# Performance Analysis of Sweet Potato Starch Versus Carboxymethyl Cellulose in Yarn Sizing

## Analiza učinkovitosti škroba slatkog krumpira u odnosu na karboksimetil celulozu kod škrobljenja pređe

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## Abstract

The study evaluates the performance of sweet potato starch (SPS), a locally available natural material, as a sizing agent in textile applications, compared to standard carboxymethyl cellulose (CMC). Sizing enhances yarn strength, reduces breakage, and improves weaving efficiency. CMC is widely used in the textile industry because of its excellent film-forming ability and low moisture regain. However, despite being derived from seaweed, an abundant natural resource, CMC production and extraction processes raise ecological concerns due to their adverse environmental impacts. In contrast, sweet potato starch is renewable, biodegradable, and economically viable, making it a promising sustainable alternative. Experiments in this study were conducted in the Textile Testing and Quality Control Laboratory at the Textile Engineering College in Noakhali, Bangladesh. Both sizing agents were evaluated and compared based on size take-up percentage, moisture regain, yarn hairiness, and surface morphology using SEM and EDX analyses. Results showed that CMC exhibited a higher size take-up percentage (33.30 ± 0.35%) than sweet potato starch (15.89 ± 0.28%), confirming its superior adhesion and film thickness. Moisture regain analysis revealed that SPS absorbed more moisture (14.07 ± 0.25%) than CMC (7.02 ± 0.12%), indicating better softness but reduced dimensional stability. SEM images confirmed smoother, more uniform film formation in CMC-sized yarns, while SPS coatings were less compact but environmentally favorable. Overall, the findings suggest that sweet potato starch can serve as an eco-friendly and cost-effective alternative to conventional sizing agents. Future research should focus on modifying SPS formulations with functional additives to enhance moisture resistance and evaluate its large-scale industrial feasibility as a sustainable sizing material.

**Keywords**: sweet potato starch; carboxymethyl cellulose; yarn sizing; yarn properties; sustainability

## Sažetak

U radu je ispitana učinkovitost škroba slatkog krumpira (ŠSK), lokalno dostupnog prirodnog materijala, kao sredstvo za škrobljenje tekstilnih materijala, u odnosu na standardnu karboksimetil celulozu (KMC). Poznato je da škrobljenje povećava čvrstoću pređe, smanjuje lomljivost i poboljšava efikasnost tkanja. KMC se široko koristi u tekstilnoj industriji zbog svoje odlične sposobnosti formiranja filma i smanjene reprize vlage. Međutim, usprkos tome što se dobije iz morskih algi - zastupljenog prirodnog resursa - procesi proizvodnje i ekstrakcije CMC-a izazivaju ekološku zabrinutost zbog svog negativnog utjecaja na okolinu. Nasuprot tome, škrob slatkog krumpira je obnovljiv, biorazgradiv i ekonomski isplativ, što ga čini obećavajućom održivom alternativom. Istraživanje u radu je provedeno u Laboratoriji za ispitivanje i kontrolu kvalitete tekstila na Fakultetu tekstilnog inženjerstva u Noakhaliju. Bangladeš. Ispitana su oba sredstva za škrobljenje te je uspoređena njihova učinkovitost u odnosu na morfološka svojstva, sposobnost apsorpcije škroba, reprizu vlage te dlakavosti pređe. Rezultati su pokazali da KMC pokazuje veći procent apsorpcije škroba (33,30 ± 0,35%) od ŠSK-a (15,89 ± 0,28%), što potvrđuje njegovu superiorniju adheziju i debljinu filma. Analiza reprize vlage pokazala je da SPS ima veću sposobnost reprize (14,07 ± 0,25%) od KMC-a (7,02 ± 0,12%), što ukazuje na bolju mekoću, ali i smanjenu dimenzionalnu stabilnost. SEM slike su potvrdile glatkije i ujednačenije formiranje filma u pređama s CMC škrobom, dok su SPS škrobljene pređe bile manje kompaktne, ali ekološki povoljnije. Sveukupno, rezultati sugeriraju da škrob slatkog krumpira može poslužiti kao ekološki prihvatljiva i isplativa alternativa konvencionalnim sredstvima za škrobljenje. Buduća istraživanja trebala bi se fokusirati na modificiranje SPS formulacija funkcionalnim aditivima kako bi se poboljšala otpornost na vlagu i procijenila njegova industrijska izvodljivost u velikim razmjerima kao održivog materijala za škrobljenje.

