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Studies on Acacia gums: Part III molecular weight characteristics of *Acacia seyal var. seyal* and *Acacia seyal var fistula*

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Abstract

Seventy four authenticated *A. seyal* samples have been studied in order to establish the molecular characteristics of this important species and the differences between the two variants *A. seyal var. seyal* (ASS) and *A. seyal var. fistula* (ASF) belonging to the Gummiferae series. Comparison is thus possible with *A. senegal* from the Vulgares series. The weight average molecular weight of *A. seyal* is at least three times greater than *A. senegal*. From average values ASF has a significantly higher molecular weight than ASS, contains less protein and more inorganic ash residue. Yet despite the high molecular weight, the intrinsic viscosities of ASF and ASS are less than for *A. senegal*, indicating a more compact molecular structure, which is supported by the root mean square radii measurements giving molecular size ratios of *A. seyal* to *A. senegal* of 0.77–1. The protein distribution in *A. seyal* is different, and whereas the protein in *A. senegal* is mainly associated with the high molecular weight component (AGP $\sim 10^6$) it is distributed differently and mainly associated with a lower molecular weight component in *A. seyal*. The Mark-Houwink plots for *A. senegal* confirm the differences in shape and size compared with *A. seyal*. The average molecular weight for ASF is 2.1×10^6, for ASS 1.7×10^6 compared with an average value of 0.6×10^6 for AS.

Keywords: Acacia gums; Vulgares; *Acacia senegal*; *Acacia seyal*

1. Introduction

The overall difference between *Acacia seyal* and *Acacia senegal* reflect the difference between Gummiferae and Vulgares series and were initially described by Anderson and McDougall (1987).

Gummiferae
- Positive optical rotation
- Low viscosity
- Arabinose/galactose ratio >1
- Low rhamnose

Vulgares
- Negative optical rotation
- More acidic than Gummiferae
- More viscous
- Arabinose/galactose ratio <1
- Higher proportion of rhamnose

These differences in molecular composition of the two species are confirmed in Part II of this series.

Previously we have shown that although *A. seyal* has a considerably higher molecular weight than *A. senegal*, the intrinsic viscosity is always lower (Part II). Moreover, there was much greater variability within the *A. seyal* complex from the point of view of molecular weight and sugar composition. In contrast, however, although the amount of protein in *A. seyal* is considerably less than in *A. senegal*, the amino acids are the same and they are present in the same proportions. Chemometric investigations have

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illustrated these differences and the method provides the best means of representing all the 27 individual analytical parameters which have been used to characterize these two Acacia species (Biswas, Biswas, & Phillips, 1995).

The specific optical rotation has in the past been taken as the most diagnostic parameter to distinguish between *A. seyal* and *A. senegal*. As might be expected from a natural product derived from different geographical locations and soils throughout the African Sahelian belt, even the taxonomically well characterized *A. senegal* and *A. seyal* gums from the same variety of these species, vary considerably in actual specific rotation (Phillips & Williams, 1993). Between and within varieties, for example *A. senegal var. senegal* (found in Sudan) and *A. senegal var. karensis* found in East African countries such as Uganda and Kenya the specific optical rotation can vary between −24° and −40°.

There is an age-old discussion whether this variation is due to structural variations or differences in sugar composition? Anderson and Weiping (1991) indicated that for a series of eight Ugandan gums the variation in the analytical parameters reflects differences in the fine structure. We have investigated in detail what determines the specific optical rotation value of Acacia gum. Our investigation related specific optical rotation of a series of Acacias to their carbohydrate composition and used this relation to develop a new classification procedure for exudates gums and their tree origins. It was shown that a genetically determined class of natural polysaccharides is characterized by a specific relationship between the optical rotation and the carbohydrate composition (Biswas, Biswas, & Phillips, 2000). In other words both the rotation and carbohydrate may vary under different conditions but the class-specific relationship remains intact. We first sought empirically analytical forms of this relationship, and observed how that varies with the class and if any individual sample of polysaccharide gum can be associated with any of the known classes. It has been possible in this way to relate the specific optical rotation (Biswas et al., 2000) to the vectorial contributions made by the individual sugars present. In a more recent study (Biswas and Phillips, 2003) this work was extended and specific optical rotation of 185 Acacia gums were computed from the carbohydrate composition. Agreement between observed and calculated values was excellent. It is clear therefore that the individual sugar compositions have a greater influence in determining specific optical rotation rather than changes in overall structural confirmations.

The question remains what are the structural differences between *A. seyal* and *A. senegal* which in turn affect its functionality, for example its effectiveness as an emulsifier. Such differences have been found in practice. Whereas good structural information is now available for *A. senegal*, the same is not true for *A. seyal*, which has considerably lower nitrogen content, and hence less protein than *A. senegal* (0.15 and 0.3%, respectively).

In the present study, to complement the molecular distribution and fractionation study in Part I of this series on *A. senegal*, and in previous investigations (Phillips & Williams, 1993) we have undertaken a similar study on *A. seyal*.

