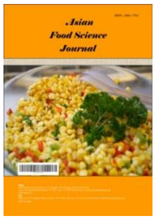

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Effect of Blanching, Varietal Difference of Irish Potato Flour and Sprouted Maize Flour on Energy Density of Gruels of Three Irish Potatoes Varieties (*Cipira*, *Pamela* and *Dosa*) in Dschang, West-Cameroon: Optimization Using Response Surface Methodology (RSM)

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Child malnutrition is a problem that usually occurs from the age of weaning. It is mostly manifested in the form of protein-energy malnutrition and mainly affects many infants in developing countries. This study is aimed at improved the energy density of gruels made from Irish potato flours by using the response surface methodology. To achieve this, blanched and unblanched Irish potato flours of three varieties (*Cipira*, *Dosa* and *Pamela*) were produced. The flours were then chemically and physically characterized. The response surface methodology using the Doelhert plan was carried out to study the effect of blanching on the energy density of gruels of the three Irish potato varieties with dry matter and optimized germinated corn flour concentration (*Kassaï* variety) as factors. As

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such that the blanching, variety and interactive effect of the blanching and variety significantly influence (*p<0.05; 0.01; 0.001*) the proximate chemical composition of all flours. The combination of optimized germinated corn flour at concentrations ranging from 3.10 to 5.76 g with Irish potato flour at concentrations between 14.50-25.45 g of dry matter has resulted in gruels with flow velocities between 100 and 160 mm/30s. The activity of germinated flour was influenced by blanching, which reduced its activity in the *Dosa* and *Pamela* varieties but increased in the case of *Cipira*. The use of optimized germinated corn flour during the preparation of the Irish potato gruels resulted in an increase of the energy density between 3.4 and 6.02. The correlation matrix shows that the fluidizing capacity of optimized germinated corn flour is significantly (*p<0.05; 0.01*) influenced by carbohydrates, ash and fibers. In view of all the above, the appropriate combination of optimized germinated corn flour and the various Irish potato flours would alleviate the problem of protein energy malnutrition.

Keywords: Irish potato; blanching; unblanching; flour; characterization; optimization; energy density.

1. INTRODUCTION

Protein energy malnutrition is a major nutritional challenge facing many children within the age (6 to 59 months) in many developing countries [1,2]. In Cameroon, 34.5% of children in this group suffer from it, more than half (18.4%) of them in the severe form [2]. Indeed, from 6 months of age, breast milk becomes insufficient energetically and nutritionally to meet the specific energy, nutrient and micronutrient needs of children [1]. Semi-liquid or solid foods (infant flours) should therefore be introduced gradually to supplement their diet [3]. Thus, in these countries, although they have the possibility of obtaining food supplements of high nutritional value from the agri-food industries on the markets but socio-economic context does not allow them to afford this luxury. The production of local children's flours therefore involves the different processing they carry out on cereals and tubers, which they may or may not supplement with legumes, in order to prepare weaning gruels [4]. However, the gruels resulting from this local production of flour pose a problem: there is increase in consistency of the starch during cooking, which gives the gruels a heavy consistency and therefore makes them difficult for children to swallow [5]. One of the first solutions mother’s found was to increase the frequency of meals, but unfortunately, given the low stomach volume (30 ml/kg) of children, they cannot consume more than 150 ml of gruels in a single meal or eat more than 3 meals per day. Faced with this, they are therefore forced to dilute these meals in order to reduce the consistency and make them easier to digest [6]. This reduces the concentration of dry matter in the gruels and consequently their energy densities [7]. It is therefore becoming urgent to offer mothers foods with a high energy density and sufficient fluid consistency to meet the needs of the infant. A first solution to this problem was provided by Tambo et al. [8,9], who demonstrated that the incorporation of small quantities of germinated maize flour into the gruels during cooking made it possible to make the gruels more digestible and also to improve their energy density and nutritional value. However, these authors did not demonstrate through their results the proportions of germinated flours that effectively addressed the problems of energy density, nutritional value and fluidity of the gruels. The proposal of processes and foods of high nutritional value for infant nutrition also requires a search for a potential food matrix that is locally available, accessible and at a lower cost. This is the case of potato tubers (*Solanum tuberosum*) whose production is important in the Western region and more particularly in Menoua Division (45.000 tonnes/year) [10]. However, although Irish potato are used in many dishes, they are not processed into flour. Indeed, the use of Irish potato flour presents a browning problem during its production, which leads to its rejection by consumers [11]. In order to obtain a flour of acceptable colour, it is essential to inactivate this enzymatic browning. For this purpose, several treatments are applied, including bleaching [12]. Nevertheless, although effective, the water blanching process results in profound changes in the texture, organoleptic, chemical and even functional properties of the food [13,14]. In view of the above, it can be seen that these authors were interested in studying the nutritional value of Irish potato and neglecting the effect of bleaching on the nutritional value of irish potatoes flours and the use of these flours in combination with amylase sources (germinated maize flours) to improve the energy density of gruels. The main objective of this work was therefore to evaluate the effect of blanching on the nutritional potential and the capacity of these flours to be used in the preparation of infant cereals of high nutritional and energitical value. In addition, the study sought to determine the proximate chemical composition of blanched and unblanched Irish potato flours and to investigate the effect of blanching on the flow rate and energy density of Irish potato gruels produced under optimal conditions.

2. MATERIALS AND METHODS

2.1 Materials

The material used for this work are of three Irish potato varieties: *Dosa*, *Cipira* and *Pamela* and one maize variety (*Kassaï*) grown in the West Region of Cameroon. They were collected from the multi-purpose station of the Agricultural Research Institute for Development (ARID) of Dschang, in December 2017. The samples collected were sent to the laboratory where they were used to produce the flours. These different flours were used for the different experiments.

