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Untersuchung der Verarbeitbarkeit von Baumwolle und der Qualität von Fasern und Garnen

(Investigation of the cotton processability and quality of fibre and yarn)

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Dipl.-Ing. Getnet Tesema

Gutachter: Prof. Dr.-Ing. Axel S. Herrmann
Prof. Dr. V.R. Sampath

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Abstrakt

Der Anstoß zu dieser Forschung war die Beobachtung des Forschers während des Mentoring-Programms für Industriepraktika, das seine Studenten verfolgten. Er beobachtete die Herausforderung der Textilfabriken in Äthiopien bei der Verarbeitung einheimischer Baumwolle. Sie waren praktisch mit vielen Endbrüchen konfrontiert, die relativ höher waren als von einem Spinner erwartet.

Auf dieser Grundlage wollte die vorliegende Studie den Beitrag von Genotypen, die in verschiedenen Anbaugebieten des Landes kultiviert werden, abschätzen, wenn sie Auswirkungen auf die Verarbeitbarkeit von Baumwolle und auf die Qualität von Fasern und Garnen zu haben scheinen.

Eine Überprüfung der Leistung von Genotypen gegen die Auswirkungen von Entkörnungsstudien im letzten Jahrzehnt ergab, dass es eine Reihe wertvoller Studien gab, die in erster Linie die Leistung von Genotypen gegen die Auswirkungen von Entkörnungs zu untersuchen versuchten. Aufgrund des Einflusses der Vermischung von Genotypen während der Entkörnung kann jedoch keine dieser Studien die Leistung reiner Genotypen gegenüber den Auswirkungen der Entkörnung wirklich und vollständig nachweisen. Diese früheren Studien waren auch nicht in der Lage, die Leistung reiner Genotypen gegenüber den Auswirkungen moderner, schnell rotierender Spinnmaschinen eindeutig nachzuweisen.

Diese Studie sollte die Lücke in der bestehenden Forschung schließen, indem die Leistung von Genotypen aus reiner Baumwolle gegen die Auswirkungen des Entkörnens und die Leistung von Genotypen aus reiner Baumwolle gegen die modernen, schnell rotierenden Spinnmaschinen untersucht wurden. Die Untersuchung der Auswirkungen dieser reinen Genotypen auf die Qualität von Zwischen- und Endprodukten war ebenfalls eines der Ziele der Studie.

Die wichtigsten Baumwollplantagezonen, die während der Probenahme abgedeckt wurden, waren: Nordäthiopien (Tigray, Amhara & Ben-ishangul Gumuz); Nordmitteläthiopien (Upper Awash, Middle Awash & Lower Awash) und Südäthiopien (Oromia, Arba Minch & Gambelia). Die in der Studie verwendeten kommerziellen Sorten wurden 2017 in allen Plantagezonen geerntet und mit denselben Prozessparametern bei derselben Ginerie entkörnt. Es wurden Proben verwendet, die groß genug sind, um den Baumwollgenotyp wiederzugeben.

Die Fasereigenschaften wurden mit drei Einzelfasern (TEXTECHNO FAVIMAT+, FAVI-GRAPH, USTER AFIS PRO 2) und zwei Bündelfasertestgeräten (USTER HVI 1000, TEXTECHNO CCS V-5) bewertet. Die Eigenschaften der Faserqualität wurden mit den von TEXTECHNO STATIMAT ME+ und USTER TESTER 5 getesteten Eigenschaften der Garnqualität korreliert.

Einzel- und Bündelfasereigenschaften wurden unter Verwendung der Varianzanalyse (ANOVA) analysiert, um festzustellen, ob die Entkörnung

genotypabhängig war oder nicht. Die zur Verarbeitung der Daten verwendete Software war IBM SPSS Version 25. Die nachgewiesene Varianzanalyse (ANOVA) zeigte, dass der Acala SJ-2-Genotyp mit höherer mittlerer Faserfestigkeit und -dehnung und niedrigerem Variationskoeffizienten der Zähigkeits- und Dehnungswerte vor der Entkörnungsbehandlung blieb mit seiner höheren Zähigkeit und Dehnung nach der Entkörnungsbehandlung als seine Konkurrenzgenotypen.

