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ANIMAL PRODUCTION

Impact of filament denier on functional performance of microfiber *in situ* bags

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ABSTRACT. *In situ* bags made from microfiber fabrics have a greater surface area and filtration efficiency that retains the fine particles and reduce the variation in the results. Also, it is more durable than that made from traditional fabrics. This work aimed to study the effect of filament denier on the performance of *in situ* bags. Two polyester microfilaments with 0.4 and 0.7 deniers were used in manufacturing of four fabrics. Physical and mechanical properties of manufactured fabrics were measured before and after incubation to show the efficiency of the manufactured samples. In vitro trail was conducted to estimate ruminal degradability after 24 and 48 hours for three feedstuffs using three cannulated rams as replicates. The mechanical properties of manufactured *in situ* bags were significantly affected with both denier per filament and weft densities. According to the statistical analysis of radar chart, sample 2 remarked the highest value which achieved the acceptable ruminal dry matter disappearance compared with Ankom bags in different incubation times.

Keywords: degradability; denier per filament; fine particles; *in situ* method; ruminal incubation; weft density.

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Introduction

In situ bag technique is an effective and widely used method for feed evaluation (Aboamer et al., 2017; Shuang-zhao et al., 2017; Pagella, Mayes, Pérez-Barbería, & Ørskov, 2018). It provides fairy good estimations for ruminal degradation kinetics nearest to that observed using in vivo studies, while saving time and cost of labor. The material of the bag should be durable, and its porosity must allow the influx of rumen microorganisms and the outflow of the degraded particles, while keep the non-degraded (Valente, Detmann, & Sampaio, 2015; Valente et al., 2011).

A microfiber is defined by many researchers as a finer filament of a linear density approximately 1 dtex or less or 1 denier, this including the staple fibers and filaments (AL Sarhan, 2011; Kaynak & Babaarslan, 2016). Its diameter equals to one third the fiber diameter of cotton, one quarter the fiber diameter of wool and one hundred times finer than human hair. The demand of using microfiber increased during the last decade due to their superior in physical and textile properties (AL-ansary, 2012; Kaynak & Babaarslan, 2016). It is relatively soft, strong and durable compared with traditional fabrics of the same weight. Also, yarn has better regularity, adequate elongation, excellent flexibility and good drapability (AL Sarhan, 2011; Abd El-Hady, 2019). The smaller filaments denier with greater number of filaments per yarn facilitate packing of yarns more tightly and increase fabric's surface area while decreasing space between fibers (Abou Nassif, 2012). These properties make microfiber fabrics as a good alternative for made *in situ* bags. This work aimed to manufacture of four woven polyester microfibers *in situ* bags with different denier per filament and its influence on the ruminal degradation of three feedstuffs.

Material and method

Manufacturing of microfibers *in situ* bags

Four sample of polyester microfibers fabrics were manufactured using two filament denier of 0.4 and 0.7 with warp count of 150, denier and weft count of 70, denier, warp density of 30 picks / inch, weft density 22 and 28 picks / inch, and plain 1/1 textile structure as following:

Sample (1): had filament denier of 0.4 and weft density of 28 picks $inch^{-1}$,

Sample (2): had filament denier of 0.4 and weft density of 22 picks $inch^{-1}$,

Sample (3): had filament denier of 0.7 and weft density of 25 picks $inch^{-1}$, and

Sample (4): had filament denier of 0.7 and weft density of 22 picks $inch^{-1}$.

The specifications of the manufactured samples are shown in Table (1). Then *in situ* bags were made using the manufactured microfiber fabrics into sizes 5 × 10 and 10 × 20 cm for incubating samples of concentrates and roughages, respectively.

Table 1. Manufactured samples specifications.