2.2 Methods of Operation

2.2.1 Production of blanched and unblanched Irish potato flours

Irish potato tubers of the different varieties were washed with tap water and separated into two batches. The first batch was peeled and cut into slices (4-7 mm thick). The Irish potato slices were dried in a "venticell" oven at 45°C for 24 hours. The dried slices were crushed with a mill and screened with a 300 µm screen stainless steel screen. The flours thus obtained were packaged in polyethylene bags and stored in a desiccator to limit moisture exchange prior to subsequent being used for analysis. The second batch of tubers was blanched with tap water at 90°C for 5 minutes. The blanched tubers underwent the same process as described above. The flours obtained were packaged in polyethylene bags and stored in a desiccator to limit moisture exchange before its use for analysis [14].

2.2.2 Production of germinated maize flour under optimal condition

The pre-sorted corn grains were soaked in distilled water at a temperature of 30°C for 20 hours. Once soaked, they were allowed to germinate for 90 hours. Germination was made up possible by spreading the grains on a fabric covered with cotton under a mosquito net and placed in a room protected from sun rays. During this process, the grains were watered twice a day with an interval of 12 hours with 35 ml of water. After germination process, the grains have been matured for 11 h. It consisted of putting the germinated grains in a well knotted polyethylene bag and stored in the dark for 11 hours. After this time, the grains were dried in a Venticell oven for 24 hours at a temperature of 45 °C and then degermed manually. After degermination, the seeds were milled and then sieved using a 300 µm sieve and the resulting flours were stored in polyethylene bag and stored in a desiccator for later use [15].

2.2.3 Chemical characterisation of Irish potato flours

The samples produced were subjected to different analyses. The moisture content was assessed using the method described by IUPAC [16]. In a crucible of known weight (P_0) a quantity each of the flours was introduced to obtain a final weight (P_1). The whole (crucible+flour) is placed in an “oven (Venticell (MM-group)” at 105 °C for 24 h. After drying, the sample was removed and weighed progressively in order to obtain the constant weight (P_2). Total lipids were extracted in Soxhlet extractor with hexane as solvent. The lipid content was determined by weighing after evaporation of the hexane from the cartridges in an oven [17]. Protein determination, fibers, ashes and carbohydrates content was done using AOAC [18], standard method. The energy value was determined by applying the ATWATER coefficients [19]: 1 g of carbohydrate or protein provides 4 kilocalories, 1 g of fat provides 9 kilocalories. The expression of the energy value was given by the following equation:

$$Ec = (4\times (\%\ carbohydrates)) + (9 \times (\%\ fat)) + (4 \times (\%\ protein))$$

2.2.4 Increasing the energy density of the gruels: Process optimization and experimental design

The response surface methodology (RSM) was used to optimize the two selected factors (flour/water ratio (m/v) and optimized sprouted flour mass). Doehlert's plan has the interesting property of presenting a uniform distribution of experimental points in the factor space. This matrix has coded variables that are transformed into an experimental matrix with real variables directly used in the laboratory for the different manipulations.

Table 1. Presentation of the experimental matrix

Tets N°	Coded values		Sprouted flour (g)	Real values Irish potato flours concentrations (g/100 g of DM)					
	X1	X2		CBF	DUBF	DBF	PUBF	PBF	CUBF
1	0	1	7	16.25	22.50	20	20	17.50	20
2	0	-1	3	16.25	22.50	20	20	17.50	20
3	0.866	0.5	6	19.50	26.83	26.50	24.33	21.83	24.33
4	-0.866	-0.5	4	13	18.17	13.51	15.67	13.17	15.67
5	-0.866	0.5	6	13	18.17	13.51	15.67	13.17	15.67
6	0.866	-0.5	4	19.50	26.83	26.50	24.33	21.83	24.33
7	0	0	5	16.25	22.50	20	20	17.50	20
8	0	0	5	16.25	22.50	20	20	17.50	20
9	0	0	5	16.25	22.50	20	20	17.50	20

CUBF: Cipira unblanched flour; CBF: Cipira blanched flour; DUBF: Dosa unblanched flour; DBF: Dosa blanched flour; PUBF: Pamela unblanched flour; PBF: Pamela blanched flour

2.2.5 Choice of factors, response and definition of the experimental matrix

The factors chosen here was the dry matter concentration (flour/water ratio; flour mass being dry matter) and concentration of the germinated maize flour (g). The optimization response was the flow velocity of the gruels. It should be noted that with regard to flow velocity, only those with flow velocities between 100-160 mm/30s were used to determine energy density. With regard to the experimental field, Table 1 gives the different factors examined and their respective scope. The previous work [8,9,20] and preliminary studies were carried out to determine the extent of the various factors used to define the experimental scope of this study. The experimental matrix obtained present the coded and real values for a 2 factor Doehlert plan. This matrix gives us a plan with 9 experiments to carry out, including 2 repetitions in the center of the field. It should be noted that all these experiments and the rest of the tests were repeated twice.

2.2.6 Proposal of a model

The proposed model should simply have the property of representing the experimental response studied in the experimental domain of interest. The polynomial models, because of their simplicity, were the ones chosen for use. On the completion of the experiments, the flow velocity was taken as the answer (Y) and we postulated a polynomial model of degree 2, for two variables. The model was as follows:

$$Y = I + ax_1 + bx_2 + cx_1^2 + dx_2^2 + ex_1x_2$$

Where Y is the predicted response; I is the constant; a and b are the linear coefficients; c and d are the square coefficients; e is the interaction coefficient; x_1, x_2, x_{12}, x_1x_2, x_{22} are the levels of the independent variables.

2.2.7 Validation of models

In order to put the observed phenomenon in the form of an equation, it was important to validate the empirical models obtained. To do this, the execution of the model is measured by comparing the values of the experimental responses obtained during the manipulations and those calculated from the mathematical equations of the models. In addition to the determination coefficient (R^2), other mathematical procedures and tools are used, such as the Absolute Analysis Mean Deviation (AAMD), which provides information on the average error of the manipulations and the Bias factor (Bf). Indeed, the chosen model will be validated when the determination coefficient (R^2) is greater than 75%, the AAMD having a standard value of 0 and the bias factor equivalent to 1.

