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Study on the Influence of Fiber Properties on Yarn Imperfections in Ring Spun Yarns

[1]J. Ochola, [2]J. Kisato, [3]L. Kinuthia, [4]J. Mwasiagi and [5]A. Waithaka
[1]School of Engineering, Moi University, Eldoret, Kenya
[2]Department of Fashion Design and Marketing, Kenyatta University, Kenya
[3]Faculty of Education and Community Development, Egerton University, Kenya
[4]College of Textile, Donghua University, Shanghai, China
[5]Department of Textiles and Leather, KIRDI, Kenya

Corresponding Author: J. Ochola, School of Engineering, Moi University, Eldoret, Kenya

ABSTRACT

Fiber to yarn conversion process has been affected by several factors which include properties of raw material, level of technology, machinery and skill of machine operators. In cotton fibre spinning, the cost of raw material plays an important role, since it accounts for over 50% of the total cost of the ring spun yarn. Yarn imperfection (neps, thick and thin places) on the other hand is an important yarn parameter which affects yarn and fabric processing, and quality parameter. In this study, the relationship between fiber properties and yarn imperfections has been investigated using statistical and Monte Carlo techniques. The linear regression analysis developed models that generated coefficient of regression (R) value of 0.68, 0.65 and 0.68, respectively for neps, thick and thin places, respectively. The sensitivity analysis for statistical models showed that yarn twist, micronaire value, fiber maturity, trash area, fiber length, fiber strength and fiber yellowness are the influential factors for affecting yarn imperfections. Others factors that included trash grade, fiber uniformity, spinning consistency index, fiber reflectance, yarn linear density, trash content, fiber elongation and short fiber index should also are considered while studying yarn imperfection of cotton ring spun yarns.

Key words: Cotton, fibers, yarns, ring spinning, statistical, Monte Carlo

INTRODUCTION

Imperfections can be defined as the total number of neps, thick and thin places in a given length of yarn. In the USTER evenness tester, thin and thick places refer to imperfections that are within the measuring sensitivity range (±50% with respect to the mean value of yarn cross-sectional size), while neps are classified as the yarn imperfections which may exceed the 200% limit. For ring spun yarn, imperfections adversely affect yarn and fabric quality (Sharieff and Vinzanekar, 1983; McCreight, 1997; Grosberg and Iype, 1999; Hebert *et al.*, 1986). A yarn with more imperfections will exhibit poor appearance grade, lower strength and poor performance in weaving is likely to produce fabric with low quality. Studies (Hebert *et al.*, 1986, 1988) indicated that the size of thick places and neps were poorly correlated to their mass. The thin places were reported to be positively correlated with their size. An analysis of thick places in carded yarns revealed that more than 75% of the imperfections were due to the presence of fiber clusters and fiber clusters with foreign matter. Several studies have published on the effects of fiber properties, spinning method and machine parameters on yarn imperfections. The neps size is important and has been investigated by several researchers (Frydrych and Matusiak, 2002; Tambe, 2003; Zhang *et al.*, 2003), who tried to determined the objectionable nep size in cotton ring spun yarns by designing a nep size prediction model which gave satisfactory results. The effect of thick places in ring spun yarn on the fabric properties was reported by Seyam and El-Shiekh (1990a), who designed a model on the effect of the yarn thickness on the fabric processing and quality characteristics, using weft with random and period thickness variations. The designed model showed that the maximum weavable fabric cover factor is always lower when using irregular thickness filling yarn than when using regular thickness yarn with the same average count. The model was reported to be effective in predicting the effect of yarn thickness on fabric quality (Seyam and El-Shiekh, 1990b; Klein, 1998; Frydrych *et al.*, 2002, 2001; Mogahzy and Farag, 2007). Mogahzy and Farag (2007) developed an empirical model which can be used to study the fiber to yarn process. The model showed some good prediction efficiency and could find application if the drawbacks of high skills needed in the designing of the model can be conquered. Other models used to study the effect of fiber properties to yarn imperfections include Artificial Neural Network (ANN) and Adaptive Neuro-Fuzzy Inference System (ANFIS) (Desai *et al.*, 2004), which have been reported to give better prediction efficiency, when compared to statistical methods. However, despite the fact that ANN and ANFIS have been widely used for determining the relationship between fiber and yarn properties (Furferi and Gelli, 2010), these techniques are still far from providing all the possible explanations of the relationship between yarn and fiber properties, in a manner that is easy to understand. There is therefore a need to improve the working of the statistical techniques to improve its prediction efficiency or to develop other yarn prediction models. A hybrid technique could also be investigated. In this study, statistical techniques were used to model the influence of fiber properties on yarn imperfections. Monte Carlo Simulation was then used to predict the yarn imperfections from the statistical models.

