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Efecto de las técnicas de extrusión y secado en rodillos sobre las propiedades reológicas de harinas compuestas de arroz, maíz, batata, fríjol, yuca y hoja de yuca

J. Aristizábal[1], A. Combariza[2], A. Fernández[3] and M. Sánchez[4]

ABSTRACT

Promoting food security in Latin-America and the Caribbean is directly related to agricultural products. The region faces a food crisis which has reduced large population groups' access to food. This work contributes to the study of obtaining precooked composite flour made from biofortified crops using protein, vitamin A and/or minerals. This study evaluated the effect of precooked flour's composition and precooking on its solubility in water, water absorption capacity, consistency and viscosity; such flour was obtained by extrusion and drying on rollers. The composite flours were obtained from cassava roots, sweet potato tubers, corn, rice and bean grains and cassava leaves. Four composite flours were formulated taking four- to six-year-old children's daily nutrient requirements (protein, iron, zinc and beta-carotenes) as a basis. The extruder was operated at 90°C, 300 rpm screw rotation speed, 17.64 g/min feed flow, with 30% moisture mixture. The dryer rollers were operated at 4 rpm roller rotation speed, 90°C surface temperature and 1 mm separation between rollers. It was determined that flour dried on rollers led to more complete cooking and modified starch granule structure than precooking by extrusion, thereby producing flour having greater solubility in water, less water absorption, higher consistency and smaller viscosity, comparable to that of pattern flour.

Keywords: Precooking, extrusion, drying on rollers, composite flour, nutrition, biofortified, rheological.

RESUMEN

La promoción de la seguridad alimentaria en América Latina y el Caribe está directamente relacionada con los productos agrícolas. La región enfrenta una crisis alimentaria que ha reducido el acceso a los alimentos a amplios grupos poblacionales. Este trabajo contribuyó al desarrollo de harinas compuestas precocidas utilizando seis cultivos biofortificados en proteína, vitamina A o minerales. Se evaluó el efecto de la composición de la harina y el proceso de precocción sobre la solubilidad en agua, capacidad de absorción de agua, consistencia y viscosidad de harinas precocidas obtenidas mediante los procesos de extrusión y secado en rodillos. Las harinas compuestas fueron obtenidas a partir de: raíces de yuca, tubérculos de batata, granos de maíz, arroz y fríjol, y lámina foliar de yuca. Fueron formuladas cuatro harinas compuestas con base en los requerimientos diarios de nutrientes (proteína, hierro, zinc y betacarotenos) para niños de 4 a 6 años. El extrusor fue operado a una temperatura de 90 °C, velocidad de giro del tornillo: 300 r. p. m., flujo de alimentación: 17,64 g/min y humedad de la mezcla: 30%. El secador de rodillos fue operado a una velocidad de giro de los rodillos de 4 r. p. m., temperatura de superficie 90 °C y separación entre rodillos 1 mm. Se determinó que las harinas secadas en rodillos producen mayor grado de cocción y modificación de la estructura de los gránulos de almidón que la precocción por extrusión, obteniéndose harinas de mayor solubilidad en agua, menor absorción de agua, mayor consistencia y menor viscosidad, las cuales fueron comparables con las harinas patrón.

Palabras clave: Precocción, extrusión, secado en rodillos, harina compuesta, nutrición, biofortificado, reología.

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Introduction

2006-2009 have provided the scenario for a global food crisis characterised by two stages: one caused by the sustained rise in international commodity prices (food and non-food) occurred from 2006/2008 and another spanning 2008/2009 caused by the ongoing financial and economic crisis. Both stages have affected households' real income, reducing access to food and other basic goods and, therefore, leading to an increase in poverty and hunger. The most affected countries import most food and energy. The incidence of hunger has grown more in urban areas than in rural areas in several Latin-American and Caribbean countries and has also increased the impact of adverse natural factors (climate change and natural disasters) which have increased low-income households' uncertainty and vulnerability. An issue of growing unease in the region concerns the coexistence of chronic malnutrition and obesity in the population, caused by inadequate nutrition during the prenatal period, infancy and early childhood, followed by high calorie and high fat intake, accompanied by poor micronutrient intake combined with a lack of physical activity (FAO, 2009).

