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Research article

Effect of bleaching and variety on the physico-chemical, functional and rheological properties of three new Irish potatoes (*Cipira*, *Pamela* and *Dosa*) flours grown in the locality of Dschang (West region of Cameroon)

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ABSTRACT

Enzymatic browning, which usually occurs during irish potato tuber processing, causes deterioration in the nutritional, functional, physical and acceptability quality of the products derived from this matrix. To fight against this phenomenon, several treatment methods have been developed, such as bleaching. This led us to investigate the effect of bleaching on the physico-chemical, functional and rheological properties of three irish potato varieties. To achieve our objective, blanched and unbleached irish potatoes flours of three varieties (*Cipira*, *Dosa* and *Pamela*) were produced. The physico-chemical, functional and rheological aspects of the flours were then studied according to standard and developped methods. It appears from this study that treatment and variety significantly influenced ($P < 0.05$) the nutritional composition of irish potatoes flours. The physical properties with the exception of titratable acidity were affected ($P < 0.05$) by the treatment and the varieties. Analysis of the functional properties revealed that unbleached flours had a higher swelling rate and water retention capacity than bleached flours. Rheological properties, such as final viscosity, are influenced by the treatment and variety. The main component analysis showed that bleaching affects the properties of the varieties *Pamela* and *Cipira*. In view of all this, we can therefore highlight the applicability of each of the flours in a specific industrial field.

1. Introduction

Food security remains one of the major problems in many developing countries. In Cameroon, roots and tubers are the most important food crops. These roots and tubers are mainly cassava (*Manihot esculenta*), sweet potato (*Ipomea batatas*), yam (*Dioscorea* sp.), cocoyam's (*Colocasia esculenta*) and irish potato (*Solanum tuberosum*). This tuber (*Solanum tuberosum*, L.), which belongs to the *Solanaceae* family and is known worldwide for its high consumption, is ranked second after cereals (FAO, 2005). Irish potatoes are so-called subsistence crop in production areas, as they do not occupy a prominent place in international trade due to transport and conservation difficulties. Potato tubers contain about three-quarters of their weight in water (77.5%). Its high carbohydrate content (19% compared to fresh matter) makes it an energy food of choice due to its starch content (Delaplace, 2007). This starch provides about 70–80% of the calories consumed by humans worldwide (FAO, 1998). A greater knowledge of the properties of local irish potato starches could be interesting in that they can be a source of starch production in Cameroon and a contribution to infant nutrition. Cooking behaviours (Rao and Tattiyakul, 1999) and technological suitability depends in part on the starch composition, the amylose/amylopectin ratio, the physico-chemical, functional and rheological properties of irish potato. The concern related to the consumption and processing of this tuber is its high water content which makes it susceptible to microbial attacks as well as enzymatic browning. The use of this tuber is influenced by various treatments, including boiling (Osundahunsi et al., 2003), drying (Yadav et al., 2006), peeling, drying temperature (Maruf et al., 2010) and bleaching (Jangchud et al., 2003). These different transformation processes have been shown to influence functional, rheological and physico-chemical properties of flours and starch. With regards to bleaching, its aim to reduce enzymatic browning due to the action of polyphenol oxidase and peroxidase, which affects the colouring of irish

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potato chunck during peeling (Sanful et al., 2016). This mechanism leads to a reduction in product acceptability due to the development of rancid compounds that affect the colour and odour of the product (Sanful et al., 2016). The fight against this phenomenon requires several methods, including the use of chemical agents such as $MgCl_2$, which has the ability to bind to the active site of enzymes responsible for browning limiting their activities (McEvily et al., 1992) and physical methods such as water bleaching (Laurila et al., 1998). The latter has been reported by Akissoé et al. (2003), as having many benefits such as improving product quality, colour preservation, microbiological quality and physicochemical properties. These properties are therefore important for characterization and industrial application purposes. It should be noted that this type of bleaching, if uncontrolled, can lead to the loss of nutritional value due to nutrient leaching, thermal degradation of compounds or alteration of starch granules following heating (Kouassi et al., 2010).

The development and study of new varieties of irish potato produced in Cameroon is of vital importance for the development of the agri-food, pharmaceutical and textile industries. It's probably due to its highly perishable nature but because of the new properties that could be its own. The Menoua division is a large production basin for this tuber because of its favourable climate and several new varieties are being developed, such as *Cipira*, *Pamela* and *Dosa*. For this purpose, the proximate chemical composition and functional properties of the *Cipira* irish potato starch has been evaluated (Ngouadjeu, 2015), but the two other varieties remain unevaluated but also introduces the effect of a treatment which is here the bleaching on the rheological, functional and physico-chemical properties of these flours. This raises the following question: could bleaching affect the functional, rheological and physico-chemical properties of the flours of the different irish potato varieties involved? The aim of this study was therefore to evaluate the effect of bleaching on the nutritional value, physical, functional and rheological properties of three new varieties of irish potatoes, as well as the interactions between their different properties in view to contribute to knowledge base of the species for product diversification and improvement.

2. Material and methods

2.1. Material

The plant material used for this work consisted of three varieties of irish potatoes (*Solanum tuberosum*, L.): *Dosa*, *Cipira* and *Pamela* grown in the West region of Cameroon. The irish potatoes used in our study were collected at the multi-purpose station of the Agricultural Research Institute for Development (ARID) of Dschang, Menoua Division (West region of Cameroon) in December 2017. The samples thus collected were sent to the laboratory where they were used to produce bleached and unbleached flours. These different flours were used for the different analyses. The choice of irish potatoes varieties was made on the basis of their availability and usefulness. The irish potatoes were also washed and separated into two batches (for each variety), one of which was bleached and the other unbleached (Figure 1).

2.2. Methods of operation

2.2.1. Production of bleached and unbleached potato flours

Irish potatoes tubers of different varieties were washed with tap water and separated into two batches. The first batch was peeled and cut into slices (4–7mm thick). The irish potatoes slices were dried in a "venticell" oven at 45 °C for 24 h. The dried chuncks were crushed with a mill and sieved with a 300μm mesh size sieve (stainless steel sieve). The flours obtained were packaged in polyethylene bags and stored in a desiccator to limit moisture exchange before analysis. The second batch of tubers was bleached with tap water at 90 °C for 5 min. The bleached tubers were peeled, sliced (4–7 mm thick), dried in a "venticell" oven at 45 °C for 24 h, crushed with a mill and screened with a 300μm mesh size screen (stainless steel screen). The flours obtained were packaged in polyethylene bags and stored in a desiccator (Figure 2).

2.3. Proximate composition, physical, functiona l and rheological properties of the various samples

2.3.1. Proximate composition

The samples produced as described above were subjected to different analyses. The moisture content was assessed using the method described by IUPAC (International Union of Pure Applied Chemistry), (1979). In fact, in a crucible of known weight (P_0) a quantity of the flours was introduced to obtain a final weight (P_1). The whole is placed in an oven dried « Venticell (MM-group) » at 105 °C for 24 h. After drying, the sample is removed and weighed progressively in order to obtain the constant weight (P_2). The content is deduced from that of the dry matter (DM) using the formula Moisture content = 100-% of DM.

$$DM(\%) = \frac{\mathrm{P2} - \mathrm{P0}}{\mathrm{P1} - \mathrm{P0}} \times 100$$

Total lipids were extracted in Soxhlet with hexane as solvent. The lipid content is determined by weighing after evaporation of the hexane from the cartridges in an oven (AFNOR, 1981). Protein determination was done by the Kjeldahl method (AOAC, 1990). Fiber content was assessed using the standard method described by AOAC (1990). The colorimetric method described by Fisher and Stein (1961) using 3,5-Dinitrosalycylic as colour agent, was used to evaluate the reducing sugar content. The ash content was determined using the standard method described by AOAC (1990), which consists of incinerating the sample at 560 °C and in an oxidizing atmosphere until a residue of constant mass was obtained. The standard method described by AOAC (1990) also made it possible to assess the carbohydrate content by difference.

$$Carbohydrates\ content\ (\%) = 100 - [Moisture\ (\%) + Proteins\ (\%) + Lipids\ (\%) + Ashes\ (\%)]$$

Starch content was evaluated by the method described by Jarvis and Walker (1993). Amylose content of the flours samples was determined colorimetrically according to the method of Chrastyl (1987) based on amylose–iodine complex formation. Amylose content was calculated

Figure 1. Irish potatoes samples (a: *Cipira*; b: *Pamela*; c: *Dosa*).

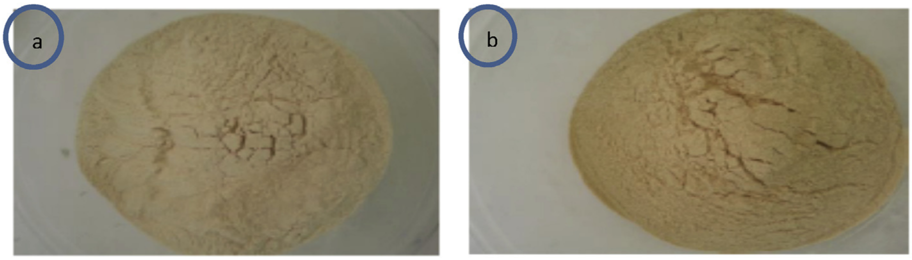

Figure 2. Unbleached (a) and bleached (b) irish potatoes flours.

from a standard curve prepared using a mixture of pure cassava starch. The amylopectin content was deducted from the amylose content, with the difference in relation to the starch content of the samples being determined by the following formula: Amylopectin content (%) = 100 - % of amylose content.

The total phenol content was evaluated using the method described by Gao et al. (2000). Total polyphenols content was determined following the Folin–Ciocalteau colorimetric method with sligth modifications. About 10 μl of sample, 1390 μl of distilled water and 200 μl of Folin–Ciocalteau reagent were mixed and let stand for 3min. After that, 400 μl of sodium carbonate solution (20%) were added, mixed and incubated in the water bath for 20min. The absorbance was measured at 760nm using UV-light spectrophotometer (Thermo scientific, GENESYS 20). The total polyphenols content was expressed as mg gallic acid equivalent per 100g dry matter (DM) of sample (mg GAE/100g of DM).