MATERIALS AND METHODS

This study was undertaken between March 2009 and September 2011, at a selected textile factory in Eldoret, Kenya through the initiative of the department of Textile Engineering of Moi University. The details of the material used and methods applied to test various quality characteristics for cotton fibers and yarns are briefly described here under.

Materials: In this study, cotton lint and yarn samples were collected from a spinning mill in Kenya. Since, the yarn manufacturing system is assumed an Ergodic system, for every fiber sample collected, the yarn made from that lot was also collected from the ringframe.

Methods: Physical characteristics of cotton samples were determined mostly with the help of High Volume Instrument (Uster Spectra 1000 HVI system) according to the standards of committee ASTM (ASTM Committee, 1997a). The cotton samples were evaluated for the following physical characteristics:

Fiber characteristics: The cotton fiber properties such as, fiber micronaire, fiber maturity, spinning consistency, fiber length, fiber uniformity, short fiber index, fiber strength, fiber elongation, trash content, fiber reflectance, trash area, trash grade, fiber yellowness were evaluated as per standard.

Yarn preparation: After evaluation of the physical characteristics of the raw material, each cotton sample was opened manually and processed in carding and drawing sections without changing any mechanical set up. The samples of sliver were processed to form roving of the same hank roving samples, roving samples. To eliminate the spinning variations, the roving samples were ring spun into yarns under the same conditions on the same spinning machine. The counts for the yarn samples collected were Nm 14 (71.43 tex), Nm 18 (55.56 tex) and Nm 43 (23.26 tex). The yarn samples thus, prepared were tested according to the standard methods as recommended by ASTM Committee (1997b).

Yarn imperfections: This involved measuring the number of neps, thick and thin places per 1000 meters of the yarn using USTER III. This was determined by measuring the capacity occurring as the yarn pass through the condenser and record in terms of total number of neps, thick places and thin places per 1000 meters of yarn on the USTER III equipment in accordance with the procedures of ASTM standards (ASTM Committee, 1997b).

Yarn count: Yarn count was determined by the Skein Method according to ASTM standard (ASTM Committee, 1997c) on Uster Autosorter.

Yarn twist: The yarn twist was measured using the opposite twist method on the digital twist tester. In this way, the random error of mean value was less than 2%.

Statistical analysis: Linear regression analysis was applied to establish a quantitative relationship between the yarn imperfection (neps, thick and thin places) with respect to fiber properties, yarn linear density and yarn twist. Meanwhile due to the large number of fiber properties linear relationship between fiber properties and yarn imperfection was assumed. The input parameters for the multiple linear regression models were: fiber properties, yarn twist and yarn count; while the output parameters were number of neps, thick and thin places. The data was subjected to statistical manipulation on computer employing Minitab 15 computer program using the procedure of Meet Minitab 15, (MINITAB®, 2006).

