Physicochemical Properties and Molecular Structures of Starches from Millet (*Pennisetum typhoides*) and Sorghum (*Sorghum bicolor* L. Moench) Cultivars in Nigeria

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ABSTRACT

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Some physicochemical properties and molecular structures of starches from millet (*Pennisetum typhoides*, Doro and Gero) and sorghum (*Sorghum bicolor*, red and white) in Nigeria were examined. Starch granules of millet and sorghum were 3–14 μm and 4–26 μm in diameter, respectively. Millet cultivars had similar peak viscosities (204–205 RVU) on pasting, while sorghum showed similar minimum viscosities (155–156 RVU). The actual amylose content (%) calculated from iodine affinity (IA, g/100 g) was 20.1 and 21.4 for sorghum and 21.3 for millet. The IA of amylopectin was high (1.27–1.42) and its average chain lengths were 20–21 with β-amylolysis limit of 56%. Amylopectins showed a polymodal molecular weight distribution on a molar basis. The distributions differed among the samples with a higher amount of larger molecules in Doro and red sorghum. Weight- and molar-based distributions of debranched amylopectins on HPSEC were polymodal with weight-based distribution showing presence of long chains. Peak DP values for A+B$_1$ and B$_2$+B$_3$ chain fractions were 13–16 and 42–43, respectively. The (A+B$_1$)/(B$_2$+B$_3$) ratio on molar basis (9.0–11.5) was similar to maize and rice amylopectins. Peak DP on molar-based distribution for white sorghum and millet amyloses were similar (490–540) and the DP$_n$ range was narrow (1,060–1,300), but weight-based distribution profiles differed. The average chain lengths were 260–270 with 3.9–4.8 chains per molecule.

Cereals are important in many parts of the world as food sources, and starches from them differ in physicochemical properties and molecular structures (Takeda 1993; Hizukuri 1996; Jideani et al 1996). Among the cereal starches, much research attention has been given to rice (Hizukuri et al 1989; Takeda et al 1986, 1987), wheat (Takeda et al 1984; Shibanuma et al 1996), barley (Takeda et al 1999; Song and Jane 2000; Yoshimoto et al 2000), and maize (Takeda and Preiss 1993). It has been reported (Fujita et al 1996) that among the starches from even the same plant cultivars and species variants exhibit differences in their properties.

Millet and sorghum are important cereal crops grown in Nigeria. They are the dominant cereals after maize and are utilized in the preparation of many traditional foods in the home (Oke 1980). Some examples of such foods include *tuwo* (a thick porridge eaten almost daily with vegetable soup and meat) (Akingbala and Rooney 1990), fermented alcoholic beverages like *burukutu* and *pito* (Okafor 1983), and nonalcoholic beverages such as *kunun zaki* (Gaffa et al 2002). Recently, interests in these cereals were renewed as valuable raw materials in the brewing and baking industries. The main chemical component of millet and sorghum grains is starch (Malleshi et al 1986; Beta et al 2000). Although these cereals are extensively utilized in Nigeria, there is a lack of information on the properties of their starches. There are, however, some reports on physicochemical properties of starches from sorghum (Lee et al 2002) and millet (Beleia et al 1980; Nandini and Salimath 2001). With the renewed interest in diverse usage of these cereals, an understanding of the properties of their starches is necessary. This will give useful information on their suitability whether in food or nonfood systems for effective application. In this study, we investigated some physicochemical properties and molecular structures of starches from millet (*Pennisetum typhoides*, Doro and Gero) and sorghum (*Sorghum bicolor*, red and white) commonly grown and used for the preparation of traditional foods in Nigeria.