**Ključne riječi**: škrob slatkog krumpira; karboksimetil celuloza; škrobljenje pređe; svojstva pređe; održivost

## 1. Introduction

Sizing is a crucial process in weaving where a protective coating is applied to the warp yarn [1]. This improves its strength, reduces breakage, and enhances weaving efficiency [2]. Carboxymethyl cellulose (CMC) is used as a sizing agent in the textile industry. It is a modified sizing agent that improves tenacity and reduces yarn hairiness. Therefore, fabric weaving performance is enhanced [3]. However, due to their chemical composition, CMC and other conventional sizing agents contribute to environmental pollution [1]. Commercially, CMC is produced from seaweed [4]. Cultivating seaweed causes the growth of environmental pathogens and parasites in the marine ecosystems. It can adversely affect local marine wildlife. Although seaweed is a renewable resource, its cultivation has ecological implications. The introduction of non-native seaweed species for industrial use has been associated with the spread of pathogens and parasites. It disrupts local marine biodiversity [5]. CMC contributes to environmental degradation due to its production processes and waste discharge [6]. It is derived from natural sources. It does not offer the same level of environmental benefits in terms of biodegradation and resource renewability [7].

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Sweet potato starch (SPS) offers superior film-forming properties which makes it ideal for textile sizing applications.
Studies demonstrate that its adhesive and hydrophilic nature enhances inter-yarn cohesion. It leads to improved warp strength during weaving. Unlike synthetic agents, sweet potato starch is biodegradable. It reduces the environmental load associated with textile processing [8]. Additionally, the local production of sweet potatoes fosters sustainable practices and contributes to rural economies [9].
Sweet potato starch is produced locally. It has emerged as a potential candidate for textile sizing. Sweet potato is the fourth most important crop in Bangladesh, followed by rice, wheat, and potato [10]. Previous studies have demonstrated the effectiveness of potato-based starch as a sizing agent. It is demonstrated by its improved hydrophilicity, solubility, film-forming capability, and adhesive potential, along with enhanced physical-mechanical properties of cotton yarns, including abrasion resistance and reduced surface hairiness [11]. Starch-based sizing agents are more environmentally friendly compared to petrochemical alternatives, reducing water and energy consumption during processing [8]. Starch sizing is sustainable due to its renewable nature and biodegradability [6]. Moreover, starch sizing is inexpensive and effective [12].
This study aims to investigate the potential of sweet potato starch as a sustainable sizing agent for yarns. Extracted starch from potatoes can be synthesized and modified to enhance its properties for sizing applications. It is a viable, eco-friendly alternative to synthetic agents [13]. In this research, the extraction of starch from sweet potato was optimized and used as sizing agent for cotton warp yarn. An experimental and statistical approach followed in the study aims to compare the quality of sweet potato starch and carboxymethyl cellulose as yarn sizing agents.
Sweet potato starch is extracted by using a standard wet milling method [14]. The starch is purified by sedimentation and filtration to remove non-starch polysaccharides and other impurities. Then, both yarns were characterized using XRD and SEM techniques. XRD is utilized to determine the crystalline structure of the extracted starch and compare it with CMC. The crystallinity index is calculated using peak intensity data, providing insights into the material's physical properties relevant to textile sizing [15]. SEM analysis examines the surface morphology of the starch and CMC films. Parameters such as particle size distribution, granule structure, and surface smoothness are analyzed to assess film-forming capabilities [16]. By comparing the properties of yarns sized with SPS and CMC, this research will provide valuable insights into the technical feasibility and benefits of using sweet potato starch in the textile industry.