Phosphorus was extracted from dryashed samples using a digestion mixture of sulphuric acid, peroxyde (30%), selenium and lithium. After digestion, phosphorus was estimated colorimetrically at 880 nm wavelength using atomic absorption spectrophotometer (AOAC, 1990).

The energy value was determined by applying the ATWATER coefficients (Merril and Watt, 1955): 1 g of carbohydrate or protein provides 4 kilocalories; 1 g of fat provides 9 kilocalories. The expression of the energy value is given by the following equation: Ec = (4× (% carbohydrates)) + (9 × (% fat)) + (4 × (% protein)). The percentage contribution to the recommended nutrient intake was expressed as a % of the RDA (Recommanded Daily Allowances).

$$RDA\ (\%) = \frac{X}{Y} \times 100$$

where X is the amount of nutrient analyzed and Y is the RDA for a given nutrient/variable.

2.4. Functional and physical properties of the different flours

Water and oil holding capacity were determined using the method of Lin et al. (1974) with slight modifications. About 3 g of the flour was suspended in 30 ml of distilled water at temperature range 30–90 °C (at intervals of 10 °C) in a centrifuge tube stirred for 20 min and then centrifuged at 4500 rpm for 15 min. The supernatant was decanted and the weight of the gel was recorded. The WHC (%) and OHC (%) were then calculated as weight of the gel divided by the weight of initial dry flour. Swelling capacity was determined using the method described by Okezie and Bello (1988) with slight modifications. One gram (1g) of the sample was taken into 15 ml centrifuge tube. 10 ml of distilled water was added and mixed gently. The slurry was heated in a water bath at 30–80 °C for 15 min and the slurry was stirred gently to prevent clumping of the flour. After 15 min, the tube containing the paste was centrifuged using refrigerated centrifuge (Heraeus) at 4500 rpm for 15 min. The supernatant was decanted and the weight of paste was taken. The swelling power was calculated as weight of wet mass sediment per unit weight of dry matter in the gel. Bulk density was determined according to Okaka et al. (1991). A 50 g flour sample was taken into a 100 ml measuring cylinder. The sample was packed gently by tapping the cylinder on the benchtop. The volume of the sample was recorded to calculate bulk density (g/ml) as weight of flour (g) divided by flour volume (ml). pH was determined in 10% aqueous solution at room temperature using a pH meter (GlowGeek Advanced Portable pH meter) according to the standard method described by AOAC (1990), and titratable acidity of different flours according to the standard method described by AFNOR (1982).

2.5. Rheological properties of the different flours

Samples ground to a flour (particle size = 300 μm) were used to determine pasting properties according to the method reported by Sanchez et al. (2009) using a Rapid Visco Analyser (RVA-4 model Thermocline Windows Control and analysis software, Newport Scientific, Switzerland). Indeed, (3g) of dry matter from each flour and starch were dispersed in distilled water (25 ml) to obtain a 12% suspension. The viscosity was recorded according to the following temperature profile: holding at 50 °C for 1 min, heating from 50 °C to 95 °C at a rate of 6 °C/min, holding at 95 °C for 5 min, cooling at a rate of 12 °C/min to 50 °C, and finally holding at 50 °C for 2 min. The first agitation at 960 rpm was applied for the first 10 s, then at 160 rpm for the remaining time of the experiment. The average over 2 replicas was calculated. Six parameters were measured on the visco-amylogram: Emptying temperature (PT), peak viscosity (PV: first peak viscosity following the pasting), holding strength (HS) and finally final viscosity (FV). Two additional parameters were then calculated: The breakdown (BD) estimated by (PV-HS), the set-back (SB) estimated by (FV - HS).

2.6. Statistical analysis

The results of the analyses carried out in triplicates were expressed as mean±standard deviations. The means were analysed by the ANOVA test at the 5% probability threshold and the Duncan test was used to compare the means using IBM SPSS software version 20.0. The graphs were drawn using Sigmaplot software version 12.0. A correlation matrix and the principal component analysis (PCA) between the physico-chemical, functional and rheological properties of the flours were also performed using IBM SPSS software 20.0 and XLSTAT 2014 software.

3. Results and discussion

3.1. Proximate chemical characterization of the different irish potatoes flours

Table 1 presents the proximate chemical compositions of the different irish potatoes flours. It appears that the water content, which is a very important parameter in predicting the stability and conservation of a food, varies from 9.36% to 10.95%. It is also observed that bleaching did not affect ($P > 0.05$) this parameter in samples from the varieties *Dosa* and *Pamela*. This is contrary to the results of Igbokwe et al. (2016), which showed that bleaching increased the water content of yam flour. This could be due to the nature of the sample and the bleaching time. In addition, it is observed that variety significantly ($P^{\circ}0.05$) affected this

Table 1. Proximate chemical composition of the different irish potatoes flours.

Flours	CUBF	CBF	DUBF	DBF	PUBF	PBF
Moisture (%)	10.95 ± 0.09^{a}	9.30 ± 0.13^{cd}	9.66 ± 0.31^{bcd}	9.39 ± 0.21^{d}	9.99 ± 0.01^{b}	9.76 ± 0.19^{bc}
Ash (% of DM)	8.50 ± 0.71^{c}	4.50 ± 0.71^{d}	7.00 ± 0.00^{b}	7.00 ± 0.00^{b}	8.50 ± 0.70^{a}	8.50 ± 0.71^{a}
Proteins (% of DM)	9.95 ± 0.21^{b}	9.35 ± 0.21^{d}	10.25 ± 0.34^{c}	10.95 ± 0.08^{b}	11.55 ± 0.07^{a}	11.15 ± 0.21^{ab}
Lipids (% of DM)	2.19 ± 0.07^{c}	2.60 ± 0.15^{abc}	2.66 ± 0.26^{abc}	3.02 ± 0.44^{ab}	3.13 ± 0.18^{a}	2.31 ± 0.70^{bc}
Digestibles carbohydrates (% of DM)	70.01 ± 0.59^{b}	74.42 ± 1.04^{a}	70.73 ± 0.33^{b}	69.29 ± 0.30^{bc}	67.37 ± 0.52^{d}	68.68 ± 0.37^{cd}
Fibers (% of DM)	9.35 ± 0.07^{b}	9.20 ± 0.00^{bc}	9.50 ± 0.00^{a}	9.50 ± 0.00^{a}	9.35 ± 0.07^{b}	9.15 ± 0.07^{c}
Energy bulk (Kcal/100g of DM)	339.95 ± 1.68^{b}	358.48 ± 1.60^{a}	347.86 ± 0.05^{ab}	348.14 ± 0.76^{ab}	343.85 ± 2.43^{ab}	340.11 ± 5.10^{b}
Starch (% of carbohydrates)	84.23 ± 2.08^{a}	78.19 ± 2.09^{a}	55.63 ± 3.13^{c}	49.55 ± 3.06^{c}	61.98 ± 5.66^{b}	55.94 ± 5.66^{bc}
Amylose (% of starch)	14.72 ± 0.12^{b}	11.61 ± 0.20^{b}	15.43 ± 2.98^{b}	12.40 ± 2.96^{a}	23.98 ± 0.28^{a}	21.00 ± 0.15^{a}
Amylopection (% of starch)	85.27 ± 0.12^{a}	88.39 ± 0.11^{a}	84.57 ± 2.98^{a}	83.46 ± 2.99^{a}	76.02 ± 0.28^{b}	74.42 ± 0.28^{b}
Amylose/Amylopectin	0.17 ± 0.002^{b}	0.14 ± 0.003^{b}	0.18 ± 0.041^{b}	0.15 ± 0.041^{b}	0.31 ± 0.005^{a}	0.28 ± 0.003^{a}
Phosphorus (mg/100g of DM)	326.51 ± 11.28^{a}	278.76 ± 11.42^{c}	310.56 ± 11.28^{ab}	318.54 ± 0.00^{ab}	318.54 ± 0.00^{ab}	302.59 ± 0.00^{b}
Phenol (mg GAE/100g of DM)	301.59 ± 65.85^{a}	211.51 ± 17.10^{bc}	215.08 ± 78.70^{ab}	198.81 ± 63.76^{abc}	263.89 ± 31.32^{ab}	186.51 ± 23.52^{c}
Reducing sugar (% DM)	0.57 ± 0.05^{c}	0.56 ± 0.20^{c}	2.54 ± 0.15^{a}	1.62 ± 0.95^{b}	0.40 ± 0.06^{c}	0.43 ± 0.06^{c}

The means ± standard deviations followed by the same letter in the same line indicate that the differences are not significant ($p > 0.05$).
DM: Dry matter; CUBF: Cipira unbleached flour; CBF: Cipira bleached flour; DUBF: Dosa unbleached flour; DBF: Dosa bleached flour; PUBF: Pamela unbleached flour; PBF: Pamela bleached flour.

parameter. Indeed, the genetic difference of each variety is said to be at the origin of this variation. The value of 14% water content is conidered as critical for the conservation of food in tropical areas. All flours have been found to have values below 11%, making them less susceptible to microbial attack (Ndangui, 2015). The evaluation of the ash content of the different samples shows that this parameter is affected ($P < 0.05$) not only by bleaching in samples from the *Cipira* variety but also by the variety. The decrease noted following bleaching could be attributed to leaks of highly soluble minerals through leaching. As for the effect of variety, this would be due to climatic conditions, genetic variation, cultivation techniques and soil types. Similar observations have also been reported by Olatunde et al. (2016) who demonstrated that ash content of sweet potato has affected by pretreatments and variety.

Proteins are very important for growth. They are involved in the process of regulating metabolic reactions, tissue formation, cartilage solidification and emulsion stabilzation. The protein content varies from 9.95 to 11.55%. It appears that there is a significant difference ($P < 0.05$) between bleached and unbleached flours of the varieties *Cipira* and *Dosa*. The increase in this parameter following bleaching is due to the destruction of phenolic compounds that can lead to protein complexation and reduce their availability. These results are similar to those observed by Igbokwe et al. (2016) on fleshed yam. Irish potato proteins are known to be of very good quality and would therefore be a source of this nutrient for people in developing countries where foods of plant origin are the main source of nutrients (International Life Sciences Institute (International Life Sciences Institute (ILSI), 2008). On the other hand, the values obtained show that these flours are favourable for the formulation of weaning foods.