The regression analysis expresses the relationship between yarn imperfections and the input variables (yarn count, yarn twist and fiber properties). Table 1, shows the regression coefficients of each variable. Arrangement of variables in the table indicates their relative importance for the models. The model for the number of neps (R = 0.68) was influenced positively by: yarn twist, fiber maturity, spinning consistency, fiber length, fiber uniformity, trash area, trash grade and fiber yellowness. Yarn count, fiber micronaire, fiber strength, fiber elongation and reflectance had a negative influence on the model for the number of neps. The model for the

Table 1: Coefficients for the multiple linear regression model for yarn imperfections

Stat. Par	B	tx	tw	mi	ma	sc	ln	un	sf	st	el	tc	rd	ta	tg	ye
Neps (np)	-35.0	-5.5	2.0	-38.4	282.0	0.2	4.4	0.9	18.1	-2.4	-0.5	0.0	-3.9	30.1	1.5	12.6
Thick (tk)	-741.0	-0.5	15.0	-17.4	761.0	-0.0	-1.1	0.9	-10.3	-2.2	4.2	1.4	0.2	-189.0	24.5	-2.8
Thin (tn)	-484.0	-0.5	1.4	-11.1	539.0	-0.2	0.7	2.1	0.3	-1.6	1.2	-0.3	-0.8	-26.2	8.2	-1.2

The positive (+) and negative (-) signs of regression coefficients of variables indicate the direction of influence B: Constant, tx: Yarn linear density, tw: Yarn twist, mi: Fiber micronaire, ma: Fiber maturity, sc: Spinning consistency, ln: Fiber length, un: Fiber uniformity, sf: Short fiber index, st: Fiber strength, el: Fiber elongation, tc: Trash content, rd: Fiber reflectance, ta: Trash area, tg: Trash grade, ye: Fiber yellowness number of thick places (R = 0.65) showed that the factors that had positive influence are: yarn twist, maturity, uniformity, elongation, trash content, reflectance, trash grade. The variables that had negative influence on the model are: yarn count, micronaire, fiber length, short fiber index, fiber strength, trash area and yellowness. The model for the number of thin places (R = 0.68) showed that it would be influenced positively by: yarn twist, fiber maturity, fiber length, uniformity, short fiber index, elongation and trash grade. The factors that had negative influence on the model are: yarn count, micronaire, spinning consistency, fiber strength, trash content, reflectance, trash area and yellowness. Therefore, the coefficients for the number of neps, thick and thin places indicate that some factors that were consistent in their direction of influence on all the three models for yarn imperfections. Thus, the factors that consistently influenced the yarn imperfections positively were: yarn twist, maturity, uniformity and trash grade. These factors would be considered to have an overall positive influence on yarn imperfections and would increase with an increase in imperfections for in a ring spun yarn. Meanwhile the factors that had a consistent negative impact on the number of yarn imperfections were: yarn linear density, micronaire and fiber strength. These factors would decrease as the number of imperfections in ring spun yarn increases.

Monte Carlo simulation method: The simulation of the multiple linear regression models for the neps, thick and thin place was performed with Monte Carlo techniques, using ModelRisk 3.0 program according the procedures suggested by Vose (2008) and supported by Al-Nasser and Al-Talib (2010).

RESULTS AND DISCUSSION

Prediction of number of neps: The simulation of the regression model for the number of neps established that there is an 80% chance that the number of neps on the ring spun yarn lies between 91 and 102 which indicates that there is a 10% probability that the number of neps could fall below 91 and a 10% probability that the number of neps could be above 102 as shown by the histogram sensitivity graph (Fig. 1).

The sensitivity analysis graph in Fig. 2 indicates that the factor that had the highest influence on the number of neps model was yarn linear density with the greatest range 5.4, short fiber index with a range of 4.2 was the next highest influential factor followed by micronaire, reflectance,

