Status of Research of Sorghum Utilization for Human Food

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*Resumen: Esfuerzos colaborativos de investigación entre el Departamento de Alimentos de la Universidad de Sonora, México y el Laboratorio de Calidad de Cereales de la Universidad de Texas A&M llevaron al desarrollo de procedimientos e investigación sobre el cocimiento tradicional de sorgo, diseño y operación de molinos decorticadores y la búsqueda de tecnología alternativas al cocimiento tradicional como lo es el cocimiento por extrusión. Estos procedimientos podrán ser empleados en los llamados países en vías de desarrollo para promover y mejorar la utilización de sorgo en alimentos humanos. Sorgo rojo y blanco comercial fue procesado en una planta piloto de la Universidad de Sonora. El cocimiento de sorgo con una concentración de 2.2% de cal y un tiempo de reposo de 16 h produjo masa pegajosas y con problemas de moldeo. La masa pegajosa produjo tortillas que se endurecieron rápidamente y por lo tanto tuvieron menor vida de almacén. Además, tortillas tuvieron colores obscuros indeseables. Los parámetros de cocimiento, por lo tanto, tuvieron que ser ajustados y optimizados hasta que se obtuvieron tortillas aceptables. Sorgo blanco (CX8145-NK) proveniente de plantas con glumas pigmentadas produjeron tortillas de menor calidad que sorgo proveniente de plantas con color de glumas claro. Esto demuestra que el sorgo blanco provenientes de plantas de color claro (pp 99)puede remplazar 50 y 75% del maíz (blanco o amarillo) para producción de tortillas, siempre y cuando el grano sea decorticado 10 y 18%, respectivamente. Por otra parte, sorgos blancos provenientes de plantas pigmentadas (P__ Q__) solamente pueden remplazar 30 y 50% del maíz (blanco o amarillo) cuando el grano es decorticado al 10 y 18%, respectivamente. Sorgos blancos de plantas de color claro (pp qq)) decorticados al 10-12% produjeron tortillas aceptables (blancas, no enrollables y con buen sabor) cuando se cocinaron con 0.8% de cal por 8 min a 84°C y el nixtamal se reposó por 15 min. Sorgo rojo comercial (ATx378*Tx430) decorticado al 18% puede remplazar 40% del maíz amarillo. Tortillas tuvieron una calidad aceptable y por lo tanto pueden ser consumidas en el sur de México donde aproximadamente el 70% de la población está localizada. Este estudio demostró que el sorgo puede ser procesado en establecimientos comerciales o tortillerías sujeto a pequeños cambios en el procedimiento de cocimiento. El tiempo de cocimiento y reposo del sorgo entero fue 57% y 50% del requerido para el maíz, respectivamente, mientras que para el sorgo decorticado dichos tiempos*

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fueron únicamente 23 y 1.2%, respectivamente. El sorgo puede ser procesado a tortillas usando la maquinaria y equipo existente en México. Los beneficios de este estudio pueden ser extendidos a otros países.

ABSTRACT

Colaborative research efforts between the Cereal Quality Lab at Texas A&M University and the Food Science Department of the University of Sonora comprised the development of traditional cooking procedures, design and operation of dry milling equipment, and the search for an alternate cooking technology such as extrusion cooking that would be used in the so-called, less-developed countries to improve the utilization of sorghum for human foods. Commercial white and red sorghums were processed in a pilot plant at the University of Sonora, Mexico. A CaO concentration of 2.2% and steeping time of 16 h resulted in sticky, nonrollable masa and off-color tortillas. A sticky masa producer a faster staling rate for tortillas, thus decreasing shelf life. These parameters were optimized until acceptable sorghum tortillas were obtained. White sorghum (CX8145-NK) from a non-tan plant color (NTPC) cultivar underwent drastic off-color changes as compared to a white sorghum with tan plant color (TPC), thus demonstrating that TPC sorghum such as those developed by the Texas Sorghum Improvement Program could replace 50% and 75% maize (white or yellow) when the grain was pearled at 10% and 18%, respectively. In contrast, NTPC sorghum could only replace 30% and 50% maize (white or yellow) when pearled at 10% and 18%, respectively. White sorghum tortillas from NTPC produce white, rollable and flavorful tortillas when processing conditions were 0.8% CaO, 8 min cooking at 84°C, 15 min steeping, and 10-12% pearling.