2. Material

The 74 samples used in the present study were collected to fulfill factors such as, soil type, different seasons and regions. The codes X and Y designated *A. seyal var. seyal* (ASS) and *A. seyal var. fistula* (ASF) collected up to February 1997, and M and N and ASF and ASS collected from the 1998 collecting season. The samples were collected by one of the authors (E.A.H.). Full details about the origin and dates of collection are given in Annex 1. In order to differentiate between the samples we shall refer to *A. senegal* sample as AS, Acacia seyal variants seyal and fistula as ASS and ASF, respectively.

3. Method

The GPC-MALL system used for the determination of the molecular weight and molecular weight distribution in the present study has been described (Part I) and only the specific features relating to the present investigation are given here. The solvent was filtered through 0.22 μm cellulose nitrate filter and delivered using a Pharmacia pump. A manual Rheodyne (Model 7125) syringe loading sample injector, fitted with a 100 μl sample loop, was connected to a Superose® 6HR 10/30 column (Pharmacia Biotech, Sweden) and the column effluent monitored sequentially with a DAWN-DSP laser light scattering photometer equipped with a He–Ne laser at wave length of 632.8 nm (Wyatt Technology, USA) and a concentration dependent detector (Optilab DSP interfometeric refractometer operated at 632.8 nm, Wyatt Technology, USA), and a UV detector at 214 nm (Pharmacia UV-M LKB Biotechnology, Sweeden). The gum nodules of each sample ground using a pestle and mortar then 0.02 g of the respective sample dissolved in 5 ml of 0.5 M NaCl. The samples were left to tumble mix for at least 10 h and were filtered through 1 μm cellulose nitrate membrane filter prior to injection. A value of 0.141 g/cm^3 was utilized for the refractive index increment (dn/dc). The data was collected and analysed by Astra software V 4.5 (Wyatt Technology. USA). In the following text and tables the expressions M_w and M_n are used for the weight and number average molecular weights and M_w/M_n for the polydispersity index (M_w/M_n) and R_g for the root mean square radius.

Ash content was determent by weighing out 1 g of the respective sample in a preweighed ashing dish followed by heating at 550 °C for 3 h. The dish was cooled to room temperature in a desiccator and weighed out again.

Table 1
Analytical data for *A. seyal var seyal* (ASS) collected up to February 1997

Sample code	Specific rotation	Intrinsic viscosity (ml/g)	Loss on drying % (w/w)	Ash % (w/w)	Nitrogen (%) (w/w)	Protein (%) (w/w)	Acid equivalent weight	Uronic acid (%)
X1	57.1	15.4	7.6	0.10	0.19	1.25	1492	11.8
X2	62.2	13.8	8.3	0.09	0.14	0.93	1470	12
X3	64	13.4	7	0.10	0.11	0.73	1492	11.9
X4	52.7	14.6	9.3	0.10	0.16	1.06	1515	11.7
X5	55.2	17.6	8.7	0.20	0.12	0.79	1538	11.5
X6	57.8	14.4	7.5	0.15	0.16	1.06	1515	11.7
X7	55.2	13.5	9.5	0.12	0.13	0.86	1492	11.9
X8	48.3	16.2	9	0.1	0.16	1.06	1470	12
X9	54.5	15.8	7.6	0.09	0.11	0.73	1470	12
X10	43.5	14.1	0.2	0.19	0.13	0.86	1470	12
X11	52.3	15.2	8.1	0.16	0.17	1.12	1515	11.7
X12	20.1	13.5	7.6	0.31	0.16	1.06	1470	12
X13	55.6	15.6	7.6	0.16	0.16	1.06	1515	11.7
X14	42.8	11.9	4.3	0.10	0.14	0.92	1470	12
X15	27.4	13.3	9	0.12	0.15	0.99	1470	12
X16	46.1	15	7.4	0.90	0.13	0.86	1470	12
X17	57.4	13.6	7.5	0.21	0.15	0.99	1470	12
X18	54.55	16.7	6.6	0.19	0.18	1.19	1515	11.8
X19	39.5	13.6	8	0.31	0.11	0.73	1492	11.9
X20	52.3	14.6	7.4	0.26	0.13	0.86	1470	12

The weight loss was calculated as a percentage of the initial weight taken.

Optical rotation, moisture content, intrinsic viscosity measurements, nitrogen content, equivalent weight and sugar analyses were performed as described previously (Chickamai, Phillips, & Casadei, 1996)

4. Result and discussion

Since the samples of *A. seyal var. seyal* and *A. seyal var. fistula* used in this investigation were collected in the Sudan by one of us (E.A.H.), we could be assured of their authenticity. Details of samples and location of their collection is given in Annex 1. Their general properties were measured. No direct previous comparison of the variant *seyal* and the variant *fistula* is available and these are now given in Tables 1–4. The codes X and Y designated *A. seyal var. seyal* (ASS) and *A. seyal var. fistula* (ASF) collected up to February 1977, and M and N and ASF and ASS collected from the 1998 collecting season. The distinction is made since storage of the gum in a hot and humid atmosphere is considered a factor in establishing its physical characteristics. In evaluating the results it must be noted that there is considerable variation in all the analytical parameters. In Part II it was evident that *A. seyal*, a member of the *Gummiferea* series is an extremely diverse product, without the coherence of *A. senegal* and the other members of the Vulgares series. Our major objective here is to compare *A. seyal* with *A. senegal* and to seek to establish whether any significant differences can be identified between ASS and ASF.

