CHAPTER 5

RESULTS

5.1 Grain hardness (by visual characterization)

Table 7 shows the mean scores for grain hardness of maize, sorghum and pearl millet varieties by visual characterization.

Table 7: Grain hardness of maize, sorghum and pearl millet varieties

Varieties	Mean scores for grain hardness
Maize PAN 6043	3.5[1]
Maize PAN 6335	3.3
Sorghum KAT 369	3.1
Sorghum NK 283	3.1
Pearl millet SDMV 89004	2.7
Pearl millet SDMV 91018	2.5

1 Scale is from 1 to 5. The categories are; from1 to 2 hard grain; from 2 to 4 hard to intermediate grain and from 4 to 5 soft grain (Rooney and Miller, 1982).

All the varieties of the three cereal grains fell in the category of intermediate grain.

5.2 Total polyphenols in the refined and unrefined flours of maize, sorghum and pearl millet

Table 8 shows the total polyphenol content of the flours of the three cereals (maize, sorghum and pearl millet).

Table 8: Total polyphenol content of the refined and unrefined flours of maize, sorghum and pearl millet

Samples	Mean total polyphenol content (mg/100g) dry weight flour
Maize PAN 6043 Unrefined	60 (60)[1]
Maize PAN 6043 Refined	51 (37)
Maize PAN 6335 Unrefined	52 (71)
Maize PAN 6335 Refined	47 (64)
Sorghum KAT 369 Unrefined	72 (54)
Sorghum KAT 369 Refined	40 (43)
Sorghum NK 283 Unrefined	169 (31)
Sorghum NK 283 Refined	100 (49)
Pearl millet SDMV 89004 Unrefined	91 (48)
Pearl millet SDMV 89004 Refined	47 (31)
Pearl millet SDMV 91018 Unrefined	149 (20)
Pearl millet SDMV 91018 Refined	23 (32)

1 Values in the brackets are standard deviations.

The amounts of polyphenols in these cereal grains were very low. Polyphenols were highest in the unrefined flours of sorghum NK 283 and pearl millet SDMV 91018, and lowest in the refined flour of pearl millet 91018. Analysis of variance could not assign significant differences as a result of large standard deviations.

5.3 Amylose content

Table 9 shows the amylose content of the refined and unrefined maize, sorghum and pearl millet flours.

Table 9: Amylose content of refined and unrefined maize, sorghum and pearl millet flours

Samples	Amylose content (% of total starch)
Maize PAN 6043 Unrefined	31.0^{a1} $(1.3)^2$
Maize PAN 6043 Refined	30.6^{ab} (0.9)
Maize PAN 6335 Unrefined	28.5^{bc} (1.2)
Maize PAN 6335 Refined	29.5^{abc} (1.0)
Sorghum KAT 369 Unrefined	29.2^{abc} (0.8)
Sorghum KAT 369 Refined	31.4^{a} (0.2)
Sorghum NK 283 Unrefined	21.7^{d} (0.3)
Sorghum NK 283 Refined	23.2^{d} (0.6)
Pearl millet SDMV 89004 Unrefined	29.9^{abc} (0.8)
Pearl millet SDMV 89004 Refined	31.2^{a} (0.7)
Pearl millet SDMV 91018 Unrefined	28.0^{c} (0.7)
Pearl millet SDMV 91018 Refined	29.9^{abc} (0.8)

1. Values with different letters in superscript are statistically significantly different ($p < 0.05$).
2. Values in the brackets are standard deviations.

There was no significant difference ($p < 0.05$) in amylose content between refined and unrefined flours of the same variety. The results for varieties and cereals were; all the varieties of maize, pearl millet and sorghum variety KAT 369 essentially had no significant differences in amylose content, but, they were significantly higher ($p < 0.05$) in amylose than unrefined and refined sorghum NK 283.

5.4 Texture

Table 10 shows the texture of stiff porridges prepared from refined and unrefined flours of maize, sorghum and pearl millet in terms of compression force (N) exerted by the probe by penetrating 4 mm deep.

Table 10: Texture in terms of compression force (N) for stiff porridges prepared from refined and unrefined flours of maize, sorghum and pearl millet

Samples	Compression Force (N)
Maize PAN 6043 Unrefined	19.3^{c}[1] (1.2)[2]
Maize PAN 6043 Refined	33.2^{a} (1.8)
Maize PAN 6335 Unrefined	20.8^{c} (1.9)
Maize PAN 6335 Refined	29.0^{b} (1.6)
Sorghum KAT 369 Unrefined	11.6^{d} (0.9)
Sorghum KAT 369 Refined	11.6^{d} (0.4)
Sorghum NK 283 Unrefined	6.6^{e} (0.3)
Sorghum NK 283 Refined	4.6^{e} (0.1)
Pearl millet SDMV 89004 Unrefined	12.0^{d} (0.4)
Pearl millet SDMV 89004 Refined	13.1^{d} (0.6)
Pearl millet SDMV 91018 Unrefined	12.7^{d} (1.2)
Pearl millet SDMV 91018 Refined	13.5^{d} (0.2)

1. Values with different letters in superscript are statistically significantly different ($p < 0.05$).
2. Values in the brackets are the standard deviations.

Refined flours of maize PAN 6043 and maize PAN 6335 produced the stiffest ($p < 0.05$) porridges while refined and unrefined flours of sorghum NK 283 produced the softest porridges. Refinement increased stiffness in maize porridge but not in sorghum and pearl millet.

5.5 *In vitro* starch digestibility

5.5.1 Starch digestibility of white wheat bread and porridges prepared from refined and unrefined flours of maize, sorghum and pearl millet.

After chewing, the bread and the maize stiff porridges formed thicker mashes than sorghum and pearl millet stiff porridges. Comparing sorghum and pearl millet, sorghum formed softer mash, especially that from sorghum NK 283. Unlike bread, sorghum and pearl millet, maize stiff porridges formed lumps in their mashes. In the process of incubation with pepsin, adjusting the pH and finally incubation with α-amylase, the mashes became thinner because these processes involved additional of solutions and gentle stirring. However, the thin mashes of maize stiff porridges were still containing lumps, but, not as larger as those in the thick mashes. On the other hand, there were no lumps present in either thick or thin mashes of the bread and those of sorghum and pearl millet stiff porridges.

Figure 8 compares the rate of *in vitro* starch digestibility of stiff porridges prepared from unrefined flours of maize, sorghum and pearl millet to that of white wheat bread.

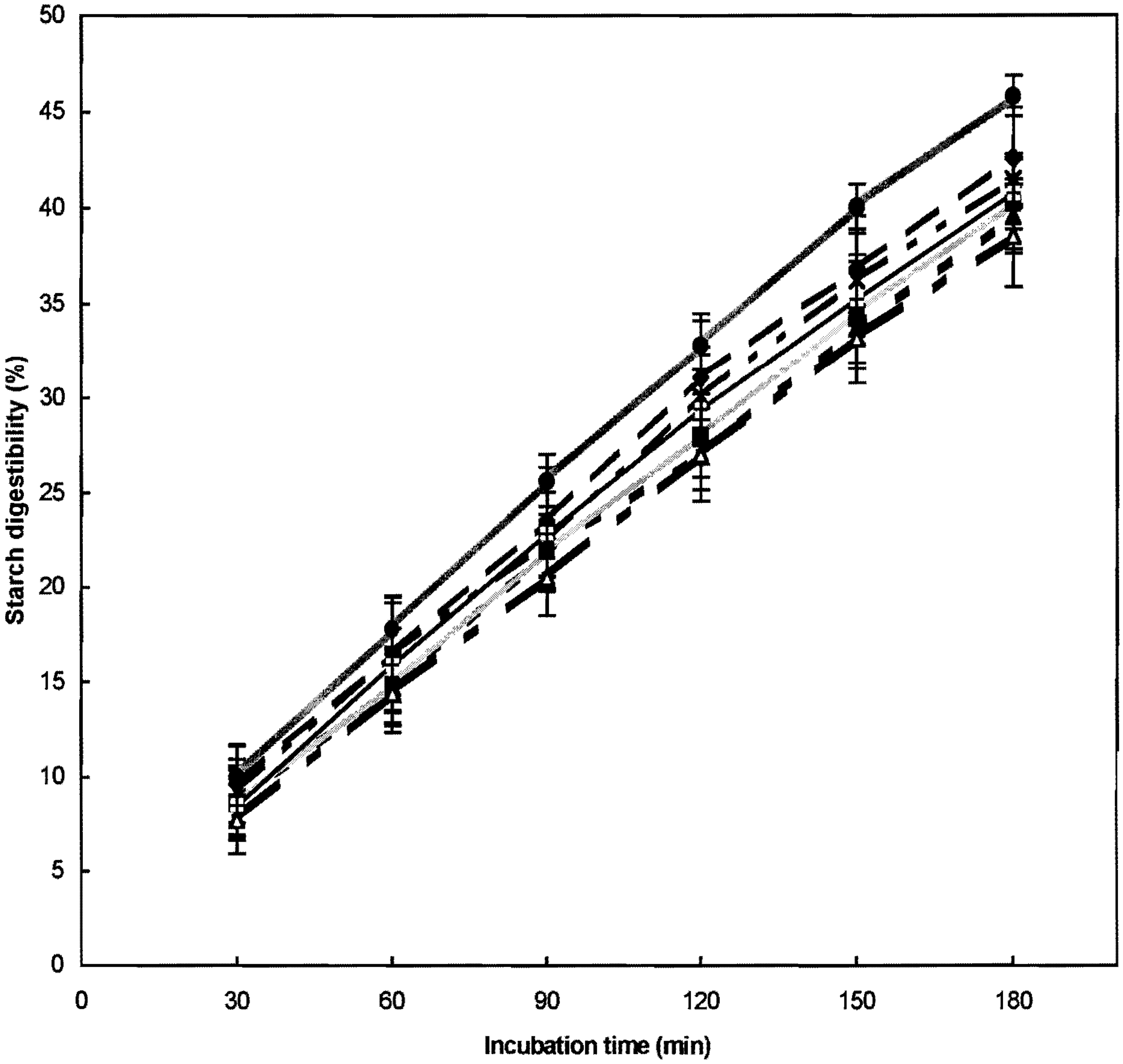

Figure 8: *In vitro* starch digestibility of stiff porridges prepared from unrefined cereal grain flours compared to white bread. (— — ▲— —) maize PAN 6043; (........■........) maize PAN 6335; (—— —◆—— —) sorghum KAT 369; (—— . ×——) sorghum NK 283; (——+——) pearl millet SDMV 89004; (—— . △—— .) pearl millet SDMV 91018 and (..........● ....) white wheat bread.