MATERIALS AND METHODS

Materials

Two millet (*Pennisetum typhoides*) cultivars popularly known in Nigeria as Doro and Gero, and two of sorghum (*Sorghum bicolor*) were obtained from Bauchi State Agricultural Supply Company, Bauchi, Nigeria. The millet cultivars have small beadlike grains (2.5 mm long, 2.0 mm wide and 1.5 mm thick) slightly pointed at one end and rounded at the other with ash gray and light brown color, respectively. Starch content ranges were 75–85%; protein, fat, crude fiber, and ash contents are 10–17%, 4.1–6.4%, 1.1–1.8%, and 1.1–2.5%, respectively (Oyenuga 1968; Jambunathan et al 1984). The red and white sorghum cultivars have seed colors of red-brown and chalky white, respectively, and are flattened spheres (4.0 mm long, 3.5 mm wide and 2.5 mm thick), usually larger than millet grains. Starch, protein, fat, crude fiber, and ash contents are 55.6–75.2%, 6.6–16.6%, 2.1–7.6%, 1.0–3.4%, and 1.6–3.3%, respectively (Stark et al 1983; Akingbala and Rooney 1990). Starch was prepared from the grains by a conventional method in the laboratory (Takeda et al 1983), which involves alkaline steeping (0.2% NaOH) to soften the protein-starch matrix and to denature enzymes. The starch samples were defatted exhaustively by three replicate dissolutions in dimethyl sulfoxide followed by precipitations with ethanol (Takeda et al 1986). Fractionation of the millet and sorghum starches (10 g for each sample) into amylose and amylopectin was performed under an atmosphere of nitrogen to avoid oxidative degradation by the method of Lansky et al (1949) with modifications (Takeda et al 1986). Amyloses were purified by ultracentrifugation, and their purity was confirmed by GPC (Takeda et al 1984) using Toyopearl HW-75F (Tosoh, Tokyo, Japan). The yield of amylose from red sorghum was 1.3 g and from white sorghum was 1.6 g, while yield of amylose in millet samples was 1.5 and 1.9 g for Doro and Gero, respectively. For amylopectins, the yields were 6.7, 6.8, 7.1, and 5.7 g for red sorghum, white sorghum, Gero, and Doro, respectively. Crystalline *Pseudomonas* isoamylase was a product of Hayashibara Biochemical Laboratories (Okayama, Japan). β-Amylase from Sigma Chemical Co. (St. Louis, MO) was further purified by the method of Marshall and Whelan (1973).

Physicochemical Analyses

Iodine affinity (IA, g/100 g) was determined by the amperometric titration method of Larson et al (1953) with modifications

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(Takeda et al 1987). Rapid Visco Analyser (RVA 3D, Newport Scientific, Narrabeen, Australia) was used in determining the pasting properties of the starch slurries as described (Yoshimoto et al 2000). Thermal behavior of starch was determined by differential scanning calorimetry (DSC-7, Perkin-Elmer, Norwalk, CT) as already described (Yoshimoto et al 2000). Average diameter of starch granules was determined by scanning electron microphotography (S-3000N, Hitachi Science Systems, Ibaraki, Japan) by measuring 100 granules randomly for each starch sample.

Analytical Methods

Blue value, $\lambda_{\max}$, and β-amylolysis limit (β-AL) were determined by the procedures already described (Suzuki et al 1981; Takeda et al 1983). Number-average degree of polymerization (DP_n) of amylose was determined by a modification of the Park-Johnson method (Hizukuri et al 1981; Takeda et al 1987). Average chain length (CL) of amylopectin was determined by two methods: the rapid Smith degradation (Hizukuri and Osaki 1978) and hydrolysis with isoamylase (Suzuki et al 1981). Average number of chains per molecule (NC) of amyloses was calculated as DP_n/CL. Total carbohydrate and reducing sugar were determined by the phenol-sulfuric acid method (Dubois et al 1956) and the Somogyi-Nelson method (Nelson 1944; Somogyi 1952), respectively, but the latter with minor modifications (Hizukuri et al 1970). Size distributions of amylose (Hanashiro and Takeda 1998), amylopectin (Takeda et al 2003), and debranched amylopectin (Hanashiro et al 2002) were determined by fluorescent labeling/HPSEC methods.

RESULTS AND DISCUSSION

Millet and Sorghum Starch Granules

Size and size distribution of the millet and sorghum starch granules are presented in Table I. Sorghum starch granules were 4–26 µm in diameter (average size 11.2 and 14.0 µm) and larger than those of millet (3–14 µm) (average size 6.6 and 7.4 µm). The proportion of small granules (<10 µm) was higher in white sorghum than in red sorghum.