Lipids play a very important role in the child's dietary intake and psychomotor development. The fat content varies from 2.19% for unbleached *Cipira* flour to 3.13% for unbleached *Pamela* flour. This parameter is not significantly ($P > 0.05$) affected by the variety. It is also noted that there is a significant difference ($P < 0.05$) between samples from the variety *Pamela*. This would be due to the leaching phenomenon that occurs during bleaching (Igbokwe et al., 2016), as well as lipid oxidation due to temperature increase (Haile et al., 2015). These results also support those of Harijono et al. (2013), who showed that bleaching reduces lipid content of water yam.

Digestible carbohydrates, along with fats and proteins, are the energy-providing molecules. The evaluation of the digestible carbohydrate content shows that this parameter is not significantly affected by the variety aspect ($P > 0.05$) but by the treatment ($P < 0.05$) in the *Cipira* samples. The increase in carbohydrate content with bleaching could be explained by the hydrolysis of certain cells on the surface of the membrane leading to the release of carbohydrates. It is also linked to the loss of fat and protein to carbohydrates during bleaching. These results are similar to those of Tumwine et al. (2018), but lower than those of Ndangui (2015), who obtained 86.6% on bleached sweet potato flour. This would be due to the nature of the samples, cultural practices, time and type of bleaching.

Fibers are the main non-digestible fraction of carbohydrates in plants and facilitate digestion. It appears from this table that their content is not significantly ($P > 0.05$) affected by the variety but by bleaching ($P < 0.05$) within the variety *Pamela*. Indeed, water bleaching causes the potato membrane to weaken, which leads to the elimination of soluble fibres by osmosis. This result is not in line with those of Jangchud et al. (2003), which showed that the fiber content of irish potato flour increased after bleaching. This difference would be explained by the variety of the sample and the duration of bleaching. The calorific energy provided by each flour depends on the composition of each flour. It is not affected by the treatment within the varieties *Pamela* and *Dosa* and generally the variety does not influence this parameter ($P > 0.05$). The results obtained are similar to those of Tumwine et al. (2018), on millet composite flour. Starch is the main form of energy reserve in plants. It is responsible for the functional and rheological properties of the flours and therefore for predicting the behaviour of this flour during formulation. The evaluation of the starch, amylose and amylopectin content of each flour shows that these parameters are not significantly affected by the treatment ($P > 0.05$) but by the variety ($P < 0.05$). These observations are not similar to those of Igbokwe et al. (2016), who demonstrated that bleaching significantly reduced starch, amylose and amylopectin content of bleached yam flours. This could be explained by the nature of the sample, processing time (5 min) and temperature (90 °C) which can lead to morphological changes in the granule and therefore reduce the levels of these components. Regarding the effect of variety, this difference would be related to the genetic characteristics of each variety, particularly that governing starch synthesis. These results corroborate those of Tambo et al. (2019), who showed that the starch, amylose and amylopectin content of cassava flours depend on the nature of the cultivar. However, these results are higher for these three parameters than those of Eke-Ejiofor (2015), on cassava, sweet potato and yam starches. The amylose/amylopectin ratio is essential in predicting the rheological behaviour of flour and therefore its applicability. It varies between 0.14 (CBF)-0.31 (PUBF). It is not affected by the treatment but on the other hand moderately by the variety. This ratio is higher in the Pamela variety due to its high proportion of amylose. This difference in the ratio between varieties is related to the

Table 2. Contribution (%) of energy, protein, and fat content from 100 g of irish potato single flour toward RDA for children aged 6–59 months.

Variables	Age group (years)	Recommanded Daily Allowances (RDA)	Contribution (%) of irish potatoes flours to RDA					
			CUBF	CBF	DUBF	DBF	CUBF	CBF
Energy (Kcal/day)	0–0.5	650[a]	52.24	55.15	53.52	53.56	52.90	52.32
	0.5–1.0	850[a]	39.95	42.17	40.92	40.96	40.45	40.01
	1–3	1300[a]	26.12	27.57	26.76	26.78	26.45	26.16
	4–6	1800[a]	18.86	19.92	19.33	19.34	19.10	18.89
Proteins (g/day)	0–0.5	13[a]	76.54	71.92	78.85	84.23	88.85	85.77
	0.5–1.0	14[a]	71.07	66.78	73.21	78.21	82.50	79.64
	1–3	16[a]	62.19	58.44	64.06	68.44	72.19	69.69
	4–6	24[a]	41.46	38.96	42.71	45.62	48.12	46.46
Fats (g/day)	0–0.5	-	-	-	-	-	-	-
	0.5–1.0	-	-	-	-	-	-	-
	1–3	16.70[b]	13.11	15.57	15.93	18.08	18.74	13.83
	4–6	23.30[b]	9.40	11.16	11.42	12.96	13.43	9.91

CUBF: Cipira unbleached flour; CBF: Cipira bleached flour; DUBF: Dosa unbleached flour; DBF: Dosa bleached flour; PUBF: Pamela unbleached flour; PBF: Pamela bleached flour.

[a] Food and Nutrition Board (1989).

[b] Alasfoor et al. (2009).

genetic factors influencing the synthesis of amylose and amylopectin within varieties.

Phenolic compounds, like parameters *L, a, b*, provide information on the brightness index of a flour as well as the degree of inactivation of enzymatic browning. The values expressed in milliequivalents of gallic acid ranged from 198.81 to 301.59 mg/100g DM. It should be noted that the treatment reduces ($P < 0.05$) the phenolic compounds content in samples of the varieties *Cipira* and *Pamela*. This result could be explained by the destruction of polyphenoloxidase, which is the enzyme responsible for enzymatic browning; the osmosis diffusion in water of the bleaching of phenolic compounds this under the effect of the weakening of the potato membrane and finally the destruction of phenolic compounds by heat during treatment. It can also be observed that the variety has little influence on this parameter. The reducing sugar content of the different samples varies from 0.40% to 2.54%. Bleaching significantly ($P < 0.05$) reduces this parameter in flour from the *Dosa* variety. The reduction in reducing sugar content after bleaching is not in agreement with those of Waramboi et al. (2011), who showed that bleaching increases the reducing sugar content of sweet potato flour. This would be due to the temperature and bleaching time applied. In addition, an observation that the variety influences the reducing sugar content has also been reported by Tambo et al. (2019), on cassava flours. Phosphorus is the only mineral element that was evaluated in this study. Indeed this ion not only intervenes in several biological functions of the body like bone mineralization but is also present on the surface of starch molecules in which it interacts with water molecules to facilitate water-starch bonds. Its content varies from 278.76 to 326.51 mg/100g of DM. It also appears from this table that the variety does not influence ($P > 0.05$) this parameter. The phosphorus values obtained in this study are greater than those obtained by Olatunde et al. (2016) who was between 70.00-190.00 mg/100g of DM in Dried sweet potato flours. This difference would be explained by the nature of the sample and the treatments applied. Indeed, soaking in metabisulfite solution followed by double drying as carried out by Olatunde et al. (2016), on these sweet potato tubers resulted in a greater loss of this mineral compared to the water bleaching we achieved.

Table 3. Physical properties of the different irish potatoes flours.

Flours	Mass density (g/ml)	pH	Titrable acidity (ml of NaOH/100 g of DM)	WHC/OHC ratio
CUBF	0.64 ± 0.16^{b}	5.20 ± 0.08^{bc}	6.25 ± 1.06^{a}	1.65 ± 0.19^{a}
CBF	0.65 ± 0.15^{b}	5.30 ± 0.06^{bc}	5.60 ± 0.71^{a}	1.70 ± 0.16^{a}
DUBF	0.68 ± 0.01^{a}	5.30 ± 0.01^{b}	4.95 ± 1.70^{a}	1.62 ± 0.28^{a}
DBF	0.70 ± 0.01^{a}	5.00 ± 0.04^{c}	4.35 ± 0.35^{a}	1.55 ± 0.14^{a}
PUBF	0.60 ± 0.00^{c}	5.70 ± 0.30^{a}	9.65 ± 1.20^{a}	1.41 ± 0.12^{a}
PBF	0.61 ± 0.01^{c}	5.50 ± 0.01^{ab}	5.10 ± 1.27^{a}	1.51 ± 0.09^{a}

The values with different letters (a, b, c...) in the same column differ significantly ($P < 0.05$).

CUBF: Cipira unbleached flour; CBF: Cipira bleached flour; DUBF: Dosa unbleached flour; DBF: Dosa bleached flour; PUBF: Pamela unbleached flour; PBF: Pamela bleached flour; WHC: Water holding capacity; OHC: Oil holding capacity.

3.2. Recommended nutritional intake (%) of the different irish potatoes flours in relation to the daily nutritional needs of children aged from 6 to 59 months in fat, protein and calorific energy

Table 2 shows the energy, fat and protein composition of flour from single irish potatoes flours as a percentage of the recommended dietary allowances for children aged 6–59 months. It can be seen that the different flours contribute to more than 50% to the recommended daily energy intake for children less than 6 months of age. In addition, this contribution varies with the treatment and variety of the sample. It can also be observed that the energy intake of these flours decreases with age. This would be explained by the fact that with growth, the body requires a little more energy for its proper functioning. In addition, as children get older, their physical activities increase and therefore require an additional contribution to compensate for these losses. The percentage of recovery of the energy needs of children of all ages by these flours is lower than that of Tumwine et al. (2018). This difference would be due to the composition of the different flours because Tumwine et al. (2018) worked on composite flours. Therefore, a supplementation of these flours with other energy sources would certainly cover these energy needs. Proteins are very important nutrients for children's growth. They are involved in the establishment and development of cellular tissues. Regarding this element, there is a reduction in coverage with age. For children in the 0–6 month range, the consumption of a food derived from this flour, such as potato flour gruel, would cover the protein needs of children in this age range from 71.92 to 88.85%. This coverage evolves ($P < 0.05$) not only with the variety but also with the treatment. The drop in protein intake with bleaching is explained by the fact that during this treatment, soluble proteins are eliminated by diffusion in the bleaching water. In addition, the reduction of this protein availability would be the effect of their association with sugars to form melanoïdines during this

Table 4. Pearson correlation coefficient (r) matrix between physico-chemical, functional and rheological properties.