As seen in Figure 8, there were some differences in the rates of *in vitro* starch digestibility between white bread and the porridges and also between the porridge samples themselves. To make these differences more clear, linear models were fitted to the data. The model is expressed in the equation $y = mx + c$, where y is starch digested (%), x is incubation time (min), m is the slope of the line and c the intercept.

Figure 9 shows the fitted lines of starch digested against incubation time of stiff porridges prepared from unrefined flours of maize, sorghum and pearl millet compared to that of white wheat bread.

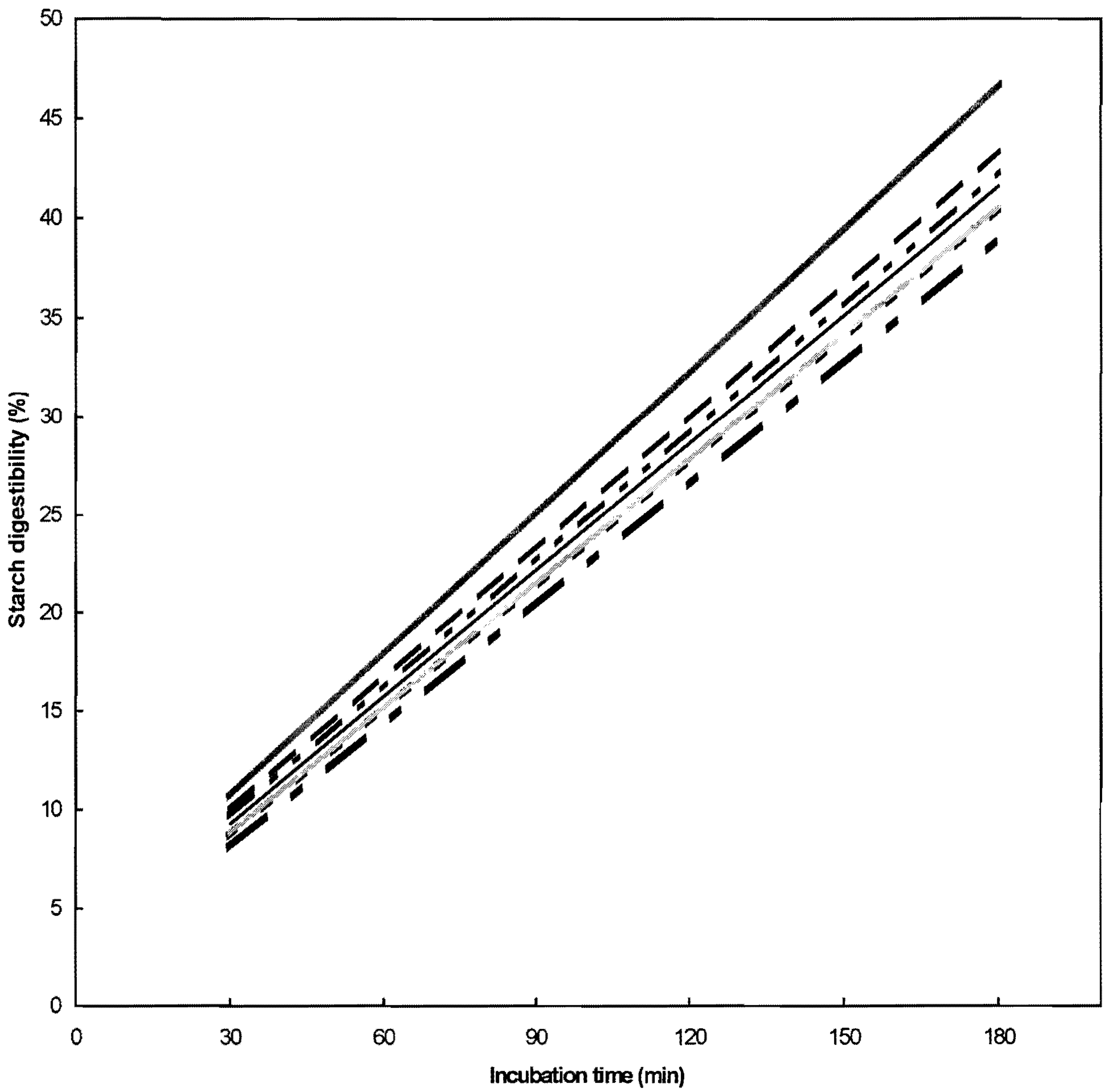

Figure 9: Fitted linear models of percentages starch digested against incubation time of stiff porridges prepared from unrefined cereal flours compared to white bread. (_ _ _) maize PAN 6043; (........) maize PAN 6335; (__ __) sorghum KAT 369; (__ . .) Sorghum NK 283; (_____) pearl millet SDMV 89004; (__ . __) pearl millet SDMV 91018 and (.........) white wheat bread.

Table 11 gives the regression statistics of the fitted models.

Table 11: Regression statistics of the linear models fitted to the data of digestibility against incubation time for white wheat bread and porridges prepared from unrefined flours of maize, sorghum and pearl millet

Sample	Coefficient of Determination (R^2)	Slope	Intercept
Maize PAN 6043	0.964	0.206[c,1]	2.58
Maize PAN 6335	0.964	0.213[bc]	2.36
Sorghum KAT 369	0.946	0.223[b]	3.32
Sorghum NK 283	0.957	0.218[bc]	3.13
Pearl millet SDMV 89004	0.962	0.215[bc]	2.81
Pearl millet SDMV 91018	0.967	0.207[c]	1.88
White wheat bread	0.999	0.241[a]	3.35

1 Slopes with different letters in the superscript are statistically significantly different ($p < 0.05$).

White wheat bread had a significantly higher rate ($p < 0.05$) of *in vitro* starch digestibility than the stiff porridges prepared from unrefined flours of maize, sorghum and pearl millet. Among the stiff porridges, only the stiff porridge from sorghum KAT 369 that had a significantly higher rate ($p < 0.05$) of *in vitro* starch digestibility than maize PAN 6043 and pearl millet SDMV 91018.

Figure 10 compares the rate of *in vitro* starch digestibility of stiff porridges prepared from refined flours of maize, sorghum and pearl millet to that of white wheat bread.

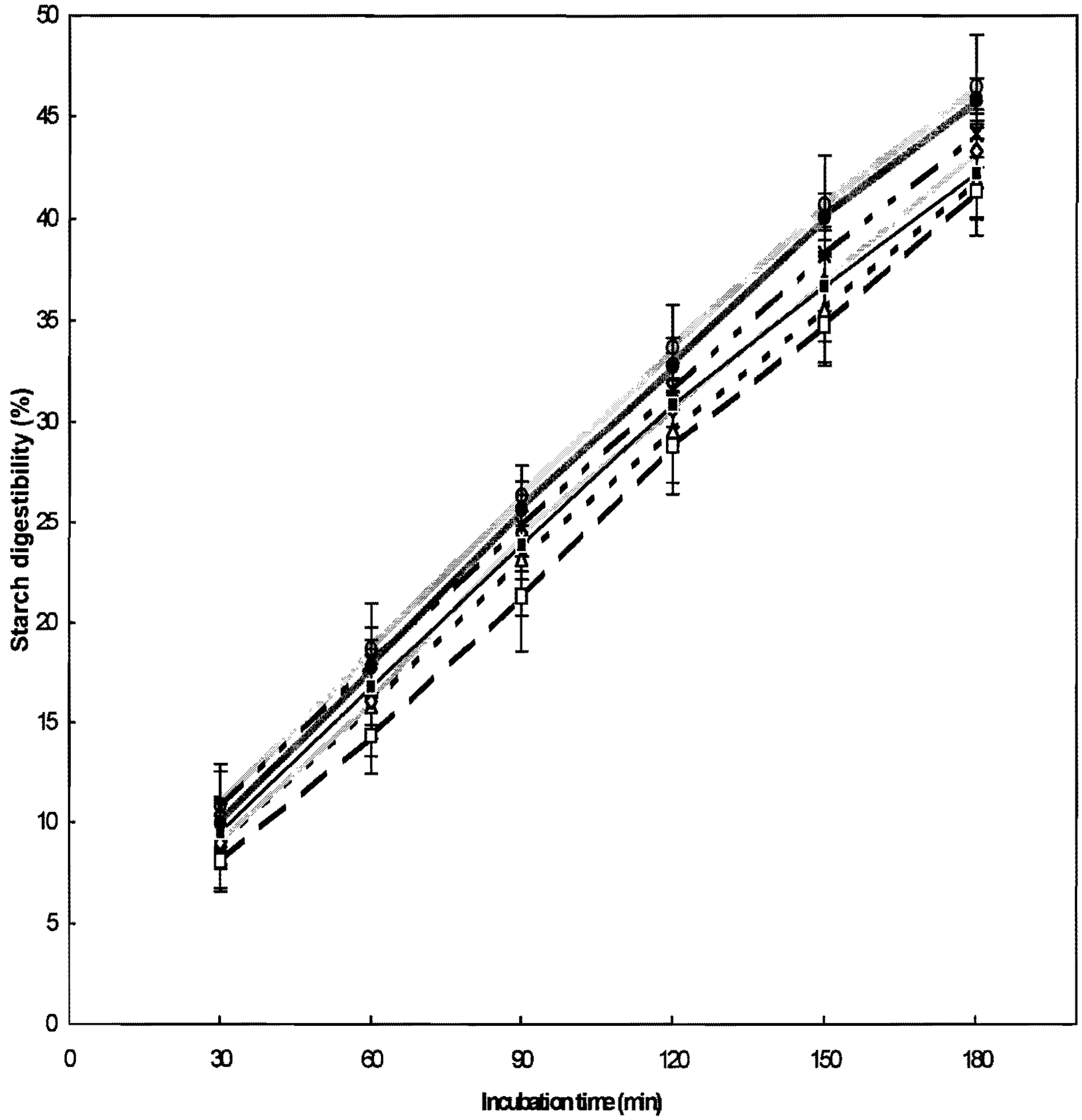

Figure 10: *In vitro* starch digestibility of stiff porridges prepared from refined cereal grain flours compared to white bread. (— — Δ — —) maize PAN 6043; (—— —□ —) maize PAN 6335; (······ ◊ ······) sorghum KAT 369; (······ O ······) sorghum NK 283; (—— · · ✻ ——) pearl millet SDMV 89004; (—— ■ ——) pearl millet SDMV 91018 and (········ ● ········) white wheat bread.

As seen in Figure 10, there were some differences in the rates of *in vitro* starch digestibility between white bread and the porridges and also between the porridge samples themselves. To make these differences more clear, linear models were fitted to the data. The model is expressed in the equation $y = mx + c$, where y is starch digested (%), x is incubation time (min), m is the slope of the line and c the intercept.