Commercial red sorghum (ATx378*Tx430), pearled at 18%, could replace 40% yellow maize, and thus produce a quality of tortilla acceptable to consumers in southern Mexico where approximately 70% of the population is located. Sorghum could be processed in a commercial tortilla plant with minor changes only in the cooking procedures used for maize. Whole sorghum cooking and steeping times were 57% and 50% of those of maize, respectively, whereas, for pearled sorghum, the cooking and steep times were 23% and 1.3% of those of maize. Sorghum could be processed with commercial tortilla equipment

used in Mexico, thus indicating that benefits from this study could be extended to other countries.

INTRODUCTION

Maize, in the form of tortillas, provides most of the calories, proteins and calcium in Mexico, Guatemala and Honduras (Trejo-Gonzalez, et al., 1982). It has been estimated that the per capita consumption of maize in Mexico is approximately 130 kg/yr. For various reasons, maize hybrids and varieties in Mexico have been gradually losing their agroeconomic potential. New, maize hybrids have not developed at the same rate as sorghum hybrids wich have outstanding yield and agronomic properties. Sorghum is now the second largest crop after maize.

Average sorghum yields in Mexico are significantly greater than those of maize, sorghum is also more drought tolerant. It has been established (Rooney et al., 1980; Bedolla and Rooney, 1982; Bedolla et al., 1983; Serna et al., 1984) that sorghum and maize have similar chemical composition and nutritional values although sorghum contains phenolic compounds that are undesirable from a processing point of view. Research conducted in recent years (Khan and Rooney, 1980; Bedolla et al., 1983; Bringas and Rozaud, 1985; Choto et al., 1985; Bedolla, 1983) indicates that sorghum tortillas of acceptable quality (color, texture, flavor) can be readily produced when sorghum grain is optimally processed. Most of this data, however, has been generated on a laboratory scale and data on a commercial basis is needed to accurately assess the use of sorghum for tortillas. This report focuses on the utilization of sorghum in a pilot tortilla plant very similar to commercial tortilla plants located in Hermosillo City, Sonora, Mexico. It summarizes experiments on the processing of sorghum without significantly changing the cooking, forming, and baking procedures used for maize tortillas.

MATERIALS AND METHODS

Two white sorghum lines (ATx623*CS3541, and Northrup King CX8145) and two red hybrids (ATx378*Tx430, and Northrup King 2775PN) were processed to find the optimun cooking and milling conditions. Three levels of decortication for white sorghum (6%, 10%, 18%) and one level (18%) for red sorghum were tested. The controls were maize tortillas produced from white maize (T250-F Northrup King) and yellow maize (T66 Northrup-King).

Cooking Procedures at University of Sonora Pilot Plant

Method 1 - Whole Sorghum and Maize: Water and calcium oxide (maize = 1.5%, sorghum = 0.8%, - based on grain "as is" basis) were brought to 93°C in a 50 kg capacity gas-fired cooker. The grain to water ratio was 1:3. Grain lots of 35 kg were processed. Upon addition of the grain to the cooker, the temperature dropped from 93°C to 83°C in approximately 5 min. Therefore, the cooking range was 83-89°C. After 20 min optimun cooking for sorghum, the heat was turned off and sorghum was steeped for 10 h. Maize was cooked for 35 min using the same procedure, but steeping time was 16 h. After steeping, the nixtamal (cooked grain) was transferred to a 50 kg capacity steep tank and washed with 40 L of water using a water hose. Then, the washed grain was stone milled (12" volcanic stones) and masa was formed into tortillas in a Celorio tortilla machine). This equipment mixes, molds, flattens, and bakes the masa.

Method 2 - Pearled Sorghum: For pearled sorghum (6%, 10%, and 18% weight removed), either white or red, the cooking procedure was that outlined for whole sorghum and maize, but the optimum cooking times were 12, 8, and 5 min for the 6%, 10% and 18% pearling levels, respectively. The cooking temperature ranged from 82-86°C and the concentration of CaO used was 0.8% for any pearling level. After attaining the optimum cooking time for each case, the heat was turned off and the grain was steeped for 15-20 min. Then, the grain was washed, stone-milled, and formed into tortillas as described for whole sorghum and maize.