Variables	*Moisture*	*Ash*	*Pro*	*Lip*	*Car*	*Fib*	*Starch*	*Amyl*	*Amyp*	*P*	*Phe*	*RS*	*MD*	*pH*	*TTA*	*PT*	*PV*	*HV*	*BD*	*FV*	*SB*	*SBR*	*STR*	*WHC*	*OHCSP*	
Moisture	1.000b																									
Ash	0.664a	1.000b																								
Pro	-0.017	**0.699a**	**1.000b**																							
Lip	-0.495	-0.122	0.491	**1.000b**																						
Car	-0.343	**-0.903b**	**-0.925b**	-0.287	**1.000b**																					
Fib	0.006	0.080	0.123	0.485	-0.222	**1.000b**																				
Starch	**0.559a**	-0.191	**-0.687a**	**-0.529a**	0.496	-0.388	**1.000b**																			
Amyl	0.235	**0.711b**	**0.777b**	0.174	**-0.759b**	-0.261	-0.260	**1.000b**																		
Amyp	0.071	**-0.522a**	**-0.779b**	-0.149	**0.635a**	**0.500a**	0.390	**-0.883b**	**1.000b**																	
P	**0.652a**	**0.794b**	0.496	0.118	**-0.759b**	**0.602a**	-0.165	0.283	0.001	**1.000b**																
Phe	**0.871b**	0.405	-0.116	-0.154	-0.190	0.141	**0.671a**	0.152	0.222	**0.559a**	**1.000b**															
RS	-0.322	-0.195	-0.102	0.227	0.100	**0.790b**	**-0.513a**	-0.387	**0.500a**	0.161	-0.314	**1.000b**														
MD	-0.373	-0.470	-0.358	0.180	0.367	**0.698a**	-0.278	**-0.809b**	**0.759b**	0.040	-0.314	**0.794b**	**1.000b**													
pH	0.093	0.359	0.463	0.130	-0.383	-0.470	-0.009	**0.888b**	**-0.782b**	-0.103	0.134	-0.473	**-0.879b**	**1.000b**												
TTA	0.359	0.370	0.393	0.377	-0.424	-0.119	0.242	**0.696a**	-0.443	0.245	**0.608a**	**-0.510a**	**-0.712b**	**0.759b**	**1.000b**											
PT	0.266	-0.046	-0.227	-0.429	0.231	**-0.898b**	**0.690a**	0.246	-0.333	-0.436	0.272	**-0.905b**	**-0.765b**	0.492	0.405	**1.000b**										
PV	-0.100	0.110	0.188	0.427	-0.251	**0.955b**	**-0.555a**	-0.168	0.381	**0.525a**	-0.049	**0.901b**	**0.678a**	-0.380	-0.219	**-0.961b**	**1.000b**									
HV	0.006	0.159	0.203	0.474	-0.297	**0.985b**	-0.464	-0.138	0.398	**0.613a**	0.106	**0.824b**	**0.626a**	-0.355	-0.087	**-0.916b**	**0.984b**	**1.000b**								
BD	-0.070	0.055	0.072	0.346	-0.157	**0.952b**	-0.473	-0.256	0.478	0.493	-0.021	**0.925b**	**0.722b**	-0.442	-0.275	**-0.946b**	**0.992b**	**0.974b**	**1.000b**							
FV	-0.128	0.122	0.248	0.486	-0.297	**0.965b**	**-0.597a**	-0.183	0.357	**0.557a**	-0.075	**0.861b**	**0.702b**	-0.432	-0.231	**-0.976b**	**0.989b**	**0.979b**	**0.972b**	**1.000b**						
SB	-0.161	0.104	0.291	**0.534a**	-0.319	**0.928b**	**-0.601a**	-0.263	0.348	**0.574a**	-0.107	**0.737b**	**0.743b**	**-0.558a**	-0.279	**-0.941b**	**0.900b**	**0.903b**	**0.874b**	**0.955b**	**1.000b**					
SBR	0.429	0.347	0.232	0.215	-0.392	0.366	0.107	-0.126	0.178	**0.675a**	0.487	-0.201	0.159	-0.408	0.154	-0.141	0.131	0.254	0.108	0.242	0.455	**1.000b**				
STR	-0.405	-0.469	-0.292	-0.324	**0.507a**	**-0.896b**	0.240	-0.030	-0.310	**-0.877b**	-0.459	**-0.540a**	-0.377	0.262	-0.135	**0.714b**	**-0.829b**	**-0.901b**	**-0.816b**	**-0.835b**	**-0.791b**	**-0.519a**	**1.000b**			
WHC	-0.093	**-0.521a**	**-0.772b**	-0.453	**0.683a**	0.240	0.208	**-0.909b**	**0.838b**	-0.204	-0.179	**0.512a**	**0.769b**	**-0.847b**	**-0.835b**	-0.304	0.239	0.168	0.340	0.216	0.218	-0.065	-0.012	**1.000b**		
OHC	-0.111	0.413	0.408	-0.322	-0.386	-0.084	**-0.612a**	0.182	-0.388	0.137	**-0.567a**	0.206	0.065	-0.104	**-0.565a**	-0.294	0.122	-0.004	0.093	0.142	0.157	-0.162	0.054	0.097	**1.000b**	
SP	-0.379	**-0.564a**	-0.462	0.138	0.477	**0.618a**	-0.166	**-0.882b**	**0.809b**	-0.049	-0.294	**0.715b**	**0.989b**	**-0.906b**	**-0.715b**	**-0.664a**	**0.574a**	**0.528a**	**0.628a**	**0.601a**	**0.658a**	0.165	-0.285	**0.811b**	-0.016	**1.000b**

The values in bold carrying a and b meaningfully differ and respectively at $P < 0.05$ et $P < 0.01$.

The bold values in the table mean that these variables contribute significantly to the formation of these axes.

treatment. When moving from the first to the second age group (6–12 months), the contribution is between 66.78 and 82.50%. Between 12 and 36 months, it is between 58.44 and 72.19%. Its contribution drops to less than 50% when you move to the 48–59 month period. Nevertheless, it must be noted that the protein contribution of these flours is very important and would be the beginning of a solution to the problem of protein-energy malnutrition. Lipids are very important elements for the proper functioning of the body in the sense that they are molecules that provide energy, components of cell membranes, involved in the absorption and transportation of certain vitamins and especially they are precursors of several biological molecules that are very important for the proper functioning of the body (Tumwine et al., 2018). It can be seen from this table that children in the 0–12 month age group do not need an external intake from a lipid source, which means that the intake of breast milk is sufficient to cover their daily needs. Beyond this range, i.e. between 12-36 months and 48–59 months, an external intake becomes necessary because with age, children need an additional supply of energy for their metabolic activities. In addition, as we age, the physiological changes that are taking place require a pool of lipids to ensure the smooth running of physiological processes such as the synthesis of certain vitamins, hormones and brain development. It should also be noted that the lipid contributions of the various samples in relation to the recommendations are very low, i.e. less than 20%. This would be explained by the fact that tubers are not essential sources of lipids. Complementing porridges formulated with irish potato flour using lipid sources such as soya and peanuts would be one way to overcome this deficit.

3.3. Physical properties

Table 3 presents the physical properties of the different flours. Mass density is a very important parameter in determining the type of material used to manufacture the packaging and food intake of foods formulated with these flours (Odadeji and Oyeleke, 2011; Mingle et al., 2017). Indeed, mass density and food intake vary in the opposite direction. From Table 3, it can be seen that the mass density varies from 0.60 to 0.70 g/ml. It is not significantly ($P>0.05$) affected by bleaching but rather by the variety of the different flours (*Cipira*, *Dosa* and *Pamela*). This can be explained by the nutrient composition, particularly in terms of protein and lipids with respect to correlations (Table 4). The results obtained are in the same range as those of Harijono et al. (2013), on bleached and unbleached yam flours. The pH assessment of the flours was also carried out. This is a parameter that influences functional properties such as food digestibility, water and oil retention capacities and acceptability of food. The pH values in this study range from 5.00 to 5.70. It is significantly ($P<0.05$) affected by bleaching within the *Dosa* variety but the variety effect is not significant ($P>0.05$). The decrease in pH observed in *Dosa* variety flours may be due to the elimination of some organic substances during this treatment (Olatunde et al., 2016). The values obtained are lower than those obtained by Buckman et al. (2015) and Mingle et al. (2017), on yam bleached and unbleached flours. This would be explained by the botanical aspect, the ecological zone and the chemical composition of the soil. The pH values obtained in this study are below the recommended range (6–6.8) for good food intake (Mingle et al., 2017). Concerning titratable acidity, it can be seen that this parameter does not vary with the treatment or the variety. Nevertheless, it can be observed that the highest values were obtained with unbleached flours, which is consistent with the pH results. The observations that treatment and bleaching do not significantly affect total titratable acidity ($P>0.05$) are not in agreement with the observations of Olatunde et al. (2016), who demonstrated that these parameters significantly influence ($P<0.05$) the total titratable acidity of different sweet potato meals. These differences would be the result of the type of bleaching that was applied to the samples and especially the nature of the samples.

The hydrophilic/lipophilic ratio (WHC/OHC) is generally related to the ability of carbohydrates and proteins to adsorb at the oil/water interface in an emulsion (Zhen et al., 2011). It is an indicator of the hydrophilic/lipophilic index that shows this balance between lipid and water binding. It is highly desirable that a perfect balance is achieved between WHC and OHC, particularly in the formulation of complex foods such as doughnuts, cakes and porridges, which are both compact solids, emulsions and air-retaining foams. This means that all properties are involved such as interfacial adsorption, hydration and texture. The ratio of lipophilic to hydrophilic varies from 1.41 for PUBF to 1.70 for CBF. No significant differences ($P>0.05$) were noted for this report between the different samples regardless of variety and treatment. It should be noted that all flours except PUBF had a hydrophilic/lipophilic ratio greater than 1.5, indicating a greater ability to fix water than oil. This strong ability to fix water rather than oil would also be related to their high carbohydrate proportions with respect to the positive correlation with water retention capacity ($r = 0.683$; $P<0.05$). Other factors such as flour PH, protein conformation and interfacial tension can also affect this ratio. The ability to retain less water from PUBF would be related to the hydrophobic amino acid composition of these proteins as shown by the negative correlation between proteins and WHC ($r = -0.772$; $P<0.01$) but positive with OHC ($r = 0.482$). It also shows that PUBF would be more suitable for the formulation of foods requiring water-oil mixtures as it could better stabilize the phases.