## 2. Experimental part

### 2.1. Materials and methods

The wet milling method was employed to purify the starch. At first, sweet potatoes were cut into pieces. The pieces were blended until smooth. The mixture obtained was then filtered through a fine mesh cloth to separate the bigger particles. The starch-rich liquid was then separated. The process of sweet potato starch extraction is shown in Figure 1.

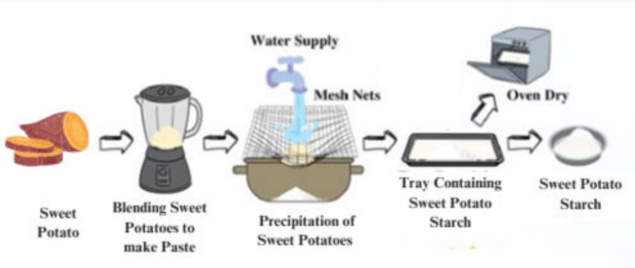


**Figure 1.** Sweet potato starch extraction process

The precipitate was then treated with a 0.25% (w/v) NaOH solution and kept at 4°C for 24 hours. The filtered mixture was allowed to settle in a beaker. During this time, the starch naturally settled at the bottom due to sedimentation. The excess water remained above. The supernatant water was carefully removed, leaving the starch residue at the bottom of the beaker. After the upper layer was removed, the precipitate was centrifuged and washed three times with distilled water until a neutral pH was achieved. The collected wet starch was then spread on foil paper and dried in an oven at 50°C for 30 minutes. This drying process reduced the moisture content, after which the dried starch was re-blended to create a fine powder form.
The final starch powder was stored in an airtight container as a sample for further testing. From an initial weight of 500 grams of sweet potato, approximately 25.70 grams of starch powder was obtained, methodology adapted from [17].

#### 2.2.1. Sizing by sweet potato starch

The sweet potato starch sizing formulation was prepared using a wet-cooking method. Initially, 100 mL of distilled water was poured into a clean beaker and stirred continuously using a magnetic stirrer. Copper sulfate ($CuSO_4$) was added at a concentration of 0.3 g to prevent microbial contamination during the preparation and storage of the size solution. Gradual addition of sweet potato starch followed, ensuring uniform dispersion and preventing agglomeration of starch granules.
The mixture was stirred continuously for approximately 30-45 minutes until the solution reached a homogenous consistency. The temperature was then gradually raised to 60 °C to facilitate starch gelatinization [15]. It is an essential step that enhances the adhesive property of the paste by breaking intermolecular hydrogen bonds and allowing amylose leaching. Controlled heating within the 55-65 °C range is optimal because it allows sufficient granule swelling for efficient starch release while preserving its native granular morphology [14]. Conversely, excessive heating (>70 °C) causes extensive gelatinization and aggregation of starch molecules, which complicates filtration and purification and may reduce the starch's functional properties for sizing applications [16]
A softener was incorporated to improve yarn flexibility and surface smoothness, followed by boiling the mixture for two hours to ensure complete gelatinization and viscosity stability. The total cooking duration was approximately 3 hours. After which, the temperature was maintained at 60 °C to preserve the solution's uniformity. The sized yarns were subsequently dried at 30 °C for 40 minutes to remove excess moisture. The process aligns with starch gelatinization and application techniques reported in sustainable sizing research [11].
This starch-based method demonstrates potential as an eco-friendly alternative to synthetic sizing agents due to its biodegradability, renewability, and low environmental footprint. Sweet potato starch exhibits high amylose content, providing desirable film-forming properties that strengthen the inter-fiber bonding and reduce yarn hairiness [8].