Iodine Affinity and Amylose Content of Starches

Iodine affinity (IA, g/100 g) and amylose content of the millet and sorghum starches are summarized in Table II. The IA of the starches was 3.09–3.66 and increased (5.05–5.18) after defatting, suggesting that both the millet and sorghum starches have amylose-lipid complex. This increase was higher in millet (36.9–38.8%) than sorghum (28.1–30.9%). The IA of amylose ranged from 18.6 (Doro) to 20.3 (white sorghum). The amylopectin of both millet and sorghum starches had a high IA (1.27–1.42). This indicates the presence of long chains (LC) in the amylopectins. The actual amylose contents calculated from IA values of defatted starch, amylose, and amylopectin were 21.3 for the millet cultivars and 21.4 and 20.1 for red and white sorghums, respectively. This amylose content for sorghum is within the range (20.9–22.2) reported by Beta and Corke (2001), and the values are similar to those of normal maize and rice (Takeda 1993; Hizukuri 1996). The apparent amylose contents, which were determined without consideration of amylopectin IA, gave similar values (25.3–25.9%) in all the samples. A wide range of apparent amylose contents (20–27.1%) is reported for both millet and sorghum (Taira and Miyahara 1983; Fujita et al 1996; Hoover et al 1996). This difference between apparent and actual amylose contents has been reported in normal maize (Takeda and Preiss 1993). The apparent and actual amylose contents of millet starches obtained in this work are higher than reported values (19.8 and 15.3%, respectively) for cattail millet (*Pennisetum typhoides*) (Jane et al 1999).

Pasting Properties

Pasting properties of the millet and sorghum starches are summarized in Table III. The properties differed among the samples. The highest pasting temperature (74.0°C) was obtained in Doro followed by red sorghum (73.9°C). The pasting temperature of 75.5°C for *S. bicolor* using a Brabender amylograph has been reported (Wankhede et al 1989). Gero and white sorghum had pasting temperatures of 69.4 and 72.6°C, respectively. Peak viscosities of Doro and Gero (205 and 204 RVU, respectively) were similar. The two sorghum cultivars exhibited similar mini-

TABLE I
Size Distribution of Millet and Sorghum Starch Granules[a]

Sample	Range (µm)	Average ± SD[a] (µm)	Distribution (%) <10 µm	Distribution (%) 10–15 µm	Distribution (%) > 15 µm
Millet					
Doro	3–14	7.4 ± 2.7	70	30	. . .
Gero	3–13	6.6 ± 2.6	81	19	. . .
Sorghum					
Red	4–26	14.0 ± 6.2	32	25	43
White	4–26	11.2 ± 5.3	48	28	24

[a] Values are the average ± standard deviation of 100 starch granules from two scanning electron micrographs.

TABLE II
Iodine Affinity and Amylose Content of Starches from Millet and Sorghum

	Millet Doro	Millet Gero	Sorghum Red	Sorghum White
Iodine affinity (IA) (g/100 g)				
Starch (A)	3.09	3.27	3.55	3.66
Defatted starch (B)	5.05	5.18	5.14	5.09
B – A	1.96	1.91	1.59	1.43
Amylose	18.6	19.1	19.3	20.3
Amylopectin	1.37	1.42	1.29	1.27
Amylose content (%)				
Apparent[a]	25.3	25.9	25.7	25.5
Actual[b]	21.3	21.3	21.4	20.1
Difference	4.0	4.6	4.3	5.4

[a] Calculated by $(\mathrm{IA}_{\mathrm{defatted\ starch}}/20) \times 100$.

[b] Calculated by $(\mathrm{IA}_{\mathrm{defatted\ starch}} - \mathrm{IA}_{\mathrm{amylopectin}})/(\mathrm{IA}_{\mathrm{amylose}} - \mathrm{IA}_{\mathrm{amylopectin}}) \times 100$.

mum viscosities (156 and 155 RVU, respectively). Other properties (peak viscosity temperature, viscosity at 40°C, breakdown, and setback) varied among the samples. The pasting temperature (74.0°C), peak viscosity (201 RVU), and setback (128 RVU) for cattail millet starch reported by Jane et al (1999) agree with our findings for Doro. White sorghum and Gero had the least and highest breakdown values, respectively. Difference in breakdown is related to variations in rigidity or fragility of swollen granules and is an indication of the degree of organization of the molecules (Krishnakumari and Thayumanavan 1998). Generally, low breakdown values indicate more stability against disintegration. The high pasting temperatures of Doro and white sorghum (74.0 and 72.6°C, respectively) with lower breakdown values (56 and 12 RVU) might be related to degree of association of the molecules. Gero and red sorghum had higher setback values (156 and 178 RVU, respectively). This suggests greater retrogradation tendency of the two starches. Amylose-lipid complexes cause restricted swelling and raise pasting temperature. The highest pasting temperature (74.0°C) was observed in Doro, which had the highest amount of amylose-lipid complex (ΔIA 1.96). However, Gero, which had a higher amylose-lipid complex (ΔIA 1.91), had a lower pasting temperature (69.4°C) than white sorghum (72.6°C), whose amylose-lipid complex is lower (ΔIA 1.43).