2.2.8 Incorporation of sprouted maize flour into Irish potato flours gruels and determination of the consistency of the supplemented gruels: Process for the preparation of gruels with incorporation of sprouted maize flour after cooking

The gruels were prepared according to the process described by Tambo et al. [9], which requires the incorporation of germinated flours after cooking. This method has the advantage of giving the best results compared to previous ones and during cooking. Indeed, for a mass of flour weighed (expressed in grams of dry matter) and contained in a beaker, distilled water (100 ml) was added. The beakers were then placed in a water bath calibrated at 99±1 °C. The mixture was stirred until the temperature of 95 °C was reached at the core of the product and the gruels were kept at this temperature for 10 minutes. These gruels were then cooled to 55 °C, which represented the optimal temperature of activity of the amylases in these flours [21] and placed in a water bath at this temperature for 10 minutes for pre-incubation. At the end of this time, the different masses of germinated corn flour (*Kassaï*) were added to the gruel and incubation was carried out for 10 minutes. The reaction was stopped by introducing the mixture into a boiling water bath (95 °C) for 10 min (amylase action time).

2.2.9 Method of determining the response and expression of the flow velocity

The consistency of the gruels was estimated by measuring the flow velocity using Bostwick's consistometer [22]. When the spray solution reached 45.0±1 °C (the temperature at which the spray solution is usually administered to children), 100 ml of spray solution was poured into the first compartment of the Bostwick consistometer, the trigger of the device was activated to release the spray solution which then flowed into the second compartment. The parameter chosen was the distance travelled by the spray liquid front in 30 s and this made it possible to evaluate the flow in mm/30 s.

2.2.10 Expression of the energy value of the gruels [19]

Here, only gruels with flow velocities between 100-160 mm/30 s were used to determine the energy values they provide. Caloric energies were determined by applying ATWATER coefficients: 1 g of carbohydrate or protein provides 4 kilocalories while 1 g of fat provides 9 kilocalories. The expression of the energy value per 100 ml of spray solution is given by the following equation:

$$Ec = (4\times (\%carbohydrate)) + (9 \times (\%lipid)) + (4 \times (\%protein)).$$

2.3 Statistical Analysis

The results of the physico-chemical analysis were expressed as mean plus or minus standard deviation and were subjected to an one way ANOVA at the 5% probability threshold and compared using the Duncan test using SPSS software version 20.0 (*$p<0.05$, 0.01, 0.001*). The analysis of variance (ANOVA) was used to determine the influence of each factor and the degree of significance of each of these effects. The significance of each factor was determined by the Fisher test. The regression equations were also subjected to the Fisher test to determine the coefficient of determination R^2. Calculations were done using MINITAB software version 17.0. The accepted confidence level was $p<0.05$ (5%). Graphical representations of the iso response curves of the models and the effect of each performed factor on the postulated response were made using MINITAB version 17.0 and SIGMA PLOT version 12.0 software. The correlation between physico-chemical properties and fluidizing capacity of amylase flour was evaluated using the SPSS 20.0 software.

3. RESULTS AND DISCUSSION

3.1 Proximate Chemical Composition of the Different Irish Potato Flours

Table 2 presents the proximate chemical composition of the Irish potato flours. It can be seen from this table that the moisture content is significantly (*$p<0.05$, 0.01, 0.001*) influenced by the treatment, the variety and the interactive effect. Infact, blanching lowers the water content and this is believed to be due to the fact that during blanching there is a change in the conformation of the plant's protoplasm structure and a break in the hydrogen bonds between water and organic molecules. This change leads to an increase in membrane permeability and thus increased water removal through evaporation [23]. Wang et al. [24], also demonstrated that water blanching reduces the water content of apples. It should be noted that the water levels obtained (<14%) are favourable for good conservation in tropical areas over a long period of time [25]. The ash content represents the inorganic matter of the plant, particularly ions [26]. Concerning this parameter, it is found that it is significantly (*$p<0.05$, 0.01, 0.001*) influenced variety, blanching and combination between these two effects. Indeed, the difference between the samples would be related to the metabolism of the plant because they use certain ions in the biosynthesis of macromolecules, which causes them to decrease. In addition, the decrease in ash content observed following blanching would be the result of leaching ash into the blanching water. Proteins play a major role in the growth and development of tissues. The protein content varied from 9.35 to 11.55%. It is significantly (*p<0.05, 0.01*) influenced by treatment, variety and interaction. This difference is explained by the treatments and cultural practices applied to each variety during cultivation. Moreover, the lowering of this parameter with the treatment would be due either to a destruction of the proteins with heat or to an elimination of these proteins by the phenomenon of osmosis during blanching. The protein levels obtained are lower than the proportion recommended (15%) by FAO/WHO [27], to cover the daily needs of children of weaning age (6-24 months). It therefore requires a supplement of these flours by protein sources such as soya beans for the formulation of infant cereals. The fat and energy content are significantly (*p<0.05*) influenced by the treatment and the variety. Indeed, during plant growth, lipids are mobilized to provide energy. This oxidation therefore leads to a reduction in the content of this parameter and this depends on the specific metabolism of each variety. Water blanching results in aqueous hydrolysis of triglyceride ester bonds releasing fatty acids. These fatty acids are therefore eliminated by the phenomenon of leaching out of the plant, which reduces the lipid content. Like proteins, a lipid source supplementation of this tuber would be favourable when formulating weaning gruels based on this flour because they all had a lower content (8%) than the FAO/WHO recommendation [27]. Digestible carbohydrates are the most representative elements of this flour. The content varies between 67.37 and 74.42%. It is significantly influenced by these different effects at different thresholds. Carbohydrate synthesis is influenced by crop treatment, soil type and climatic conditions at the growing site [26]. Just like carbohydrates, fibers are also influenced by the same factors as earlier mentioned. The lowering of the fiber content by the treatment would be the consequence of a destruction of these compounds by heat treatment and elimination in the blanching water. Similar observations have also been reported by Wang et al. [24], who observed a loss of water-soluble compounds such as fibres following blanching. The interactive effect would be due to the fact that the different varieties of Irish potato studied are very rich in soluble fiber, which would therefore be easily extracted and eliminated by blanching water.