From the mass of results arising from this investigation we have summarized the average values in Table 5. There seem to be less protein in ASF, but more ash, due to inorganic matter. Otherwise in equivalent weight, uronic acid content, and specific optical rotation there dose not appear to be significant differences. The storage does not appear to result in less total loss on drying (moisture) or a higher intrinsic viscosity. This type of change was previously reported (Phillips & Williams, 1993).

In Part I and II it was shown that the molecular distribution of individual components and protein provides a good diagnostic indicator of the particular molecular characteristics of Acacia gums. The method is now applied in the same way to *A. seyal* with particular attention to comparing ASS and ASF.

The elution profiles monitored by the refractive index, light scattering detector diode at 90° and the detector at 214 nm, as an indicator of protein distribution, were similar

Table 2
Analytical data for *A. seyal var seyal* (ASS) starting in 1998 collecting season

Sample code	Specific rotation	Intrinsic viscosity (ml/g)	Loss on drying %(w/w)	Acid equivalent weight
N1	46	12.83	8.5	1502
N2	48	13.95	8.6	1439
N3	46	15.54	7.9	1553
N4	50	16.12	8.1	1472
N5	52	12.74	7.9	1489
N6	46	12.85	8.1	1462
N7	52	13.98	8.3	1596
N8	45	13.11	8.1	1598
N9+	45	13.62	9.3	1472
Average	47.77	13.86	8.3	1509

Table 3
Analytical data for *A. seyal var fistula* (ASF) collected up to February 1997

Sample code	Specific rotation	Intrinsic viscosity (ml/g)	Loss on drying % (w/w)	Ash % (w/w)	Nitrogen (%) (w/w)	Protein (%) (w/w)	Acid equivalent weight	Uronic acid (%)
Y1	41.3	13.4	8.1	1	0.05	0.33	1695	10.44
Y2	46.1	14.2	7.8	1.9	0.07	0.462	1724	10.22
Y3	49.7	14.1	8	1.6	0.07	0.462	1666	10.62
Y4	36.2	15.1	6.4	1.3	0.07	0.462	1695	10.57
Y5	54.5	14.5	7.3	0.98	0.08	0.528	1587	11.15
Y6	56.3	15	6.7	1.9	0.05	0.33	1667	10.65
Y7	59.3	15.9	7.5	0.02	0.06	0.396	1613	10.97
Y8	53.4	15.1	6.8	1.9	0.05	0.33	1613	10.97
Y9	56.7	15.	7.2	2	0.04	0.264	1786	9.71
Y10	53.8	13.6	7.5	1.3	0.06	0.396	1613	10.97
Y11	51.9	16.9	7.7	1.5	0.09	0.594	1587	11.15
Y12	44.6	13.8	7.6	1	0.1	0.66	1613	10.97
Y13	55.6	16.1	7.5	1.9	0.09	0.594	1587	11.15
Y14	43.9	13.6	7.3	1.2	0.06	0.396	1639	10.78
Y15	50.8	13.7	5.2	1.9	0.08	0.528	1613	10.97
Y16	41	15.5	8.3	2.1	0.09	0.594	1613	10.97
Y17	44.6	12.7	7.8	2.3	0.09	0.594	1587	11.15
Y18	50.4	14.8	12.7	1.1	0.1	0.66	1639	10.78
Y19	49.5	12.7	7.8	2	0.05	0.33	1587	11.15
Y20	17.2	16.2	8.2	1.2				

to that reported and interpreted previously (Williams, Idris, & Phillips, 2000; Williams and Phillips 1993, Part 2). Figs. 1–3 show representative plot for ASS, ASF and *A. senegal*. The GPC fractionation profiles, in a general way are similar for AS, ASS and ASF. There are three main components with high, medium and low molecular weights, but the actual values for these are difference for AS and ASS/ASF (Fig. 4). These cannot, however, be regarded as molecularly discrete, and the distributions throughout these complex molecules are also different for AS and ASS/ASF (Fig. 5). The GPC fractions monitored by three detectors have been shown to be an indicator of the overall structure. Following fractionation, the data were processed for the whole gum to give an average molecular weight and also the two main peaks processed separately. The following information can be calculated: weight average molecular weight (M_w), mass recovery, polydispersity index (M_w/M_n), and the root mean square radius (R_g) of these components.