Figure 11 shows the fitted lines of starch digested against incubation time of stiff porridges prepared from refined flours of maize, sorghum and pearl millet compared to that of white wheat bread.

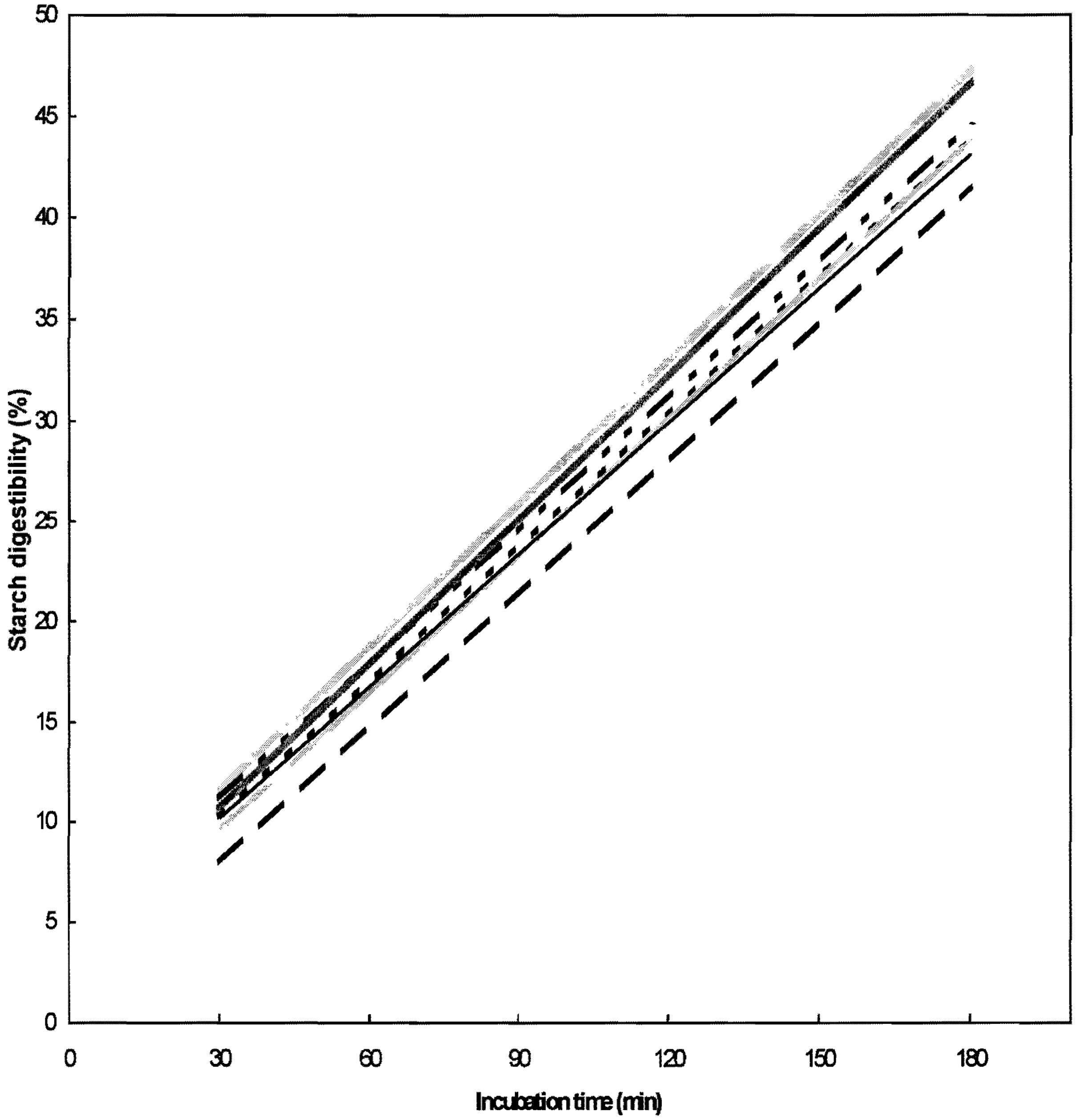

Figure 11: Fitted linear models of percentages starch digested against incubation time of stiff porridges prepared from refined cereal grain flours compared to white bread. (— — —) maize PAN 6043; (—— ——) maize PAN 6335; (..........) sorghum KAT 369; (..........) sorghum NK 283; (—— . .) pearl millet SDMV 89004; (——) pearl millet SDMV 91018 and (..........) white wheat bread.

Table 12 gives the regression statistics of the fitted models.

Table 12: Regression statistics of the linear models fitted to the data of digestibility against incubation time for white bread and porridges prepared from refined flours of maize, sorghum and pearl millet

Sample	Coefficient of Determination (R^2)	Slope	Intercept
Maize PAN 6043	0.953	$0.219^{c,1}$	2.82
Maize PAN 6335	0.972	0.224^{c}	1.28
Sorghum KAT 369	0.980	0.229^{bc}	2.70
Sorghum NK 283	0.969	0.240^{ab}	4.31
Pearl millet SDMV 89004	0.983	0.223^{c}	4.53
Pearl millet SDMV 91018	0.968	0.219^{c}	3.64
White wheat bread	0.999	0.241^{a}	3.35

1 Slopes with different letters in the superscript are statistically significantly ($p < 0.05$) different.

With the exceptional of stiff porridge prepared from sorghum NK 283, white bread had a significantly higher rate ($p < 0.05$) of *in vitro* starch digestibility than all the stiff porridges prepared from refined flours of maize, sorghum and pearl millet. Porridges prepared from refined flours of maize and pearl millet had in general the slowest rate of *in vitro* starch digestibility. There was no significant difference in the rate of *in vitro* starch digestibility between the two sorghum varieties.

Figure 12 compares the rate of *in vitro* starch digestibility of stiff porridges prepared from refined and unrefined flours of maize PAN 6043 to that of white wheat bread.

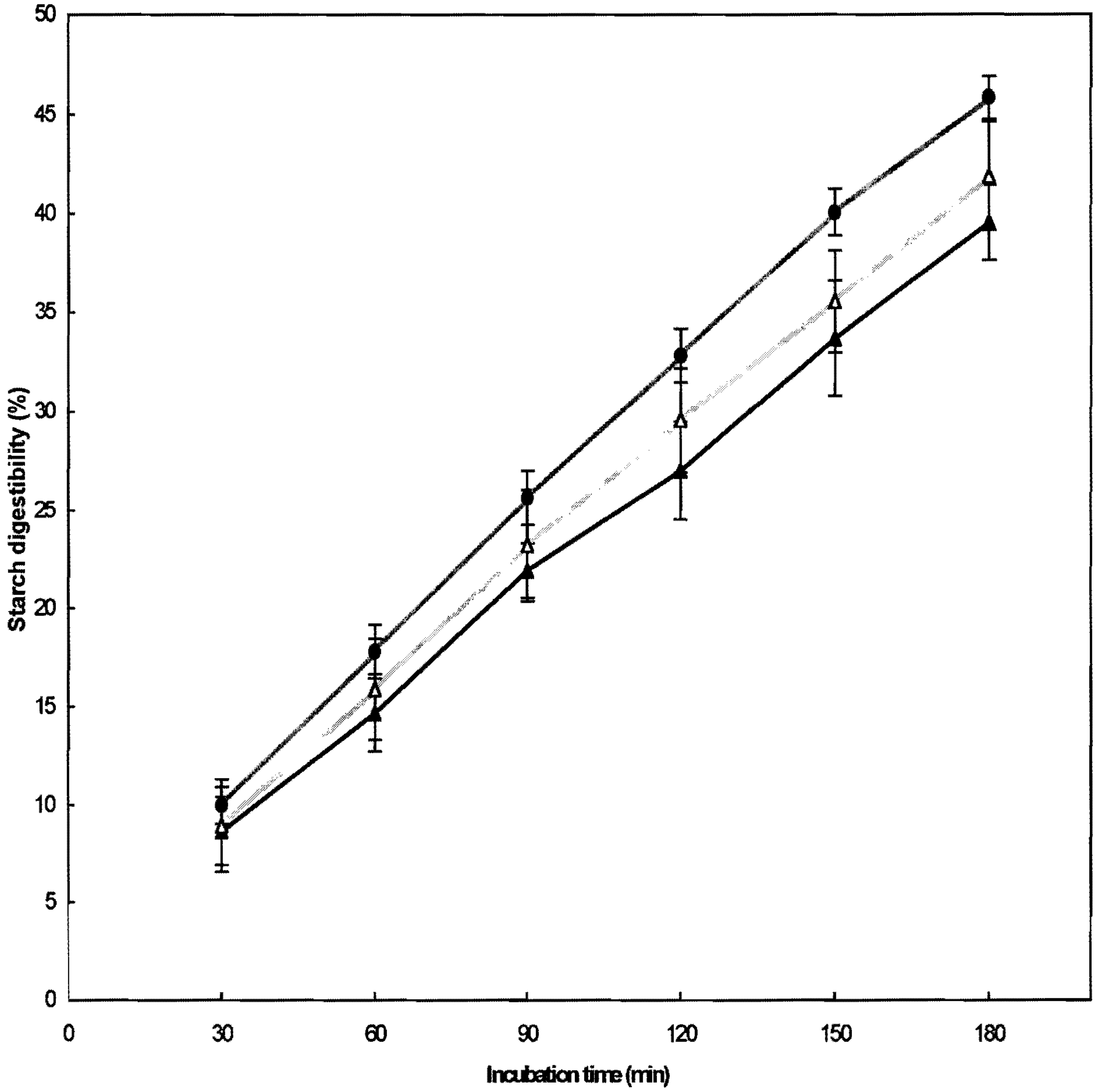

Figure 12: ***In vitro*** **starch digestibility of stiff porridges prepared from refined (Δ) and unrefined (▲) flours of maize PAN 6043 compared to that of white wheat bread (●)**

As seen in Figure 12, there were differences in the rates of *in vitro* starch digestibility between white wheat bread and stiff porridges prepared from both refined and unrefined flours of maize PAN 6043. To make these differences more clear, linear models were fitted to the data. The model is expressed in the equation $y = mx + c$, where y is starch digested (%), x is incubation time (min), m is the slope of the line and c the intercept.

Figure 13 shows the fitted lines of starch digested against incubation time of stiff porridges prepared from refined and unrefined flours of maize PAN 6043 compared to that of white wheat bread.