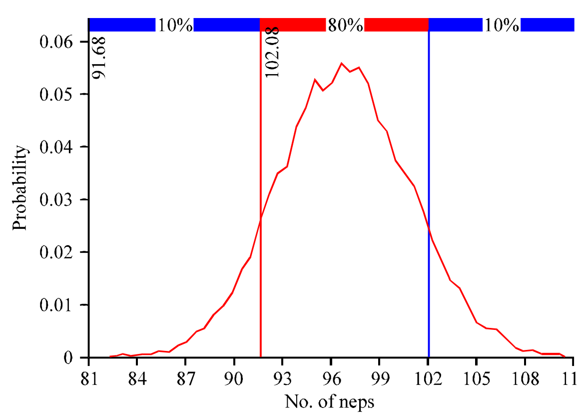

Fig. 1: Cumulative line graph for neps

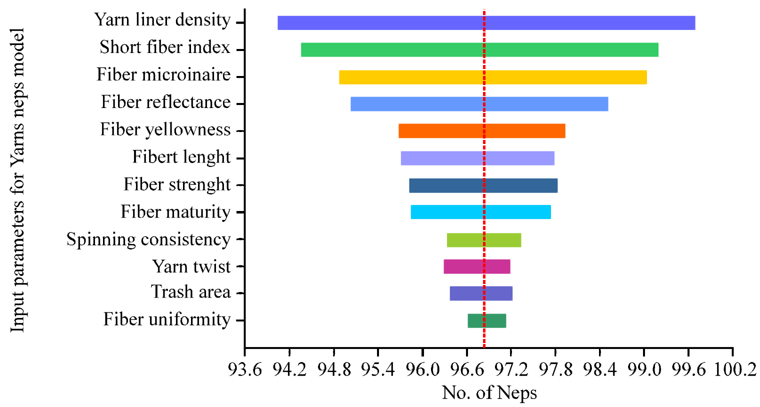

Fig. 2: Sensitivity plot for neps

yellowness, fiber length, strength and maturity. These results are consistent with findings of Kluka *et al.* (1998) and Frydrych and Matusiak (1999) who ascertained that there are two main factors influencing the neppiness of cotton yarns: the characteristics of raw material used for production and conditions of the spinning process. It was determined from the sensitivity analysis of the model for number of neps that yarn linear density was had the most influence on the number of neps in ring spinning, this implies that a coarser yarn will have less neps while fine yarns would have more neps. This agrees with the USTER (2009) which established that when fibers of a given number of neps are processed into coarse and fine yarns, the testing equipment will count less neps in the coarse yarn and more neps in fine yarns. Since all deviations are referred to the mean value of the yarn, neps of a given size are less significant in coarse yarns. Furthermore, Mwasiagi (2006) while studying Kenyan cotton also established that the study of the effect of count increased with a decrease in imperfections.

The sensitivity analysis also established that fiber micronaire value had significant influence on the number of neps, showing that fibers, which are finer, would be spun into yarns with more neps than those which are coarse. This is probably due to the fact that fibers with low micronaire have been found to cause excessive nepping during spinning as established by Frydrych *et al.* (2001).

The fiber maturity and fiber yellowness in the model also portrayed significant influence on the number of neps in ring spinning which would mean that as the maturity and yellowness of cotton fibers increase yarn neps will increase. This agrees with the findings of Kluka *et al.* (1998) and Hebert *et al.* (1986). Fiber yellowness is directly linked to the growth environment. Bright creamy-white fibers which have higher reflectance, are more mature. Premature termination of fiber maturation by application of growth regulators, frost, or drought characteristically increases the saturation of the yellowness. It means that higher yellowness is related to poorer quality and probably the reason behind the positive influence of fiber maturity on the number of neps in ring spun yarn for our model. However, this abnormal behavior of fiber maturity may also be explained from Azzam and Mohamed (2005) results, while undertaking a case study of the Egyptian cotton spinning industry they revealed that the main reason for quality problems were unsuitable quality levels, large quality variations and unexplained quality exceptions. According to Azzam and Mohamed (2005) the unsuitable quality levels arise due to individual factories coming up with their own quality standards. This makes it difficult to compare products from different factories. This problem can however be solved by adapting internationally acceptable standards.

According to the sensitivity analysis, fiber length also showed significant impact on the model for the number of neps which agrees with the studies done by Kluka *et al.* (1998).

Meanwhile the short fiber index and uniformity also had influence on the model for the number of neps, this relationship means that as the short fibers and uniformity increase the number of neps in yarn would increase. This is supported by Ozcelik and Kirtay (2006), who established that to predict the number of yarn neps, the uniformity index and short fiber content are the crucial properties for determining yarn neps.