The results are tabulated in Table 6 and summarized in Table 7. The molecular weight is higher for *A. seyal* samples than for *A. senegal* samples. This relates to a higher M_w of peak 1, which has an average M_w of 5.8×10^6, 5.3×10^6 and 2.2×10^6 for *A. seyal var. fistula*, *A. seyal var. seyal* and *A. senegal*, respectively. The weight average molecular weight as well as M_w for peak 1 for *A. seyal var. fistula* was found to be higher than that of *A. seyal var. seyal* (Table 7). Generally the *A. senegal* samples contain a slightly more of peak 1. The main component of all samples is peak 2, whereas peak 3 is present in only small quantities and can only be observed with a UV-detector, which indicates protein content. Table 7 gives average molecular parameter values for all samples. Using samples with average values

Table 4
Analytical data for *A. seyal var fistula* (ASF) starting in 1998 collecting season

Sample code	Specific rotation	Intrinsic viscosity (ml/g)	Loss on drying %(w/w)	Acid equivalent weight
M1		12.26	10.6	1801
M2		13.51	9.8	1713
M3		13.12	10.8	1721
M4		12.81	11.1	1756
M5		14.21	10.5	1619
M6		12.38	10.3	1713
M7		12.56	9.7	1812
M8		12.81	9.9	1674
M9		13.49	11.3	1876
M10		14.61	10.3	1589
M11		13.81	10.7	1669
M12		13.66	9.6	1543
M13		13.63	8.1	1782
Average		13.29	10.2	

Table 5
Summary of the average analytical parameters of *A. seyal var. seyal* and *A. seyal var. fistula*

Category	*A. seyal var. fistula*	*A. seyal var. seyal*
Number of samples	29	32
Protein (%)	0.59	0.96
Acid equivalent weight	1661	1489
Uronic acid (%)	10.75	11.88
Loss on drying	7.7; 10.2[a]	7.4; 8.3[a]
Intrinsic viscosity (ml/g)	14.8; 13.3[a]	14.6; 13.9[a]
Ash	1.52	0.21
Specific optical rotation	50	53

[a] For fresh samples after 1998 collecting season.

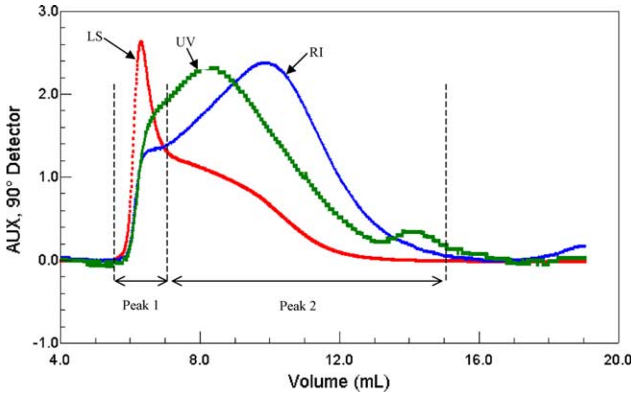

Fig. 1. GPC chromatogram showing the elution profiles monitored by light scattering (LS), refractive index (RI) and an ultraviolet monitor at 214 nm (UV) for *A. seyal var. seyal* (sample S1).

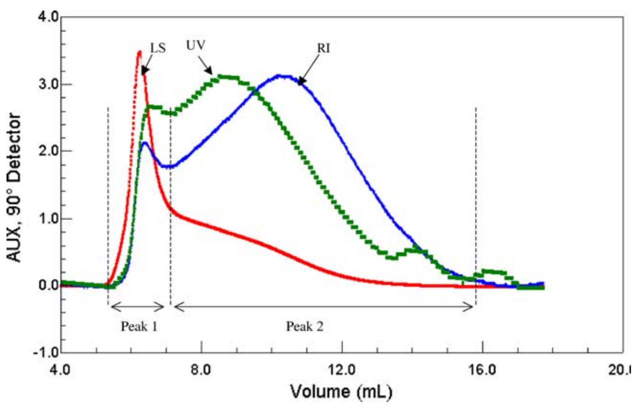

Fig. 2. GPC chromatogram showing the elution profiles monitored by light scattering (LS), refractive index (RI) and an ultraviolet monitor (UV) at 214 nm for *A. seyal var. fistula* (sample Y14).

A. seyal var. fistula, *A. seyal var. seyal* and *A. senegal* are shown in comparison in Figs. 4 and 5.

There is a significant difference in protein distribution between *A. seyal var. seyal* and *fistula* compared to *A. senegal* in the UV elution profile. Most of the protein content is located in peak 1 for *A. senegal*, whereas in *A. seyal* more of the protein is associated with peak 2. It is doubtful, therefore, if the allocations of AGP, AG and GP, now established for the main components in *A. senegal*, apply also to *A. seyal*. This relationship of protein distribution to structure will be considered in more detail later.