A growing number of countries are beginning to implement strong hunger reduction programmes in an attempt to contribute towards fulfilling two World Food Summit resolutions (1996 and 2002) and the Millennium Declaration commitment to reduce world hunger by half by 2015. This has represented recognition by the major development and international cooperation institutions and the decisive role of small-scale farmers regarding agricultural production, food security, poverty reduction and sustainable use of natural resources. The ALCSH initiative was launched in 2005 to promote and implement public policy aimed at eradicating hunger in the region through a partnership between government, civil society and the private sector, supported by the United Nations' Food and Agriculture Organisation (FAO). This initiative proposes adopting a strategic framework for action; this would include increasing access to food, increasing family farms or small and medium rural areas' production and productivity and introducing policies for urban food security (Lahoz-Rallo and De Loma-Ossorio, 2007).

The present work formed part of a project entitled, "Combating hidden hunger in Latin-America: biofortified crops containing improved vitamin A, essential minerals and quality protein," led by a group of research centres in Latin-America and the Caribbean, including CLAYUCA, CIAT, CORPOICA Univalle, INTA, CIMMYT, CIP, EMBRAPA, CNPMF / CNPH sponsored by CIDA. The project was aimed at improving the nutritional status of some populations in Colombia, Brazil and Nicaragua and increasing their income by providing nutritious food products which have been processed using biofortified crops like rice, corn, beans, sweet potato and cassava, having high protein, iron, zinc and beta-carotene content. Such foodstuffs have been especially directed at school-children, the elderly and pregnant or nursing women. This study has contributed towards the scientific study of precooking using extrusion and drying rolling techniques for obtaining a product having rheological and physical properties comparable to those of commercial products.

Precooking refers to thermal treatment (in some cases thermo-mechanical) for obtaining gelatinised starch, inactivated enzymes and microbes and decreased cooking-time necessary for food preparation and storage. Precooked flour obtained from cereal and starch presents an interesting option as vehicles for fortifying it with protein and also having the advantage of facilitating the preparation of traditional food like puree. There are many technologies for pre-cooking flour but the best-known are extrusion and drying on rollers; such technology has been used for safety, convenience and conserving processed food's flavour (Sharma et al., 2003). These techniques allow foods' physical and functional properties (such as nutritional value) to become developed, as cooking the grains causes improved digestibility, taste, development of flavour and better texture. A farinaceous grain or hard product becomes restructured into a plastic or elastic material during cooking. The high temperature pasteurising the product increases its shelf life (stability) and inactivates anti-nutritional factors in some raw food and denatures enzymes (Singh et al., 2007).

The raw materials' components directly affect the precooking technique and the final product's properties. The relative amounts of amylose and amylopectin influence the direction of expansion, causing greater linear expansion of amylose, while amylopectin makes it expand radially. Heat increases intercellular space vibration thereby allowing greater water penetration and absorption, with consequent swelling and amylose and amylopectin molecule release from starch. When starch is precooked, it becomes gelatinised, thereby providing strong binding to other uniformly shaped constituents in the final product. Furthermore, gelatinised starches tend to be more digestible than raw starch. Water absorption capacity and solubility increase linearly with the extrusion conditions of increased temperature and decreased moisture content to a point where solubility continues increasing but absorption capacity begins to decrease (Guy, 2002). Proteins create elasticity, thus limiting expansion. Fat plays an important physical role in precooking because it acts as a lubricant, thereby reducing mechanical energy conversion and expansion, further weakening cell structure and causing fusion and porosity. Sugars usually liquefy and act as lubricants, reducing mechanical energy conversion and reduced expansion in combination with lower water activity. Fibre density seems to become increased during precooking probably due to the mechanical action of breaking and compression which makes fibres become curled (Pérez et al., 2008).

Ocoró (2005) studied the thermoplastic extrusion of cassava flour, evaluating the effects of cassava variety and presence or absence of shell in the flour on the extrusion technique and the extruded product's e characteristic. A single screw extruder was used in this study, having a 3:1 compression ratio; temperature at the end of the barrel (95°C -105°C), screw rotation speed (350 to 550 rpm) and flour moisture content were all varied (13% and 15%). The results indicated that variety and shell presence had no effect on extrusion. High screw speeds produced non-uniform extruded products, having broken grain. Temperatures below 90°C led to material being undercooked, having a moist and brittle appearance whilst temperatures above 100°C led to material clogging inside the barrel and the appearance of non-uniform product.