Method 3 - Sorghum/Maize Mixtures: Sorghum (either whole or pearled) and maize were cooked separately using the cooking procedures described previously. Then, the following mixtures were formulated: for whole white sorghum and white or yellow maize (25/75, 50/50, and 75/25); for pearled white sorghum and white or yellow maize (50/50 and 75/25); and, for pearled red sorghum and white or yellow maize (50/50). The mixtures were blended in a horizontal mixer for 5 min and stoneground to masa. Forming and baking were as described previously.

Equipment

The procurement, installation, operation, and training activities for the pilot plant equipment were accomplished in about six month. One 50 kg gasfired cooker, one steep tank, one horizontal mixer and one abrasive disc mill were designed and built at the University of Sonora. The stone mill and the Celorio were purchased well-known brands.

Method 4 - Commercial Cooking Procedures Used in Sonora, Mexico: An exhaustive review of the maize tortilla processing steps was made in two tortilla plants at Hermosillo before the INTSORMIL project was started. In one factory, considered one of the most popular and important in Sonora, the maize contained both white and yellow kernels (30/70). Maize was often accompanied by sticks, soil, stems, rocks and other impurities, thus requiring scalping and sieving operations. Scalped maize was placed in a 600 kg capacity cooker containing 2000 L hot water (93°C and 9 kg calcium oxide. A wooden paddle was used to turn the mass of grain and a wire screen was used to remove floating impurities. Upon addition of the grain to the cooker, the temperature dropped to 81°C where it remained for almost 40 min; then, it started to decrease (pattern not measured beyond this point). The grain was steeped for approximatley 18 h at pH 12. Cooking and steeping waters were dacanted, grain was washed with water (volume 1x5 approximately), and lime-cooked grain was stone-milled to masa. Approximately 60 ml water per one kilogram of nixtamal were added while stone milling. Lots of 25 kilos of nixtamal were stone-milled and masa obtained was kneaded for 3 min in a horizontal mixer. Masa was formed and baked into tortillas with a tortilla machine having a set of two non-corrugated rollers. The baking temperature and time were 250°C and 1.0 min, respectively.

RESULTS AND DISCUSSION

Preliminary Cooking Trials

Based on the commercial cooking procedure outlined for maize (Method 4), one experiment was planned for white sorghum (Table 1) where steep time, CaO concentration, and sample size were independent variables. The results discussed here are for each block only. Increasing the steep time from 10-16 h (Treatment I and II) resulted in sorghum nixtamal and tortillas with flavor similar to traditional maize products. However, the color of sorghum tortillas was not acceptable, thus indicating that the level of CaO should be reduced. More data is needed in the area of flavor development, particularly on the effects of CaO concentration and steep time on flavor development for different white and yellow sorghum. Masa was sticky and could hardly be mechanically handled .

A decrease in the CaO concentration (treatments III vs IV) produced a nonsticky masa (particularly at 0.8% CaO), improved the color of tortillas, but the flavor of sorghum tortillas was not as strong as it was for maize. Sample size (treatments V vs VI) did not affect color, stickiness, or flavor at the levels tested.

Up to this point color of tortillas and masa stickiness were controlled, but none of the treatments produced acceptable rollable tortillas, thus indicating that more heat was required.

Table 1. Treatment combinations used during the alkali-cooking of white sorghum (X8145) in a commercial tortilla plant following cooking procedures used for maize.

	Block 1		Block 2		Block 3	
Variable/Treatment	I	II	III	IV	V	VI
Sample size (kg)	20	20	20	20	20	30
Concentration of CaO (%)	2.2	2.2	2.2	1.5	0.8	0.8
Steep Time (min)	10	16	16	16	16	16

Note: The pH of cooking and steeping waters was 12.0-12.6, the starting water temperature was 93°C, and the grain to water ratio was 1:2.