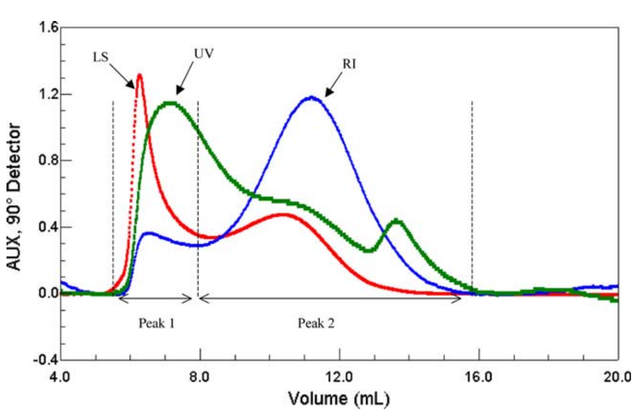

Fig. 3. GPC chromatogram showing the elution profiles monitored by light scattering (LS), refractive index (RI) and an ultraviolet monitor (UV) at 214 nm for *A. senegal var senegal* (M_w 6×10^5, Part I).

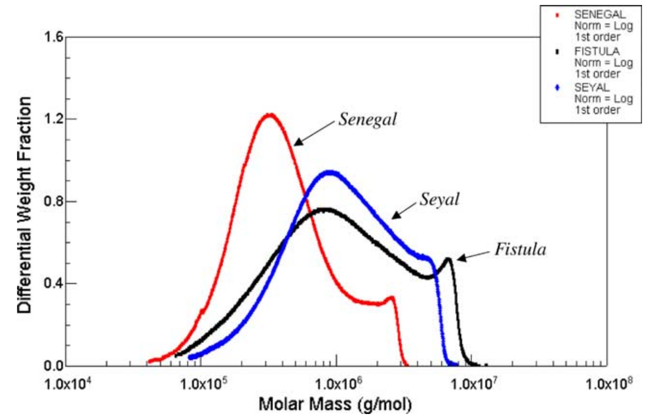

Fig. 4. Molecular weight distribution of *A. seyal var. seyal* (S1), *A. seyal var. fistual* (Y14) and *A. senegal var. senegal* (Part I). The samples represent the average M_w value for each variety.

In Part I of this series we investigated the Mark-Houwink relationship for 68 samples of *A. senegal* obtained from suppliers and users. In this investigation we have plotted log M_w versus log $[\eta]$ (Fig. 6) for *A. seyal var. seyal* and *A. seyal var. fistula* in comparison with standard K and a plots. (Anderson & Rahman,1967; Idris, Williams, & Phillips, 1998; Vandevelde & Fenyo,1985). For *A. senegal* log $[\eta]$ against log M_w fall on a straight line from which Mark-Houwink constants can be determined. This behaviour also indicates that the different molecular weight samples are structurally homogenous. No correlation was found between the origin of the sample and date of collection for either of the *A. seyal* variants. The intrinsic viscosity for *A. seyal* is lower for a given molecular weight compared with *A. senegal*. This confirms the conclusion that

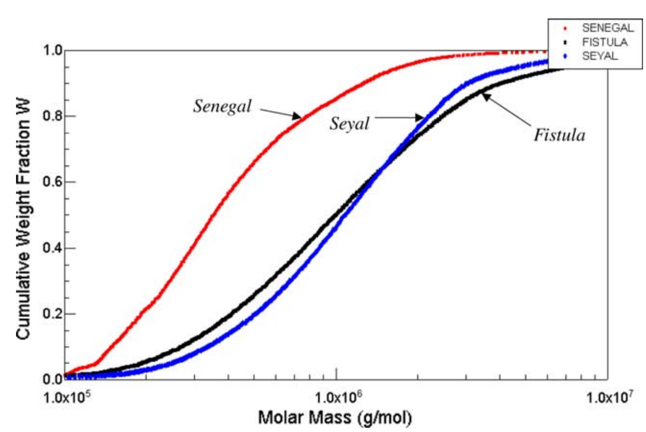

Fig. 5. Cumulative plot of *A. seyal var. seyal* (S1), *A. seyal var. fistula* (Y14) and *A. senegal var. senegal* (Part I). The samples chosen represent the average M_w value for each variety.

Table 6
Molecular weight parameters of *Acacia senegal*, *A. seyal var. seyal* and *A. seyal var. fistula*