3.4. Functional properties of the different flours

3.4.1. Water holding capacity (WHC)

Figure 3 shows the water holding capacity of the various bleached and unbleached irish potatoes flours. This is a parameter that provides information on the behaviour of starch molecules at a certain temperature in relation to water molecules. It also gives information on the possible viscosity of the flours. Figure 3 shows that between 30 °C and 60 °C the water holding capacity is constant for all flours. Between 60 and 70 °C, all flours retain water significantly and reach their maximum retention at 70 °C except bleached *Pamela* flour which reaches its maximum at 80 °C. However, it should be noted that unbleached *Dosa* flour has higher water retention than all the others ($P < 0.05$). This would be due to its amylose/amylopectin ratio (positive correlation with amylopectin $r = 0.838$; $P<0.01$) and its nutritional composition. The increase in WHC with temperature in all flours would be justified by the fact that at high temperatures, hydrogen bounds stabilizing the semi-crystalline structure of starches open, rupture and are replaced by water molecules (Kim et al., 1989). A high WHC could also be due to a weak internal organization resulting from the negative charge between phosphate groups and starch granules (Tijani et al., 2017). It can also be attributed to granule sizes because small granules retain more water than large granules (Tambo et al., 2019). A high WHC can also be attributed to the high presence of polar amino acids, low amylose-lipids complex and starch content in these flours (Harijono et al., 2013). Above 70 °C, there is a drop in the retention of all flours except for flour from the *Pamela* variety, which falls at above 80 °C. This is the consequence of the breakage of the water-starch bonds due to the fact that the temperature at the end of gelatinization was reached, which therefore led to the breakdown of the hydrogen bonds, thereby reducing the water holding capacity. It is also due to the release of low molecular weight components (amylose, intermediate material) from the granule. The high water retention capacity of *Dosa* flour would be an advantage if it was used in bread-making because it would give consistency to the flour but on the other hand a disadvantage in infant feeding because it would give too viscous porridges (Tumwine et al., 2018).

3.4.2. Oil holding capacity of flours (OHC)

Figure 4 present observations of the effect of temperature on the oil retention capacities of the different flours. This parameter is very important in the food industry because it makes it possible to define the type of formulation to which certain flours or ingredients can be associated. Depending on the retention rate and temperature, this may or may not be considered beneficial for any formulation. For example,

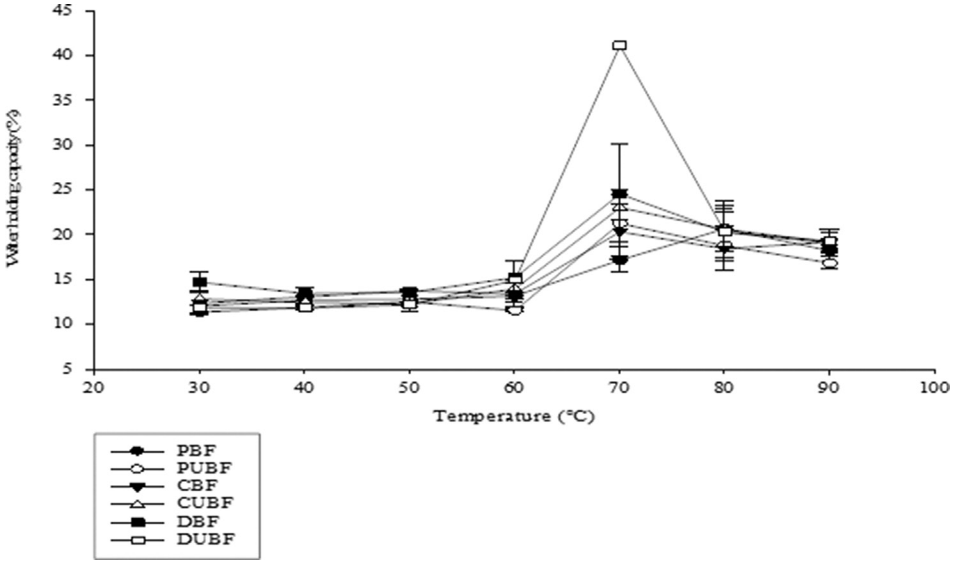

Figure 3. Water retention capacity: of bleached and unbleached flours in relation to temperature changes. CUBF: Cipira unbleached flour; CBF: Cipira bleached flour; DUBF: Dosa unbleached flour; DBF: Dosa bleached flour; PUBF: Pamela unbleached flour; PBF: Pamela bleached flour.

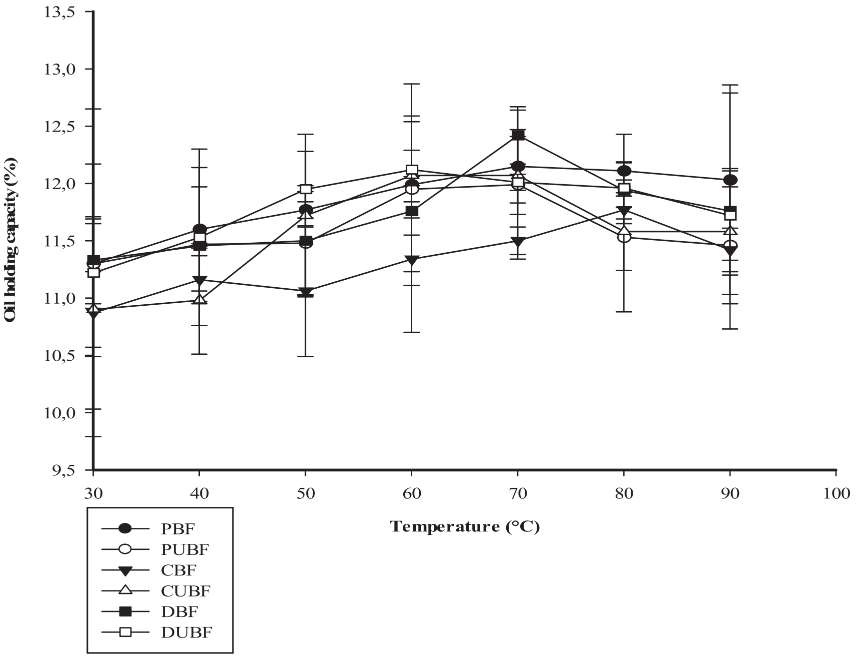

Figure 4. Oil retention capacity: of the different flours according to temperature variations. CUBF: Cipira unbleached flour; CBF: Cipira bleached flour; DUBF: Dosa unbleached flour; DBF: Dosa bleached flour; PUBF: Pamela unbleached flour; PBF: Pamela bleached flour.

more oil-retaining flours would be very beneficial in infant flour formulations because lipids are compounds responsible for the flavour and softness of foods (Eke-Ejiofor, 2015). It can therefore be seen from the figures below that all oil holding capacity increases with increasing temperature to a peak and falls further. This increase in retention with increasing temperature is due to the unfolding of the crystalline structure of the starch molecules in flours and those of the starch sources causing the weakening and breaking of the hydrogen bonds that stabilize them. The broken hydrogen bonds precede the establishment of hydrogen bonds between the polar heads of the lipids and the –OH groups of the starches molecules, thereby causing oil holding. In addition, during the heating process, the proteins that make up flours and starches also retain oil molecules thanks to the hydrophobic amino acids in their chains (Harijono et al., 2013). In addition, it also appears from Figure 4 that, with the exception of bleached *Cipira* flour, which had low peak water retention at 80 °C, all the others observed maximum oil retention at 70 °C. It should also be noted that *Cipira* flour has less oil retention while bleached *Dosa* flour has more oil holding. This difference could be explained by the amino acid composition of these two flours and also by the presence of a surplus of phenolic compounds in *Cipira* flours, which can complex proteins and thus prevent their actions. It can be seen that above this peak temperature, oil retention drops in all flours. This drop marks the rupture of protein/starch-oil bonds following the reaching of the starch gelatinization peak or the rupture of low energy bonds binding these different molecules due to temperature.

3.4.3. Swelling capacity of flours

The swelling power indicates the intensity of cohesion forces between polymers in the amorphous phase and those in the crystalline region of starch granules (Singh et al., 2003). The increase in swelling of starch granules is negatively correlated with the decrease in the intensity of cohesion forces between polymers (Ikegwu et al., 2004). Figure 5 presents the profile of the swelling rate of the different flours as a function of temperature. This figure shows that the swelling power does not vary between 30 °C and 50 °C for all flours. This is explained by the presence of hydrogen bonds binding the components of starch molecules, preventing them from binding the water molecules and swelling. It's also due to the presence of non-carbohydrate molecules such as proteins, lipids and fibers that interact with the –OH groups of starch molecules, preventing them from binding water molecules and swelling (Caprita et al., 2010). It is also noted that the flour from unbleached *Cipira* irish potato reaches its peak swelling at 60 °C, whereas for all others it reaches 80 °C. It can also be observed that beyond these peak temperatures, the swelling capacity of all flours falls. This fall follows the bursting of molecules leading to the molecular dispersion of these constituents. It can be deduced from these observations that between 60 and 90 °C, representing the cooking interval of infant gruels, the size of the starch molecules increases until it reaches a peak of swelling, ruptures and releases the low molecular weight components (amylose) which have the ability to degrade, thereby causing the consistency of the gruels (Sarkar et al., 2013). The significant swelling observed may be due to the fact that at high temperatures and in the presence of excess water, the bonds stabilizing the semi-crystalline structure of the starch break and are replaced by water molecules, causing the granules to swell (Ratnayake et al., 2002). The low values of the swelling capacity can be explained by the low pH values; because a pH below 7 reduces the WHC and therefore also reduces the swelling capacity (Tabilo-Munizaga and Barbosa-Canovas, 2004). The results obtained in this study are not in line with those of Harijono et al. (2013), who showed that yam bleached flours swelled less than unbleached yam flour because of their small size (about 46 μm).

3.5. Rheological properties of the different flours

Figure 6 shows the staling and demotion profiles of bleached and unbleached irish potatoes flours. It appears that the stench temperature is lower at DBF and higher at CBF. In addition, DUBF has the highest maximum viscosity while CBF and PBF have the lowest viscosities. The viscosity drop is greater at DUBF, but there is no breakdown at CBF and PBF. The ability to demote is highest for DBF and lowest for CBF and PBF.