The sensitivity analysis plot in Fig. 3 indicates the ranks for factors in model for number of neps. The sensitivity plot shows that the variable which had the greatest positive influence was short fibre index (rank = +0.32) which implies that an increase in short fibers would lead to an increase in neps in ring spinning, this is probably because the short fibers would easily entangle into folds to form neps in the yarn. The second significantly ranked positive factor was yellowness (rank = +0.16) and this would increase with increase in the number of neps, because as the number of yellowness increase there would be more tendency of the fibers to entangle into neps. The factor that had highest significant negative influence on the model was yarn twist (rank = -0.40) which suggest that as the twist in the yarn increase the chance of nep formation in ring spinning would decrease which is due to the fact that at high twist the fibers are do not have a chance to entangle so that less neps are formed. The fiber micronaire value (rank = -0.32) also had a significant negative impact on our model for the number of neps, implying that the micronaire value would increase as the number of neps decrease, this is probably due to the fact that the yarn nippiness will be more in finer fiber than they would appear in coarse fibers.

Prediction for the number of thick places: The simulation results for the regression model for the number of thick places established that there is an 80% chance that the number of thick places will lay between 101 and 114 thick places. This indicates that there is a 10% probability that the number of thick places could fall below 101 and a 10% probability that the number of thick places could be above 114 as shown by the histogram sensitivity graph (Fig. 4).

The sensitivity analysis plot in Fig. 5 indicates that the factor that had the highest influence on the number of thick places model was yarn twist with the greatest range of 7, trash grade (5.6) and trash area (5.6) were the next highest influential factors. The yarn twist for the ring spun yarn