Sample code	Warp count (denier)	Weft count (denier)	No. of filament per yarn	Denier per filament	Fabric cover factor	Fabric setting	Pore size (µm)	Fabric weight (g m^{-2})	Fabric thickness (mm)
1	150	70	144	0.4	17.2	30*28	40.50	112.5	0.22
2	150	70	144	0.4	16.2	30*22	62.80	97.0	0.23
3	150	70	96	0.7	16.7	30*25	76.66	81.7	0.19
4	150	70	96	0.7	16.2	30*22	77.66	68.9	0.23

The performances of the manufactured bags were examined to meet the *in situ* bags specification before and after incubation.

Fabrics' mechanical properties were measured using standard test methods, tensile strength using ASTM D5035, tear strength using ASTM D2261 and air permeability using ASTM D737 (Hanafy, Hamoda, Khattab, & Aboamer, 2020). Three replicates were measured for two laboratory tests breaking load and elongation and air permeability in both directions warp, weft and the average values were taken, while in tear strength tests three replicates were measured. The five highest peak forces for each replicate were calculated and the average values for the fifteen reading were calculated.

In situ trial

In situ degradability for three feedstuffs were measured as described by (Ørskov, Hovell, & Mould, 1980) to evaluate the performance of manufactured bags in field. Three cannulated rams (50.60 ± 3.05 kg- body weight) at the Marryot Research Station, Desert Research Centre, Ministry of Agriculture, 35 km south of Alexandria, Egypt were used as replicates. Rams were fed at maintenance level 40:60 concentrate to roughage. *In situ* dry matter degradability was determined for two sources of concentrates (soybean meal and wheat bran) and one roughage source (berseem hay). Feed samples were grinded to 2 mm and 1.5 – 2.0, g of concentrates or 3.5 – 4.0, g of roughages were inserted into a previously weighted, clean, dry and numbered bag.

At 1 hour after feeding bags were incubated in the rumen for 24 and 48 hours. At the end of incubation bags were removed and dipped immediately into cold water to stop microbial activity, then washed under running cold water until the water was clear, then bags were drained, dried for 72 h at 60°C according to (Cunniff, 1997), cooled in a desiccator and weighed. The solubility or washing loss at 0 hour was defined as weight loss after soaking the bags, with the substrate, for 1 hour in water at 38°C then washing and drying in a similar way. Dry matter disappearance for each feedstuff at each individual incubation time was calculated as the difference between the contents in the initial samples and the residues remaining after incubation in the rumen and expressed as a percentage of the content of the initial sample. New bag was used for each feed sample in order to study the effect of incubation and frequently drying and washing on the physical and mechanical properties of the manufactured bags.

Scanning electron microscope (SEM)

A scanning electron probe micro analyzer (type T-scan–Czech Republic) was used to scan samples. The *in situ* sample was cut at size about 1*1 cm, an individual instrument was used for staining sample sections using Chrome. Two different magnifications were used to image the surface morphology of samples (200x, 500x), at 5kV accelerating voltage.

Statistical analyses were carried out based on the mean values of observation with their standard error of means, using IBM® SPSS® Version 24 for Windows (SPSS, 2016). ANOVA Two-way Repeated

Measurements were used to statistically analyze the significant difference between variables for samples before and after incubation. Differences in *in situ* ruminal degradability were statistically analyzed using One-way ANOVA and means compared using Tukey HSD test. The level of significance was at p value = 0.05.

Results and discussion

Fabric's physical and mechanical properties

Table 2 represents different physical and mechanical properties of the manufactured *in situ* bags before and after incubation in the rumen. Bags have a pore size ranging from 40.5 to 77.66, µm and it was significantly affected by both denier per filament and weft density (p < 0.001). Sample 4 recorded the highest pore size, while sample 1 recorded the lowest pore size. Furthermore, fabrics' pore size was decreased by increasing number of filaments per yarn and vice versa.

Table 2. Fabrics properties.