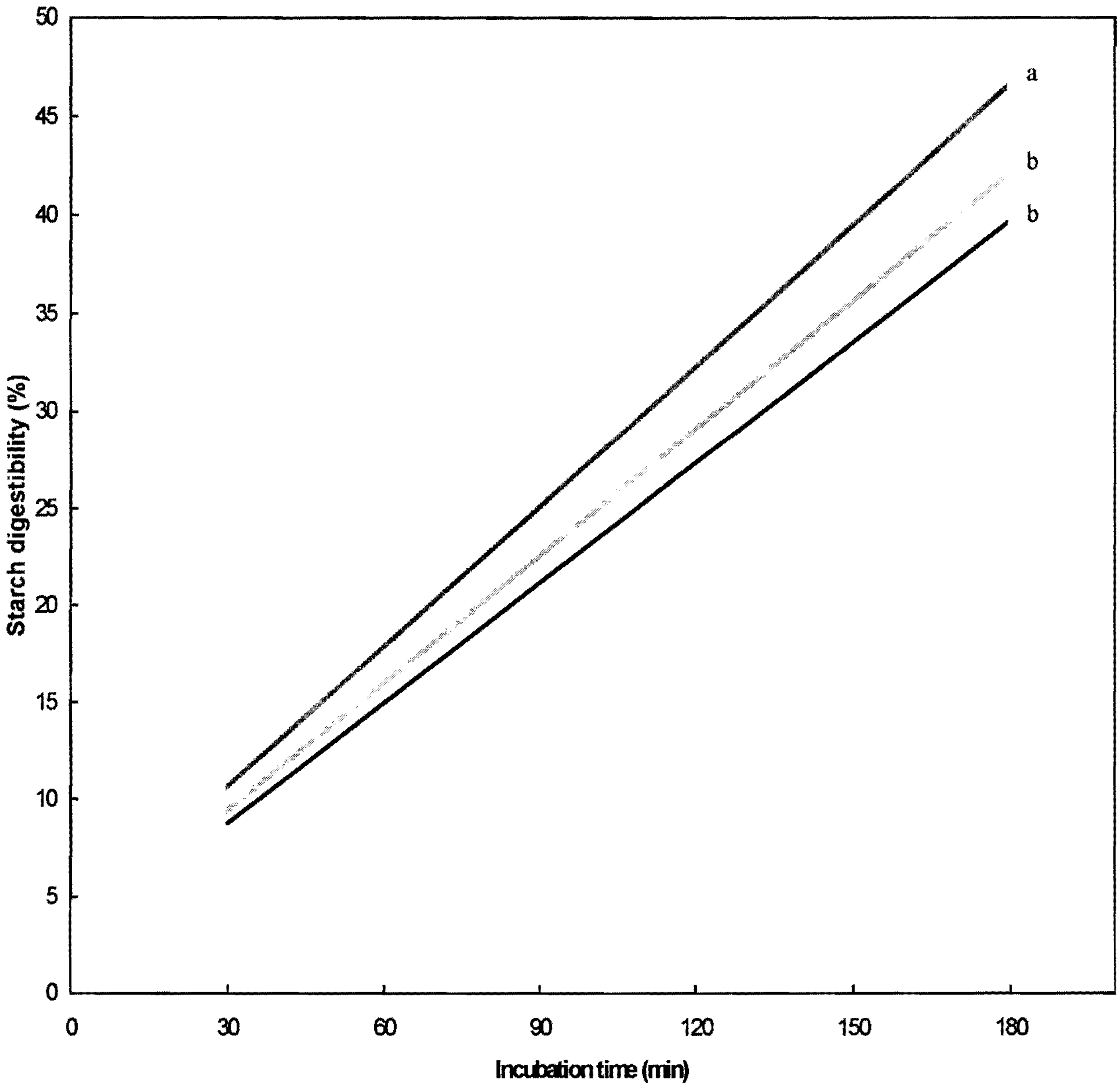

Figure 13: Fitted linear models of percentages starch digested against incubation time of stiff porridges prepared from refined (········) and unrefined (———) flours of maize PAN 6043 compared to that of white wheat bread (········)

The fitted lines with different letters show the samples that were significantly different.

The fitted lines in Figure 13 show that white wheat bread had a significantly higher rate ($p < 0.05$) of *in vitro* starch digestibility than those from the stiff porridges prepared from refined and unrefined flours of maize PAN 6043. There was no significant difference ($p < 0.05$) in the rate of *in vitro* starch digestibility between the stiff porridge prepared from refined and that prepared from unrefined flour of maize PAN 6043.

Figure 14 compares the rate of *in vitro* starch digestibility of stiff porridges prepared from refined and unrefined flours of maize PAN 6335 to that of white wheat bread.

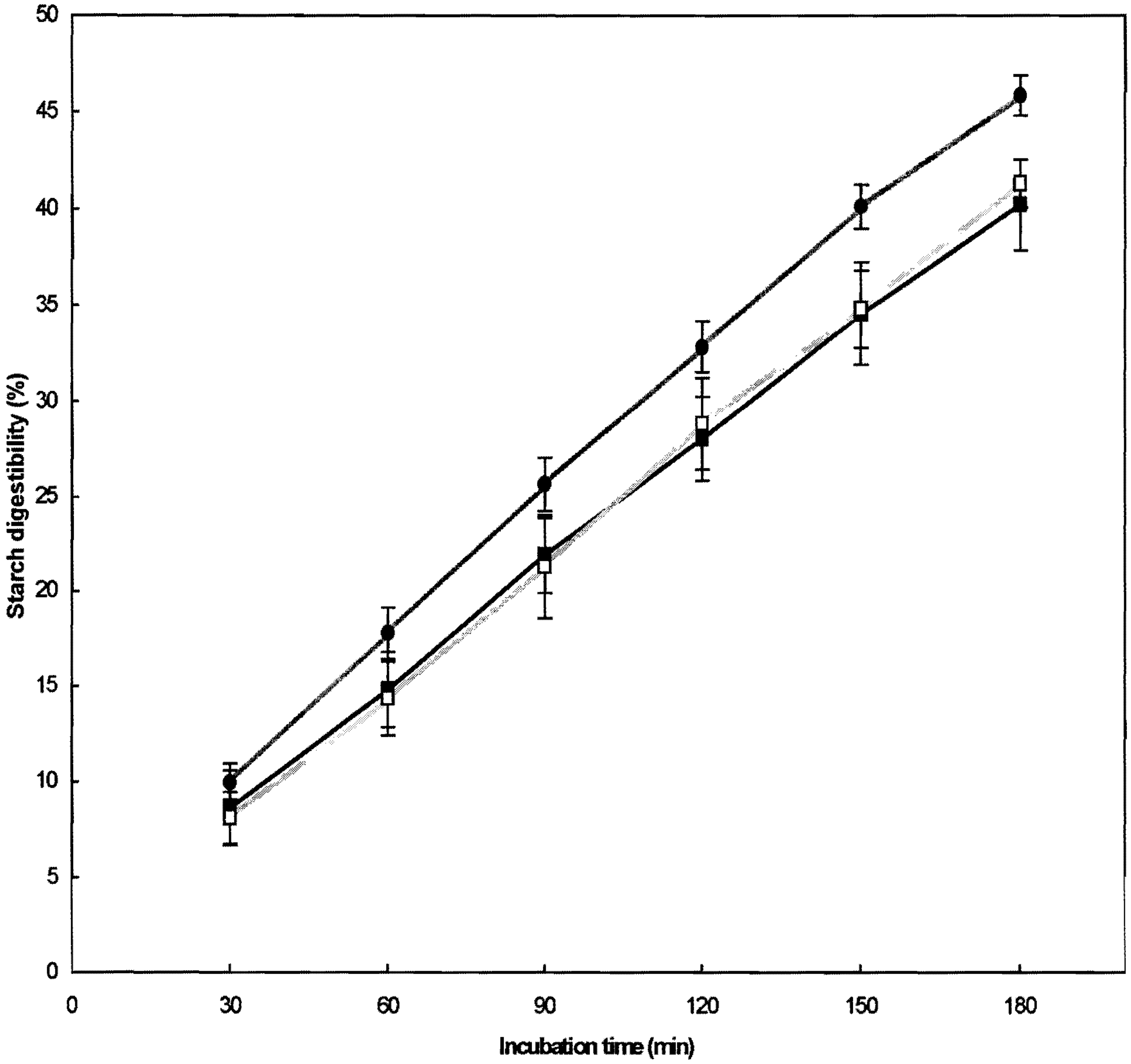

Figure 14: ***In vitro*** **starch digestibility of stiff porridges prepared from refined (□) and unrefined (■) flours of maize PAN 6335 compared to that of white wheat bread (●)**

As seen in Figure 14, there were differences in the rates of *in vitro* starch digestibility between white wheat bread and both of the stiff porridges prepared from refined and unrefined flours of maize PAN 6335. To make these differences more clear, linear models were fitted to the data. The model is expressed in the equation $y = mx + c$, where y is starch digested (%), x is incubation time (min), m is the slope of the line and c the intercept.

Figure 15 shows the fitted lines of starch digested against incubation time of stiff porridges prepared from refined and unrefined flours of maize PAN 6335 compared to that of white wheat bread.