Acevedo (2005) evaluated the influence of precooked cassava chips' storage (-5°C to -20°C for 24 h) and roller rotation speed (1 and 3 rpm) on the characteristics of chips obtained using a dryer roller with two varieties of cassava. Roller speed significantly affected consistency, viscosity and water absorption (WAI) and water soluble indices (WSI). Material exposed to high cooking (1 rpm) had higher starch gelatinisation, increased ability to absorb water and higher viscosity and WAI and WSI values. Measuring the behaviour of flakes in obtaining puree-type masses led to determining that such flakes were too sticky and had low consistency (low fluidity).

Materials and Methods

The biofortified crops used were supplied by CIAT (rice and bean), CIMMYT (corn) and CLAYUCA (cassava, sweet potato and cassava leaves). The varieties used were CT-11275 rice, CORPOICA H122 corn, Tainung 66 sweet potato, Calima bean, CM 523-7 cassava and MCOL 1505 cassava leaves.

Clean rice, corn and bean grains were ground similarly and separately in a roller mill, except beans which were heated for 30 min at 60°C prior to milling for reducing grain moisture to prevent material going hard on the mill's rollers. The thick material obtained from the first milling was ground again to reduce its size.

Cassava roots and potato tubers were washed with pressurised water in a cylindrical washer and then immersed in a container containing a sodium hypochlorite solution at 20 ppm for 20 minutes to reduce the microbial load. They were then chopped in a vertical disc chipper. The pieces were placed on covered mesh and wooden frame trays to protect the material from contamination and then sun-dried until 13% moisture content was achieved. The size of the pieces of each material was reduced in a mill using a 3 mm mesh sieve and then a 177 µm mesh.

Cassava leaves were selected; their petioles were withdrawn, leaving only the leaf for use in the process. They were cleaned and immersed in a sodium hypochlorite solution at 20 ppm for 10 min. The material was then ground in a food processor (Essen) using a grating disc because this allows greater HCN release in the product (Giraldo, 2006). The material was dried in a hot air circulation tray dryer (Despath VF23) at 60°C with 2 cm bed thickness for 18-20 h. Milling was carried out in the mill-sieve used for obtaining cassava and sweet potato flour.

All the flours obtained had greater than 150 µm and less than 212 µm particle size. Ocoró (2005) observed that very fine particle size led to increased friction and therefore increased heating through the barrel, which may have contributed to equipment stability and operation problems; it was thus decided to work with a particle size less of than 212 µm. All flours were sieved to obtain material having 60%> 150 µm and <177 µm, 25%> 177 µm and <212 µm and the remaining <150 µm. Table 1 shows the physical-chemical analysis of the flours so obtained.

As references could not be found using extrusion or drying on rollers concerning mixtures of all the raw material used in this work, preliminary tests were conducted to observe equipment operability and define the appropriate operating conditions for the mixtures. Initial tests were based on studies by Ocoró (2005) and Acevedo (2005) who evaluated precooking cassava flour in extruder and dryer rollers, respectively, using the equipment used in this work. Different mixtures were prepared which included all the raw materials in the same proportion (19.5%) for the preliminary test, except for cassava leaf meal which was included in all assays at 2.5% bh because its high fibre content decreases protein digestibility (Giraldo, 2006). Other mixtures included each particular crop as the major component (39.5%) and mixtures of the other components in the same proportions (without including cassava leaf meal).

The extruder used involved a barrel consisting of a set of three areas (two having water circulating inside and an area adjacent to the feeding zone having an electric resistance), a single 39 cm length screw, 27 steps and 3:1 compression ratio. Three process variables were defined: screw speed (300 and 350 rpm), moisture mixture (25, 30, 35 and 40%) and temperature (90 and 100°C). Feed flow was 17.64 g / min.