Item	Sample No.	Denier per filaments (µ)	Weft density (picks inch^{-1})	Incubation		SEM	P value[1]			
				Before	After		F	D	I	I*W*D
Pore size (µm)	1	0.4	28	76.7[c]		1.01	< 0.001	< 0.001		
	2		22	37.4[a]						
	3	0.7	25	77.7[c]						
	4		22	62.8[b]						
Warp tensile strength (N)	1	0.4	28	709.3	604.7	9.59	< 0.001	< 0.001	< 0.001	0.249
	2		22	650.5	464.2					
	3	0.7	25	634.2	464.2					
	4		22	415.1	245.2					
Warp tensile elongation (%)	1	0.4	28	28.7	48	0.95	< 0.362	0.002	< 0.001	0.320
	2		22	25.7	30.7					
	3	0.7	25	23.7	46.3					
	4		22	18	37.7					
Weft tensile strength (N)	1	0.4	28	516.5	369.4	4.42	< 0.001	0.010	0.004	0.427
	2		22	519.8	496.9					
	3	0.7	25	196.1	156.9					
	4		22	143.8	196.1					
Weft tensile elongation (%)	1	0.4	28	23	41.7	1.15	< 0.600	0.026	< 0.001	0.794
	2		22	23.7	35.3					
	3	0.7	25	21	48					
	4		22	16	33.7					
Warp tear strength (N)	1	0.4	28	38.3	80.6	0.89	< 0.001	0.050	< 0.001	< 0.001
	2		22	36.3	124.4					
	3	0.7	25	35.3	88.0					
	4		22	43.6	54.5					
Weft tear strength (N)	1	0.4	28	41.8	73.7	1.11	< 0.001	0.527	< 0.001	< 0.001
	2		22	32.1	120.3					
	3	0.7	25	18.5	72.7					
	4		22	22.1	38					
Air permeability (cm^3 cm^{-2}.sec)	1	0.4	28	27.7	25.9	0.20	< 0.001	< 0.001	0.137	< 0.001
	2		22	12.8	7.9					
	3	0.7	25	37.3	52.4					
	4		22	42.9	31.1					
Water permeability (L sec.$^{-1}$)	1	0.4	28	1.52[c]		0.01	< 0.001	< 0.001		
	2		22	1.29[a]						
	3	0.7	25	1.52[bc]						
	4		22	1.46[b]						

[a–d]Means with different superscripts differ (p < 0.05). [1]Probability of significant effect due to the denier per filament (F), weft density (D), and their interaction (I × F × D). Water permeability interaction was significant.

From the statistical analysis done for manufactured samples, it was shown from Figure 1 that warp breaking load before incubation has the highest values compared with the warp breaking load after incubation, this is interpreted due to exposure the samples to conditions that weakens its strength (oven and incubation). Sample 2 recorded the highest warp breaking load, while sample 3 recorded the lowest breaking load before and after incubation, this is mainly due to increasing the number of filaments per yarn for sample 2 which equals 144 and decreasing it for sample 3 which equals to 96. Warp breaking load was significantly affected by denier per filament, weft density and incubation ($p < 0.001$) with no significant interaction, while warp breaking elongation was not significantly affected by denier per filament ($p < 0.362$) and was significantly affected by weft density and incubation ($p < 0.002$, $p < 0.001$ respectively) with no significant interaction.