3.2 Increase in the Energy Density of Irish Potato Gruels: Effect of Maize Germinated Flour and Dry Matter Concentration on the Flow Velocity and Energy Density of Irish Potato Gruels

The flow velocities of the different gruels prepared according to the concentration of germinated maize flour and dry matter (DM) are presented in Table 3. The experimental values obtained made it possible to determine the influence of the factors, to define the mathematical models, to determine the areas of interest relating to flow velocities and to evaluate the increase in the energy density of the different gruels. It was discussed to apply these flours in the preparation of the gruels in order to determine the maximum DM concentration necessary to have a flow velocity between 100 and 160 mm/30 s. It can be seen from this table that flow velocities are influenced by the nature of the flour, blanching, concentrations of germinated maize flour and Irish potato flour. The highest flow velocity (551.67 mm/30 s) was obtained with the mixture germinated corn flour/blanched *Cipira* flour (13.00/4.00). It can be seen that at the same concentration of *Cipira* potato flour and at a high concentration of germinated maize flour, the flow velocity decreases. This is explained by the fact that germinated maize flour in addition to its amylase content is also a source of starch [8,9]. The same applies to the varieties *Dosa* blanched (experiments 3 and 6), unblanched *Cipira*, unblanched *Dosa*, blanched *Pamela* and unblanched *Pamela* (experiments 4 and 5). It also appears from this table that for flow velocities between 100 and 160 mm/30s, the various flours had optimal dry matter concentrations. The choice of these different concentrations of optimal dry matter also depends on the ratio of flour to germinated flour mass. Thus for this flow interval, unblanched *Cipira* flour had an optimal dry matter concentration of 24.33 g of DM, blanched *Cipira* flour 19.50 g of DM for a germinated flour concentration of 6 g, unblanched *Dosa* flour 26.83 g of DM (4 g of germinated flour), blanched *Dosa* and unblanched *Pamela* 20.00 g of DM for a germinated flour mass of 3 g, blanched *Pamela* 13.17 g of DM for a germinated flour mass of 6 g.

Table 2. Proximate chemical composition of different Irish potato flours

Flours	Moisture (%)	Ash (% DM)	Proteins (% DM)	Lipids (% DM)	Digestibles carbohydrates (% DM)	Fibers (% DM)	Energy bulk (Kcal/100g of DM)
CUBF	10.95±0.09^{a}	8.50±0.71^{c}	9.95±0.21^{c}	2.19±0.07^{c}	70.01±0.59^{b}	9.35±0.07^{b}	339.55±1.68^{b}
CBF	9.30±0.13^{cd}	4.50±0.71^{d}	9.35±0.21^{d}	2.60±0.15^{abc}	74.42±1.04^{a}	9.20±0.00^{bc}	358.48±1.60^{a}
DUBF	9.66±0.31^{bcd}	7.00±0.00^{b}	10.25±0.34^{c}	2.66±0.26^{abc}	70.73±0.33^{b}	9.50±0.00^{a}	347.86±0.05^{ab}
DBF	9.39±0.21^{d}	7.00±0.00^{b}	10.95±0.08^{b}	3.02±0.44^{ab}	69.29±0.30^{bc}	9.50±0.00^{a}	348.14±0.76^{ab}
PUBF	9.99±0.01^{b}	8.50±0.70^{a}	11.55±0.07^{b}	3.13±0.18^{a}	67.37±0.52^{d}	9.35±0.07^{b}	343.85±2.43^{ab}
PBF	9.76±0.19^{bc}	8.50±0.71^{a}	11.15±0.21^{ab}	2.31±0.70^{bc}	68.68±0.37^{cd}	9.15±0.07^{c}	340.11±5.10^{b}
Effects							
Treatment (T)	*	*	**	*	*	*	*
Variety (V)	**	***	**	*	**	**	*
T x V	**	**	**	NS	**	**	NS

The means ± standard deviations followed by the same letter in the same column indicate that the differences are not significant (p>0.05).
DM: Dry matter; CUBF: Cipira unblanched flour; CBF: Cipira blanched flour; DUBF: Dosa unblanched flour; DBF: Dosa blanched flour; PUBF: Pamela unblanched flour; PBF: Pamela blanched flour, NS: Not significant.
**, **, ***Significant effects at p <0.05, 0.01, 0.001 respectively.*

Table 3. Experimental values of the flow velocities of the gruels as a function of the dry matter and the mass of germinated corn flour

Tests N°	Experimental values												
	Germinated flour Concentration	Dry matter concentration (g of DM)						Flow velocities (mm/30s)					
		CUB	CB	DUB	DB	PUB	PB	CUB	CB	DUB	DB	PUB	PB
1	7	20	16.25	22.50	20	20	17.50	184.0	228.00	211.33	99.00	85.5	55.00
2	3	20	16.25	22.50	20	20	17.50	146.5	321.67	353.00	111.00	119.5	56.67
3	6	24.33	19.50	26.83	26.50	24.33	21.83	85.0	126.67	124.67	65.33	54.0	53.33
4	4	15.67	13	18.17	13.51	15.67	13.17	457.0	551.67	508.67	339.33	389.0	161.33
5	6	15.67	13	18.17	13.51	15.67	13.17	332.5	465.00	466.67	243.67	340.0	146.67
6	4	24.33	19.50	26.83	26.50	24.33	21.83	104.5	186.00	111.33	67.33	56.5	56.00
7	5	20	16.25	22.50	20	20	17.50	156.5	300.00	224.67	106.33	102.5	81.67
8	5	20	16.25	22.50	20	20	17.50	151.0	288.33	193.33	121.67	110.0	65.00
9	5	20	16.25	22.50	20	20	17.50	76.0	314.67	206.00	112.00	84.5	88.33