#### 2.2.2. Sizing by carboxymethyl cellulose

For comparison, conventional sizing was conducted using carboxymethyl cellulose (CMC), a widely used modified cellulose derivative known for its superior film-forming ability, adhesion, and moisture resistance [3]. The CMC sizing paste was prepared by dissolving 18 g of CMC, 5 g of wax, and 2 g of emulsifier in 100 mL of distilled water. The solution was stirred continuously on a magnetic stirrer until the required viscosity was achieved. Proper solubilization of CMC and uniform dispersion of the additives was ensured. The mixture was gradually heated to 60 °C to enhance the dissolution rate and to allow partial thermal expansion of the polymer chains. A softener was added to promote yarn suppleness and improve abrasion resistance during weaving. The mixture was boiled for two hours, followed by maintaining a constant temperature of 60 °C for an additional hour to stabilize the viscosity and film-forming consistency.
The total preparation time was approximately three hours. The sized yarns were dried at 30 °C for 40 minutes, ensuring even moisture removal without thermal degradation of the coating film. CMC based sizing forms a smooth and continuous film over the yarn surface, minimizing inter-fiber friction and enhancing weaving efficiency. However, although CMC exhibits superior technical performance, its production from seaweed has been linked to environmental concerns related to the disruption of marine ecosystems [5]. Thus, this comparative study evaluates the potential of sweet potato starch as a sustainable and economically viable substitute for CMC in warp sizing applications.

### 2.3. Testing parameters

The testing parameters used in this study are listed in Table 1.

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**Table 1.** Testing parameters

| Test parameter | Standards |
|---|---|
| Yarn count (Tex) | ASTM D1907 |
| Iodine (starch) test / apparent amylose indicator | ISO 6647-1:2020 |
| SEM (surface morphology) & EDX (elemental analysis) | ISO 18115 |
| Size take-up (%) | ISO 139 |
| Yarn hairiness | ISO 16549 (Uster tester method) |
| Moisture regain (%) | ASTM D2654-22 |

All measurements were performed under controlled environmental conditions in a lab of 20 ± 2 °C and 65 ± 2 % of relative humidity. Each test was conducted three times, and the mean values were reported with their respective standard deviations.

### 2.3.1. Yarn count

The fineness (yarn count) of raw cotton yarn sized with sweet potato starch and carboxymethyl cellulose was calculated by using the Wrap Reel situated in the TTQC lab of Textile Engineering College, Noakhali, following equation (1), [18].

$$Yarncount(Tex) = \frac{LWx1000}{L} \quad (1)$$

### 2.3.2. Amylose indicator

The presence of starch in the extracted sweet potato starch sample was confirmed by the Iodine test following the spectrophotometric approach of ISO 6647-1:2020. A small quantity of the starch suspension was placed on a clean watch glass. Then, a few drops of 0.1 M hydrochloric acid (HCl) were added to acidify the medium. Subsequently, two drops of standard iodine–potassium iodide ($I_2$/KI) solution were introduced and mixed gently. The development of a deep, dark-black coloration confirmed the formation of the amylose–iodine complex, indicating the presence of the starch [15].

### 2.3.3. Size take-up

The amount of sizing agent adhered to the yarn surface was calculated gravimetrically, following equation (2) of ASTM D2494–20, [19].

$$Sizetake-up(\%) = \frac{Ws - Wu}{Wu} x100\% \quad (2)$$

Table 2 shows the weight of the yarns prior and after sizing with the CMC and the SPS sizing agents.

**Table 2.** Yarn weight during sizing

| Yarn type | Weight ± SD (g) |
|---|---|
| Raw yarn | 11.89 ± 0.35 |
| CMC sized yarn | 15.85 ± 0.21 |
| SPS sized yarn | 13.78 ± 0.28 |

### 2.3.4. Yarn hairiness

Yarn hairiness was measured using the Uster Tester method following ISO 16549, which quantifies the number and average length of protruding fibers.