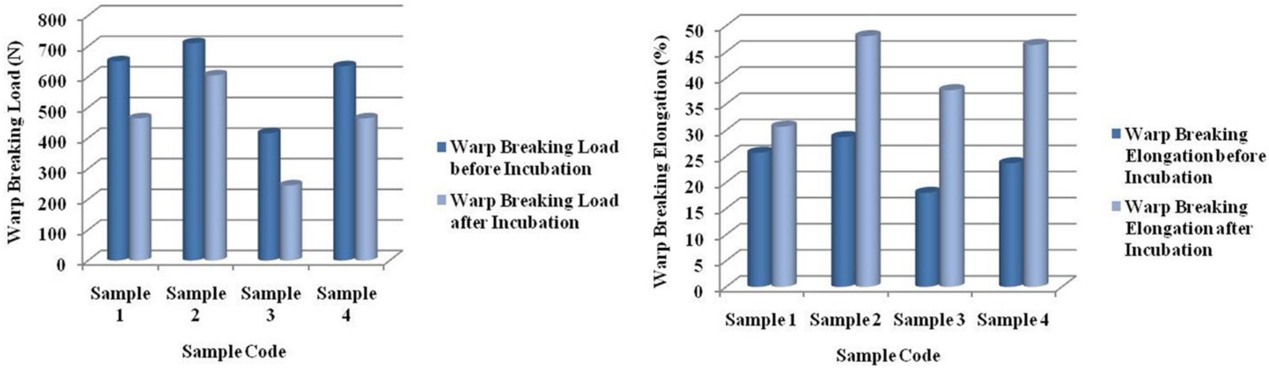

Figure 1. Warp breaking load and elongation before and after incubation.

It was shown in from Figure 2 that weft breaking load before incubation has the highest values compared with the weft breaking load after incubation. This is interpreted due to exposure the samples to conditions that weakens its strength (oven and incubation). Sample 1 recorded the highest warp breaking load, while sample 3 recorded the lowest breaking load before and after incubation, this is mainly due to increasing the number of filament per yarn for sample 1 which equals 144 and decreasing it for sample 3 which equals to 96. For Weft breaking load was significantly affected by denier per filament, weft density and incubation ($p < 0.001$, $p = 0.010$ and $p < 0.004$ respectively) with no significant interaction, while weft tensile elongation was not significantly affected by denier per filament ($p < 0.600$) and was significantly affected by weft density and incubation ($p < 0.026$, $p < 0.001$ respectively) with no significant interaction.

It was observed from tear strength for Figure 3 that the tear strength after incubations for both directions warp and weft gives high values than the tear strength before incubation. This can be resulted from the particles of feedstuff accumulation between yarns after incubation which results in resisting the tearing of samples for both directions. At warp tear strength before incubation, sample 3 recorded the highest value while sample 4 recorded the lowest value.

For weft tear strength before incubation sample 2 recorded the highest value while sample 4 recorded the lowest value. For both warp tear strength after incubation and weft tear strength after incubation sample 1 recorded the highest values while sample 3 recorded the lowest values respectively. Both directions were affected significantly with denier per filament and incubation ($p < 0.001$) and also it was affected significantly for warp direction with weft density ($p = 0.050$), while it was not significantly affected by effect with weft density at weft direction ($p = 0.527$).

The statistical analysis results of Figure 4 showed that the air permeability after incubation gives the highest values than before incubation, samples exposure to different periods 0- 24 and 48 hours. Therefore it can be exposed for more than those periods till its air permeability after incubation be less than its air permeability before incubation. For air permeability before incubation sample 3 recorded the highest value while sample 1 recorded the lowest value; for air permeability after incubation sample 4 recorded the highest value and in the other side sample 1 recorded the lowest value. Air permeability was affected significantly by both denier per filament and weft density $p < 0.001$; also it was not affected by incubation $p = 0.137$, with significant interaction $p < 0.001$. Also, water permeability was significantly affected by both weft density and denier per filament $p < 0.001$.