CUB: Cipira unblanched; CB: Cipira blanched; DUB: Dosa unblanched; DB: Dosa blanched; PUB: Pamela unblanched; PB: Pamela blanched

3.3 Proposal of Mathematical Models, Analysis of Variance of Models and Contributions of Input Variables

The regression equations below were predicted from the data in Table 3 with variables X_1 representing the concentration of germinated maize flour, X_2 the concentration of Irish potato flour and Y the flow velocity which is still the answer. It can therefore be seen from these equations that the flow velocities of gruels prepared on the basis of the flours CUBF, DUBF and PUBF are negatively affected by the linear effects of factors X_1 and X_2 but on the other hand positively affected by the quadratic and interactive effects of these two factors. The interactive effect was also reported by Tsopbeng et al. [20], who demonstrated that the flow velocities of gruels made from fermented maize flour were positively affected by the dry matter concentration of fermented maize flour, flour and amylase extract from sprouted maize and rice. For CBF, DBF and PBF flours, it is noted that in addition to the linear effects of X_1 and X_2, the quadratic effect of maize germinated flour decreases the response while the quadratic effect of the Irish potato flour concentration X_2X_2 as well as the interactive effect of the two factors X_2X_1 increase the flow velocities. In addition to its high amylase content, germinated corn flour is also a source of starch [8,9]. This starch also has the ability to bind water molecules and increase consistency. In addition, enzymes are molecules that act at a certain concentration. When their concentration is higher or close to that of the substrate, the enzymatic action or reaction rate is reduced.

Cipira unblanched flour (CUBF)

$$Y_1 = 127.8 - 11.5 X_1 - 173.2 X_2 + 37.4 X_1X_1 + 143.4 X_2X_2 + 60.6 X_1X_2$$

Cipira blanched flour (CBF)

$$Y_2 = 301.00 - 55.56 X_1 - 234.7 X_2 - 26.2 X_1X_1 + 67.3 X_2X_2 + 18.2 X_1X_2$$

Dosa unblanched flour (DUBF)

$$Y_3 = 208.0 - 52.0 X_1 - 246.5 X_2 + 74.2 X_1X_1 + 135.6 X_2X_2 + 36.9 X_1X_2$$

Dosa bleached flour (DBF)

$$Y_4 = 113.3 - 20.3 X_1 - 150.1 X_2 - 8.3 X_1X_1 + 120.3 X_2X_2 + 62.4 X_1X_2$$

Pamela unblanched flour (PUBF)

$$Y_5 = 99.00 - 19.92 X_1 - 206.18 X_2 + 3.5 X_1X_1 + 195.6 X_2X_2 + 31.0 X_1X_2$$

Pamela blanched flour (PBF)

$$Y_6 = 78.33 - 3.44X_1 - 57.35 X_2 - 22.50 X_1X_1 + 42.17 X_2X_2 + 6.9 X_1X_2$$

Table 4, presents the validation model. It can be seen from this table that dry matter significantly affects (*p<0.05*) the flow velocity of gruels regardless of the variety and treatment applied. With the exception of gruels prepared from CUBF and CBF flour, it is noted that a quadratic effect of dry matter significantly affects (*p<0.05*) the flow velocities of gruels from flour of other varieties. Finally, we note that the mass of germinated flour significantly affects (*p<0.05*) the flow velocities of gruels from CBF. Uvere et al. [28]; Klang et al. [20] also showed that the viscosity of gruels made from maize, Irish potato, yams and cassava was more influenced by the dry matter concentration of flours than by the concentration of amylase-rich flour. It is also observed that the different contributions of each factor are concomitant with the previous data where factor X_2 was found to be the parameter that significantly affected the response. It can also be seen from this table (Table 4) that each of the six proposed mathematical models presented coefficients of determination (R^2) ranging from 80.05-99.15%. These values are higher than the standard value (75%) reported by Joglekar and May [30], as being the standard value of the coefficient of determination above or from which an experimental mathematical model is accepted. The values of the Absolute Analysis Mean Deviation obtained in this work range from 0.00-0.03. The same applies to the values of the bias factor, which is between 0.75 and 1.25 for the six different Irish potato flours [31]. In view of all the above, it is therefore concluded that the experimental design and the different mathematical models are accepted on the basis of these three parameters (R^2, AAMD and Bf).

3.4 Effects of the Main Factors on the Flow Velocity of Gruels

Fig. 1. show the main effects of dry matter concentration and sprouted maize flour concentration on the flow velocity of gruels made from blanched and unblanched Irish potato flour. These figures show that the flow velocity of the gruels decreases with the increase in dry matter

concentration until it reaches the maximum and beyond, it stabilizes. This phenomenon is observed regardless of the variety and treatment. This is explained by the starch content, which increases with the dry matter concentration. The observations were noted regarding the decrease in flow velocity, following the increase in dry matter concentration on the main effects curves are in agreement with those of Tambo et al. [8,9], who demonstrated that the flow velocities of gruels made from cassava flour were inversely proportional to the flour dry matter concentration. Similarly, Yibeltal et al. [32], also demonstrated that sweet potato flour gruel formulations increased in viscosity with increasing dry matter concentration. This can be explained by the fact that the increase in dry matter during the preparation of the gruels leads to an increase in the quantity of starch which, at high temperature, retains water strongly and swells [33], thus causing the consistency or increase in the viscosity of the gruels to set or increase, thereby reducing fluidity [20,32]. In addition, this figure shows that with regard to the Irish potato flour concentration factor, gruels from unblanched *Cipira* flours, bleached *Dosa*, unblanched *Pamela* and blanched *Pamela* showed peaks in concentrations. It should be noted that the addition of sprouted flour results in a decrease in the flow rate of porridges made from PUBF, CBF and DBF. This can be explained by the composition of these flours and more particularly their protein content. Indeed, proteins are present on the surface of the starch granules preventing them from gelatinizing during cooking and thus from presenting their bonds to amylases. These proteins limit substrate enzyme contact, which leads to inactivity of amylase-rich flour [8,9]. In addition, amylases being hydrolases require water for their catalytic actions; during cooking, most of this water is fixed by starch molecules. This would therefore lead to a reduction in the hydrolytic activity of amylases. On the other hand, in the case of CUBF and DUBF flours, it is observed that the addition of sprouted flour reduces the flow rate to a threshold (125 mm/30 s). In addition to the presence of amylases in germinated maize flour, there is also a presence of starch. This starch also has the ability to bind water molecules to contribute to an increase in the viscosity of the gruels [28]. For gruels made from PBF flours, there is an increase in flow velocity with that of germinated flour to an optimum and then a decrease in flow velocity with the evolution of the quantity of germinated maize flour. This increase would result in the hydrolytic activity of the amylases in optimized germinated corn flour, which has fragmented the starch molecules with high swelling power and consisting of small molecules such as dextrins, maltose and glucose which have a low swelling capacity [9,33,34].