### 2.3.5. Moisture regain

Moisture regain was determined by following equation (3), according to ASTM D2654–22. Yarn samples were cut into equal lengths, conditioned as per ISO 139, and weighted to obtain the initial mass ($W_o$). The samples were then oven-dried at 105 °C for 2-3 hours, cooled in a desiccator, and reweighted ($W_d$), [20].

$$MR\% = \frac{(Wo - Wd)}{Wd} x100 \quad (3)$$

### 2.3.6. Surface morphology

The surface morphology of raw, sweet potato starch-sized, and carboxymethyl cellulose-sized yarn samples was examined using Scanning Electron Microscope (SEM Zeiss EVO MA10), equipped with an Energy Dispersive X-ray (EDX) detector for elemental analysis. The SEM operates with a high-vacuum tungsten filament electron source and a resolution of 3.0 nm at 30 kV. Before imaging, yarn samples were conditioned at 20 ± 2 °C and 65 ± 2% relative humidity, as specified in ISO 139:2005. The micrographs were captured at accelerating voltages of 15-20 kV with a working distance of 10 mm. Images were recorded at magnifications ranging from 500× to 2500×, allowing for the observation of film uniformity, surface smoothness, and the degree of coverage achieved by each sizing agent. The EDX spectra were obtained at 15 kV and processed using INCA software (Oxford Instruments) for semi-quantitative elemental composition analysis of the coated surfaces.

## 3. Results and discussion

### 3.1. Yarn count measurement

The yarn count results presented in Table 3 indicate that both sizing agents increased the linear density of the yarn compared to the raw cotton yarn.

**Table 3.** Yarn count

| Yarn type | Yarn fineness ± SD (Tex) |
|---|---|
| Raw yarn | 49.25 ± 0.20 |
| CMC sized yarn | 59.06 ± 0.25 |
| SPS sized yarn | 73.83 ± 0.32 |

The CMC-sized yarn (59.06 ± 0.25 Tex) and sweet potato starch (SPS)-sized yarn (73.83 ± 0.32 Tex) became coarser after sizing due to the formation of a film layer around the fibers. This film increased the yarn's mass per unit length, confirming successful size deposition. The higher Tex value of SPS yarns suggests that sweet potato starch produced a thicker coating layer compared to CMC.

### 3.2. Confirmation of the starch presence

In this test, the solution turned deep blue, confirming the presence of the starch. Sweet potato starch and carboxymethyl cellulose starch reacted with the Iodine, but the sweet potato starch exhibited a more intense dark blue coloration.

### 3.3. SEM and EDX analyses

The SEM and EDX analyses (Figures 2-13) provide a comparative visualization of the yarn surfaces. SEM enables the visualization of fine histological features in yarns, such as fiber cross-sections [21]. It also facilitates comparisons between different yarn types and allows the analysis of structural differences that affect performance and application in textiles [22].
The EDX spectrum of the raw yarn, Figure 2, indicates that the major elements present are carbon (C), nitrogen (N), and oxygen (O), which is typical of natural fibers. This reflects the raw fiber's unprocessed state.

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Figure 3 (SEM micrograph of the raw yarn) shows the surface morphology, thus the raw fibers exhibit an uneven surface with visible imperfections, numerous protruding fibers and void spaces between, indicating a lack of coating or smoothening from the sizing agents [23].