The question then was why was maize cooked adequately in the commercial plant without further heating? Hypothetically, the absortion of heat in a large mass of grain (600 kg) is slower from the exterior to the center compared to lots of 20 kg (our experiments), thus cooking the grain at a higher temperature. This hypothesis was partially proven when temperature measurements were made in the 20 kg lots being cooked in the 600 kg capacity cooker. The temperature dropped from 93 to 71°C upon addition of 20 kg sorghum grain to the boiling CaO-water mixture. In contrast it dropped from 93°C to 81°C for a 600 kg maize batch. These results led us to construct a 50 kg capacity cooker and steep tank to simulate more closely the cooking conditions of a 600 kg batch. However, results indicated that a minimun holding time at a certain temperature is required for both maize and sorghum (Table 2) when cooking less than 600 kg batches. After this modification, sorghum required only 57% of the cooking time of maize and 50% of the steep time. On the other hand, pearled sorghum (10%) required only 23% the cooking time of maize and 1.2% the steep time, thus saving significant energy and time.

Table 2. Optimun cooking times determined experimentally for white sorghum (NK CX8145) and white maize (T250-F) using 20 kg lots in a 600 kg capacity cooker.

Treatment	Cooking/Holding Time (min)	Steep Time (min)	CaO (%)	Cooking Temperature Range (°C)
Sorghum	20	600	0.8	82-84
Maize	35	1200	1.5	82-84
Pearled Sorghum				
6%	12	15	0.8	82-84
10%	8	15	0.8	82-84
18%	5	15	0.8	82-84
Comercial Maize†				
	0	960	1.5	81-93

†Cooking procedure used in tortilla plants at Sonora, Mexico (see Materials & Methods, Method 4).

Table 3 shows another set of cooking experiments that were made in the pilot plant a University of Sonora. The optimum cooking times determined in the commercial tortilla plant (Table 2) were used to process sorghum, maize, and two sorghum-maize mixtures. Table 4 displays the yields of nixtamal, masa and tortillas, water added during stone milling, and milling time. Sorghum nixtamal yields at 20 or 30 min cooking time were higher than that of maize. However, tortilla yields for the 20 min cooked sorghum were similar to that of maize. This was because maize nixtamal required more water at the milling stage. The 30 min cooked sorghum showed higher tortilla yields but stickiness was apparent and milling was very difficult. Tortillas from sticky masa showed numerous cracks and were not rollable. The 50/50 and 75/25 sorghum-maize mixtures gave excellent masa and rollable tortillas after 48 h, thus indicating that 20 min was the optimal cooking time for sorghum. Tortillas from the 50/50 mixture had acceptable color whereas those from the 75/25 mixture did not. In addition, results suggested that mixing optimally cooked sorghum and maize nixtamal was the best way to use sorghum in tortillas.

Table 3. Parameters used in pilot plant cooking trials of white maize, white sorghumand maize-sorghum tortillas.

Treatment	Cooking/Holding Time (min)	Steep Time (min)	CaO (%)	Cooking Temperature (°C)
I White Sorghum (CX8145)	20	10	0.8	75-88
II White Sorghum (CX8145)	30	10	0.8	75-88
III White Maize (Method 4)	35	16	1.5	81-93
IV† 50WS / 50WM†	Sorghum & maize were cooked separately before making these mixtures.			
V† 75WS / 25WM				

†WS = white sorghum from 20 min cooking treatment, WM = white maize from maize treatment.

Table 4. Properties Measured During the Alkaline Processing of Sorghum, Maize, and Sorghum-Maize Mixtures in a Pilot Plant

Treatment		Cooking Time (min)	Nixtamal Yield (kg/kg grain)	Masa Yield (kg/kg grain)	Tortilla Yield (kg/kg grain)	Milling Rate (kg/min)	Water Added to Nixtamal at Mill (ml/kg)
I	White sorghum x8145 20 min cooking	20	1.82	1.83	1.40	3.6	127
II	White sorghum x8145 30 min cooking	30	1.94	2.07	1.75	1.4	241
III	White maize	35	1.46	2.61	1.33	1.8	260
IV†	50 WS/50 WM	Mixture	-.-	-.-	1.24	3.9	206
V†	75 WS/25 WM	Mixture	-.-	-.-	1.31	4.2	133

†WS= white sorghum x8145 from Treatment I.
Note: The size of the starting sample was 20 kg of grain.

The moisture content of nixtamal, masa and tortillas for sorghum, maiz and their two mixtures are presented in Table 5. Moisture content of sorghum nixtamal was significantly higher than that for maize or any sorghum-maiz mixture. Moisture content of masa for each of the treatments shown was an indication of the water requirements during stone milling. Maize tortillas had less moisture than tortillas from sorghum or from the best, cooked sorghum-maize mixtures (Treatments I, IV and V).