3.5 Model-Predicted and Experimental Flow Velocities

Table 5 presents the flow velocities predicted by the model and the experimental flow velocities. These predicted viscosities were obtained from the iso response curves. It can be seen from this table that the flow velocities predicted by the model for dry matter and mass of germinated maize flour do not differ significantly ($p>0.05$) from those found experimentally. These results are in agreement with those found previously (Table 4) and further confirm the acceptability of this model. It also appears that the desirability, which is a parameter indicating the degree of reproducibility of a test, is 1 (100%) for the different tests. This proves and demonstrates that the factors, response and domains for each flour have been well chosen. Also, it appears the experimental and predictive response values are influenced by the dry matter concentration of Irish potato flours, the concentration of sprouted maize flour, the variety and the treatment.

Indeed, the dry matter concentrations presented in Table 5 have flow velocities between 100-160 mm/30 s for concentrations ranging from 14.50 to 25.45 g of DM, regardless of the flour. The flow velocities obtained for such dry matter concentrations are due to the combination with optimized germinated maize flour because Tambo et al. [8], demonstrated that cassava flour gruels above 10% concentrations completely lost their fluidity. Indeed, the amylases present in these flours have made it possible to digest the starch in Irish potato flours in order to reduce its swelling capacity [29,35]. These results are in agreement with those of Singhavanich et al. [36], who demonstrated that incorporation of small quantities of amylase-rich flours into heavy and viscous gruels leads to a decrease in viscosity and dry matter concentration. It also appears that DUBF flour had the best ratio or best ratio with optimized germinated maize flour (25.45 g of DM/3.12 g), unlike PBF which had the lowest ratio (14.50 g of DM/3.26 g) for the same flow velocity interval (100-160 mm/30 s).

3.6 Factors for Multiplying the Energy Density of Irish Potato Flours Gruels with Flow Velocities between 100-160 Mm/30 S

Table 6, shows the energy density multiplication factors and energy densities of Irish potato flours gruels with flow velocities between 100-160 mm/30 s. It can be seen from this table that the velocities prepared without the incorporation of optimized germinated maize flour have very low dry matter concentrations between 4.00-5.00 g of DM and energy densities all below 20 kcal/100 ml of gruels (15.07-19.76 kcal/100 ml of gruels). These gruels have very low concentrations of dry matter and energy. They are far below the energy density (120 kcal/100 ml of gruels) recommended by FAO/WHO for children aged 6 to 12 months for a complementary meal [6]. Similar data were also reported by Elenga et al. [37], who showed that in the absence of germinated maize flour, the prepared cassava gruels were of low dry matter concentrations and low energy density. Following the incorporation of low levels of optimized germinated corn flour (3-5 g), it can be observed that gruels with low dry matter concentrations and low energy densities are multiplied by factors ranging from 3.40-6.40. With regard to energy density, it appears that in the presence of optimized germinated maize flour, the gruels have energy densities ranging from 54.62 to 98.20 kcal/100 ml of gruels. This incorporation of optimized germinated corn flour therefore results in an improvement in the energy density of the gruels by a value ranging from 39.55 kcal/ 100 ml (PBF) to 82.77 kcal/100 ml of gruels (PUBF).

These results are in line with those of Tambo et al. [9], who demonstrated that the use of low levels (1 - 2%) of germinated maize flour in the preparation of cassava flour-based gruels resulted in a flow velocity between 100 and 160mm/30s for 23% DM, i.e. a multiplication of 5.48 of the dry matter compared to gruels not supplemented with germinated maize flour. In addition, Elenga et al. [22], demonstrated that the pre-cooking of maize and peanut gruels followed by the addition of malt at 50°C with or without carbonate made it possible to prepare gruels with flow velocities of both 120 mm/30 s and multiplication factors ranging from 4.25 to 4.75 times. It should be noted that unbleached flours have had higher energy densities and higher dry matter concentration multiplication factors than blanched flours. This would be due to the composition of the different flours and the loss of certain nutrients during blanching. Although it has led to an improvement in energy density, it is still the case that supplemented gruels have lower energy densities (120 kcal) than the standard for a weaning food. This is believed to be due to the fact that tubers are mainly rich in carbohydrates; however, the formulation of a weaning food also requires the addition of sources of fat (peanuts), protein (soya) and minerals (*Moringa oleifera*) to fight against protein-energy malnutrition and hidden hunger [7].