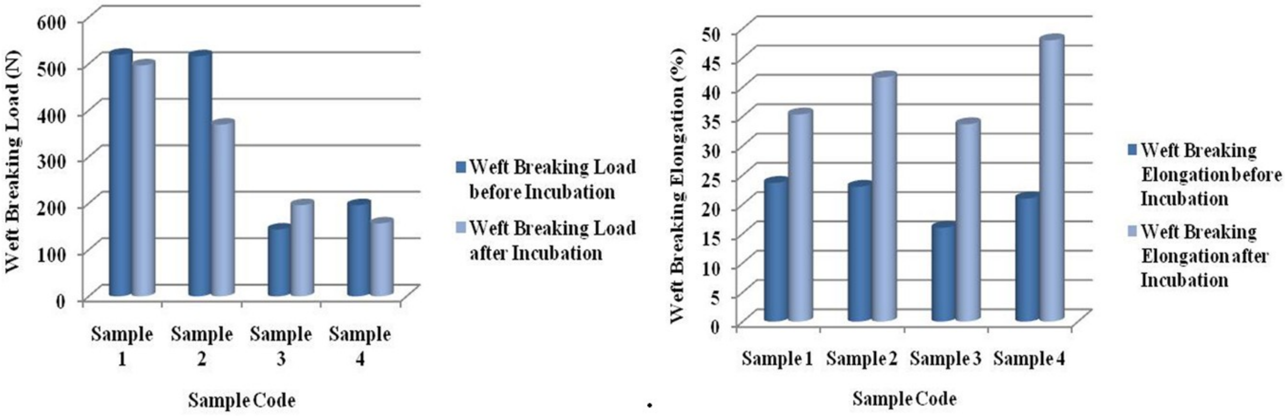

Figure 2. Weft breaking load and elongation before and after incubation.

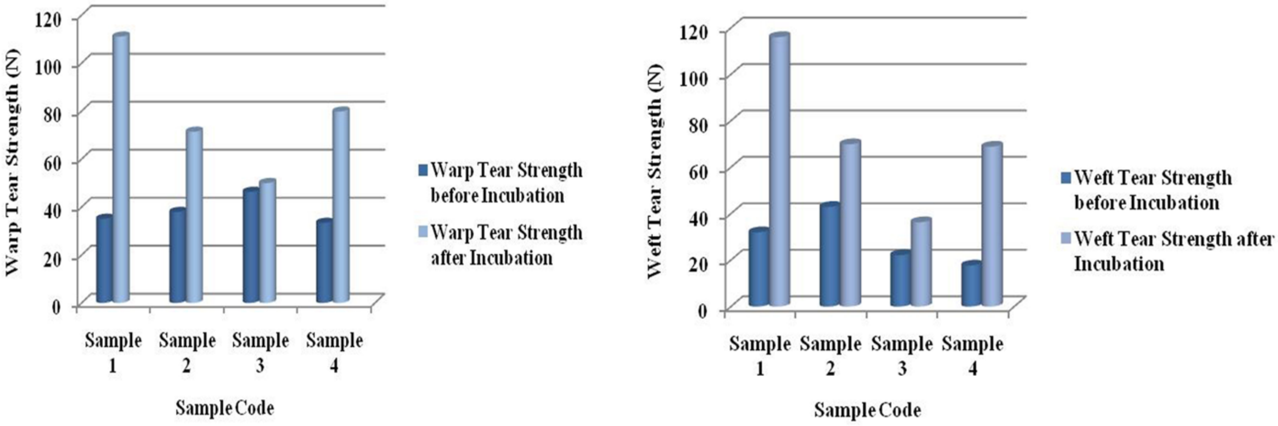

Figure 3. Warp and weft tear strength before and after incubation.

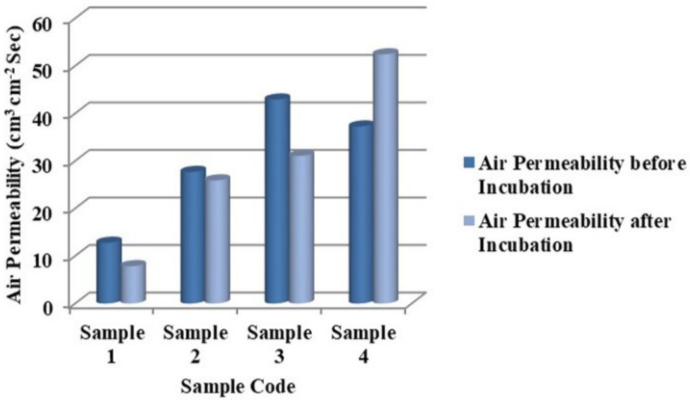

Figure 4. Air permeability before and after incubation.

In situ dry matter degradability

Table 3 represents the *in situ* dry matter disappearance for the tested feedstuffs compared with ANKOM bags. Data show no significant difference between samples 2 and 3 and ANKOM bag at 0h and 48 after incubation. At 24h after incubation, there were a significant difference between ANKOM bag and all samples for soybean meal.