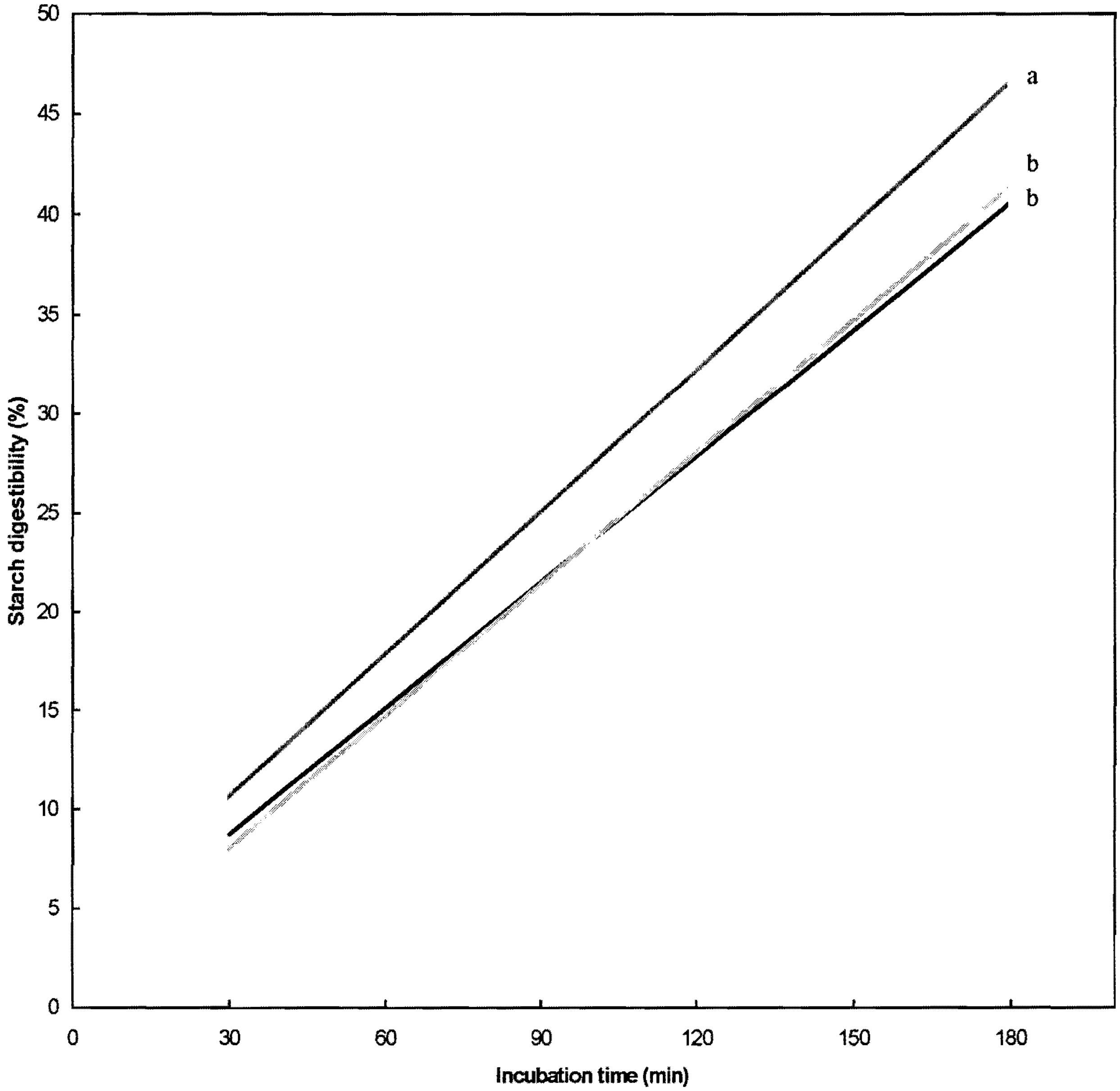

Figure 15: Fitted linear models of percentages starch digested against incubation time of stiff porridges made from refined ( ) and unrefined ( ) flours of maize PAN 6335 compared to that of white wheat bread ( )

The fitted lines with different letters show the samples that were significantly different.

The fitted lines in Figure 15 show that white wheat bread had a significantly higher rate ($p < 0.05$) of *in vitro* starch digestibility than those from the stiff porridges prepared from refined and unrefined flours of maize PAN 6335. There was no significant difference in the rate of *in vitro* starch digestibility between the stiff porridge prepared from refined and that prepared from unrefined flour of maize PAN 6335.

Figure 16 compares the rate of *in vitro* starch digestibility of stiff porridges prepared from refined and unrefined flours of sorghum KAT 369 to that of white wheat bread.

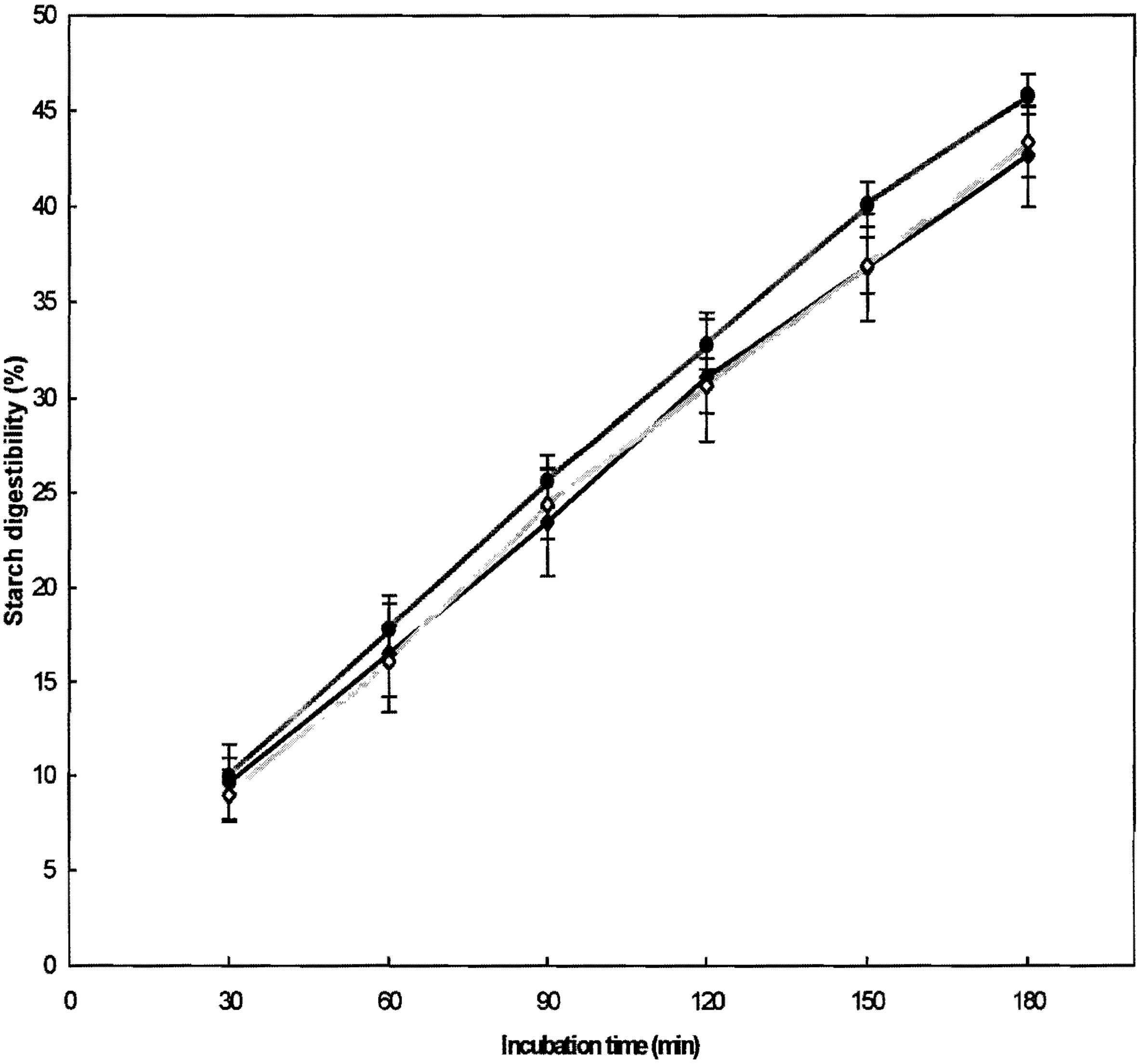

Figure 16: *In vitro* starch digestibility of stiff porridges prepared from refined (◊) and unrefined (◆) flours of sorghum KAT 369 compared to that of white wheat bread (●)

As seen in Figure 16, there were some differences in the rates of *in vitro* starch digestibility between white wheat bread and both of the stiff porridges prepared from refined and unrefined flours of sorghum KAT 369. To make these differences more clear, linear models were fitted to the data. The model is expressed in the equation $y = mx + c$, where y is starch digested (%), x is incubation time (min), m is the slope of the line and c the intercept.

Figure 17 shows the fitted lines of starch digested against incubation time of stiff porridges prepared from refined and unrefined flours of sorghum KAT 369 compared to that of white wheat bread.

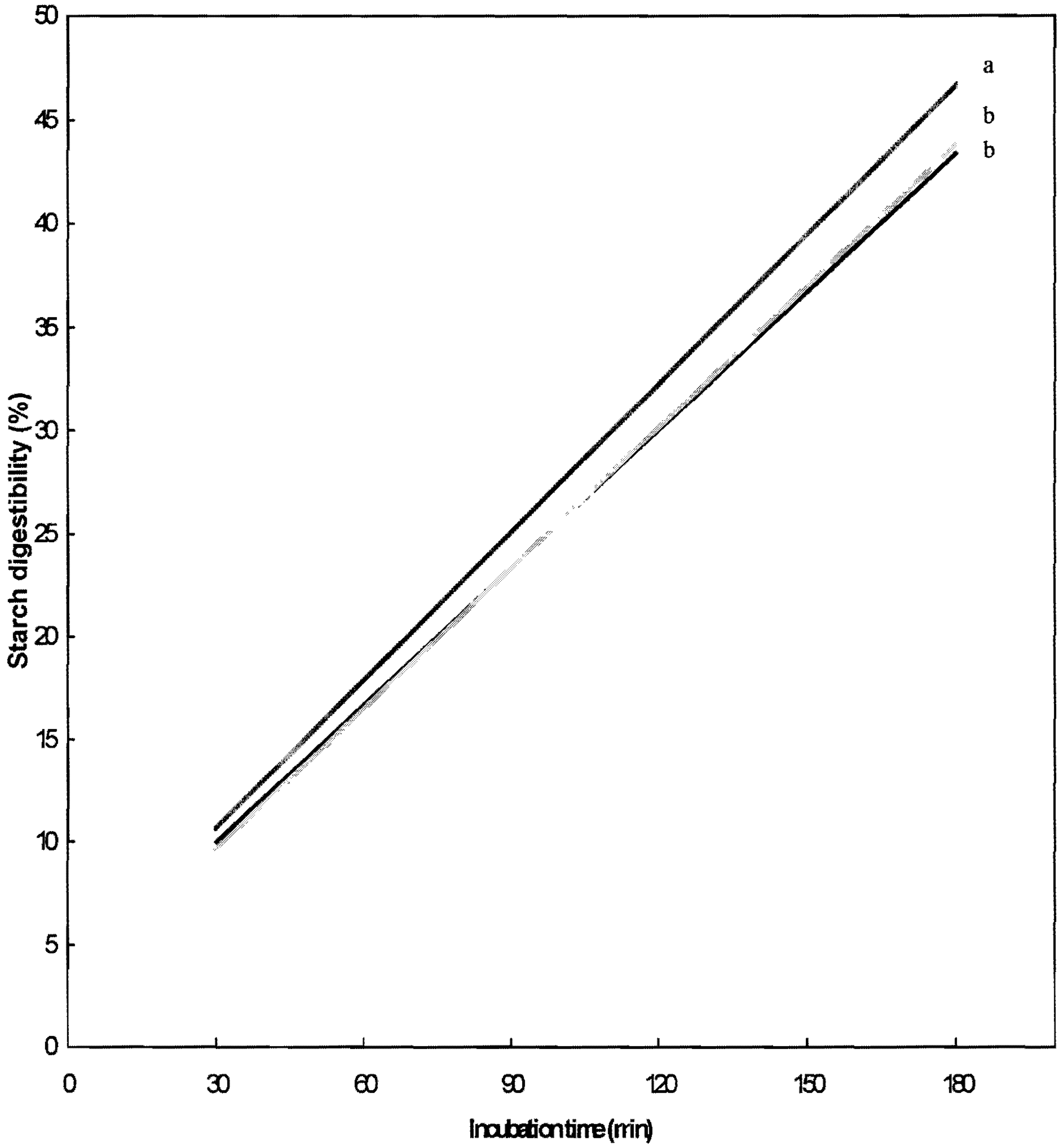

Figure 17: Fitted linear models of percentages starch digested against incubation time of stiff porridges prepared from refined (⸻) and unrefined (⸻) flours of sorghum KAT 369 compared to that of white wheat bread (⸻)

The fitted lines with different letters show the samples that were significantly different.