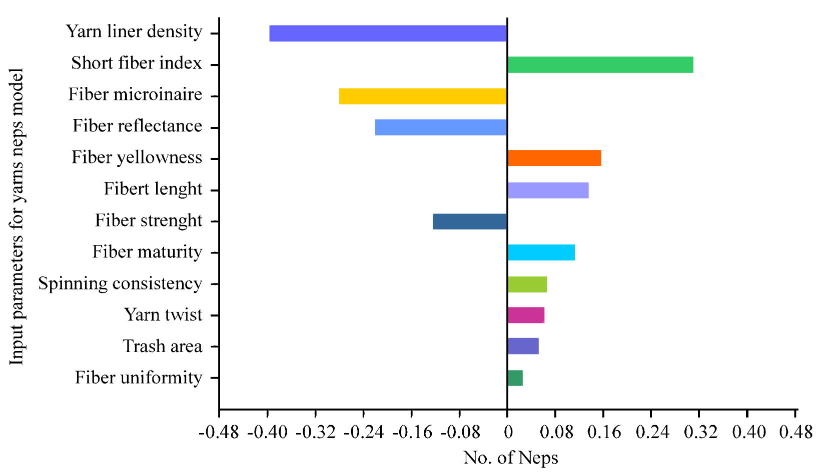

Fig. 3: Rank correlation plot for yarn neps

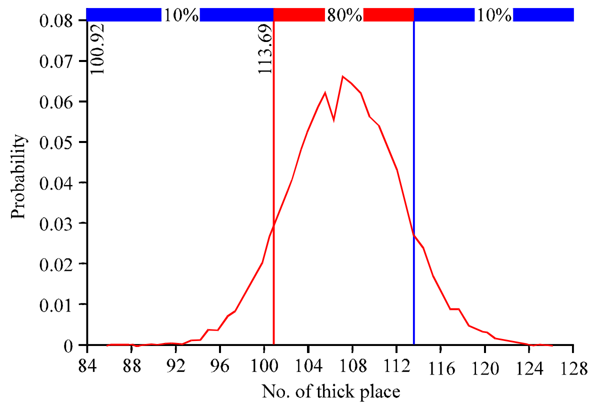

Fig. 4: Cumulative line graph for thick places

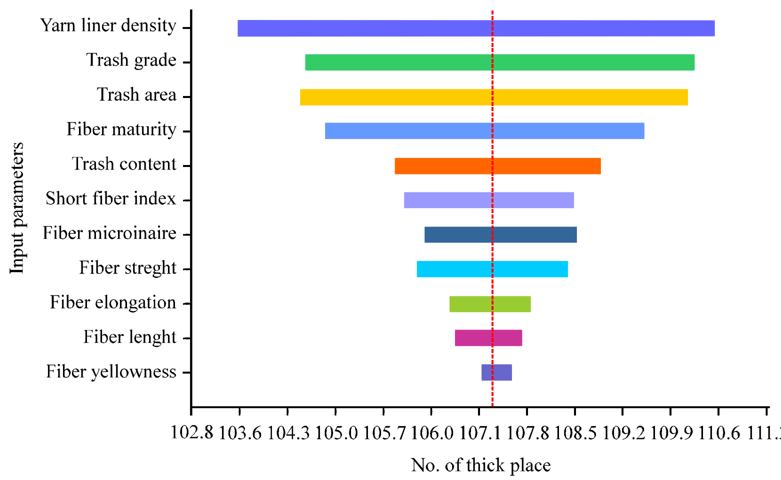

Fig. 5: Tornado plot for thick places

emerged as an influential factor on the number of thick places in ring spinning because fibers are assembled together into a twisted strand to constitute a yarn. In the process of yarn twisting, more fibers in the cross-section result in a higher resistance to torsion leading to the formation of thick places in the yarn. Thick places have therefore, in many cases, a yarn twist which is lower than the average. The yarn tension in the yarn at the position of the thick place is only in very few cases proportional to the number of fibers. The trash in the fiber also portrayed a high significant probably due to the fact that the availability of impurities during ring spinning leads to the presence of imperfections in ring spun yarn.

The sensitivity analysis plot Fig. 6 shows that the variable which had the greatest significant positive influence on the number of thick places was yarn twist (rank = +0.40) which suggest that as the twist imparted on the yarn increase the appearance of thick places would increase, this probably because at high twist the areas along the yarn will expose those areas on the yarn that has more fiber hence thicker and those that have fewer yarn hence thinner. The model for the number of thick fibers also showed that trash grade (rank = +0.32) had a positive significant impact on the number of thick places and would therefore increase with increase in the number of thick

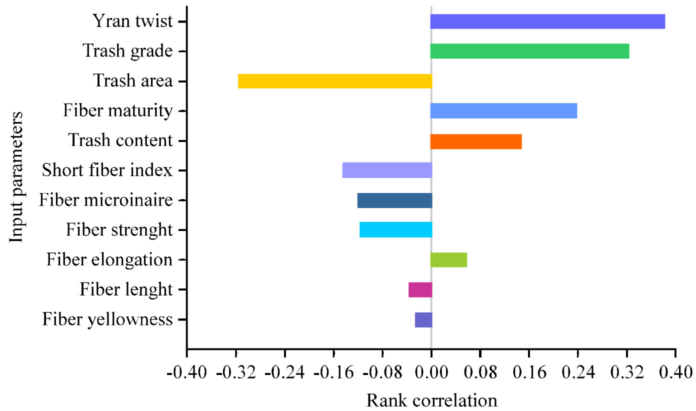

Fig. 6: Rank correlation plot for thick places

places which suggests that as the amount of trash in the cotton during ring spinning will cause the emergence of more thick places in the yarn. The model for the number of thick places further portrayed that fiber maturity was another significantly positive factor (rank = +0.24), thus, indicating that the more the mature fibers during ring spinning the more the number of thick places, this is because as the fibers become more mature they are able to be well arranged along the fiber strand and thus incase of any variations in twist the yarn formed will show some areas which are thicker than others. Meanwhile the factor that had highest significant negative influence on the model for the number of thick places was trash area (rank = -0.32), this suggests that as the area occupied by trash increases the number of thick places in the yarn will decrease, this is probably because the area on the yarn with trash may result into increase in breakage during ring spinning and therefore, the increase in the number of thin places and less thick places. the short fiber index (rank = -0.16) also had a significant negative influence on the model which suggests that the short fiber index will increase as the number of thick places decrease, this is probably due to the fact that the more the short fibers at high twist the fibers will be spun into thinner yarns leading to a decrease in thick places along the yarn.