Table 4. *p* values of the ANOVA of the models of the flow velocity of Irish potato gruels with germinated corn flour and model validation

Sources	Dry matter (g)					
	DUBF	DBF	CUBF	CBF	PUBF	PBF
	p	p	p	p	p	p
X_1: germinated flour	0.056	0.196	0.747	0.010*	0.057	0.609
X_2: dry matter	0.001*	0.002*	0.013*	0.00*	0.00*	0.002*
X_1X_1	0.071	0.695	0.520	0.17	0.760	0.100
X_2X_2	0.033*	0.019*	0.069	0.065	0.001*	0.022*
X_1X_2	0.419	0.144	0.420	0.065	0.136	0.607
Constance	208.0	113.3	127.8	301.00	99.00	78.33
Validation of model						
Detemination Coefficient (R^2)	95.74%	94.58%	80.05%	98.45%	99.15%	93.53%
Absolute Analysis of the mean deviation (AAMD)	0.00	0.00	0.03	0.00	0.01	0.00
Bias factor (Bf)	1.00	1.01	1.03	1.00	1.01	1.00

*$p < 0.05$ values indicate that the factors contribute significantly to the response.

CUBF: Cipira unblanched flour; CBF: Cipira blanched flour; DUBF: Dosa unblanched flour; DBF: Dosa blanched flour; PUBF: Pamela unblanched flour; PBF: Pamela blanched flour

Table 5. Model-predicted flow velocities and experimental flow velocities

Flours	DM (%)	Germinated maize flour (g/100ml)	Optimal predictive values	Optimal experimental values	Désirability
CUBF	24.10	5.76	102.76[a]	105.00±21.20[a]	1
CBF	17.26	4.69	158.43[a]	132.50±10.60[a]	1
DUBF	25.45	3.12	147.04[a]	120.00±7.10[a]	1
DBF	20.49	3.16	138.91[a]	104.00±19.80[a]	1
PUBF	20.285	3.10	111.07[a]	117.50±31.80[a]	1
PBF	14.50	3.26	118.33[a]	134.00±48.1[a]	1

The means followed by the same letter in the same line indicate that the differences are not significant (p>0.05). DM: dry matter; CUBF: Cipira unblanched flour; CBF: Cipira blanched flour; DUBF: Dosa unblanched flour; DBF: Dosa blanched flour; PUBF: Pamela unblanched flour; PBF: Pamela blanched flour

Table 6. Multiplication factor of the energy density of gruels with flow velocities between 100-160 mm/30 s

Flours	Without germinated flour (g of DM)	EB (kcal)	With germinated flour (g of DM)	MF	EB (kcal)	Additional Energy Bulk (kcal)
CUBF	4.00	15.08	24.10	6.02	90.85	75.77
CBF	5.00	19.76	17.26	3.40	68.22	48.46
DUBF	4.00	15.43	25.45	6.40	98.20	82.77
DBF	4.00	15.44	20.49	5.12	79.12	63.68
PUBF	4.00	15.25	20.28	5.05	77.32	62.07
PBF	4.00	15.07	14.50	3.62	54.62	39.55

EB: Energy bulk ; MF : Multiplicating factor; DM: Dry matter; CUBF: Cipira unblanched flour; CBF: Cipira blanched flour; DUBF: Dosa unblanched flour; DBF: Dosa blanched flour; PUBF: Pamela unblanched flour; PBF: Pamela blanched flour; MF: Multiplicating factor; EB: Energy bulk

3.7 Study of the Correlations between the Physico-chemical Properties of the Different Flours and the Capacity of Optimized Germinated Maize Flour to Reduce the Flow Velocities of the Gruels

Table 7 shows the correlations between the physico-chemical properties of the different flours and the fluidizing capacity of optimized germinated maize flour. It can be seen from this table that the flow velocity is significantly correlated with ash (r= -0.517; *p<0.05*), Fib (r= -0.813; *p<0.01*) and Car (r= 0.561; *p<0.05*). The flow velocity is influenced by the consistency of the gruels, particularly due to the carbohydrate content and composition of his starch. Another phenomenon is that during cooking, starches swell, retain water and give consistency to the gruels [6]. The higher this content is, the more important is the consistency and hydrolytic action of the amylases insignificant. In addition, germinated maize flours are essentially rich in alpha amylase hydrolysing alpha 1-4 bonds. However, amylopectin consists of both alpha 1-4 and alpha 1-6 bonds, from which the enzyme can hydrolyze only the 1-4 bonds and not the 1-6 bonds, which will reduce the flow of gruels. This reduction could also be due to steric congestion within amylopectin molecules, which would reduce the catalytic action of enzymes. Unlike proteins and lipids, which not only form complexes with amylose molecules but also form a barrier around starch granules, making it difficult to access catalytic sites, digestible carbohydrates are the substrates [38]. A matrix rich in carbohydrates would therefore easily facilitate the action of amylases since they are the substrates of amylases unlike lipids and proteins. Fibers represent the non-digestible fractions of carbohydrates because they are made up of daring molecules linked by Beta 1-4 bonds. Amylases, as alpha amylase cannot digest these bonds. This inaction of the amylases will therefore lead to the consistency of the gruels because the fibers also have the ability to retain water and swell during cooking. In addition, as these fibers are very large macromolecules, they can also limit amylase-starch contact by masking starch molecules. The ash content is influenced by the mineralogical composition of a matrix. Amylases are metalloproteins and their actions are dependent on the presence and concentration of certain ions such as calcium, copper, iron, sodium, magnesium [21]. Indeed, Tambo et al. [21], have shown that amylase extracts of maize and sweet potato lose more than 80% of their activities in the presence of copper ions at a concentration of 5 mM. In addition, these ions are most often present in plants as phytates that have the ability to complex the divalent cations which are necessary for the action of amylases.