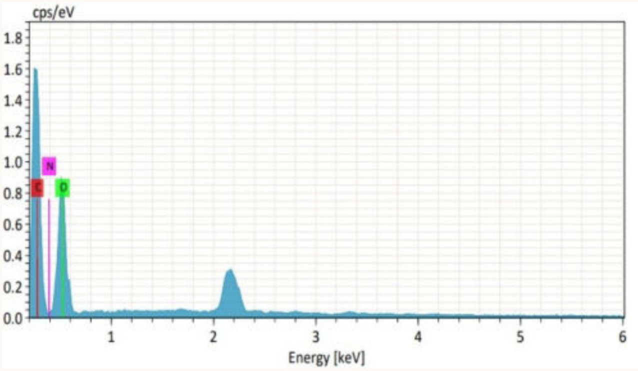


**Figure 2.** EDX spectrum of the raw yarn

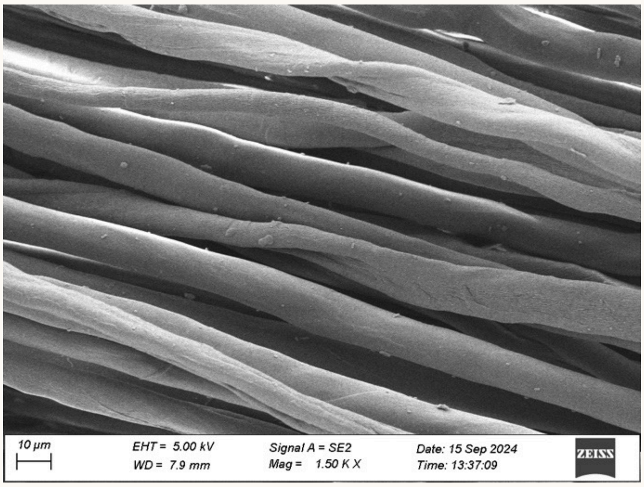


**Figure 3.** SEM micrograph of the raw yarn (mag. 1.5 KX)

The EDX analysis of the SPS sized yarn reveals a high carbon (C) content, accompanied by nitrogen (N) and oxygen (O), like the raw sample, but with a slight increase in the oxygen content due to the starch's molecular structure (primarily composed of polysaccharides), Figure 4. Nitrogen is also relatively high. It contributes to better moisture retention and flexibility in yarn during sizing, as indicated by the higher moisture regain (%) further on in the results and discussion.

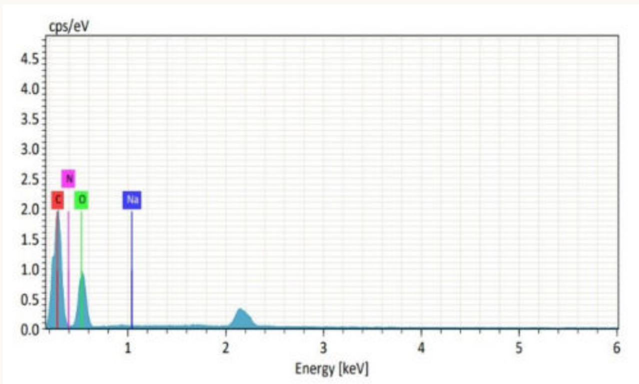


**Figure 4.** EDX spectrum of the SPS sized yarn

SEM micrograph of the SPS sized yarn, Figure 5, shows a relatively smooth surface, with reduced protruding fibers and partially coating filled surface voids, demonstrating moderate adhesion and uniform coverage of the sweet potato starch. The continuous SPS film suggests more compact structure, that will potentially improve the fiber's mechanical properties, such as tensile strength and abrasion resistance.

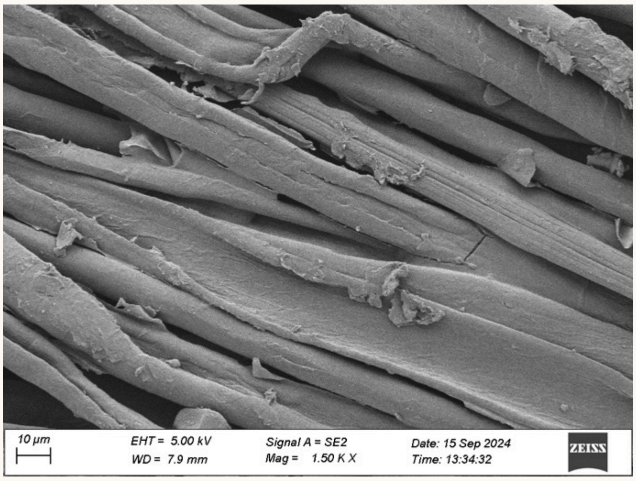


**Figure 5.** SEM micrograph of the SPS sized yarn (mag. 1.5 KX)

Carboxymethyl cellulose starch showed much higher percentages of both sodium and chlorine, Figure 6, which are indicative of a more complex chemical structure involving salts. Higher sodium content could account for the better performance in size take-up percentage since salts may boost film formation properties in sizing.

