering from celiac disease in the current scenario seeing that children suffer from gluten intolerance so casava muffin is a better option to consume it, compared to the market muffin. Cassava starch can be used to prepare directly for further processing to develop value-added products, edible coating materials, and biodegradable packaging films as well as to make rodent trappers. Due to the unique properties of cassava starch, it is suggested for markets such as baby foods and non-allergenic products.

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Conflicts of interest

The authors have no conflicts of interest to declare. All co-authors have seen and agree with the manuscript's contents and there is no financial interest to report. We certify that the submission is original work and is not under review at any other publication.

References

1. Abass, A. Onabolu, A.O. and Bokanga, M. (1998). Impact of the high-quality cassava flour technology in Nigeria. In Akoroda, M. O. & Ngve, J. M. (Eds). Root crops in the 21th century. Proceedings of the 7th Triennial Symposium of the International Society for Tropical Root Crops Africa Branch (ISTRC- AB). Cotonou, Benin, 11-17 October. Benin: Center International des Conferences.
2. Abu, J.O., Duodu, K.G., Minnaar, A., (2006). Effect of γ-irradiation on some physicochemical and thermal properties of cowpea (Vigna unguiculata L. Walp) starch. Food Chem. 95:386-393
3. Adesina, B. S., andBolaji, O. T. (2013). Effect of milling machines and sieve sizes on cooked cassava flour quality. Nigerian Food Journal, 31(1):115–119.
4. Adzahan, N., Hashim, M., Muhammad, D., Abdul Rahman, K., Ghazali, R.Z., and Hashim, K., (2009). Pasting and leaching properties of irradiated starches from various botanical sources. International Food Research Journal. 16: 415-429
5. Ahmed, M.M., Abdalla, I.G., Salih, A.M., and Hassan, A.B., (2018). Effect of gamma radiation on storability and functional properties of sorghum grains (Sorghum bicolor L.). Foods science and nutrition. 6:1933-1939.
6. AOAC, 2012. Official methods of analysis, 4th edition Association of official Analytical Chemist, Washington DC.
7. Apeji, Y.E., Oyi, A.R., and Musa, H., (2011). Studies on the Physicochemical Properties of Microcrystalline Starch Obtained by Enzymatic Hydrolysis Using A-Amylase Enzyme. Pharmacophore. 2:9-15
8. Ayetigbo, O., Adebayo Abass, S.L., and Muller, J. (2018). Comparing Characteristics of Root, Flour and Starch of Biofortified Yellow-Flesh and White-Flesh Cassava Variants, and Sustainability Considerations: A Review. Sustainability. 10:1-32
9. Bashir, K., Swer, T.L., Prakash, K.S. and Aggarwal, M. (2016). Physico-chemical and functional properties of gamma irradiated whole wheat flour and starch. Food Science and Technology. 76:131-139
10. Bhat, R., Sridhar, K. R., and Seena, A. (2008). Nutritional quality evaluation of velvet bean seed (Mucuna pruriens) exposed to gamma irradiation. International Journal of Food Science and Nutrition, 54:261–278.
11. Botticella, E., Sestili, F., Sparla, F., Moscatello, S., Marri, L., Cuesta -Seijo, J.A., Falini, G., Battistelli, A., Trost, P., and Lafiandra, D., (2018). Combining mutations at genes encoding key enzymes involved in starch synthesis affects the amylose content, carbohydrate allocation and hardness in the wheat grain. Research Article.
12. Briani, C., Samaroo, D., Alaedini, A. (2008). Celiac disease: from gluten to autoimmunity. Autoimmunity Reviews. 7:644-650
13. Carr, R.L., (1965). Evaluating flow properties of solids. Chem. Eng. 72:163-168
14. Ceballos H., Sanchez T., Morante N., Fregene M., Dufour D., Smith A., Denyer K., Perez J., Calle F. and Mestres C. (2006). Discovery of an amylose-free starch mutant in cassava (Manihot esculenta Crantz). Journal of Agriculture and Food Chemistry, 55:7469-7476.
15. Chandra, S., Singh, S., and Kumari, D. (2015). Evaluation of functional properties of composite flours and sensorial attributes of composite flour biscuits. J Food Sci Technol. 2015 Jun; 52(6): 3681–3688.
16. Chavez, A.L., Sanchez, T., Jaramillo, G., Bedoya, J.M., Echeverry, J., Bolanos, E.A., Ceballos, H. and Iglesias C.A. (2005). Variation of quality traits in cassava roots evaluated in landraces and improved clones. Euphytica, 143(1–2):125-133.
17. Chinma, C.E., Ariahu, C.C., and Abu, J.O., (2013). Chemical composition, functional and pasting properties of cassava starch and soy protein concentrate blends. Journal Food Science Technology 50:1179–1185
18. Chung, H.J., and Liu, Q., (2010). Molecular structure and physicochemical properties of potato and bean starches as affected by gamma-irradiation. Int. J. Biol. Macromolecule. 47:214-222
19. Comelles, F., Caelles, J., Parra, J., and Leal, J.S., (1992). Transparent gels: study of their formation and assimilation of active ingredients through phase diagrams. International Journal of Cosmetic Science. 14: 183-195