The fitted lines in Figure 17 show that white wheat bread had a significantly higher rate ($p < 0.05$) of *in vitro* starch digestibility than those from the stiff porridges prepared from refined and unrefined flours of sorghum KAT 369. There was no significant difference ($p < 0.05$) in the rate of *in vitro* starch digestibility between the stiff porridge prepared from refined and unrefined flours of sorghum KAT 369.

Figure 18 compares the rate of *in vitro* starch digestibility of stiff porridges prepared from refined and unrefined flours of sorghum NK 283 to that of white wheat bread.

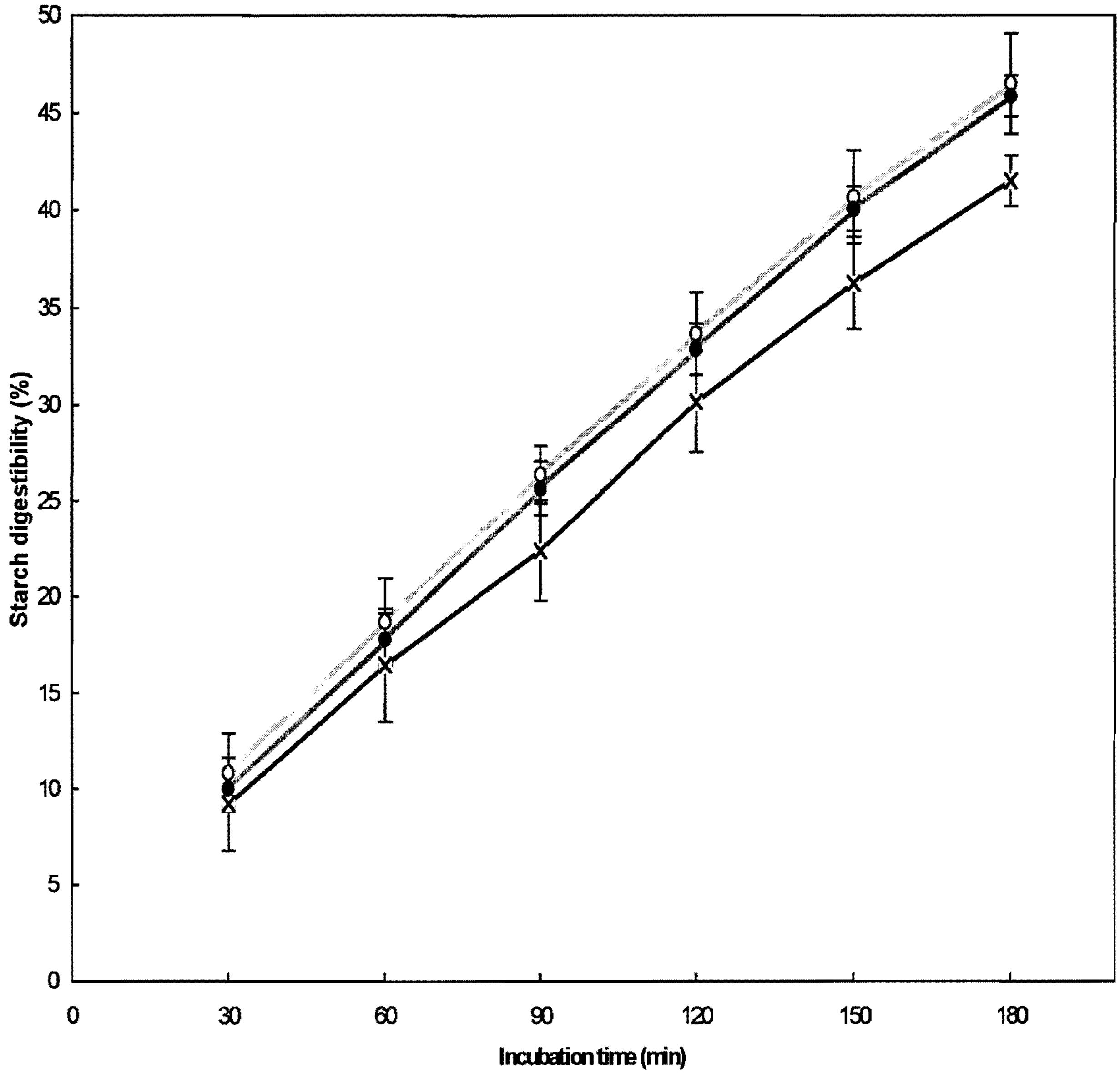

Figure 18: ***In vitro*** **starch digestibility of stiff porridges prepared from refined (O) and unrefined (X) flours of sorghum NK 283 compared to that of white wheat bread (●)**

As seen in Figure 18, there was a difference in the rates of *in vitro* starch digestibility between white wheat bread and the stiff porridge prepared from unrefined flour of sorghum NK 283. To make these differences more clear, linear models were fitted to the data. The model is expressed in the equation $y = mx + c$, where y is starch digested (%), x is incubation time (min), m is the slope of the line and c the intercept.

Figure 19 shows the fitted lines of starch digested against incubation time of stiff porridges made from refined and unrefined flours of sorghum NK 283 compared to that of white wheat bread.

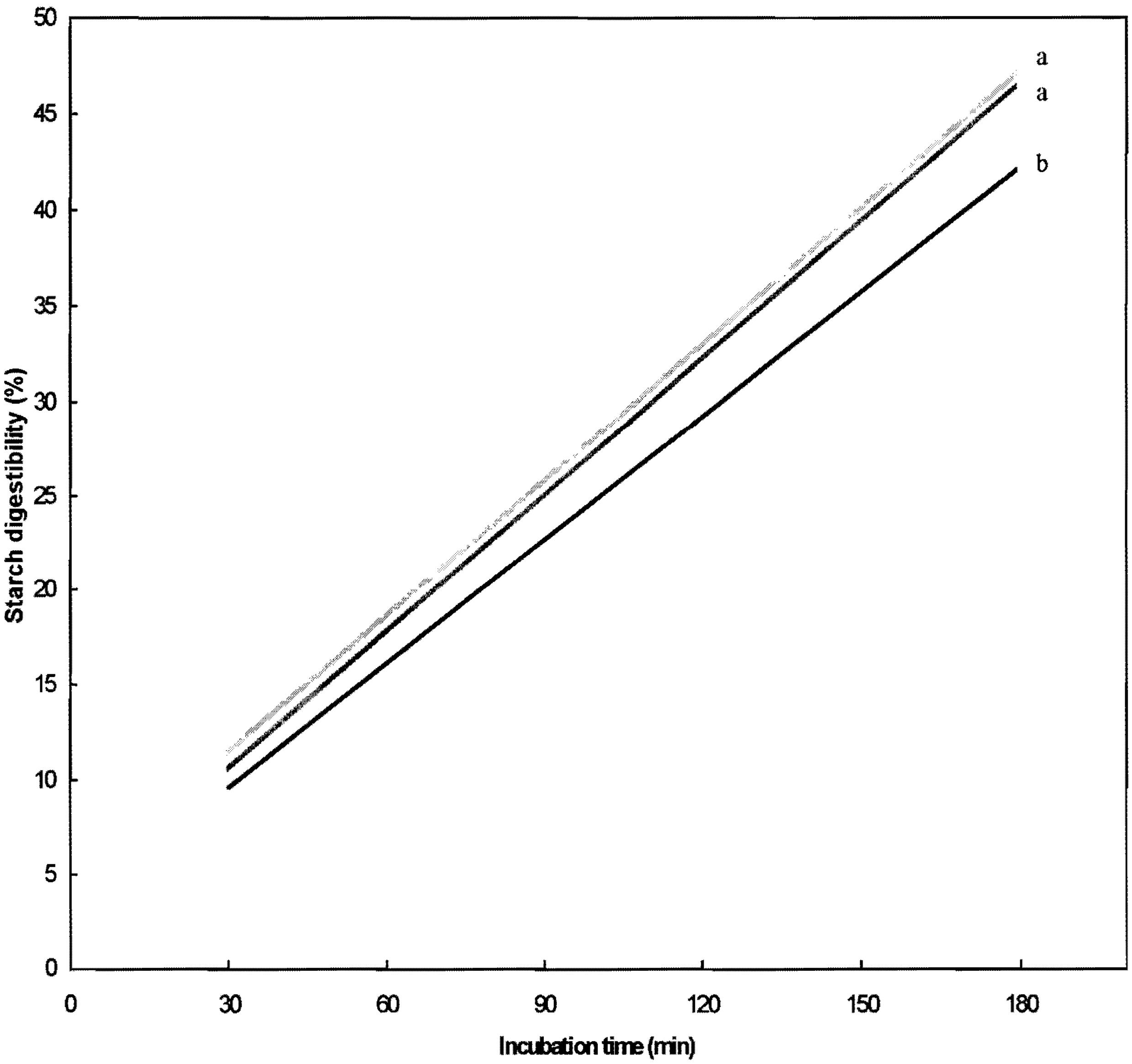

Figure 19: Fitted linear models of percentages starch digested against incubation time of stiff porridges prepared from refined ( ) and unrefined ( ) flours of sorghum NK 283 compared to that of white wheat bread ( )

The fitted lines with different letters show the samples that were significantly different.

The fitted lines in Figure 19 show that white wheat bread had a significantly higher rate ($p < 0.05$) of *in vitro* starch digestibility than that of the stiff porridge prepared from unrefined flour of sorghum NK 283. On the other hand stiff porridge prepared from refined flour of sorghum NK 283 did not differ significantly ($p < 0.05$) from the white wheat bread.

Figure 20 compares the rate of *in vitro* starch digestibility of stiff porridges made from refined and unrefined flours of pearl millet SDMV 89004 to that of white wheat bread.