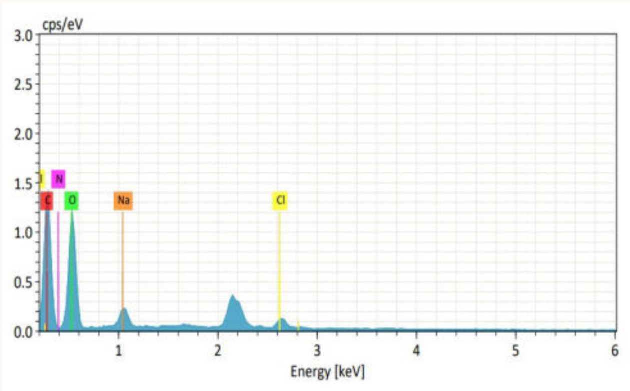


**Figure 6.** EDX spectrum of the CMC sized yarn

CMC starch gives a more uniform and complete coverage compared to the SPS. The fibers get thicker coating layers than when coated with SPS, which gives them more roughness-free surfaces with no crevices, Figure 7. Thus, dense layer formation indicates strong adhesion and superior film-forming ability of the carboxymethyl cellulose compared to sweet potato starch, which would further offer better protection against mechanical wear as well as reduced water uptake into the fibers or enhanced longevity.

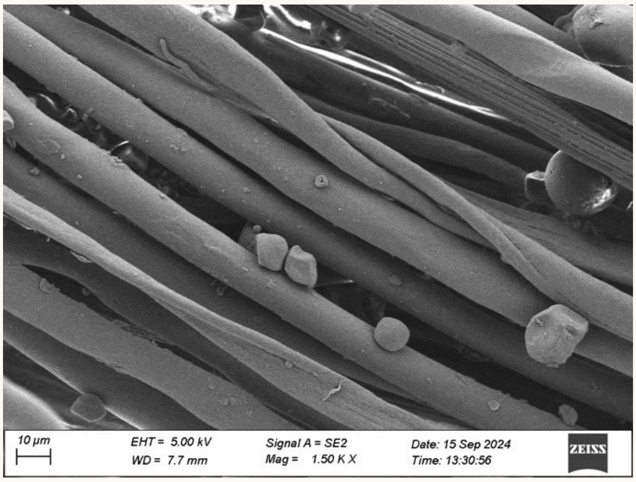


**Figure 7.** SEM micrograph of the CMC sized yarn (mag. 1.5 KX)

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### 3.4. Size take-up ability

Table 4 shows the take-up percentage of the two sizes. The CMC sized yarn recorded a higher size take-up of 33.30 ± 0.35 %, than the SPS sized yarn of 15.89 ± 0.28 %.

**Table 4.** Size take-up percentage

| Yarn type | Size take-up (%) |
|---|---|
| CMC sized yarn | 33.3 |
| SPS sized yarn | 15.9 |

This difference indicates that CMC forms a denser and more adhesive coating, leading to greater mass addition. The lower take-up of the SPS suggests a thinner film, which may yield a softer handle and improved flexibility, which is desirable for lightweight or fine yarn applications. It can be advantageous in specific textile processes where less bulky fabrics are required [27].