A BUFLOVAK roller dryer (BLAW-KNOX co.) was used which consisted of two parallel 15 cm diameter rollers, 20 cm in length and having 960 cm2 surface area. Rotation speed was regulated by a REEVES gear-motor. The scraper blades were arranged across the width of each cylinder at 45° Inclination. According to Acevedo's study (2005), 90°C was defined as process temperature and 1mm separation between rollers was also taken. Two process variables were assessed: feed solution concentration (15-25%) and roller rotation speed (1-6 rpm).

Precooking operating conditions were defined based on preliminary tests and mixture composition was re-formulated according to the daily recommended intake (DRI) for 4-6 year-old children: protein (24 g), iron (10 mg), zinc (10 mg), vitamin A (beta-carotene) (500 mg) (Moreira et al., 2011) (Table 2).

Table 2. Mixtures formulated, based on daily recommended intake

Mixture	Composition (% bh)					
	Rice	Corn	Bean	Cassava	Sweet potato	Cassava leaf
M1	30	15	25	17.5	10	2.5
M2	15	30	25	17.5	10	2.5
M3	25	15	30	17.5	10	2.5
M4	30	15	25	20	10	0

A multilevel factorial design was used for precooking tests. The order of the tests was determined using STATGRAPHICS Plus 5.0 (licensed to the Universidad del Valle's School of Food Engineering), considering three replicates of each test. The results were subjected to variance analysis using a 95% confidence level.

The following response variables were defined for evaluating the precooked flour: water soluble index (WSI), water absorption index (WAI) and consistency and viscosity profile. The WSI and WAI determine the quality and degree of flour or starch gelatinisation (Aristizabal and Sanchez, 2007). Flour slurry consistency

Table 1. Physicochemical analysis of flour

Crop	Moisture (%)	Protein (g/kg)	Crude fibre (g/kg)	Ether extract (g/kg)	Ash (g/kg)	Iron (g/kg)	Zinc (g/kg)	Beta-carotene (µg/g)
Rice	10.81	56.77	21.80	6.60	5.60	0.36	0.02	-
Corn	11.31	73.58	60.20	54.60	15.80	0.41	0.02	-
Sweet potato	11.80	40.74	55.80	13.80	59.00	0.93	0.02	0.49
Bean	10.20	186.52	122.60	22.60	57.60	0.87	0.03	-
Cassava	5.20	31.57	34.20	8.00	33.20	0.47	0.01	0.13
Cassava leaf	7.60	255.02	346.40	84.80	75.80	0.40	0.04	180.68

determines flow characteristics and is a measure of water absorption capacity determining the degree of starch modification. This was measured using a Bostwick consistometer which reports the distance covered (in centimetres) for a determined volume of a suspension at room temperature, flowing under its own weight through a channel during a determined time (Acevedo, 2005). The viscosity profile was determined using a visco-amylograph (RVA Series No. 4) which measures a flour-water suspension's resistance to stirring during heating and cooling at constant shear rate.

The preliminary extrusion equipment tests led to determining that problems occurred at 350 rpm screw speed, as temperature increased and a non-uniform product appearance was obtained. Conversely, the same mixtures extruded at 300 rpm flowed continuously to produce an acceptable product. A sweet potato flour mixture having higher than 19.5% content resulted in material clogging in the barrel and the feeding hopper, thereby clogging the outflow and impeding continuous equipment operation. Including cassava leaves in the mixtures did not affect the equipment's performance but did affect product appearance, giving it a greenish colour. The mixture which had the best performance during the operation had 30% moisture content; higher moisture led to a product which was too wet and insufficiently precooked whilst lower moisture caused an accumulation of the mixture and clogging within the screw barrel.

Preliminary tests on the dryer rollers led to determining that concentrations lower than 20% (heated to boiling for 3 min) had too fluid consistency thereby hampering feeding to the dryer. Conversely, concentrations above 20% did not flow due to high viscosity. The material became burned when using a 1 rpm rotation speed (maximum residence time). The material did not hydrate enough with 6 rpm rotation speed due to reduced time in contact with the rollers' surface. Tests involving a 4 rpm speed led to obtaining dry flakes which were easily removed from the dryer drum.