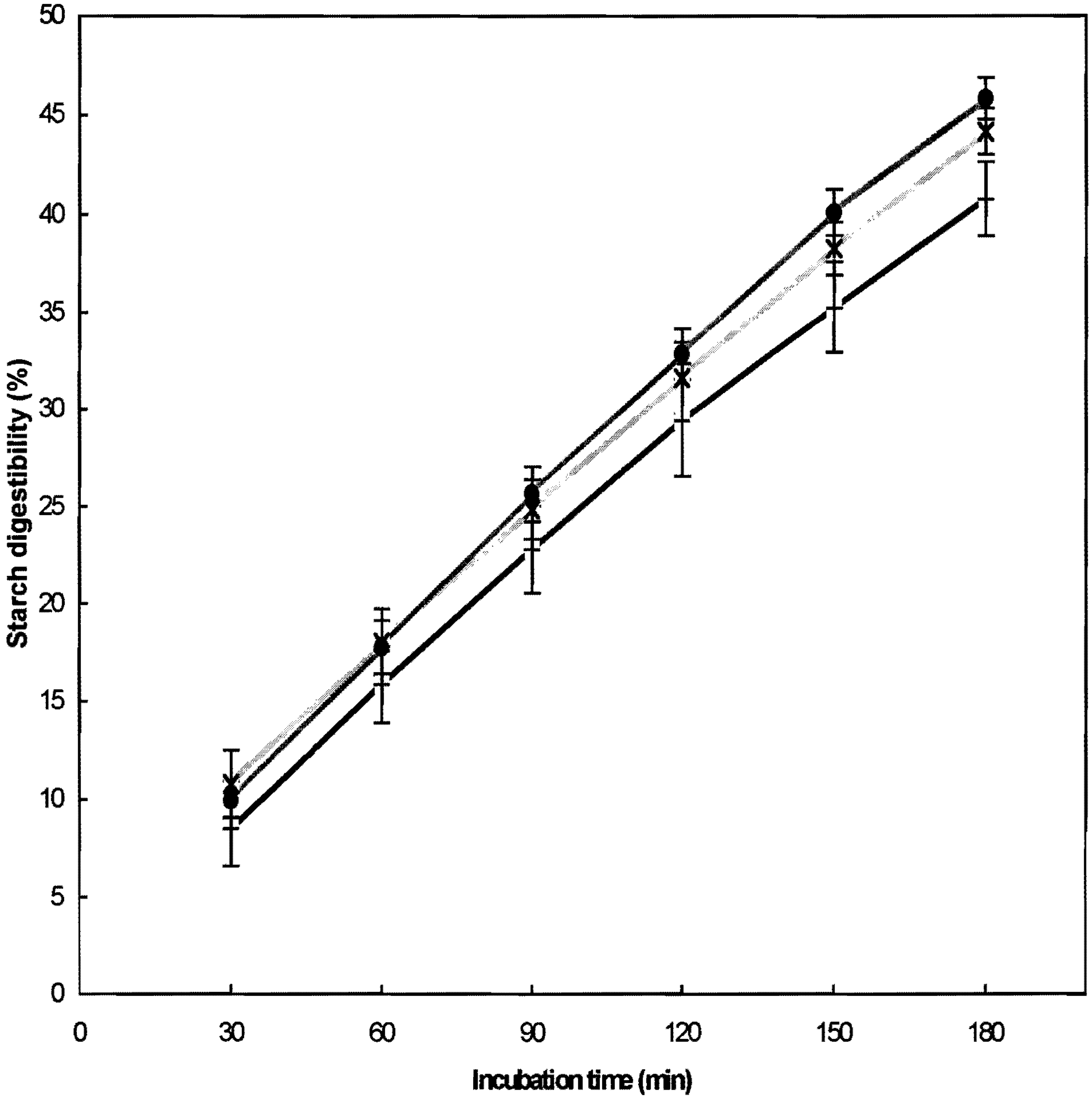

Figure 20: *In vitro* starch digestibility of stiff porridges made from refined (✻) and unrefined (+) flours of pearl millet SDMV 89004 compared to that of white wheat bread (●)

As seen in Figure 20, there were differences in the rates of *in vitro* starch digestibility between white wheat bread and the stiff porridges prepared from refined and unrefined flours of pearl millet SDMV 89004. To make these differences more clear, linear models were fitted to the data. The model is expressed in the equation $y = mx + c$, where y is starch digested (%), x is incubation time (min), m is the slope of the line and c the intercept.

Figure 21 shows the fitted lines of starch digested against incubation time of stiff porridges made from refined and unrefined flours of pearl millet SDMV 89004 compared to that of white wheat bread.

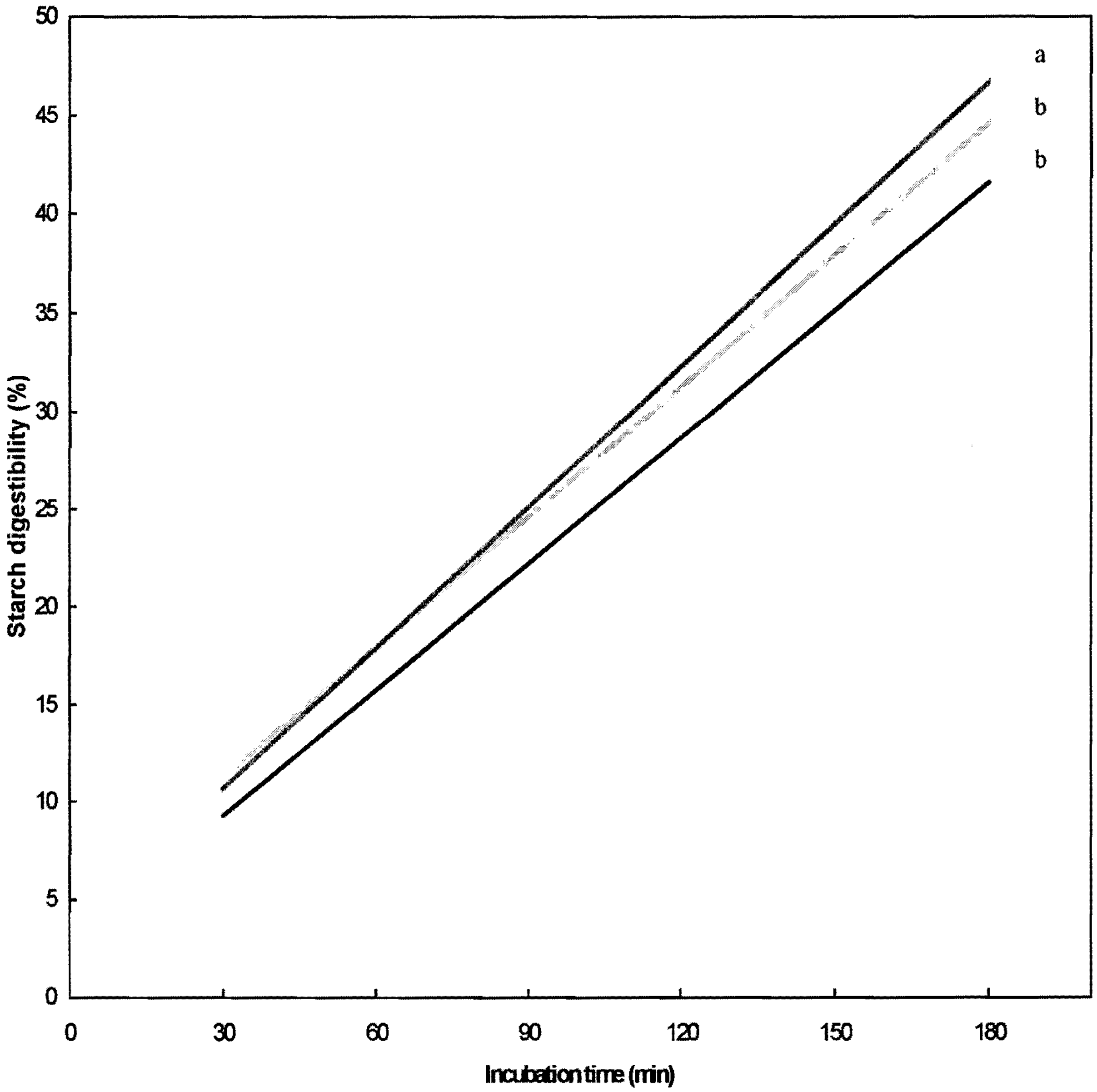

Figure 21: Fitted linear models of percentages starch digested over time of stiff porridges made from refined (········) and unrefined (———) flours of pearl millet SDMV 89004 compared to that of white bread (········)

The fitted lines with different letters show the samples that were significantly different.

The fitted lines in Figure 21 show that bread had a significantly higher rate ($p < 0.05$) of *in vitro* starch digestibility than those from the stiff porridges prepared from refined and unrefined flours of pearl millet SDMV 98004. There was no significant difference ($p < 0.05$) in the rate of *in vitro* starch digestibility between the stiff porridge prepared from refined and that prepared from unrefined flour of pearl millet SDMV 89004.

Figure 22 compares the rate of *in vitro* starch digestibility of stiff porridges made from refined and unrefined flours of pearl millet SDMV 91018 to that of white wheat bread.