Table 5 Properties measured during Alkaline Processing of Sorghum, Maize and Sorghum-Maize Mixtures in a Pilot Plant.

		Moisture Content		
Treatment		Nixtamal	Masa	Tortilla
I	White sorghum CX8145 20 min cooking	49.2	56.2	45
II	White sorghum CX8145 30 min cooking	54.3	59.8	46.4
III	White maize T25F	42.3	56.2	38.5
IV†	50 WS/50 WM	46.7	55.0	41.3
V†	75 WS/25 WM	47.5	54.6	40.8

†WS=white sorghum CX8145 from Treatment I.
Note: The size of the starting sample was 20 kg of grain

Tortilla color was darker than masa color, thus indicating further reaction between phenols and CaO during the baking process. The darkest tortillas were from either sorghum or any sorghum-maize mixture. Maize produced the lightest colored tortilla; i.e., higher color value (Table 6). Mixing sorghum with maize improved the color of tortillas considerably, but not to a level of acceptability. Any tortilla that contained sorghum had undergone a color change 24 h after baking whereas no change in maize existed. This confirms that white sorghum grain from non-tan colored plants are not the best grain source for manufacturing tortillas. Sorghum cultivars being developed in the Texas Improvement Program have tan plant color, tan glumes, thin pericarp, normal endosperm, and are better suited for making white colored tortillas (Miller, 1984) . Technological solutions to solving the off-colored sorghum tortilla problem are white grained sorghum with tan glumes and tan plant color, use sorghum-maize mixtures, and use abrasive dry milling to partially remove the pericarp where some phenols are located.

The water absorption index (Table 6) of dry masa did not correlate with the moisture content of nixtamal for the treatments shown. Perhaps, drying the masa caused some unknown changes in major chemical components. It was obvious that sticky masa of sorghum cooked for 30 min could not be handled by the tortilla machine and storage for 24 h was not feasible based on color and rollability parameters. The other sorghum

Table 6 Color, water absorption Index, Stickness and Rollability Masa and Tortilla produced from white sorghum X8145, White Maize (T250F) and their mixtures in a 20 kg batch Pilot Plant.

Treatment	Degree of Masa Stickiness (Subjective)	Tortilla Color† Masa 0 h	Tortilla Color† Tortilla 24 h	Tortilla Rollability‡ Masa 0 h	Tortilla Rollability‡ Tortilla 24 h
I White sorghum CX8145 20 min cooking					
	Low	30.5	29.0	1	2
II White sorghum CX8145 30 min cooking					
	High	27.6	26.6	4	5
III White maize T25F					
	Low	47.4	47.0	2	3
IV∞ 50 WS/50 WM					
	Very Low	39.0	38.2	1	2
V∞ 75 WS/25 WM					
	Very Low	35.0	34.1	1	2

†Measured with the green mode, which gave the widest difference among treatment, on a Agtron Color Meter. High values indicate lighter colored tortillas.

‡Subjectives rollability where, 1 = highly rollable with no cracks, and 5 = nonrollable, breakable, notacceptable.

∞WS= white sorghum from Treatment I; WM = white maize of Treatment III.

treatments produced better rollable tortillas than the maize control, which probably is due to their higher moisture content.

Chemical Composition

The protein content of pure sorghum tortillas was 2% higher than that of maize tortillas and but it was similar to tortillas of either mixture (Table 7). This was because more maize protein was lost during cooking and soaking (see numbers in parenthesis). However, lipid content of maize tortillas was higher than that for sorghum or any mixture.

Tortillas from Pearled Sorghum (PS) and PS-Maize Mixtures

Pearled (10% weight removed) white sorghum ATx623*CS3541, from Texas A&M University produced whiter, more rollable and flavorful tortillas of all white sorghums used. Cooking conditions were as follows: CaO = 0.8%; water to grain ratio = 2.5:1.0; cooking time = 8-10 min at 84°C; and, steep time = 15 min. The only problem encountered was the rapid staling rate (hard texture formation) exhibited after baking the tortillas. This may have been associated with the amount of pericarp present and masa particle size.