Code	M_w (1 Peak)×10^6	Mass (%)	M_w/M_n	R_g (nm)	M_w (2 peaks)×10^6	Mass (%)	M_w/M_n	R_g (nm)	*Senegal var.*
Hashab	0.59±0.01	100	2.07	25	2.18±0.14	17.2	1.51	32	*Senegal*
					0.30±0.01	82.8	1.19	-	
X1	1.53±0.06	106	2.38	27	5.26±0.14	11.6	1.14	28	*Seyal*
					1.08±0.03	95.0	1.85	26	
X2	2.40±0.05	104	2.38	31	7.01±0.14	20.9	1.33	35	*Seyal*
					1.23±0.18	83.6	1.43	-	
X3	1.07±0.03	111	2.32	28	4.34±0.13	10.8	1.18	32	*Seyal*
					0.72±0.22	100	1.70	26	
X4	1.89±0.04	106	2.60	30	5.12±0.10	24.9	1.25	32	*Seyal*
					0.91±0.21	81.5	1.56	25	
X6	2.75±0.09	100	2.62	36	8.06±0.24	21.9	1.41	33	*Seyal*
					1.26±0.05	78.4	1.49	37	
X8	2.05±0.05	109	1.87	26	5.80±0.15	19.0	1.28	29	*Seyal*
					1.25±0.03	89.7	1.33	26	
X16	1.22±0.03	93.9	3.6	32	6.76±0.27	5.72	1.30	30	*Seyal*
					0.85±0.18	88.1	2.72	26	
X19	2.24±0.05	92.9	2.34	26	6.82±0.13	17.0	1.23	29	*Seyal*
					1.21±0.02	76.0	1.51	24	
S1	1.58±0.03	104	1.90	27	5.44±0.11	10.1	1.1	29	*Seyal*
					1.15±0.02	90.4	1.5	26	
S2	1.11±0.03	100	1.89	27	3.22±0.08	13.1	1.12	29	*Seyal*
					0.79±0.24	86.6	1.49	26	
S3	2.37±0.04	108	2.22	27	5.43±0.10	29	1.26	28	*Seyal*
					1.25±0.02	79.1	1.5	27	
S4	3.56±0.10	95.6	2.94	34	9.28±0.26	27.4	1.55	36	*Seyal*
					1.22±0.03	68.0	1.33	32	
S5	0.84±0.21	104	1.69	26	4.33±0.16	24.0	1.10	28	*Seyal*
					0.76±0.18	102	1.5	25	
S6	1.45±0.03	95.4	1.77	26	4.70±0.12	89.8	1.16	27	*Seyal*
					1.11±0.2	86.3	1.47	25	
S8	1.05±0.02	91	1.49	27	2.06±0.04	17.28	1.07	30	*Seyal*
					0.83±0.24	76.97	1.34	26	
S9	1.07±0.03	104	1.63	30	3.19±0.09	7.64	1.09	30	*Seyal*
					0.89±0.30	95.8	1.45	26	
N6	1.62±0.03	101	1.57	22	4.82±0.11	9.61	1.11	25	*Seyal*
					1.28±0.02	91.6	1.35	21	
N8	1.34±0.06	99	1.77	34	5.01±0.06	7.3	1.16	38	*Seyal*
					1.05±0.05	91.8	1.47	34	
Y6	3.87±0.15	97	1.86	30	7.44±0.31	36.3	1.32	32	*Fistula*
					1.72±0.06	60.3	1.14	28	
Y11	3.12±0.05	103	1.63	23	5.99±0.10	34.1	1.20	25	*Fistula*
					1.708±0.02	69.1	1.16	22	
Y14	1.99±0.05	95	3.42	26	9.03±0.29	10.2	1.38	34	*Fistula*
					1.13±0.02	84.4	2.15	25	
Y16	1.99±0.37	103	2.54	29	5.13±0.07	23.6	1.26	32	*Fistula*
					1.07±0.02	80.0	1.68	28	
M6	3.08±0.06	94.3	1.8	25	6.47±0.06	28.4	1.23	28	*Fistula*
					1.618±0.06	65.8	1.25	24	
M8	0.98±0.06	99.8	2.4	28	5.58±0.06	37.6	1.87	27	*Fistula*
					0.80±0.05	96.1	2.09	25	
F1	1.59±0.03	102	2.00	25	4.56±0.09	12.1	1.10	27	*Fistula*
					1.19±0.02	90.4	1.66	25	
F3	2.23±0.04	96.0	2.23	30	6.30±0.11	20.5	1.30	35	*Fistula*
					1.12±0.02	75.6	1.36	29	
F4	0.66±0.19	106	1.68	28	3.86±0.19	14.5	1.25	32	*Fistula*
					0.61±0.16	104	1.59	28	
F5	0.34±0.14	103	2.01	32	2.99±0.19	6.34	1.25	31	*Fistula*
					3.13±0.12	96.6	1.32	30	
F6	3.96±0.14	96	2.04	28	7.58±0.30	37.6	1.38	29	*Fistula*
					1.63±0.03	58.5	1.19	28	
F8	1.52±0.03	108	1.9	26	4.78±0.06	13.0	1.17	28	*Fistula*
					1.05±0.02	91.6	1.49	26	

Table 7
Summary of the average molecular weight parameters of *A. seyal var. seyal*and *A. seyal var. fistula* compared to standard *A. senegal var. senegal*

Category	*A. seyal var. fistula*	*A. seyal var. seyal*	*A. senegal var. senegal*[a]
Number of samples	12	18	1
Average M_w ($\times 10^5$)	21	17	6
High M_w component (peak 1) ($\times 10^5$)	58	53	22
Major component ($M_w \times 10^5$)	14	10	3

[a] Average A. senegal from Part I.