Thermal Properties

The summary of thermal behavior of the starches is presented in Table IV. The starches showed two transitions over a similar temperature range. The first peak (peak 1, 66.2–91.3°C) indicates melting of a crystalline region that is mainly amylopectin (Morrison et al 1993), while the second peak (peak 2, 91.7–110°C) indicates melting of amylose-lipid complexes (Kugimiya et al 1980). In the first peak, the onset (T_o 66.2–68.9°C), peak (T_p 69.7–72.5°C), and completion temperature (T_c 86.3–91.3°C) as well as enthalpy change (ΔH 13.3–14.7 J/g) were similar for all the starches. The gelatinization temperatures obtained in this work agreed with the findings (67–71°C) of Beta and Corke (2001) for sorghum cultivars. The ΔH values (13.3–14.7 J/g) were higher compared with the values for barley starches (10.1–10.9 J/g) (Yoshimoto et al 2001) but similar to values (14.4 J/g) reported for *P. typhoides* by Jane et al (1999). Fujita et al (1996) obtained ΔH values for millet at 8.2–13.5 J/g. The higher amount of energy required for melting the amylopectin crystalline region in the millet and sorghum starches suggests that the arrangement of molecules in starch granules in these samples is of a higher order of magnitude. It may also be a reflection in the number of double helices that unravel and melt during gelatinization (Hoover et al 1996). In the second peak, onset (T_o 91.7–94.9°C), peak (T_p 99.4–

TABLE III
Pasting Properties of Starches from Millet and Sorghum on RVA[a]

	Millet		Sorghum	
Properties	**Doro**	**Gero**	**Red**	**White**
Pasting temperature (°C)	74.0	69.4	73.9	72.6
Peak viscosity (RVU)	205	204	224	167
Peak viscosity temperature (°C)	87.8	85.4	81.6	82.6
Minimum viscosity (RVU)	149	112	156	155
Viscosity at 40°C (RVU)	278	268	334	278
Breakdown (peak – minimum) (RVU)	56	92	68	12
Setback[b]	129	156	178	123

[a] Starch concentration 9% (w/w).

[b] Viscosity at 40°C – minimum (RVU).

TABLE IV
Thermal Properties of Millet and Sorghum Starches[a]

	First Peak				Second Peak			
Sample	T_o (°C)	T_p (°C)	T_c (°C)	ΔH (J/g)	T_o (°C)	T_p (°C)	T_c (°C)	ΔH (J/g)
Millet								
Doro	67.2	71.4	91.0	14.3	91.7	102.8	110.0	1.53
Gero	66.2	69.7	86.3	14.7	94.2	99.4	108.0	1.11
Sorghum								
Red	67.4	70.6	91.3	14.1	94.0	103.8	109.0	0.68
White	68.9	72.5	90.0	13.3	94.9	102.1	109.0	0.48

[a] T_o = onset temperature; T_p = peak temperature; T_c = complete temperature; ΔH = enthalpy.

TABLE V
Properties of Millet and Sorghum Amylopectins

	Millet		Sorghum	
Property	**Doro**	**Gero**	**Red**	**White**
Blue value	0.18	0.18	0.19	0.19
λ_{max} (nm)	572	574	571	569
DP_n	9,100	9,000	12,600	8,900
Average chain length				
Isoamylolysis	20	20	20	21
Smith degradation	20	21	20	20
Labeling	21	20	21	20
β-Amylolysis limit (%)	56	56	55	56
External chain length[a]	13.2	13.8	13.0	13.8
Internal chain length[b]	5.8	6.2	6.0	6.2

[a] Calculated as (CL × β-AL/100) + 2, where β-AL is β-amylolysis limit.

[b] Calculated as CL – (external CL) – 1.

103.8°C), and completion temperature (T_c 108–110°C) were similar. The starches of millet had higher enthalpy change values (ΔH 1.11–1.53 J/g) than sorghum (ΔH 0.48–0.68 J/g). This result supports previous data (see Table II) on IA before and after defatting of starch.