Figures 1 and 2 show that mixtures extruded at 100°C had greater WSI and lower WAI than mixtures extruded at 90°C, indicating that a higher extrusion temperature and consequently higher degree of cooking meant that the starch increased its water absorption capacity followed by a decline in WAI as a consequence of the start of dextrinisation. Starch molecules thus began to break into small fragments, contributing to increased WSI. It was also observed in mixtures M1, M2 and M3 that incorporating cassava leaf flour increased precooked flour solubility. The temperature/composition interaction had a significant effect on WSI values, but was not significant regarding WAI values.

The intrinsic characteristics of each raw materials' starch granules makes their susceptibly to degradation during heat treatment different. Thus, rice flour which has very resistant granules and small particle size (1-3 µm) made mixtures M1 and M4 (higher rice content) have greater water absorption due to the higher resistance of their dextrinisation granules.

Figure 3 shows that extruded mixture temperature and composition had no significant effect on consistency. Figure 4 shows that extruded mixtures' M1 and M4 viscosity profiles had higher viscosity as a result of their higher rice content. It was observed that including cassava leaf flour decreased the mixtures' viscosity. It was noted that composition significantly affected viscosity whereas temperature had no effect on it.

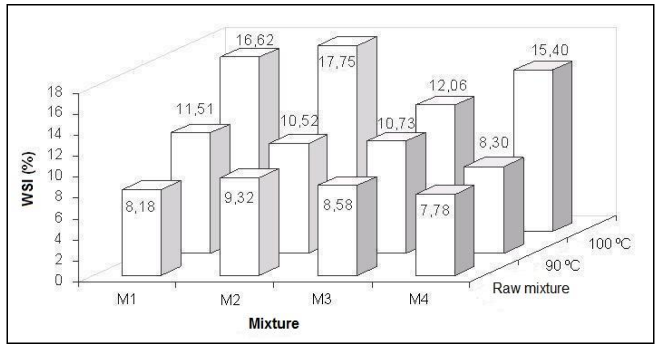

Figure 1. The effect of temperature and composition on WSI during extrusion

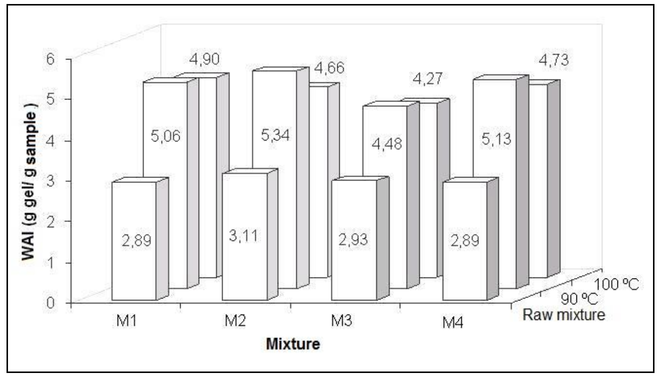

Figure 2. The effect of temperature and composition on WAI during extrusion

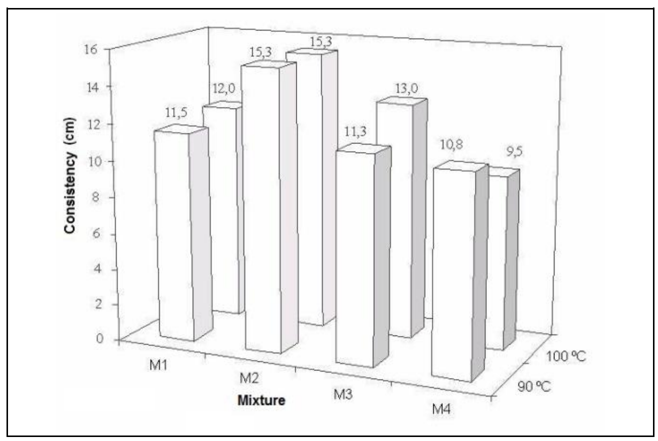

Figure 3. The effect of temperature and composition consistency during extrusion

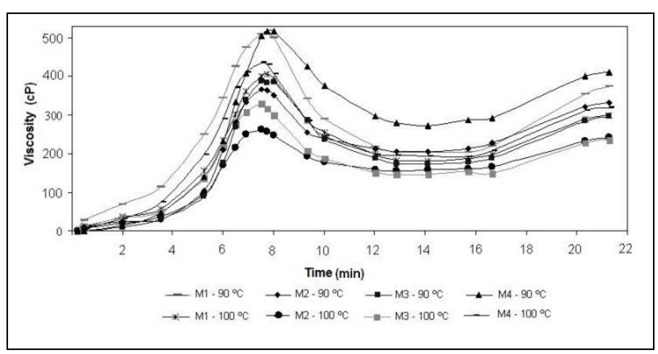

Figure 4. The effect of temperature and composition on viscosity during extrusion