Prediction for the number of thin places: The simulation results for the regression model for the number of thick and thin places established that there is an 80% chance that the number of thin places will lay between approximately 8 and 13 thin places. This indicates that there is a 10% probability that the number of thin places could fall below 8 and a 10% probability that the number of thin places could be above 13 as shown by the histogram sensitivity graph (Fig. 7).

The sensitivity analysis plot in Fig. 8 indicates that the factor that had the highest influence on the number of thin places model was maturity with the greatest range 3.3, trash grade with a range of 1.8 was the next highest influential factor followed by strength and micronaire. The fiber maturity in the model also portrayed highest significant influence on the number of thin places in ring spinning which would mean that the maturity of cotton fibers would course the appearance of yarn thin places on a ring spun yarn the most. This is probably because with higher number of immature fibers causes fiber damages during processing and hence it affects the yarn quality which is supported by the research by Basu (2006).

According to Basu (2006) the fineness of cotton evaluated by micronaire value is a combined measure of fineness and maturity, implying that an immature fiber shows lower weight

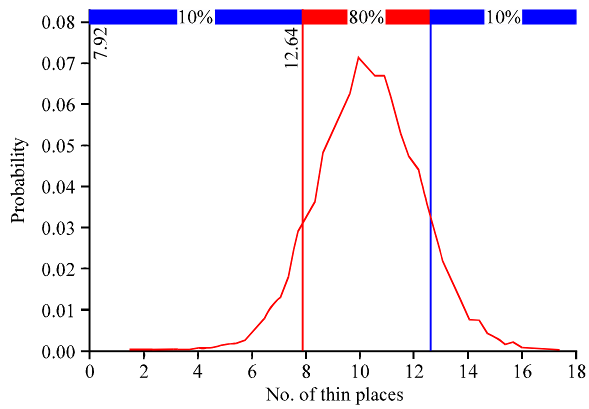

Fig. 7: Cumulative line graph for thin places

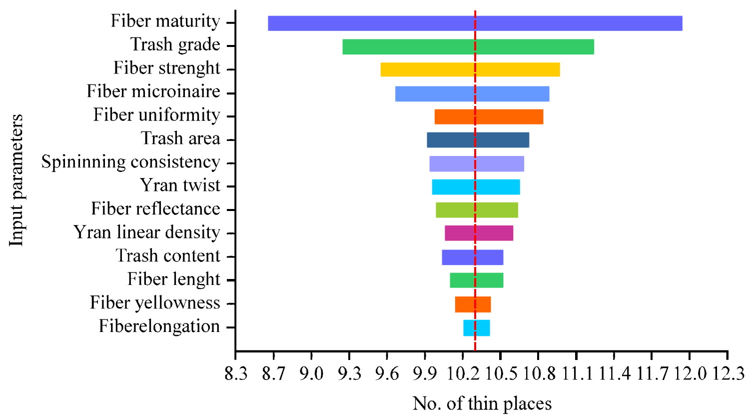

Fig. 8: Tornado plot for thin places

per unit length than mature fibers. This is probably why in our model for the number of thin places fiber micronaire value also emerged as an influential factor on the number of thin places because the natural fibers are highly variable. The variations in fiber micronaire could be due to different rates of cell development owing to changes in environmental conditions and fiber fineness. The fineness of cotton fibers could influence thin places on a ring spun yarn because fiber size directly affects yarn cross sectional shape and size.

The fiber trash in the cotton was as also a major factor in the study of the number of thin places probably because the impurities in cotton would play the biggest role in producing faulty yarns in the ring spinning process. Hence, the mass of each section may differ. The positive influence shows that the number of thin places would be higher when the trash in the fiber is high.

Fiber strength had influence on yarn thin places in ring spinning because when fiber strength is low the rate of rapture is high which leads to irregularities along the yarn surface; however, fibers may be prevented from rupture due to higher strength.