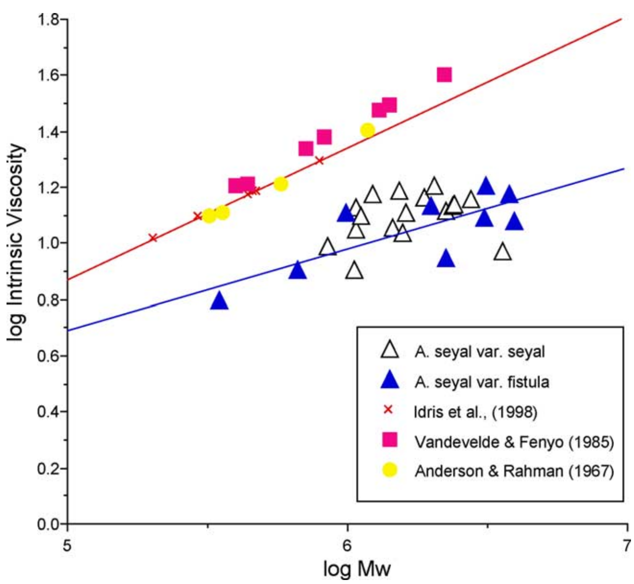

Fig. 6. log M_w plotted as a function of log [η] for *A. seyal var. seyal* and *fistula* compared with the reported literature values obtained for *A. senegal*.

molecular structure is more compact for *A. seyal*, but also that there is a much variability in this product.

Our findings can, therefore, be summarized:

The average molecular weight of *A. seyal* is at least three times greater than *A. senegal*. This is due the larger molecular weight of peak 1 component in *A. seyal*, which is at least double the molecular weight of the high molecular weight component of *A. senegal*.

ASF appears to have a significantly higher molecular weight than ASS due to a larger molecular weight of component associated with peak 1 in the eluent profiles.

Despite the considerably higher molecular weight, the average intrinsic viscosity is less than that of *A. senegal*, indicating a more compact structure. This is in keeping with relative average root mean square radii of gyration (R_g) of the two molecules: *A. seyal* 25.7 and *A. senegal* 33.1 nm. Thus the molecular size ratio of *A. seyal* to *A. senegal* is 0.77–1.

The protein distribution in *A. seyal* is different from in *A. senegal*. Whereas it is exclusively associated with the high molecular weight component (AGP), for *A. seyal* the protein is distributed between the molecular weight fractions and the lower ($\sim 1 \times 10^5$) molecular weight component. This observation could influence its functional performance. *A. seyal* does not obey the Mark-Houwink relationship in contrast to the behavior of characteristic samples of *A. senegal*.

Appendix A

See Table A1.

Table A1
Details about the origin and dates of collection for *A. seyal* samples used in this investigation

Sample code	Botanical source	Place of collection	Date of collection	Type of soil
Y1	*A. seyal var. fistula*	Eldalanj	Jan. 1997	Clay
Y2	*A. seyal var. fistula*	Khartoum (shambat)	Feb. 1997	Clay
Y3	*A. seyal var. fistula*	Karkoj	Nov. 1996	Clay
Y4	*A. seyal var. fistula*	Khartoum (shambat)	Feb. 1997	Clay
Y5	*A. seyal var. fistula*	Elrusairis	Dec. 1996	Clay
Y6	*A. seyal var. fistula*	Elrusairis	Dec. 1996	Clay
Y7	*A. seyal var. fistula*	Eldalanj	Jan. 1997	Clay
Y8	*A. seyal var. fistula*	Eldalanj	Jan. 1997	Clay
Y9	*A. seyal var. fistula*	Eldalanj	Jan. 1997	Clay
Y10	*A. seyal var. fistula*	Eldalanj	Jan. 1997	Clay
Y11	*A. seyal var. fistula*	Khartoum (Shambat)	May 1997	Clay
Y12	*A. seyal var. fistula*	Eldalanj	Jan. 1997	Clay
Y13	*A. seyal var. fistula*	Eldalanj	Jan. 1997	Clay
Y14	*A. seyal var. fistula*	Eldalanj	Jan. 1997	Clay
Y15	*A. seyal var. fistula*	Khartoum (Shambat)	Jan. 1997	Clay
Y16	*A. seyal var. fistula*	Khartoum (Shambat)	May 1997	Clay
Y17	*A. seyal var. fistula*	Khartoum (Shambat)	Feb. 1997	Clay
Y18	*A. seyal var. fistula*	Khartoum (Shambat)	Feb. 1997	Clay
Y19	*A. seyal var. fistula*	Khartoum (Shambat)	Feb. 1997	Clay
Y20	*A. seyal var. fistula*	Khartoum (Shambat)	Feb. 1997	Clay

(*continued on next page*)

Table A1 (*continued*)