The technique was observed to influence the rheological properties of the flours so obtained when comparing extrusion and drying on rollers at 90°C. In this regard, the precooking technique had a significant effect on the composite flours' WSI, WAI, consistency and viscosity.

Figures 5 and 6 show that the products obtained using the roller dryer had higher ISA and lower IAA, compared to the extruded products. This was because the material fed to the rollers had had prior precooking treatment, resulting in a greater starch granule modification. Increased cooking time probably increased the degree of swelling of and damage to starch granule structure, resulting in increased solubility. Regarding composition, it appears that WSI had a significant effect when precooking was carried out on the dryer rollers.

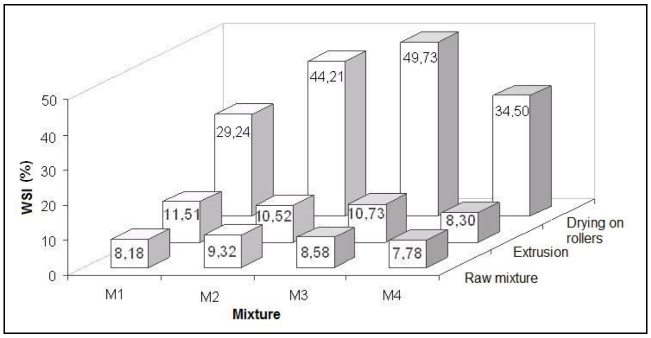

Figure 5. The effect of precooking on composite flour WSI

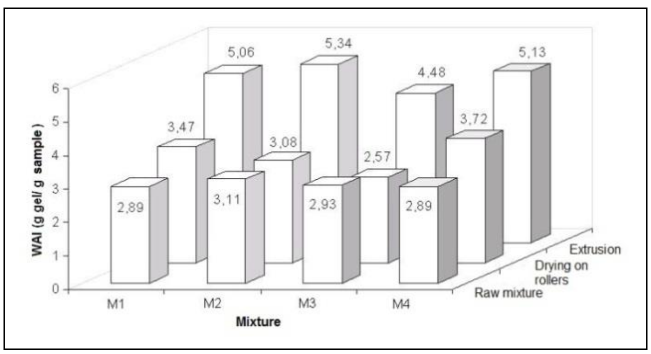

Figure 6. The effect of precooking on composite flour WAI

Extruded product consistency was lower than that of products obtained on the dryer rollers (as shown in Figure 7) and extruded product viscosity was consequently higher (as observed in Figure 8 viscosity profile). Heat treatment and higher cooking on the dryer rollers decreased the mixtures' viscosity. It was noted that mixtures M2 and M3 obtained using drying on rollers (whose major component was corn and beans, respectively) had high fluidity which was reflected in an inability to measure suitable consistency with the consistometer. The WAI was directly related to the development of consistency; thus mixtures having higher WAI were those which could develop high viscosity. Extruded mixtures M1 and M4 had the highest peak viscosity, given the higher percentage of rice in their mixtures. Similarly, composition had a significant effect on the consistency of the products obtained in the dryer rollers and on extruded product viscosity.