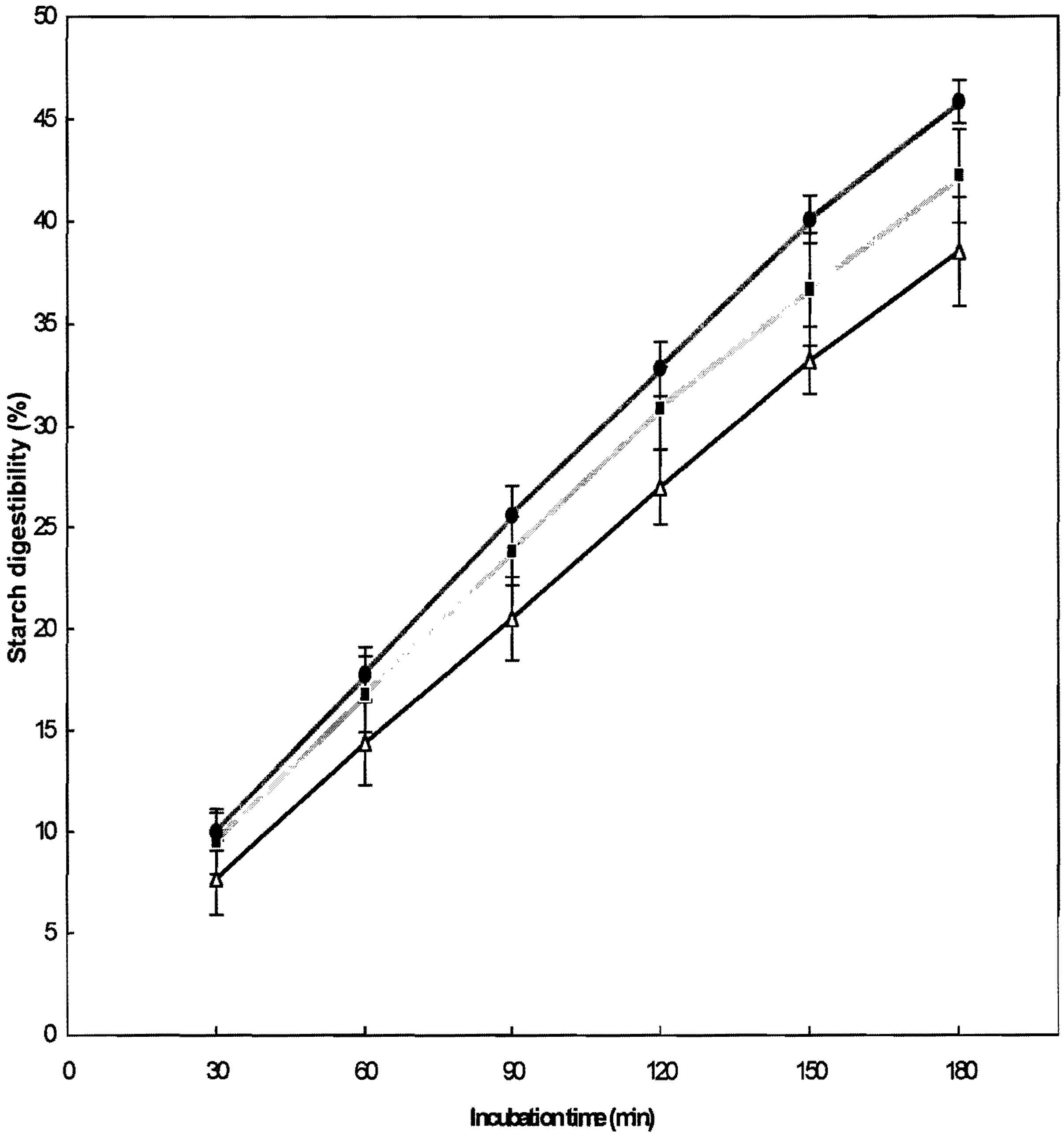

Figure 22: *In vitro* starch digestibility of stiff porridges made from refined (■) and unrefined (Δ) flours of pearl millet SDMV 91018 compared to that of white wheat bread (●)

As seen in Figure 22, there were differences in the rates of *in vitro* starch digestibility between white wheat bread and both of the stiff porridges prepared from refined and unrefined flours of pearl millet SDMV 91018. To make these differences more clear, linear models were fitted to the data. The model is expressed in the equation $y = mx + c$, where y is starch digested (%), x is incubation time (min), m is the slope of the line and c the intercept.

Figure 23 shows the fitted lines of starch digested against incubation time of stiff porridges made from refined and unrefined flours of pearl millet SDMV 91018 compared to that of white wheat bread.

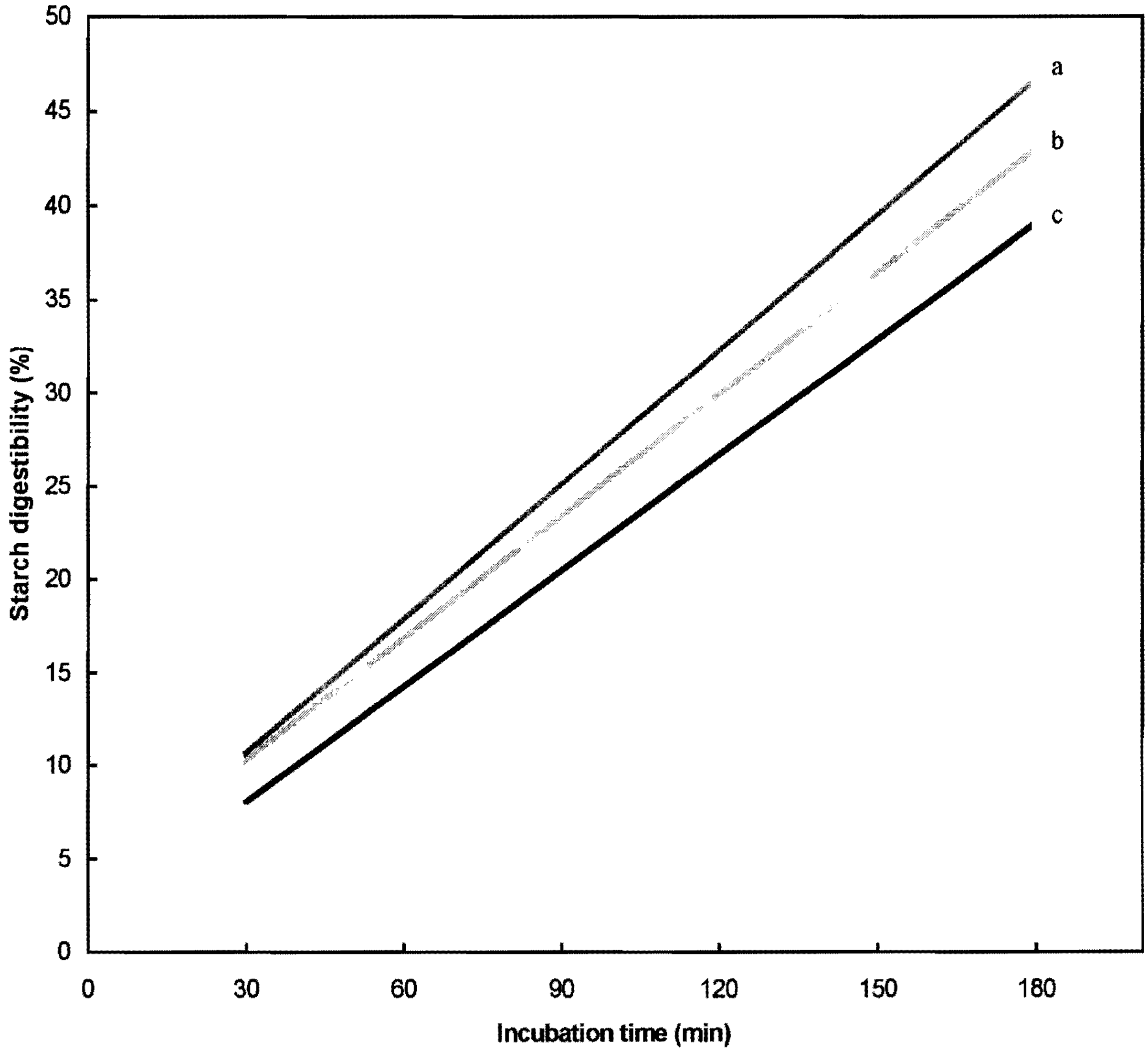

Figure 23: Fitted linear models of percentages starch digested over time of stiff porridges made from refined (……) and unrefined (——) flours of pearl millet SDMV 91018 compared to that of white wheat bread (……)

The fitted lines with different letters show the samples that were significantly different.

The fitted lines in Figure 23 show that white wheat bread had a significantly higher rate ($p < 0.05$) of *in vitro* starch digestibility than those from the stiff porridges prepared from refined and unrefined flours of pearl millet SDMV 91018. Also the stiff porridge prepared from refined flour of pearl millet SDMV 91018 had a significantly higher rate ($p < 0.05$) of *in vitro* starch digestibility than that prepared from unrefined flour.

5.6 ANOVA between the unrefined and refined treatments on maize, sorghum and pearl millet

Table 13 below shows the mean percentage starch digestibility of the stiff porridges and the 'F' value from the analysis of variance between the unrefined and refined treatments on the three cereals.

Table 13: Mean percentage starch digestibility and ANOVA between the unrefined and refined treatments on maize, sorghum and pearl millet

Treatments	Mean percentage starch digestibility of the stiff porridges
Unrefined	25.6 (11.4)[1]
Refined	27.4 (12.1)
F = 0.4601 (Not significant)	

1 Values in the brackets are standard deviations.

The results of the analysis of variance between the unrefined and refined treatments showed that, overall, there was no significant difference between the two treatments.

5.7 Hydrolysis index (HI) and predicted glycaemic index (GI)

Granfeldt (1994), according to Akerberg *et al.* (1998) found a significant correlation ($r = 0.862$) between HI and GI which was used to predict GI by using the equation $GI = 0.862HI + 8.198$. Table 14 below shows the calculated HI and predicted GI for the bread and stiff porridges by using bread and glucose references.

Table 14: Hydrolysis index (HI) and predicted glycaemic index (GI) of maize, sorghum, pearl millet and bread

Samples	HI	GI (Bread ref.)	GI (Glucose ref.)
Bread	100^{a1} $(0)^2$	94^a (0)	66^a (0)
Maize PAN 6043 Unrefined	92^{bc} (1)	87^{bc} (1)	61^{bc} (1)
Maize PAN 6043 Refined	96^{ab} (1)	90^{ab} (1)	63^{ab} (1)
Maize PAN 6335 Unrefined	87^c (6)	83^c (5)	58^c (4)
Maize PAN 6335 Refined	88^c (2)	84^c (1)	59^c (1)
Sorghum KAT 369 Unrefined	91^{bc} (5)	87^{bc} (4)	61^{bc} (3)
Sorghum KAT 369 Refined	90^{bc} (6)	86^{bc} (5)	60^{bc} (3)
Sorghum NK283 Unrefined	92^{bc} (1)	88^{bc} (1)	61^{bc} (1)
Sorghum NK 283 Refined	102^a (0)	96^a (0)	67^a (0)
Pearl millet SDMV 89004 Unrefined	86^c (1)	83^c (1)	58^c (1)
Pearl millet SDMV 89004 Refined	92^{bc} (6)	88^{bc} (5)	61^{bc} (3)
Pearl millet SDMV 91018 Unrefined	85^c (0)	81^c (0)	57^c (0)
Pearl millet SDMV 91018 Refined	92^{bc} (4)	88^{bc} (4)	61^{bc} (3)

1 Values with different letters in superscript in the same column are statistically significantly different ($p < 0.05$).

2 Values in the brackets are standard deviations.

Bread and the stiff porridges prepared from refined flours of sorghum NK 283 and maize PAN 6043 had a significantly higher ($p < 0.05$) hydrolysis and glycaemic indices than all the other stiff porridges prepared from unrefined and refined flours of maize, sorghum and pearl millet.

Porridges prepared from the unrefined flours of pearl millet SDMV 89004 and SDMV 91018 and unrefined and refined flours of maize PAN 6335 had the lowest HI and GI.