The sensitivity analysis plot Fig. 9 indicates the ranks for factors in the model for number of thin places. The sensitivity plot shows that the variable which had the greatest significant positive influence was maturity (rank = +0.5), this indicates that as more mature cotton fibers are used in ring spinning the number of thin places would also increase significantly in the yarn. The model

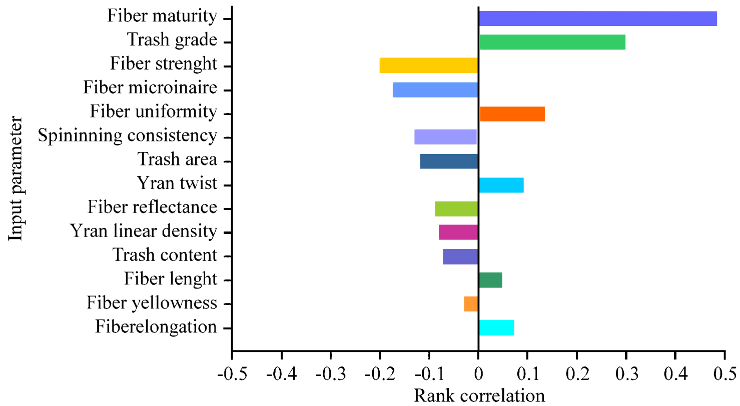

Fig. 9: Rank correlation plot for thin places

for the number of thin places also showed that the second positive significantly ranked factor was trash grade (rank = +0.3) which shows that according to our model an increase in the trash grade would lead to a net increase in the number of thin places. Meanwhile according to our model on the number of thin places the factor that had highest significant negative influence on the model was fiber strength (rank = -0.2), this implies that as the strength of fiber increases the number of thin places would decrease significantly. The fiber micronaire value (rank = -0.1) this indicates that as the fineness and maturity of cotton fibers increase the number of thin places would decrease significantly in a ring spun yarn.

The sensitivity analysis of the model for the number of thick and thin places further established that most factors had influence on both thick and thin places in ring spinning which portrays some level of co-relation between the number of thick and thin places. This fact is supported in a study undertaken by Gabriela and Sandra (2010) which established that the number of thick and thin places of a yarn is highly correlated, this is because near a thin place is a thick place and near a thick place is a thin place.

CONCLUSION

In this study, the relationship between fiber properties and yarn imperfections has been modeled using statistical and Monte Carlo techniques. The parameters of the fiber samples tested were: micronaire value, maturity, spinning consistency, fiber length, fiber uniformity, short fiber index, fiber strength, fiber elongation, trash content, fiber reflectance, trash area, trash grade and fiber yellowness. The yarn parameters tested were twist, linear density and imperfections (neps, thick and thin places). The fiber parameters, yarn linear density and twist were used as inputs, while neps, thick and thin places were used as the outputs. The R-value for the yarn imperfections were 0.68, 0.65 and 0.68 for neps, thick and thin places, respectively. The factors, which showed significant influence on yarn neps, were; yarn linear density (count), short fiber index, micronaire, fiber reflectance, fiber yellowness, fiber length, fiber strength and fiber maturity. Yarn twist, trash grade, trash area, fiber maturity, trash content, short fiber index, fiber micronaire and fiber strength, were recorded as the most influential factors affecting the number of thick places in ring spun yarn. For the number of thin places, the most influential factors were fiber maturity, trash grade, fiber strength, micronaire, fiber uniformity, trash area, spinning consistency index and yarn twist. Considering all the three factors (neps, thin and thick places), the factors which showed significant effect on yarn imperfections of ring spun yarn were; yarn twist, micronaire, fiber maturity, trash area, fiber length, fiber strength, and fiber yellowness. Others factors, which included trash grade, fiber uniformity, spinning consistency index, fiber reflectance, yarn linear density, trash content, fiber elongation, and short fiber index, should also be considered studying yarn imperfection of cotton ring spun yarns.

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