20. Craig, S. A. S., Maningat, C. C., Seib, P. A., and Hoseney, R. C., (1989). Starch paste clarity. Cereal Chemistry. 66:173-182.
21. Donovan, J. W. (1979). Phase transitions of the starch–water system. Biopolymers. 18:263-275
22. Edition, S. (2007). Cassava research and development strategies in India. In Holwer, R.H. Centro Internacional de Agricultura Tropical (CIAT). Cassava Research and development in Asia: Exploring New opportunities for an Ancient Crop. Proc. 7th Regional Workshop, held in Bangkok, Thailand during oct 28-Nov1, 2002. 13-24
23. Emmanuel, O., Clement, A., Agnes, S., Chiwona-Karltun, L., and Drinah, B., (2012). Chemical composition and cyanogenic potential of traditional and high yielding CMD resistant cassava (Manihot esculenta Crantz) varieties. International Food Research Journal. 19:175-181.
24. Fakir, M.S.A., Jannat, M., Mostafa, M.G., and Seal, H., (2012). Starch and flour extraction and nutrient composition of tuber in seven cassava accessions. J. Bangladesh Agril. Univ. 10:217-222.
25. Falade, K.O., Ibanga-Bamijoko, B., and Ayetigbo, O.E., (2019). Comparing properties of starch and four of yellow-fesh cassava cultivars and effects of modifications on properties of their starch. Journal of Food Measurement and Characterization. 44:11-22
26. Fernandez and Alejandro Q. (1996). Effects of processing procedures and cultivar on the properties of cassava flour and starch. PhD thesis, University of Nottingham.
27. Fernandez and Alejandro Q. (1996). Effects of processing procedures and cultivar on the properties of cassava flour and starch. PhD thesis, University of Nottingham.
28. Gani, A., Gazanfar, T., Jan, R., Wani, S.M., and Masoodi, F.A., (2012). Effect of gamma irradiation on the physicochemical and morphological properties of starch extracted from lotus stem harvested from Dal Lake of Jammu and Kashmir, India. Journal of the Saudi Society of Agricultural Sciences. 12:109-115
29. Geetha, R., Sankari, A., Pugalendhi, L., Vennila, P., Swarnapriya., R and Thangamani, C. (2021). Studies on functional properties of cassava var. Yethapur Tapioca-2 for its suitability as an ideal industrial substitute for the grain starches. The Pharma Innovation Journal 2021; 10(5):09-12
30. Ghali, Y., Ibrahim, N., and Aziz, H., (1979). Modification of corn starch and fine flour by acid and gamma irradiation. Part 1. Chemical investigation of the modified product. Starch/Starke 31:325-328.
31. Haiqin Lu., Guo, L., Zhang., Caifeng Xie., Wen Li., Bi Gu1., and Kai Li. (2019). Study on quality characteristics of cassava flour and cassava flour short biscuits. Food Sci Nutr. 00:1–13
32. Hassana, A. B., Mahmouda, N. S., Elmamounb, K., Adiamoc, O. Q., and Mohamed Ahmed, I. A. (2018). Effects of gamma irradiation on the protein characteristics and functional properties of sesame (Sesamum indicum L.) seeds. Radiation Physics and Chemistry. 144:85-91.
33. Iwe, M., Onyeukwu, U., and Agiriga, A. (2016). Proximate, functional and pasting properties of FARO 44 rice, African yam bean and brown cowpea seeds composite flour. Cogent Food & Agriculture. 2:114-2409.
34. Karim, A.A., Norziah, M., and Seow, C., 2000. Methods for the study of starch retrogradation. Food Chemistry. 71: 9-36.
35. Khan, A., Erum, S., Rashid, N., and Riaz, N., (2018). Evaluation of potato genotypes for quality of French fries and chips. Academia Journal of Agricultural Research. 6: 117-120.
36. Kumar, P., Prakash, K.S., Jan, K., Swer, T.L., Jan, S., Verma, R., Deepika, K.M., Dar, M.Z., Verma, K., Bashir, K., (2017). Effects of gamma irradiation on starch granule structure and physicochemical properties of brown rice starch. Journal of Cereal Science. 77:194-200
37. Laswai, H.S., Pacific, R., Hussein, J. (2017). Suitability of Cassava Starch in Making Baked and Fried Composite Flour Products. Tanzania Journal of Agricultural Sciences. 16:9-16.
38. Morante, N., Ceballos, H., Sanchez, T., Rolland-Sabate, A., Calle, F., Hershey, C., Gibert, O., and Dufour, D., (2016). Discovery of new spontaneous sources of amylose-free cassava starch and analysis of their structure and techno-functional properties. Food Hydrocolloids. 56: 383-395.
39. Niba, L.L., Bokanga, M.M., Jackson, E.L., Schlimme, D.S. and Li, B.W. (2001). Physicochemical properties and starch granular characteristics of flour from various Manihot esculenta (cassava) genotypes. Journal of Food Science. 67:1707-1705
40. Niewinski, M.M. (2008). Advances in celiac disease and gluten free diet. Journal of American Diet Association. 108:661-672.
41. Oladunmoye, O.O., Aworh, O.C., Dixon, B.M., Erukainure, O.L., and Gloria, N., (2014). Elemo. Chemical and functional properties of cassava starch, durum wheat semolina flour, and their blends. Food Science and Nutrition. 2:132-138
42. Pearce, K.N., Kinsella, J.E., (1978). Emulsifying Properties of Proteins: Evaluation of a Turbidimetric Technique. J. Agric. Food Chem. 26:716–723
43. Pereira, B.L. and Leonel, M. (2014). Resistant starch in cassava products. Food Sci. Technol, Campinas, 34(2): 298-02
44. Peroni, F.H.G., Rocha, T.H., and Franco, C.M.L., (2006). Some Structural and Physicochemical Characteristics of Tuber and Root Starches. Food Sci Tech Int. 12:505-513
45. Petrusha O., Daschynska O., and Shulika A. (2018). Development of the measurement method of porosity of bakery products by analysis of digital image. Chemical Engineering: Food Production Technology. 40:61-66