Table 5 presents the starch parameters for bleached and unbleached irish potatoes flours. This is a common method for evaluating the bonding and cooking properties of starch products. They also allow us to conclude on the functionality of starchy matrices in food formulations (Rojas et al., 1999). The starch filling temperature corresponds to the temperature at which the starches start to gelatinize. High starch temperatures are generally attributed to particle size, amylose/amylopectin ratio and lipid-starch or starch-protein interactions (Liu and Rosentrater, 2016). The starch loading temperature provides information on the minimum temperature required for gelatinization/cooking of starchy products (Shimelis et al., 2006). It appears that the filling temperature varies from 70.9 °C to 77.87 °C. This parameter is significantly ($P˂0.05$) affected by bleaching within the *Cipira* variety. This variation within the Cipira variety is explained by the difference in composition in amylopectin and lipids. Moreover, it varies little with the variety. The results obtained are significantly higher than those of Eke-Ejiofor (2015), which was 70.20 °C for cassava starch. This would be explained by the fact that cassava compared to irish potato is very low in protein and lipids and therefore the starch-lipid or starch-protein bonds are much reduced in this flour. They are also higher than those of Tumwine et al. (2018), which ranged from 55.7 °C to 67.9 °C. This would be explained by the flour composition. Indeed, tubers have a complex set of compounds like phenolics compounds compared to cereals that block starch molecules, thereby blocking heat transfer. These results also show that it takes more time and energy to prepare foods based on these flours (Tumwine et al., 2018).

Peak viscosity is an indicator of amylose content, water holding capacity and starch swelling in flours (Alcázar-Alay and Meireles, 2015). It also indicates the points at which starches reach their maximum viscosity during gelatinization. It can be seen from this table that the peak viscosity varies from 550.00 cP (CBF) to 3990.50 cP (DUBF). It can be seen that there is a significant difference ($P˂0.05$) between bleached and unbleached flours of any variety. It is equally affected by the variety. The differences observed between the varieties can be explained by their differences in phosphorus, amylose, lipids and protein composition. Indeed, flour with high amylose content showed the highest peak viscosities and this was also reported by Zaidul et al. (2007) with yam starch. The low peak viscosities of bleached flours could be explained by the modification of starch during bleaching, in particular the reduction of the amylose content, which is known to be mainly responsible for water retention and including swelling within the starch (Tumwine et al., 2018). This low peak viscosity of bleached flours makes bleached irish potato flours suitable for the formulation of infant foods, while unbleached flours are suitable for the formulation of cakes and breads.

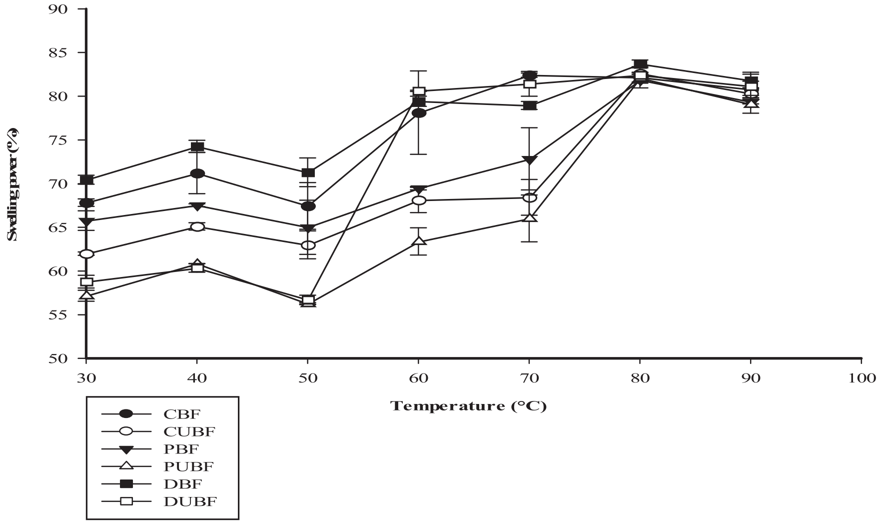

Figure 5. Swelling capacity: of bleached and unbleached flours as a function of temperature. CUBF: Cipira unbleached flour; CBF: Cipira bleached flour; DUBF: Dosa unbleached flour; DBF: Dosa bleached flour; PUBF: Pamela unbleached flour; PBF: Pamela bleached flour.

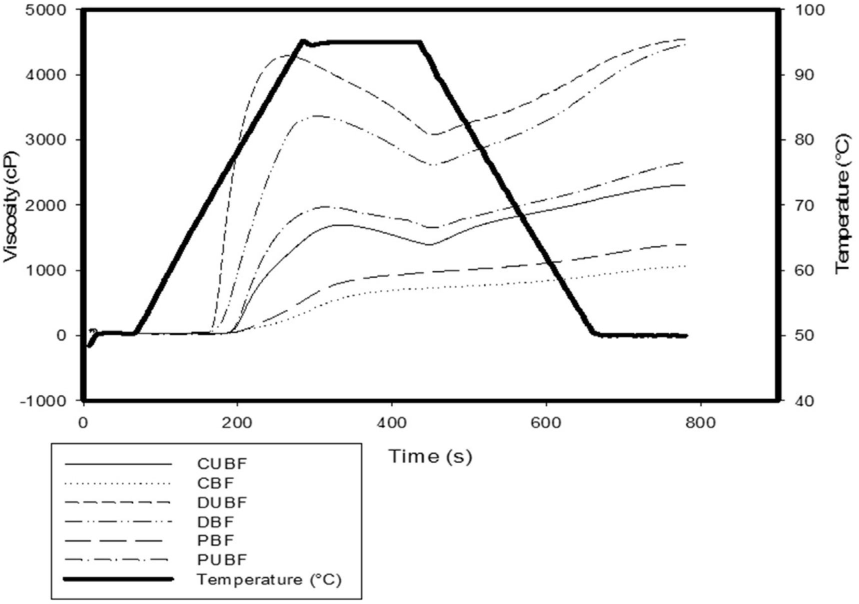

Figure 6. Starch profile of blanched and unbleached irish potato flours. T °C: Temperature: CUBF: Cipira unbleached flour; CBF: Cipira bleached flour; DUBF: Dosa unbleached flour; DBF: Dosa bleached flour; PUBF: Pamela unbleached flour; PBF: Pamela bleached flour.

Table 5. The following emptying parameters were measured from the empting and demotion profiles of bleached and unbleached flours presented in Figure 5.

Paramètres	CUBF	CBF	DUBF	DBF	PUBF	PBF
PT (°C)	76.25 ± 0.49^{b}	77.875 ± 0.53^{a}	70.925 ± 1.67^{c}	70.90 ± 0.00^{c}	75.825 ± 0.03^{b}	76.625 ± 0.03^{ab}
PV (cP)	1689.50 ± 34.65^{d}	550.00 ± 7.07^{ef}	3990.50 ± 70.00^{a}	3273.00 ± 22.63^{b}	1934.00 ± 56.57^{c}	796.50 ± 58.69^{e}
HV (cP)	1415.50 ± 4.95^{c}	0.00 ± 0.00^{d}	3198.50 ± 147.78^{a}	2695.50 ± 3.53^{b}	1697.00 ± 76.37^{c}	0.00 ± 0.00^{d}
BD (cP)	274.00 ± 39.60^{c}	0.00 ± 0.00^{d}	792.00 ± 77.78^{a}	577.50 ± 26.16^{b}	234.00 ± 19.80^{c}	0.00 ± 0.00^{d}
FV (cP)	2311.00 ± 24.04^{c}	1053.00 ± 42.43^{e}	4543.50 ± 60.10^{a}	4457.50 ± 17.68^{a}	2648.00 ± 111.75^{b}	1391.00 ± 11.31^{d}
SB (cP)	895.50 ± 28.99^{d}	503.00 ± 15.56^{c}	1345.00 ± 87.68^{b}	1762.00 ± 14.14^{a}	951.00 ± 35.35^{c}	594.50 ± 16.26^{d}
SBR	1.63 ± 0.02^{a}	1.46 ± 0.01^{c}	1.42 ± 0.04^{c}	1.65 ± 0.01^{a}	1.56 ± 0.00^{b}	1.46 ± 0.03^{c}
STR	0.83 ± 0.02^{c}	1.30 ± 0.03^{a}	0.80 ± 0.01^{c}	0.82 ± 0.01^{c}	0.88 ± 0.01^{c}	1.21 ± 0.06^{b}

The means ± standard deviations followed by the same letter in the same line indicate that the differences are not significant (p˃0.05).
CUBF: Cipira unbleached flour; CBF: Cipira bleached flour; DUBF: Dosa unbleached flour; DBF: Dosa bleached flour; PUBF: Pamela unbleached flour; PBF: Pamela bleached flour; PV: peak viscosity; PT: pasting temperature; HV: holding viscosity; BD: breakdown; FV: final viscosity; SB: setback; SBR (FV/HV): setback ratio; STR (HV/PV): stability ratio.

Final Viscosity (FV) refers to the variation in viscosity after maintenance at a certain temperature (50 °C). It is also an indicator of starch stability and therefore indirectly provides information on the amylose/amylopectin ratio (Osungbaro et al., 2010). The highest final viscosity was observed with unbleached *Dosa* flour (4543.00 cP) and the lowest with bleached *Cipira* flour (1053.00 cP). This parameter is affected (P˂0.05) by bleaching in the varieties *Cipira* and *Pamela*. This difference is explained by the fact that the bleaching resulted in the destruction of the starch granules as a result of the temperature at the end of gelatinisation already reached. Based on the information provided by this parameter, it can be said that unbleached *Dosa* variety would be suitable for use in bakery and deli meats products. The results obtained are still greater than those of Tumwine et al. (2018), which ranged from 17.70 cP to 96.20 cP. This difference would be due to the fact that the millet flours have undergone enzymatic treatment, which has affected the starch. Unbleached flours would therefore be suitable for baking because starches that do not downgrade are sought in this industry.