Structure of Amylopectins

Some properties of the millet and sorghum amylopectins are summarized in Table V. Values of λ_{max} were 569–574 nm and were similar. Blue values were also similar at 0.18–0.19. Madhusudhan and Tharanathan (1996) reported λ_{max} as 551–591 nm for foxtail millet (*Setaria italica*) whereas Fujita et al (1996) gave values of 579–600 nm, which are higher than values obtained in this work. In comparison with reported values of λ_{max} for other cereals, barley (542–578 nm) (Yoshimoto et al 2001), wheat (535–548 nm) (Shibanuma et al 1996), maize (569 nm) (Takeda and Preiss 1993), and rice (531–575nm) (Takeda et al 1986), the millet and sorghum amylopectins seem to resemble those from barley, maize, and rice. The iodine absorption indicated by blue value and λ_{max} depends on several factors including chain length and degree of branching (Beleia et al 1980). The chain lengths (CL) of Doro (20), Gero (21), red (20), and white sorghum (21) were similar to those reported for sweet potato (20–21) (Hizukuri 1996), normal maize (21) (Takeda and Preiss 1993) and indica rice (IR32 and IR36) (21) (Takeda et al 1987). However, the CL were longer than that for japonica waxy rice (17.1) (Hizukuri et al 1983). The outer and inner CL values obtained (13–14 and 5.8–6.2, respectively) in this work agreed with previous findings (12–16 and 6.3 for outer and inner chain lengths, respectively) (Hizukuri 1986; Madhusudhan and Tharanathan 1996). β-Amylolysis limit was similar for all the samples.

HPSEC of the amylopectins revealed a polymodal size-distribution of the molecules on a molar basis (Fig. 1) and is similar to the well-known feature for weight-based distributions (Takeda et al 2003). The polymodal distribution was more discernible in the sorghum cultivars. Among the millet cultivars, Doro contained a slightly larger amount of large molecules than Gero but a lesser amount of small molecules. Similarly, a considerable difference was observed in the relative proportions of peaks in sorghum cultivars. Red sorghum had a higher amount of larger molecules compared with white sorghum but smaller molecules dominated in the latter. The weight-based distributions were similar for all the samples with a prominent peak in the region of large molecules. The DP_n of all the amylopectins was similar (8,900–9,100) except for red sorghum (12,600). The lowest DP_n was in white sorghum (8,900). The DP_n obtained for the samples falls within the range for rice (8,200–12,900) and is similar to that in waxy maize (9,600) and sweet potato (9,900) (Takeda et al 2003).

CL distribution of the amylopectins was examined by the labeling method after debranching with isoamylase. The weight- and molar-based distributions are shown in Fig. 2. Both distributions were polymodal. The fluorescent profiles were grouped into $A+B_1$, B_2+B_3 and LC in the reverse order of elution. The peak DP of the $A+B_1$ (short chain fraction) and B_2+B_3 chain fractions (long chain fraction) were 13–16 and 42–43, respectively, for all the amylopectins. This agrees with the range (11–19 and 41–52 for short and long chain fractions, respectively) previously reported (Hanashiro et al 2002). There were small peaks (DP 6) at the end of the fluorescent profiles in all the samples and they were similar to those of wheat and normal maize but more small peaks have been reported (Hanashiro et al 2002) in sweet potato and potato amylopectins.

The distribution by weight showed the presence of LC (7–8%) in all the samples. This agrees with the high IA values of the amylopectins (see Table II). The weight and molar ratios of the fractions ($A+B_1$, B_2+B_3, and LC) are presented in Table VI. The distributions showed that there was a slight difference between the millet and sorghum amylopectins on a weight basis. The amylopectins from millet had a higher wt% (72–73%) for the $A+B_1$ chains than sorghum (70%), but the mol% for millet (91–92%) and sorghum (90–91%) were similar. Mol% of $A+B_1$ chains for both the millet and sorghum amylopectins were 90–92%, which was similar to reported values (90–93%) for maize, rice, and wheat. The $(A+B_1)/(B_2+B_3)$ ratio (9.1–11.5) by mole was also