46. Sathe, S.K., Deshpande, S.S., and Salunkhe, D.K., (1982). Functional properties of winged bean proteins. J. Food Sci. 47:503-509
47. Shittu, T. A., Dixon, A., Awonorin, S. O., Sanni, L. O. and Maziya-Dixon, B. (2008). Bread from composite cassava–wheat flour. II: Effect of cassava genotype and nitrogen fertilizer on bread quality. Food Res. Int., 41:569-78.
48. Singh, N., Singh, J., Kaur, L., Sodhi, N. S., and Gill, B. S. (2003). Morphological, thermal and rheological properties of starches from different botanical sources. Food Chemistry. 81:219-231.
49. Singh, S., Singh, N., Ezekiel, R., and Kaur, A., (2011). Effects of gamma-irradiation on the morphological, structural, thermal and rheological properties of potato starches. Carbohydrate Polymers. 83:1521-1528
50. Staniforth, J.N. (1996). Powder flow. In: Pharmaceutics: The science of dosage form design. Aulton M. L. (Ed) ELBS:615.
51. Teixeira, B.S., Inamura P.Y., and Mastro, N.L.D., (2015). The Influence of Gamma Irradiation on Texture, Color and Viscosity Properties of Potato Starch. International Nuclear Atlantic Conference - INAC 2015 São Paulo, SP, Brazil, October 4-9, 2015. ISBN: 978-85-99141-06-9
52. Toan V.N., (2018). Preparation and improved quality production of flour and the made biscuits from purple sweet potato. Journal of Food Nutrition. 4:1-14.
53. Verma, R., Chauhan, N., Singh, B.R., Samsher, Chandra, S., and Sengar, R.S., (2022). Evaluation of physicochemical and flow properties of cassava flour. The Pharma Innovation Journal. 11:190-196.
54. Verma, R., Jan, S., Rani, S., Kulsum., Swere, T.L., Prakash, K.S., Dara, M.Z., and Bashir, K., (2018). Physicochemical and functional properties of gamma irradiated buckwheat and potato starch. Radiation Physics and Chemistry. 144:37-42
55. Wani, I. A., Jabeen, M., Geelani, H., Masoodi, F. A., Saba, I., and Muzaffar, S. (2014). Effect of gamma irradiation on physicochemical properties of Indian Horse Chestnut starch. Food hydrocolloids. 35: 253-263
56. Wani, I.A., Sogi, D.S., Wani, A.A., Gill, B.S., and Shivhare, U.S (2010). Physico-chemical properties of starches from Indian kidney bean (Phaseolus vulgaris) cultivars. Int. J. Food Sci. Technol. 45:2176-2185.
57. Whistler, R.L., and Daniel, J.R., (1985) Carbohydrates. In: Fennema, O.R. (Ed.), Food Chem., second ed., Marcel Dekker Inc., New York. 69-125.
58. Williams, P.C., Kuzina, F.D., and Hlynka, I., (1970). A Rapid Colorimetric Procedure for Estimating the Amylose Content of Starches and Flours. Cereal Chem. 47:411-421
59. Yalmaz, I., and Geçgel, U., (2007). Effects of gamma irradiation on trans fatty acid composition in ground beef. Food Control. 18:635-638.