Breakdown (BD) refers to the degree to which the viscosity of starches drops after gelatinization, making the dough firm and difficult for enzymes to digest (Limpisut and Jindal, 2002). It can be seen from this table that bleached flours slightly downgrade or even do not downgrade for some varieties. This is explained by the pregelatinization of their starch during bleaching. Bleached flours would therefore be more susceptible to enzymatic attacks than unbleached flours. This slight demotion would also be the consequence of low amylose content in these flours. Bleached flours would therefore be suitable for infant feeding because they are less viscous and easy to digest (Sandhu et al., 2006).

The Setback is a parameter who positively correlated with amylose content and chain length (Mishra and Rai, 2006). It is an indicator of the degree of demotion or return to the native conformation of amyloidosis. It also confirms the Breakdown observations. Setback values range from 503.00 cP (CBF) to 1762.00 cP (DBF), it should be noted that there is a significant difference (P˂0.05) between bleached and unbleached flours of the three varieties. This parameter is negatively affected by bleaching on *Cipira* and *Pamela* flours. This is related to the reduction in amylose content during this treatment. A weak setback implies a low demotion. It can therefore be concluded that bleached flours would be more easily digestible than unbleached flours. In addition, they would be suitable for infant food formulations. This test therefore confirms the precedent that allowed us to recommend the use of bleached flours for infant foods formulation.

The Holding viscosity (HV) corresponds to the viscosity at the end of the shear. It's between 0.00 cP (CBF and PBF) to 3198.00 cP (DUBF). It should be noted that there is a significant difference (P˂0.05) between bleached and unbleached flours of any variety. In addition, it is observed that the variety also affects this parameter ($P < 0.05$). This difference can be explained by the rigidity of the bonds stabilizing the swollen starch granules and the nutritional composition, particularly proteins and lipids that protect the starch granules, making it difficult for them to hydrolyze even gelatinized. A high shear strength value would be related to a low ability of the inflated starch to withstand temperature and shear stresses (Tsakama et al., 2010). These observations are different from those of Akissoé et al. (2003), who demonstrated that only the variety influenced this property.

Stability and setback reports were also evaluated. These parameters give an idea of the ability of starches and therefore flours to maintain their structures and forms following processing. These two parameters vary respectively from 1.42 to 1.65 for SetBack ratio and 0.89 to 1.12 for Stability ratio. It can be seen from this table that these parameters are affected ($P < 0.05$) by variety and bleaching. Indeed, bleaching reduces the setback ratio excluding the *Dosa* variety which it increases. This reduction would be due to hydrolysis of the osidic bonds (α-1→4) of the amylose molecules during bleaching and leaching of them, thereby reducing their content. In addition, it is observed that bleached and unbleached *Dosa* flours had the highest and lowest setback ratio values respectively. This is related to their different proportions in amylose. This makes bleached *Dosa* flour not recommended for infant feeding because of its high final viscosity. In terms of stability ratio, unbleached *Dosa* flour and bleached *Cipira* flour had the lowest and highest values respectively. This difference is due to the length of the branched chain, amylopectin and phosphorus contents on these flours (Kuar et al., 2005). It also makes it possible to conclude on the high stability of gels derived from *Cipira* flour during processing (Tsakama et al., 2010).

3.6. Study of the correlations between physico-chemical parameters, functional and rheological properties of differents flours: principal component analysis (PCA)

Table 4 presents the correlation matrix between the physico-chemical, functional and rheological properties of differents flours. The correlations marked with a and b are significant ($P < 0.05$ and $P < 0.01$ respectively). This correlation matrix shows that the variables and observations characteristic of the different flours are correlated in small groups. Principal component analysis (PCA) allows us to mark variables (starch, fat, fiber, protein, phosphorus, OHC, PV, PT, SB, BD, FV, HV, SBR, STR, WHC, amylopectin, amylose, SP, reducing sugar, ash, phenols, TTA, pH, carbohydrates, mass density and moisture) and observations (DBF, DUBF, CBF, CUBF, PBF and PUBF) according to their correlation and proximity. The main components are extracted in order to explain the maximum possible variations. In the case of our analysis, 5 components F1, F2, F3, F4 and F5 explain 100% of the variations with respective contributions of 42.6%, 27.9%, 15.4%, 8.7% and 5.2%. The contributions of the variables and observations to the formation of each main axis and the classes to which they belong are grouped in Tables 6 and 7. It appears that Fib, MD, SP, pH, RS, RS, PT, PV, HV, BD, FV, SB, STR contribute to the formation of the F1 axis. The DUBF, DBF and PBF observations also contribute to the formation of this F1 axis. The formation of this axis is mainly influenced by functional and rheological properties. This allows us to say that the PBF, DUBF and DBF samples have the best functional and rheological properties. With regard to axis F2, Prot, Ash, Car, WHC, Amyl, Amyl, Amyp, P and TTA contribute to its formation on the variable side and on the observation side, we have CBF and PUBF instead. This axis is influenced by the chemical composition, more particularly the nutritional value. The flours that contribute to its formation are more nutritious. For axis F3, Moisture, Starch and Phe are the main contributors. Finally, axis F4 is formed by the OHC and lip variables while axis F5 is formed by SBR only. As for observations, the formation of axis F3 is mainly due to CUBF. The hierarchical bottom-up classification of the variables made it possible to highlight the different correlation circles or classes. It appears that Moisture, Ash, Pro, Lip, Fib, Amyl, RS, MD, pH, TTA, STR, WHC and OHC form the first grouping. The second is represented by Car, Starch, Amyp, P, Phe, PT and SP. The third is represented by PV and HV. The fourth circle or class is represented by BD, FV and SB. As for the observations, the hierarchical bottom-up classification made it possible to highlight 3 classes: the CBF–PBF class, the DBF-DUBF class and finally CUBF–PUBF. This analysis shows that bleaching affects the different properties within flours from the *Cipira* and *Pamela* varieties.

Table 6. Contributions of observations to the formation of the different axes (%) and classes.

	F1	F2	F3	F4	F5	Classes
CUBF	0.3233	0.0039	**68.7739**	14.1940	0.0383	1
CBF	9.8535	**55.4680**	0.1407	17.2643	0.6068	2
DUBF	**26.7492**	0.1422	2.6511	0.1987	53.5922	3
DBF	**34.6169**	0.0837	2.7411	0.2156	45.6761	3
PUBF	7.9483	**43.2603**	0.1743	31.9115	0.0389	1
PBF	**20.5089**	1.0419	25.5190	36.2159	0.0476	2

CUBF: Cipira unbleached flour; CBF: Cipira bleached flour; DUBF: Dosa unbleached flour; DBF: Dosa bleached flour; PUBF: Pamela unbleached flour; PBF: Pamela bleached flour.
The bold values in the table mean that these variables contribute significantly to the formation of these axes.

Table 7. Contributions of variables to the formation of the different axes (%) and classes.

	F1	F2	F3	F4	F5	Classes
Moisture	0.3348	1.7709	**16.5622**	6.0549	2.2145	1
Ash	0.1187	**9.9946**	0.8323	9.7880	0.3095	1
Pro	0.0104	**10.8552**	3.9007	0.1304	3.7313	1
Lip	1.0396	2.1696	2.2413	**23.5265**	7.4296	1
Car	0.0024	**12.7752**	0.1350	2.1882	1.2164	2
Fib	**7.7629**	1.0410	0.7649	1.3659	0.1713	1
Starch	1.9036	2.4091	**14.9289**	0.2383	0.6016	2
Amyl	2.2325	**9.1045**	1.1818	0.0323	3.1813	1
Amyp	3.2380	**4.9733**	6.6577	0.3264	0.3497	2
P	1.4285	**7.5971**	5.2392	3.2094	0.4402	2
Phe	0.1874	1.3493	**21.2396**	0.5922	0.9867	2
RS	**7.2504**	0.0953	1.2076	0.0061	1.4198	1
MD	**7.2353**	2.4470	0.0367	0.0113	13.922	1
pH	**4.3075**	3.5611	1.1719	3.6944	9.045	1
TTA	2.0338	**5.1080**	2.2180	13.5826	0.441	1
PT	**8.1653**	0.5896	1.1936	0.0454	0.2511	2
PV	**7.7518**	1.1488	0.0475	0.2538	3.6906	3
HV	**7.3231**	1.7614	0.2163	0.9702	2.2039	3
BD	**8.0011**	0.5290	0.0076	0.1222	5.3165	4
FV	**8.0149**	1.3530	0.0836	0.1939	0.4342	4
SB	**7.8089**	1.1485	0.0500	0.0333	3.5890	4
SBR	0.5420	1.5001	7.6113	0.3064	**38.2677**	1
STR	**4.6354**	4.3186	4.0890	0.0065	0.5963	1
WHC	2.3619	**8.1413**	0.7799	4.7387	0.5544	1
OHC	0.1217	0.4010	7.6002	**28.5701**	0.0087	1
SP	**6.1879**	3.8575	0.0030	0.0127	2.4950	2

Li: lipids; Pro: proteins; Car: carbohydrates; Fib: fibers; Phe: phenols; TTA: total titrable acidity; RS: reducing sugar; MD: mass density; WHC: water holding capacity; SP: swelling Power; Amyl: amylose; Amyp: amylopectin. SP: swelling power; WHC: water holding capacity; OHC: oil holding capacity; PV: peak viscosity; PT: pasting temperature; HV: holding viscosity; BD: breakdown; FV: final viscosity; SB: setback; SBR (FV/HV): setback ratio; STR (HV/PV): stability ratio.
The bold values in the table mean that these variables contribute significantly to the formation of these axes.