The lower values for ruminal disappearance may be due to the greater efficiency of microfiber fabrics to reduce losing of fine feed particles (Richards, 2005). Also, it seemed that the differences were faded after 48 h of incubation. In contrast, for wheat bran the differences between the observed values of degradability were not significant.

Table 3. *In situ* dry matter disappearance for tested feedstuffs.

Feedstuff	Incubation time (h)	DM degradability, %				Ankom bags	SEM	*P* value
		0.4		0.7				
		30*28	30*22	30*28	30*22			
		Samples No.						
		1	2	3	4			
Soybean meal	0	22.5	19.3	23.2	22.4	19.7	0.54	0.054
	24	56.1^{a}	55.5^{a}	66.1^{b}	64.3^{b}	72.2^{c}	1.74	<0.001
	48	91.3^{c}	83.4^{b}	83.5^{b}	77.7^{a}	82.1^{ab}	1.24	<0.001
Wheat bran	0	12^{a}	21.1^{b}	19.9^{b}	23.4^{b}	22.7^{b}	1.17	<0.001
	24	64.7	65.1	66.2	67.7	68.4	0.53	0.079
	48	74.3^{ab}	72.2^{ab}	77.3^{b}	73.8^{ab}	68.1^{a}	0.96	0.012
Berseem hay	0	18.3^{ab}	19.1^{ab}	19.1^{ab}	20.7^{b}	15.3^{a}	0.61	0.030
	24	55.7^{ab}	50.9^{a}	58.5^{b}	58.2^{b}	59.7^{b}	0.98	0.009
	48	58.7	59.2	61.6	61.6	56.5	0.79	0.215

$^{a-d}$Means with different superscripts differ ($p < 0.05$).

Evaluation of the mechanical properties of *in situ* bags samples to determine the best specimen in terms of quality suitable for the end use using radar chart

The results of the physical and mechanical properties for samples before and after incubation were evaluated using radar charts in order to plot the best performance of samples in terms of suitable quality for the end use Figures 5 and 6. From radar charts area for samples properties before incubation it was showed that sample 1 recorded the highest area followed by samples 2, 3 and 4 respectively, while for samples properties after incubation sample 2 recorded the highest area followed by samples 3, 4 and 1 Table 4.

Scanning electron microscope (SEM)

According to the radar chart, SEM was done for sample 2 before and after incubation and it was magnified in 200 and 500X. Figure 7 show numbers of fibers before incubation and after washing. Figure 8 show the gathering of feedstuff particles between fibers and above the surface of the fabric after incubation due to the different incubation conditions (strength; humidity; oven; temperature).

Table 4. Show the order of radar area for samples from best sample to lowest sample before and after incubation.

Before incubation		After incubation	
Sample 1	44216.91017	Sample 2	35398.17261
Sample 2	44077.13317	Sample 3	24691.51366
Sample 3	40381.91831	Sample 4	24420.96484
Sample 4	38491.48419	Sample 1	14147.62434