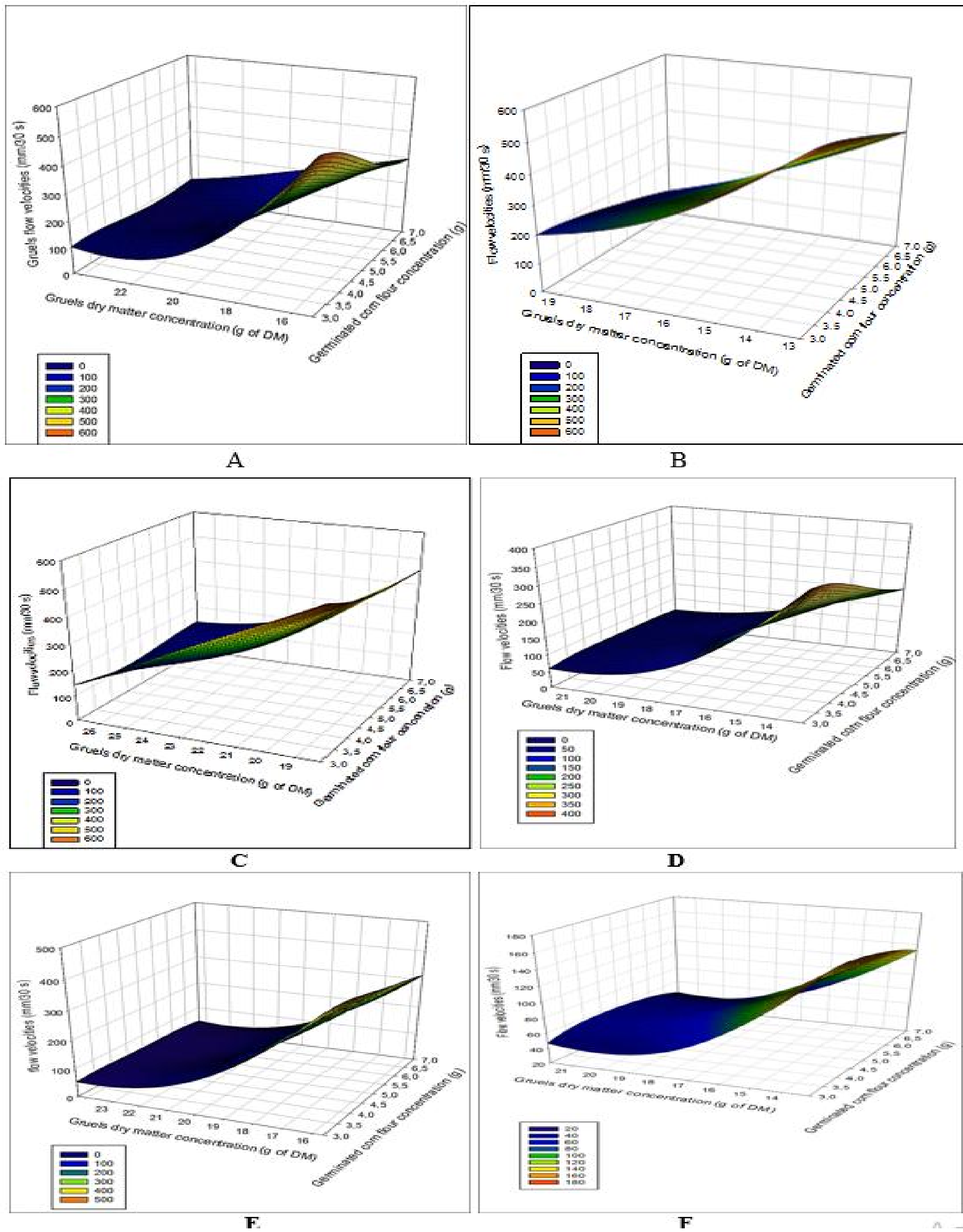

Fig. 1. Curves of the main effects of the germinated flour concentration and the dry matter concentration of Irish potato flours on the flow velocity of the gruels

A: Cipira unblanched flour (CUBF); B: Cipira blanched flour (CBF); C: Dosa unblanched flour (DUBF); D: Dosa blanched flour (DBF); E: Pamela unblanched flour (PUBF); F: Pamela blanched flour (PBF)

Table 7. Pearson correlation coefficient (r) matrix between physico-chemical and gruels flow velocities

Variables	Ash	Pro	Lip	Car	Fib	FV
Ash	1.000b					
Pro	0.645a	1.000b				
Lip	0.884b	0.598a	1.000b			
Car	0.088	-0.906b	-0.417	1.000b		
Fib	0.400	0.132	0.305	-0.229	1.000b	
FV	-0.517a	-0.261	-0.164	0.516a	-0.813b	1.000b

The bold values bearing a and b differ significantly and respectively at the probability threshold p<0.05 and p<0.01. Li: lipids; Pro: proteins; Car: carbohydrates; Fib: fibers; FV: final viscosity

4. CONCLUSION

In conclusion of this work, where the aim was to valorize Irish potato tubers in the form of flour that can be used in infant gruels, it appears that blanching, variety and interactive effect of blanching and variety influenced the ash, water, fibers and carbohydrates contents in all flours. As for lipids and energy density their proportions are not influenced by the three parameters. The combination of optimised germinated maize flour at concentrations ranging from 3.10 to 5.76 g with Irish potato flour at concentrations ranging from 14.50 (blanched *Pamela* flour gruel) to 25.45 g of DM (unblanched *Dosa* gruel) has resulted in gruels with flow velocities ranging from 100 to 160 mm/30 s. The action of germinated flour was influenced by blanching, which reduced its activity within the *Dosa* and *Pamela* varieties but increased in the case of *Cipira*. The use of optimised germinated maize flours during the preparation of the meals resulted in an increase of the energy density between 3.4 and 6.02. For all Irish potato varieties, blanching reduces the factors for multiplication of the energy density. The correlation matrix shows that the fluidizing, calorific and nutritive capacity of optimized germinated maize flour is influenced by the contents of carbohydrates, ash and fibers. In view of all the above, the appropriate combination of optimized germinated maize flour and Irish potato flours would be a solution in the fight against problem of protein and caloric malnutrition.

HIGHLIGHTS/NOVELTY OF THE WORK

- The optimal conditions for obtaining Energy density of the six flour samples have been demonstrated;
- The influence of the variety and blanching on Energy density as well as their concentration and mass of germinated corn flours were also observed;
- The combination of unblanching Irish potato flours and germinated corn flour has improved the energy density of the gruels.

ETHICAL APPROVAL

This article does not contain any studies with humans or animals participants performed by any of the authors.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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