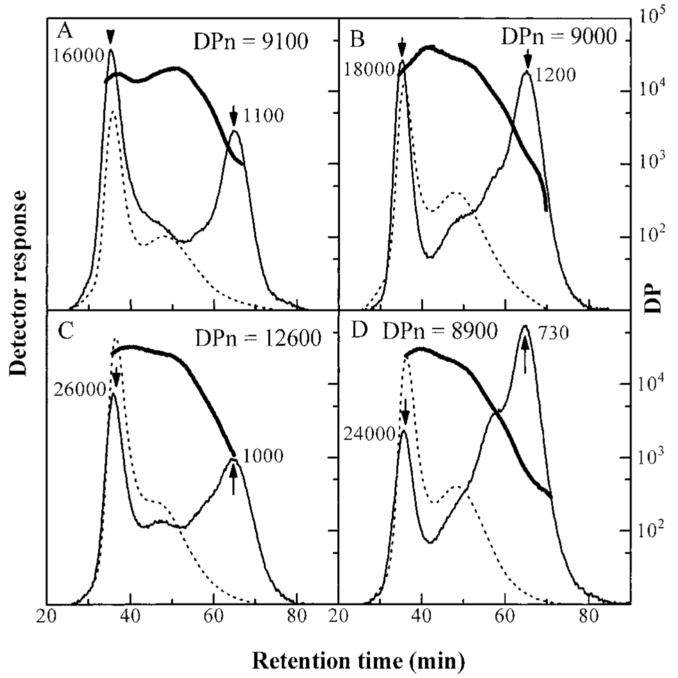

Fig. 1. Weight- and molar-based distributions of amylopectin molecules from millet and sorghum. **A**, Doro; **B**, Gero; **C**, red sorghum; **D**, white sorghum. Fluorescence response (mole [——]), RI response (weight [· · · · · ·]), degrees of polymerization (DP[——]). Numbers with arrows indicate peak DP values.

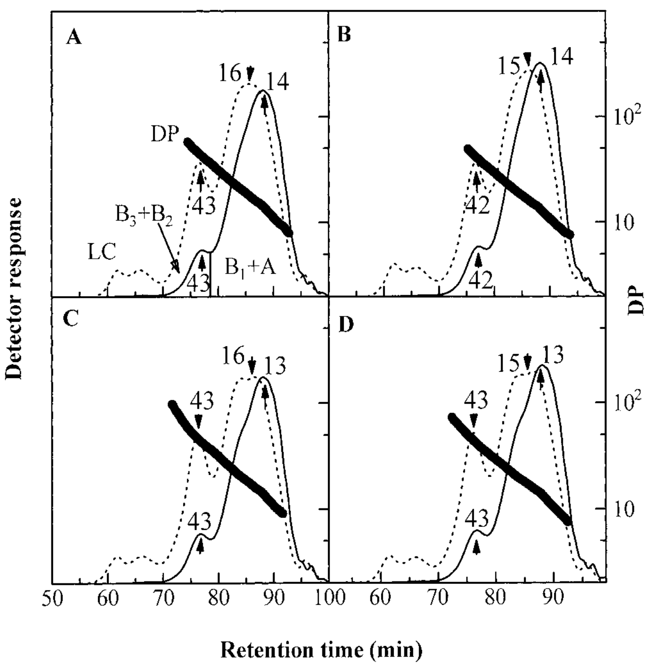

Fig. 2. Weight- and molar-based distributions of unit chains of amylopectins **A**, Doro; **B**, Gero; **C**, red sorghum; **D**, white sorghum. Fluorescence response (mole [——]), RI response (weight [· · · · · ·]), degrees of polymerization (DP[——]) long chain (LC). A, B_1, B_2, and B_3 are fraction designations. Numbers with arrows indicate peak DP values.

similar to those (10–10.8) for maize, rice, and wheat. Starches from wheat are A crystalline type and their values are higher than those of amylopectins from B crystalline type starches (68–87%, ratio 2.1–6.5). The results on the millet and sorghum starches A crystalline type (data not shown) confirmed the relationship between a crystalline type and an $A+B_1$ amount or an $(A+B_1)/(B_2+B_3)$ ratio (Hanashiro et al 2002).