Sample code	Botanical source	Place of collection	Date of collection	Type of soil
X1	*A. seyal var. seyal*	Karkoj	Apr. 1996	Clay
X2	*A. seyal var. seyal*	Kordufan	Season 95/96	Clay
X3	*A. seyal var. seyal*	Gadarif	Nov. 1995	Clay
X4	*A. seyal var. seyal*	Khartoum (Burri)	Mar.1996	Clay
X5	*A. seyal var. seyal*	Southern Blue Nile	Dec. 1996	Clay
X6	*A. seyal var. seyal*	Khartoum (Halfaia)	Mar. 1997	Clay
X7	*A. seyal var. seyal*	Khartoum (Soba)	Feb. 1997	Clay
X8	*A. seyal var. seyal*	Khartoum (Shambat)	May 1997	Clay
X9	*A. seyal var. seyal*	Khartoum (Burri)	Mar. 1997	Clay
X10	*A. seyal var. seyal*	Khartoum (Shambat)	Mar.1997	Clay
X11	*A. seyal var. seyal*	Khartoum (Shambat)	May 1997	Clay
X12	*A. seyal var. seyal*	Khartoum (Shambat)	Mar. 1997	Clay
X13	*A. seyal var. seyal*	Khartoum (Shambat)	May 1997	Clay
X14	*A. seyal var. seyal*	Khartoum (Shambat)	May 1997	Clay
X15	*A. seyal var. seyal*	Khartoum (Shambat)	May 1997	Clay
X16	*A. seyal var. seyal*	Khartoum (Shambat)	May 1997	Clay
X17	*A. seyal var. seyal*	Sinar	Dec. 1996	Clay
X18	*A. seyal var. seyal*	Khartoum (Shambat)	Jun. 1997	Clay
X19	*A. seyal var. seyal*	Sinar	Dec.1997	Clay
X20	*A. seyal var. seyal*	Khartoum (Shambat)	Dec. 1996	Clay
M1	*A. seyal var. fistula*	Khartoum (Shambat)	Dec. 1998	Clay
M2	*A. seyal var. fistula*	Khartoum (Shambat)	Dec. 1998	Clay
M3	*A. seyal var. fistula*	Khartoum (Shambat)	Feb. 1999	Clay
M4	*A. seyal var. fistula*	Eldamazeen	Feb. 1999	Clay
M5	*A. seyal var. fistula*	Elrusairis	Feb. 1999	Clay
M6	*A. seyal var. fistula*	Eldamazeen	Feb. 1999	Clay
M7	*A. seyal var. fistula*	Elhawata	Feb. 1999	Clay
M8	*A. seyal var. fistula*	Eldamazeen	Feb. 1999	Clay
M9	*A. seyal var. fistula*	Eldamazeen	Feb. 1999	Clay
M10	*A. seyal var. fistula*	Eldamazeen	Feb. 1999	Clay
M11	*A. seyal var. fistula*	Eldamazeen	Feb. 1999	Clay
M12	*A. seyal var. fistula*	Eldamazeen	Feb. 1999	Clay
M13	*A. seyal var. fistula*	Eldamazeen	Feb. 1999	Clay
N1	*A. seyal var. seyal*	Khartoum (Shambat)	Dec. 1998	Clay
N2	*A. seyal var. seyal*	Khartoum (Shambat)	Dec. 1998	Clay
N3	*A. seyal var. seyal*	Khartoum (Shambat)	Dec. 1998	Clay
N4	*A. seyal var. seyal*	Khartoum (Shambat)	Dec. 1998	Clay
N5	*A. seyal var. seyal*	Khartoum (Shambat)	Dec. 1998	Clay
N6	*A. seyal var. seyal*	Eldamazeen	Feb. 1999	Clay
N7	*A. seyal var. seyal*	Eldamazeen	Feb. 1999	Clay
N8	*A. seyal var. seyal*	Eldamazeen	Feb. 1999	Clay
N9	*A. seyal* (commercial)	South Kordufan	Season 1998	Clay
S1	*A. seyal var. seyal*	Kordufan	Jan. 1999	Sand
S2	*A. seyal var. seyal*	Kordufan	Aug. 1997	Sand
S3	*A. seyal var. seyal*	Eldamazeen	Apr. 1999	Clay
S4	*A. seyal var. seyal*	Sinar	Dec. 1996	Clay
S5	*A. seyal var. seyal*	Elmitaimeer	Apr. 1999	
S6	*A. seyal var. seyal*	Neyala	Feb. 1999	Clay
S8	*A. seyal var. seyal*	Khartoum (Shambat)	Apr. 1999	Clay
S9	*A. seyal var. seyal*	Khartoum (Shambat)	Dec. 1998	Clay
F3	*A. seyal var. fistula*	Eldaain	Jan. 1999	Clay
F4	*A. seyal var. fistula*	Abu-jibaiha	April 1999	Clay
F5	*A. seyal var. fistula*	Eldalanj	Dec. 1996	Clay
F6	*A. seyal var. fistula*	Eldamazeen	Jan. 1997	Clay
F8	*A. seyal var. fistula*	Eldamazeen	April 1997	Clay

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