### 3.5. Yarn hairiness property

The results of the yarn hairiness are summarized in Table 5. The SPS size reduced yarn hairiness compared to the raw yarn, but less effectively than the CMC. These values correlate with the SEM images (Figures 5 and 7), where CMC created a smoother surface and stronger binding film that trapped fiber ends, resulting in lower hairiness. SPS improved smoothness moderately, though the natural starch granule structure led to minor irregularities in coating uniformity.

**Table 5.** Yarn hairiness

| Yarn type | Hairiness ± SD (no. of hairs / m) | Mean hair length ± SD (mm) |
|---|---|---|
| Raw yarn | 72 ± 3 | 2.5 ± 0.2 |
| SPS sized yarn | 48 ± 2 | 1.9 ± 0.1 |
| CMC sized yarn | 31 ± 2 | 1.5 ± 0.1 |

### 3.6. Moisture regain efficiency

Moisture regain (MR) data (including initial weight $W_o$ and dry weight $W_d$) are presented in *Table 6*. The CMC sized yarn exhibited a mean regain of 7.02 ± 0.12 %, while the SPS sized yarn showed a significantly higher value of 14.07 ± 0.25 %.

**Table 6.** Moisture regain %

| Yarn type | $W_o$ (g) | $W_d$ (g) | MR (%) |
|---|---|---|---|
| Raw Yarn | 11.89 | 11.05 | 7.60 |
| CMC sized yarn | 14.81 | 15.85 | 7.02 |
| SPS sized yarn | 13.78 | 12.08 | 14.07 |

The higher moisture regain of SPS corresponds to its more hydrophilic polysaccharide structure, which allows higher water absorption. This enhances fabric softness and comfort but can reduce dimensional stability under humid conditions. Conversely, the lower regain of the CMC indicates better resistance to humidity and improved fabric dimensional stability during weaving.

## 4. Conclusions

This study compared the performance of sweet potato starch and carboxymethyl cellulose as sizing agents for cotton yarn, emphasizing their surface morphology or film-forming efficiency, moisture regain ability, and their influence on yarn hairiness. The experimental findings summarized in Tables 3-5 and illustrated in Figures 2-7, lead to the following conclusions: the CMC sized yarn exhibited a significantly higher size take-up (33.30 ± 0.35 %) than the SPS sized yarn (15.89 ± 0.28 %), confirming CMC's superior adhesion and film density. However, the moderate coating of the SPS produced a lighter, more flexible yarn, which could be advantageous in applications demanding softer fabrics. In term of moisture regain, the SPS sized yarn showed higher moisture regain ability (14.07 ± 0.25 %) than the CMC sized yarn (7.02 ± 0.12 %). The enhanced hydrophilicity of the SPS provides greater softness and comfort but may compromise dimensional stability under humid conditions. The yarn hairiness test and SEM analysis demonstrated that the CMC significantly reduced the number and length of protruding fibers (31 ± 2 hairs $m^{-1}$; 1.5 ± 0.1 mm) compared to the SPS (48 ± 2 hairs $m^{-1}$; 1.9 ± 0.1 mm). This smoother film supports higher weaving efficiency and lower warp breakage rates. Finally, the SEM images revealed that the CMC formed a continuous and uniform film, while SPS provided partial coverage with visible micro-voids. The EDX spectra confirmed higher sodium and chlorine levels in the CMC sized yarn, contributing to its cohesive film formation. In terms of sustainability aspect, despite the slightly lower technical performance, the SPS is biodegradable**,** locally available, and economically viable. Thus, it makes it a sustainable substitute for CMC in eco-friendly textile sizing.

On the other hand, the CMC remains as the more efficient sizing agent in terms of adhesion and smoothness, but the SPS size represents a promising renewable alternative. With optimized modification, such as blending it with softeners or cross-linking agents, the SPS can potentially achieve comparable performance to the CMC while offering significant environmental benefits. Future research should focus on chemical enhancement of SPS, pilot-scale trials, and assessment of fabric weaving performance to advance its industrial applicability as a sustainable sizing agent.

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