Structure of Amyloses

Chromatograms of millet and sorghum amyloses are presented in Fig. 3, and a summary of the amylose properties is presented in Table VII. The weight-based distribution profiles for the millet and sorghum amyloses were different. Similarly, the molar-based distributions were different in red sorghum, which showed larger molecules. The peak DP on a weight basis for millet (2,650–2,740) and sorghum (3,300–3,530) were similar among the samples. On a molar basis, white sorghum and millet cultivars (490–540) showed similarity and their distributions are similar to rice (peak DP 500) (Hanashiro and Takeda 1998). The DP_n of red sorghum (1,390) and white sorghum (1,330) was large. The amylose distribution profile of red sorghum on a molar basis resembled that of barley (Hanashiro and Takeda 1998). The DP_n of the amyloses (Table VII) determined by a colorimetric method showed similar values (1,060–1,300) for all the samples and were similar to the chromatography results. The labeled amyloses gave DP_n values of 1,170, 1,250, 1,390, and 1,330 for Doro, Gero, red, and white sorghum, respectively. The β-amylolysis limit was 80–84%. Blue value (1.3–1.5) and λ_{max} (645–646 nm) were in agreement with reports on amyloses generally (Hizukuri 1996). Both the high β-amylolysis limit and λ_{max} values (80–84% and 645–646 nm, respectively) reflect the fact that the degree of branching in the amyloses is low. The CL was 260–270 with number of chains per molecule in the range of 3.9–4.8 being similar to maize and rice (2.9–4.3) (Takeda et al 1986; Takeda 1993).

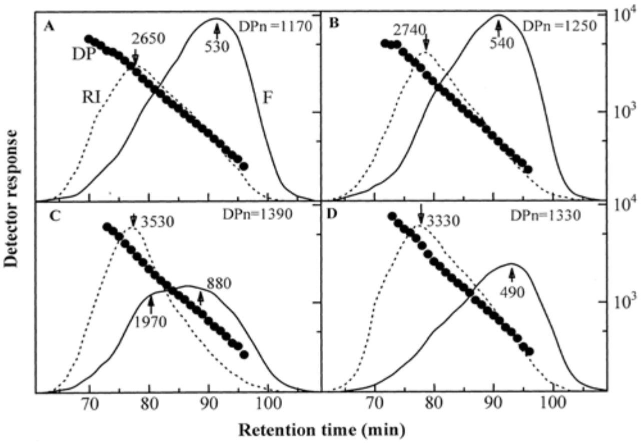

Fig. 3. Weight and molar distributions of millet and sorghum amyloses. **A**, Doro; **B**, Gero; **C**, red sorghum; **D**, white sorghum. Fluorescence response (mole[——]), RI response (weight [· · · · · ·]), degrees of polymerization (DP [••••••]). Numbers with arrows indicate peak DP values.

CONCLUSIONS

Millet and sorghum starches have structural characteristics similar to other cereal starches. The actual amylose content of the starches was 20–21% and was similar to maize. This value was 4–5% lower than the apparent amylose content due to the presence of LC in the amylopectins. Millet starch had a higher amount of amylose-lipid complex than sorghum. The low breakdown in pasting properties of white sorghum starch in its unmodified state is of interest. Millet and sorghum amylopectins had similar average chain lengths and chain length distributions. These distributions were similar to rice. Millet and sorghum amyloses had different molecular-size distributions on a weight basis, but on a molar basis, only red sorghum showed a different distribution. The DP_n of the amyloses was similar in all the samples. Millet and sorghum starches have some characteristics in common.

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TABLE VI
Weight and Molar Ratios of Chain Length Fractions of Amylopectin Unit-Chains

	Wt%			Mol%			
Sample	**LC**	**B_2+B_3**	**$A+B_1$**	**LC**	**B_2+B_3**	**$A+B_1$**	**$(A+B_1)/(B_2+B_3)$**
Millet							
Doro	7	21	72	nd[a]	9	91	10.1
Gero	8	19	73	nd	8	92	11.5
Sorghum							
Red	7	23	70	nd	9	91	10.1
White	7	23	70	nd	10	90	9.0

[a] Not detected.

TABLE VII
Properties of Millet and Sorghum Amyloses

	Millet		Sorghum	
Property	**Doro**	**Gero**	**Red**	**White**
Blue value	1.30	1.41	1.50	1.30
λ_{max} (nm)	645	646	648	645
DP_n[a]				
Colorimetric[b]	1,070	1,060	1,300	1,150
Labeling	1,170	1,250	1,390	1,330
Average chain-length	270	260	270	260
β-Amylolysis limit (%)	80	84	83	80
Average number of chains	3.9	4.1	4.8	4.4

[a] Number-average degrees of polymerization.

[b] Modified Park-Johnson method (Hizukuri et al 1981; Takeda et al 1987).

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