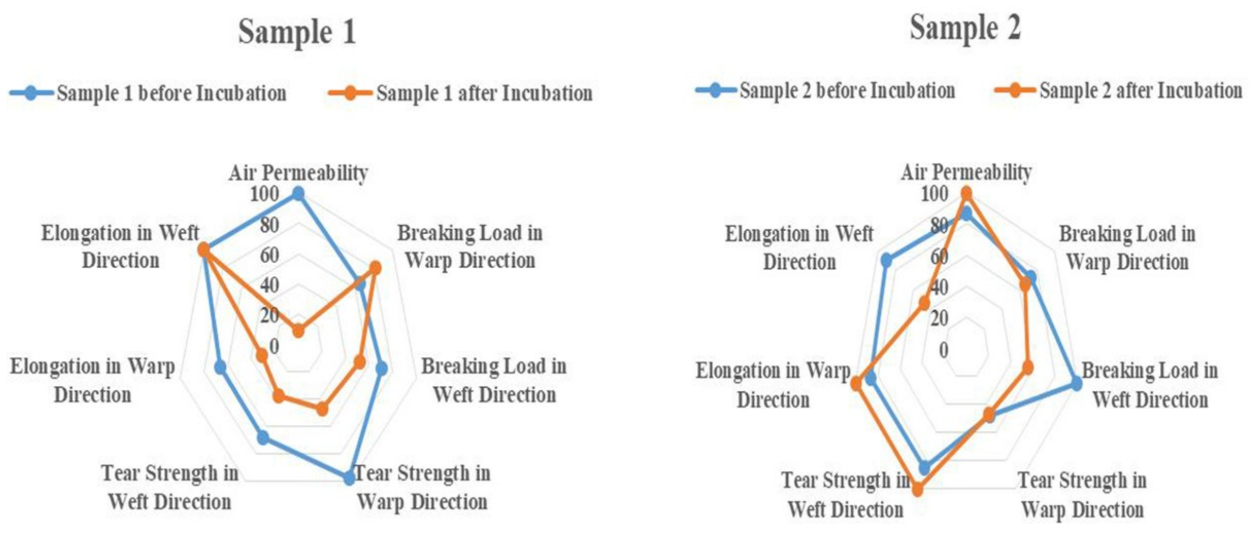

Figure 5. Radar chart for samples 1 and 2 before and after incubation.

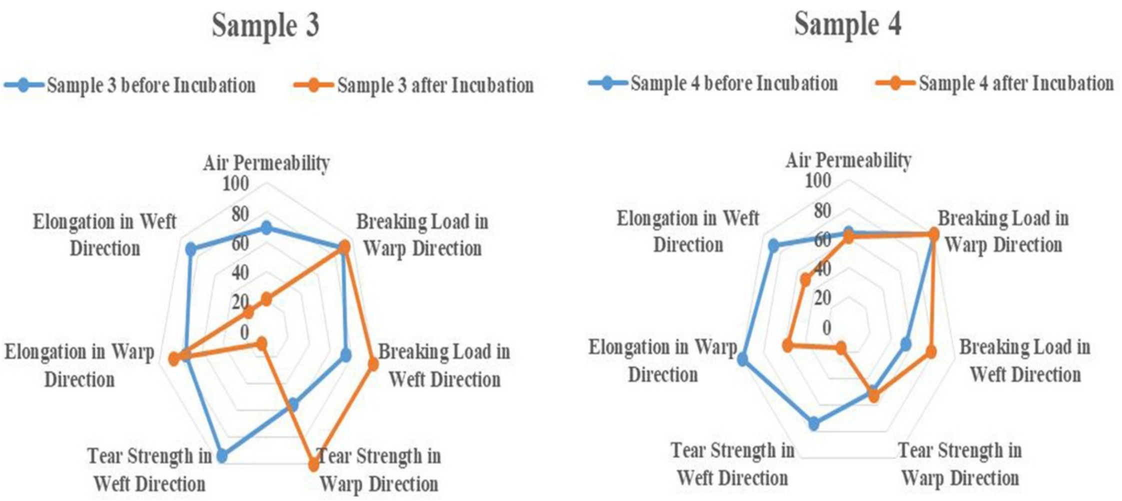

Figure 6. Radar chart for samples 3 and 4 before and after incubation.