The precooked composite flours were compared to precooked flour available on the market known as Siete Granos (a mixture of flour from plantain, rice, beans, lentils, corn, soybeans and oats), Soya-Platano (a mixture of flour from soybeans and plantain) and non-commercial flour Bienestarina (a mixture of flour from wheat, corn. soybeans and milk powder). Table 3 shows the functional properties evaluated here. It was noted that WSI,

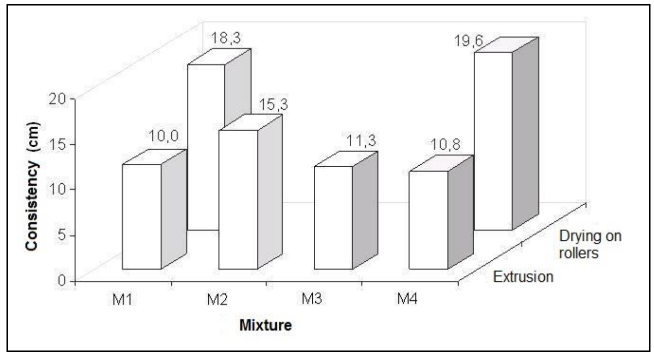

Figure 7. The effect of precooking on composite flour consistency

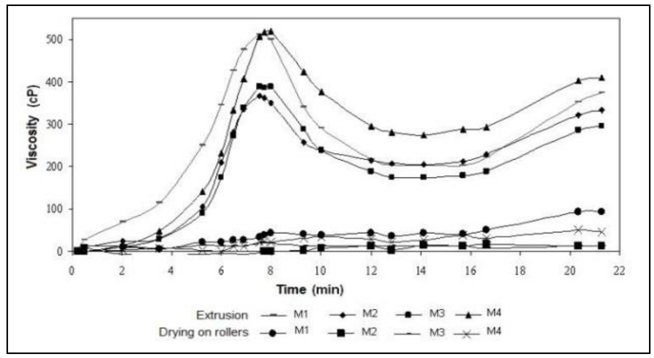

Figure 8. The effect of precooking on composite flour viscosity

WAI, maximum viscosity and the consistency of the flour obtained on dryer rollers were comparable to the values for the aforementioned comparison flours.

Table 3. Comparing flour obtained by extrusion and drying on rollers and flours available on the market

Flour		Property			
		WSI (%)	WAI (g gel/g sample)	Consistency (cm)	Maximum viscosity (cP)
Siete Granos		**14.57**	**2.79**	*	**67**
Soya-Plátano		**16.23**	**2.69**	**9.0**	**25**
Bienestarina		**31.77**	**3.33**	**6.8**	**40**
Extrusion	M1	**11.51**	**5.06**	**10.0**	**446**
	M2	**10.52**	**5.34**	**15.3**	**358**
	M3	**10.73**	**4.48**	**11.3**	**336**
	M4	**8.3**	**5.13**	**10.8**	**497**
Drying on rollers	M1	**29.24**	**3.47**	**18.3**	**48**
	M2	**44.21**	**3.08**	*	**32**
	M3	**49.73**	**2.57**	*	**28**
	M4	**34.50**	**3.72**	**19.6**	**30**

Conclusions

Based on the tests carried out, the most suitable operating conditions were established for extrusion and drying on rollers regarding composite flour from rice, corn, sweet potato, bean, cassava and cassava leaf which led to obtaining precooked flour having similar water absorption index and consistency to that of commercially available (comparison) flour;

A marked influence was found on precooked flours' rheological properties regarding flour composition and precooking;

Composite flour extrusion temperature and composition had a significant effect on precooked products' water soluble index;

Regarding precooking techniques, it was found that drying on rollers produced a greater degree of cooking and starch granule structure modification compared to extrusion, thereby producing flour having a higher water soluble index, lower water absorption index, greater consistency and lower viscosity;

Precooked composite flours containing a greater proportion of rice had higher viscosity than those having low rice content; and

Using cassava leaf flour in composite flour decreased precooked product viscosity.

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Acronyms

ALCSH	América Latina y el Caribe sin Hambre
CIAT	Centro Internacional de Agricultura Tropical
CIDA	Canadian International Development Agency
CIMMYT	Centro Internacional de Mejoramiento de Maíz y Trigo
CIP	Centro Internacional de la Papa
CLAYUCA	Consorcio Latinoamericano y del Caribe de Apoyo a la Investigación y al Desarrollo de la Yuca
CNPMF /CNPH	Centro Nacional de Pesquisa de Frutas / Hortaliças
CORPOICA	Corporación Colombiana de Investigación Agropecuaria
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuária
INTA	Instituto Nicaragüense de Tecnología Agropecuaria
UNIVALLE	Universidad del Valle

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