Table 7. Chemical composition of tortillas from sorghum, maize, and their mixtures processed in a pilot plant.

Treatment	Protein % (Nx6.25)	Lipids (%)	Ash (%)	Moisture Content (%)
I White sorghum X8145 20 min cooking				
	11.1 (11.4)‡	3.5 (4.1)	1.9 (1.6)	46.0
II White maize T250F				
	9.4 (11.9)	4.8 (5.2)	1.6 (1.3)	39.0
III† 50 WS/50 WM				
	10.1	4.0	1.7	42.0
IV† 75 WS/25 WM				
	10.6	3.9	34.12	40.8

†WS= white sorghum X8145 from Treatment I; WM = white maize from Treatment II.

‡: Numbers in parenthesis are values for the grain before processing into tortillas.

Pearled sorghum could replace approximately 50% maize (white or yellow) without any textural problem. At 18% pearling, this sorghum could replace about 75% of either maize.

Pearled white sorghum X8145, when abrasively-milled to remove 610, and 18% of the original weight could replace 20, 30, and 50% of ATx378*Tx430 white or yellow maize, respectively. Pearled red sorghum (18% weight removed, could replace a maximum of 40% white or yellow maize. Tortillas from the pearled red sorghum (18%), in combination with any type of maize, would be very acceptable in southern Mexico where colored tortillas are prefered. Northern consumers prefer white or slightly cream-colored tortillas such as those from the white sorghum ATx623*CS3541.

FINDINGS AND PROBLEMS

Sorghum tortillas were produced in a 20 kg batch pilot plant from whole grain sorghum (white or red), pearled sorghum, and from sorghum-maize mixtures. In these experiments, sorghum masa was formed into tortillas in machines that had one set of rollers and in those having an extrusion mechanism (Celorio brand). These are the two types of machines used in Mexican tortilla factories, thus the potential for using sorghum in tortillas with commercial equipment was demonstrated.

Although processing equipment is the same for sorghum or maize, minor changes should be made in the maize cooking procedure used for maize if sorghum is to be used in tortillas. These modifications would be advantageus to operators because they reduce energy consumation and increase productivity; i.e., less cooking and steeping time.

Quality of sorghum tortillas could be enhanced in three ways. First, sorghum could be cooked in the cook and steep waters used for maize. This would add a maize flavor to sorghum tortillas. It would also concentrate the resulting liquors and make solids more easily recovered thus avoiding pollution. Second, sorghum could be added to the maize batch at the end of its cooking period when the temperature is about 84°C. This would produce partially cooked sorghum and avoid drastic off-color reactions and improve tortilla flavor. Third, pearled red sorghum could be extended with pearled white sorghum and cooked as previously described to produce acceptable tortillas from only sorghum grain.

The most significant problem that may be encountered is the stickiness that occurs when sorghum is overcooked; this may happen in a period of 2-4 min. Overcooking and/or inappropriate stone-milling could lead to loss in tortilla texture and a rapid rate of staling. These problems are related to masa particle size and to the degree of starch gelatinization which needs more study. However, stickiness could be overcome by mixing a sticky masa with an optimally cooked maize masa and letting it rest for 25 min.

The Celorio tortilla-forming machine is widely used in Mexico. It requires masa with a very small particle size (i.e., only a few coarse particles) and a precise moisture content. Otherwise, the machine will clog and not form tortillas. If this happens, the hopper holding the masa has to be disassembled to remove the large particles of masa. This prodcedure calls for a skilled operator which are customary in Mexican tortilla plants.

The roller-forming machine is easier to work with since only two rollers have to be cleaned if clogging occurs. This type of machine requires a coarser particle size than the Celorio equipment. However, some customers claim that tortillas from this machine do not puff as well as those made in the Celorio. Puffing is a quality parameter for some customers.

These studies indicated that sorghum can be used solely or in mixtures with maize for tortilla production. Sorghum requires less cooking and steeping time and lower levels of alkali. Sorghum by itself has a bland flavor. A white sorghum with purple plant color produced significantly off-colored tortillas. Pearling the sorghum to remove the pericarp reduced soaking time and improved the color of the tortillas significantly. Modifications in the standard cooking procedure are needed to ulilize sorghum for tortillas but they can be accomplished with minimal effort under commercial conditions.

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