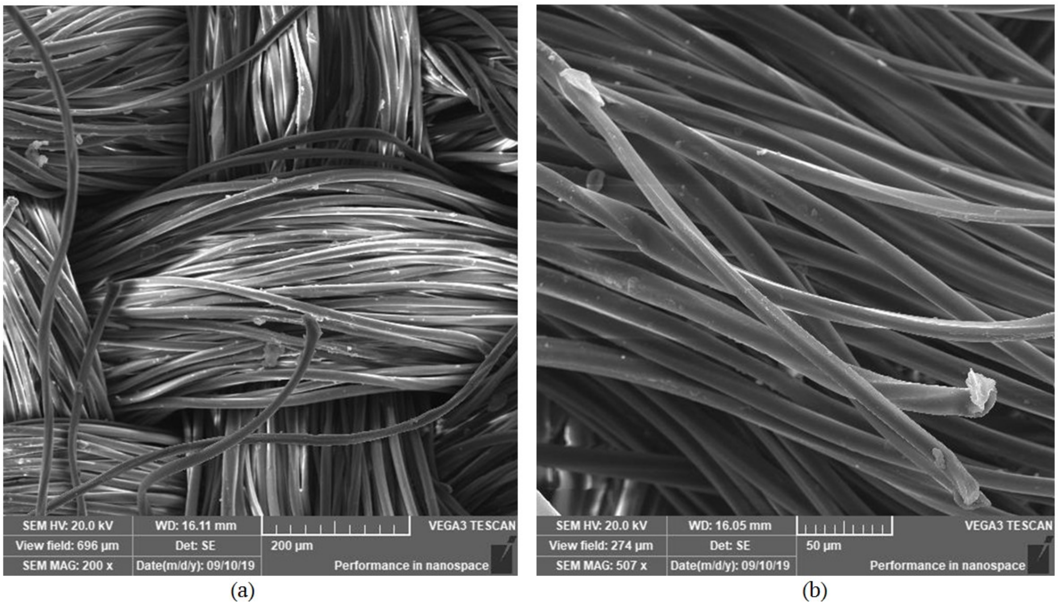

Figure 7. Represent the SEM for sample 2 before incubation with magnifications X200 and X500.

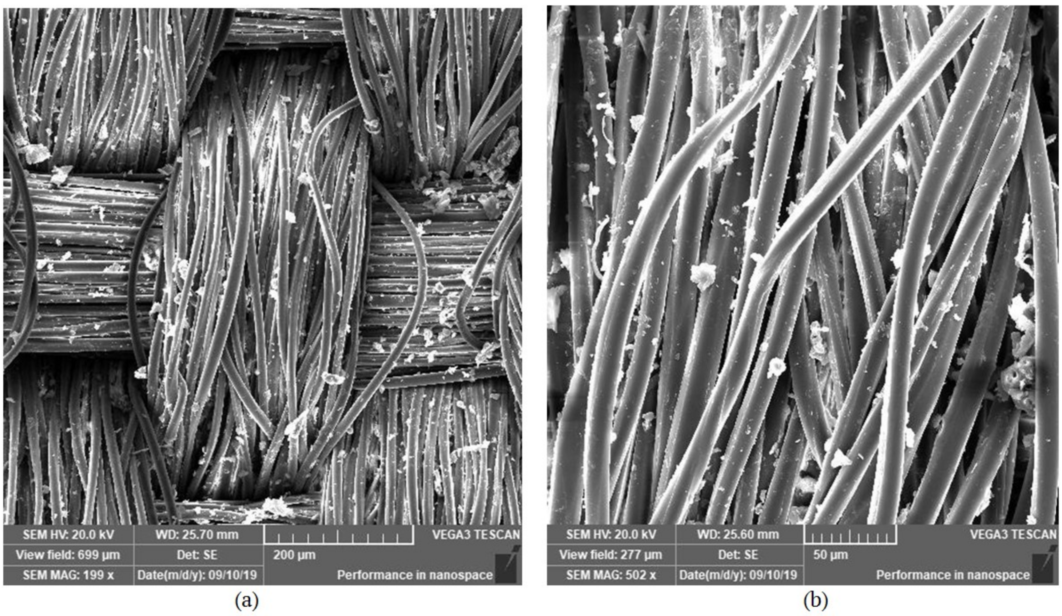

Figure 8. Represent the SEM for sample 2 after incubation with magnifications X200 and X500.

Conclusion

The difference in denier per filament has a great effect on the *in situ* bags properties, according to the results obtained by increasing the number of filament per yarn, samples properties increased. Also, mechanical properties before incubation have the highest scores than after incubation that's mainly due to the conditions which the samples were exposure. Sample 2 had better withstanding for incubation and laboratory conditions and produced an acceptable value for *in situ* degradability compared with ANKOM bag.

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