The PCA diagrams of the variables or variable correlation circles (Figure 7) show the grouping between these variables. These figures confirm once again the correlations presented by the correlation matrix (Table 4). Thus, RS, MD, WHC, Amyl, Ash, pH, Prot, Lip, Moisture, TTA, SBR, STR, OHC and Fib form a group. SBR reflects the trend towards the demotion of starches. It is due to the reassociation of amylose molecules. Starches with high amylose content have a strong tendency to demote (Klang, 2015). Pro is significantly ($P < 0.01$) correlated to Amyl (r = 0.777) and WHC (r = -0.772). Indeed, both proteins and lipids are present on the surface of starch molecules and form complexes with amylose molecules (Svihus et al., 2005). These proteins mask the –OH groups of the starch components, thereby limiting their interactions with water. In addition, the amino acid composition of proteins is also reported to be a limiting factor (Debet and Gidley, 2007). Proteins rich in apolar amino acids will tend to lower this parameter because they cannot bind water molecules. It is also noted that these results are contrary to those of Klang (2015) with regard to the negative correlation between proteins and STR. Ash is significantly correlated to Pro (r = 0.699; $P < 0.05$), Amyl (r = 0.711; $P < 0.01$) and WHC (r = -0.521; $P < 0.05$). Ashes represent the inorganic matter of plants or animal tissues. These ashes are represented by ions. In the cell, some ions appear bound to proteins and starch. This is the case of haemoglobin iron and phosphorus present on the surface of the starch. These ions represent a major obstacle to water retention in flours (Blennow et al., 2000). There is also a correlation between fib and RS (r = 0.790; $P < 0.01$), MD (r = 0.698; $P < 0.05$), STR (r = -0.896; $P < 0.01$). Mass density is influenced by granule size and nutritional composition (Adebowale et al., 2008). Since fibres are high molecular weight compounds, they will tend to increase mass density. Fibers-rich flours form unstable gels and at a certain temperature they tend to relarge this water. Amyl is significantly correlated with MD (r = -0.890; $P < 0.01$), pH (r = 0.858; $P < 0.01$), TTA (r = 0.696; $P < 0.05$) and WHC (r = -0.909; $P < 0.01$). Starch consists of two components, amylose and amylopectin. Amylose represents the minority fraction and is of low molecular weight. Flour containing a starch rich in amylose will therefore have a low molecular weight. The pH and TTA are influenced by the presence of compounds with ionization potential and organic acids. Amylose as mentioned above has phosphorous ions and proteins on its surface. These compounds have the ability to ionize under certain conditions and influence pH and TTA. Flours rich in amylose have a strong tendency to demote and thus reduce water retention to a certain level (Klang, 2015). Indeed, the previous results show that the gelatinization temperature is between 60 and 70 °C and beyond that a drop in water retention has been observed and the parameter has been evaluated at a temperature of 90 °C (average temperature of technological treatments applied in industries). So the higher the amylose content, the lower the WHC will be at high temperature (Niba, 2001). RS is correlated to WHC (r = 0.512; $P < 0.05$). Reducing sugars are compounds with –OH groups on their surfaces. These polar groups therefore have the ability to form hydrogen bonds with water molecules and retain them (Shimelis et al., 2006). There is a significant correlation ($P < 0.01$) between MD and pH (r = -0.879), TTA (r = -0.712), WHC (r = 0.769). Mass density is influenced by size and nutritional composition (Adebowale et al., 2008), particularly in fat, protein and carbohydrates. The latter are very hydrophilic and interact strongly with water. It should be noted that these chemical compounds are very poorly ionizable and would therefore reduce the pH. The pH is negatively related to WHC (r = -0.847; $P < 0.01$). Indeed, the peak water retention rate of flours is between 7 and 7.5 (Tabilo-Munizaga and Barbosa-Canovas, 2004). The decrease in pH would lead to a change in the ionization state of hydrophilic groups and consequently a reduction in the ability to fix water molecules. The TTA is negatively correlated with WHC and OHC. TTA is influenced by the presence in the plant of organic compounds such as lactic acid. These organic compounds, although polar, interact weakly with water. This low interaction also leads to the formation of low viscosity gels.

Another group is Car, Starch, SP, P, Phe, Amyp, PT. There is a positive correlation between Car and SP, even if it is not significant. Carbohydrates are hydrophilic compounds with hydroxyl groups on their surface that have the ability to bind water molecules and therefore increase swelling (Tijani et al., 2017). A similar but this time very significant observation ($P < 0.01$) was made between Amyp and SP (r = 0.809). Starch consists of two main molecules, amylose and amylopectin. The amylose/amylopectin ratio of a starch molecule influences its functional properties, in particular its ability to swell and stabilize. Indeed, at high temperatures, granules rich in amylose tend to break, releasing amylose molecules. The latter will therefore reassociate at low temperatures resulting in an increase in final viscosity and a drop in swelling (Debet and Gidley, 2007). Starch is correlated to phenolic compounds (r = 0.671) and PT (r = 0.690). Phenolic compounds are polar substances that can be found on the surface of starch granules. The presence of these compounds limits the water-starch interaction which limits starch swelling. This limitation of the binding of molecules would therefore require a higher temperature to allow starch gelatinization (Klang, 2015). PT is correlated to SP (r = -0.664). Indeed, when a starch molecule reaches its gelatinization peak following high swelling capacity, we witness a rupture and dispersion of its molecular components, which thus return to their initial state. This high swelling leads to a lowering of the gelatinization temperature.

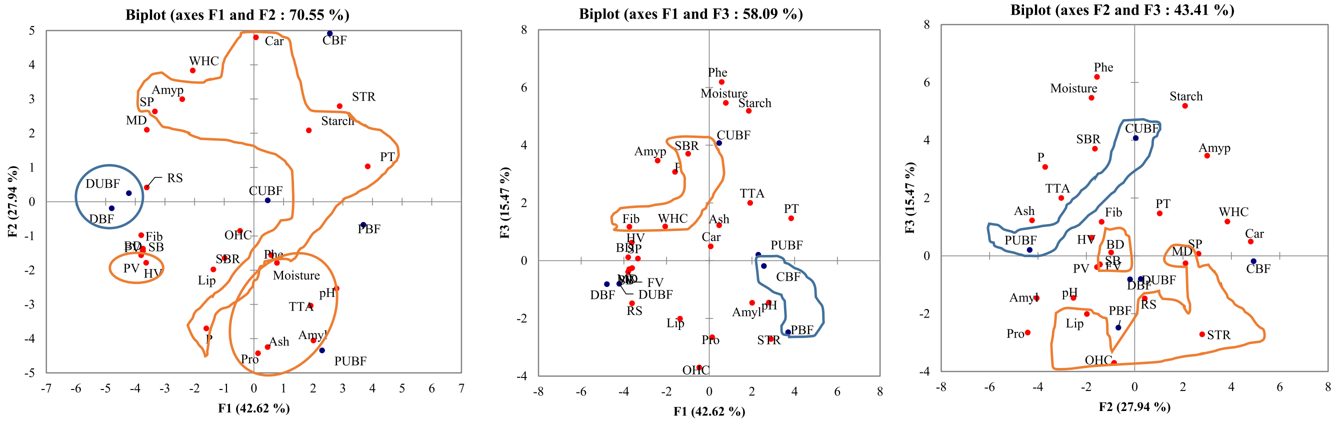

Figure 7. Biplot diagram: of physicochemical, functional and rheological properties of the different flours. Li: lipids; Pro: proteins; Car: carbohydrates; Fib: fibers; Phe: phenols; TTA: total titrable acidity; RS: reducing sugar; MD: mass density; WHC: water holding capacity; SP: swelling Power; Amyl: amylose; Amyp: amylopectin. SP: swelling power; WHC: water holding capacity; OHC: oil holding capacity; PV: peak viscosity; PT: pasting temperature; HV: holding viscosity; BD: breakdown; FV: final viscosity; SB: setback; SBR (FV/HV): setback ratio; STR (HV/PV): stability ratio; CUBF: Cipira unbleached flour; CBF: Cipira bleached flour; DUBF: Dosa unbleached flour; DBF: Dosa bleached flour; PUBF: Pamela unbleached flour; PBF: Pamela bleached flour.

The PV and HV form the third grouping and are two parameters related to the amylose/amylopectin ratio in a starch. These two parameters are associated with the amylose content, while swelling is related to the amylopectin content (a molecule that does not retrograde). The viscosity at the end of the holding time is determined at 95 °C (Hormdork and Noomhorm, 2006). PV and HV are positively correlated ($r = 0.984$; P˂0.01). Similar observations were also reported by Klang (2015). Indeed, PV represents the viscosity at gelatinization temperature and the higher a starch swells, the higher its peak viscosity is (Ragaee and Abdel-Aal, 2006). HV represents the stability of the gel when the temperature is lowered.

BD, FV and SB form the fourth group. There is a very significant correlation (P˂0.01) between BD and FV ($r = 0.972$), SB ($r = 0.874$). Breakdown reflects the ability of starches to resist shear and temperature. BD causes a disintegration of the amyloses that release water and return to their initial state. Final viscosity provides information on the ability of starch to gel and Setback on the ability of starch to downgrade. Indeed, beyond the temperature at the end of gelatinization, the starch granules, especially those rich in amylose, break quickly and release their contents. The reelarged amylose molecules re-associate with each other and cause an increase in the final viscosity (Tsakama et al., 2010). Indeed, Srichuwong et al. (2005), demonstrated that the positive correlation between FV and BD was the result of an easily reassociation of dissociated starch granules following the demotion.

The positive correlation between FV and SB ($r = 0.955$; P˂0.01) could be explained by the fact that starch-rich flours with a high proportion of amylose quickly retrograde and form gels of high consistency at low temperatures.

4. Conclusion

At the end of this study, the main objective which was to evaluate the effect of bleaching on the nutritional value, the physical, functional and rheological properties of irish potatoes flours as well as the interactions existing between these different properties. Instead of a point, it appears that, bleaching has an influenced on the composition and properties of flours. This is as in the case of the content of ash, starch, amylose, amylopectin, reducing sugars, water, fibers, phosphorus, carbohydrates, lipids, phenols, swelling capacity, water retention capacity, peak viscosity, holding viscosity, breakdown, final viscosity and setback that were reduced following this treatment unlike the gelatinization temperature which is improved after treatment. It also appears that, these flours would be a good source of carbohydrates and proteins for the formulation of infant foods. The main component analysis showed that apart from the *Dos*a samples, the treatment affected the properties of the other two varieties. Moreover, it also emerged from these analyses that the variety had little influence on these different properties compared to bleaching. In short, this study provides us with strong basis for a future application of the flours and varieties of these irish potatoes in different industrial fields.

Declarations

Author contribution statement

Julie Mathilde Klang, Stephano Tambo Tene, Leonie Gaytane Nguemguo Kalamo, Gires Teboukeu Boungo, Serge Cyrille Ndomou Houketchang, Hermann Arantes Kohole Foffe, Hilaire Macaire Womeni: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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