In der Studie wurde die Sorte Acala SJ-2 mit größerer Einzel- und Bündelzähigkeit und Dehnungseigenschaften vor der Entkörnungsbehandlung auch dadurch begünstigt, dass sie im Vergleich zu den kommerziellen Konkurrenzsorten Arba und DP-90 weniger Faserbruch sowie relativ wenig Neps aufwies. Darüber hinaus erhöht die Entkörnung mit einer Geschwindigkeit von 9 Ballen/h den Gehalt an Kurzfasern und Neps im Vergleich zur Entkörnung mit 7 Ballen/h. Die praktischen Mittel zur Kontrolle des Faserbruchs und des Kurzfasergehalts für die untersuchten Sorten sind daher die Entkörnung mit 7 Ballen/h und die Einhaltung der Entkörnungsrate innerhalb der empfohlenen Grenzen.

Die Studie ergab, dass es wichtig ist, die Unterschiede in der Zähigkeit und Dehnung vor und nach dem Entkörnen zu verstehen, um die richtige kommerzielle Fasersorte auszuwählen, die während des Entkörnens und weiterer Spinnprozesse eine bessere Leistung erbringen kann. Es ist offensichtlich, dass eine kommerzielle Sorte mit hervorragender Entkörnungs- und Spinnleistung die gewünschten Qualitätsanforderungen an das Endprodukt am besten erfüllen kann.

Während der Studie war es wichtig, die Variation der Faserfestigkeit und -dehnung sowohl auf der Ebene der einzelnen Fasern als auch der Bündel innerhalb einer Probe, innerhalb eines Ballens und zwischen den Ballen sowie die Varianz der Faserfestigkeit und -dehnung zu verstehen. Ein Bündel mit einer großen Variation der Faserfestigkeit und Dehnung von Faser zu Faser verhält sich nicht wie ein perfektes Bündel, bei dem alle Fasern identisch sind, selbst wenn die Durchschnittswerte für Faserfestigkeit und Dehnung identisch sind (alle anderen Fasereigenschaften sind konstant). Das Bündel mit großer Variabilität in Zähigkeit und Dehnung wurde als schwächer befunden. Dies lag an der Tatsache, dass die auf das Bündel ausgeübte Spannung nicht alle Fasern gleichermaßen beeinflusst (vorausgesetzt, alle Fasern sind an beiden Enden festgeklemmt). Die Fasern mit geringer Dehnung brechen zuerst und der Widerstand der verbleibenden Fasern gegen die ausgeübte Kraft nimmt ab und das Bündel bricht aufgrund des Kaskadeneffekts.

Das gefundene Ergebnis ermöglicht es den Züchtern und Spinnern, Faserdaten aus Einzel und Bündeltestergebnissen effektiver für Auswahlzwecke zu verwenden, um die Verarbeitbarkeit von Baumwolle und auch die Qualität der Endprodukte zu verbessern.

In dieser Studie wurden Ansätze zur Entscheidungsfindung nach mehreren Kriterien (MCDM) und zur linearen Programmierung (LP) verwendet, um die

Faserqualitätswerte der Genotypen zu identifizieren, die für das optimale Mischen in einem bestimmten Spinnszenario verwendet wurden. Das Präferenzranking der Genotypen wurde mit den Tools PROMETHEE II und V durchgeführt. Der GAIA-Ansatz wurde zur geometrischen Analyse von Genotypen verwendet. Die Prioritätskriteriengewichte zwischen den Faserqualitätseigenschaften wurden unter Verwendung eines analytischen Hierarchieprozesses (AHP) bestimmt, bei dem es sich um eine subjektive Bewertungsmethode handelt, die auf einem paarweisen Vergleich der Kriterienwerte basiert.

Es wird beobachtet, dass das eingeführte Modell ein großes Potenzial hat, die Genotypalternativen der Wettbewerber nach ihren Faserqualitäten vom Besten zum Schlechtesten zu klassifizieren und die am besten bewerteten Genotypen zu identifizieren (z. B. Acala SJ-2, Sille 1 (Stoneville), Bulk 202, BPA). Die lineare Computerprogrammiertechnik wurde verwendet, um die Bestandteile der Fasern in der endgültigen Mischung zusammen mit ihren Anteilen herauszufinden, die für ein entworfenes Spinnszenario erforderlich sind.

In dieser Studie wurde ein neuer modifizierter Faserqualitätsindex (MFQI) formuliert, um die untersuchten kommerziellen äthiopischen Baumwollsorten instrumentell zu charakterisieren und ihre Anwendbarkeit auf die kommerziellen Baumwollsorten von US UPLAND, US PIMA und Egyptian Giza 87 zu testen. Die erhaltenen Ergebnisse zeigten, dass die Kombination von Bündeleigenschaften (von USTER® HVI 1000) und Einzelfasereigenschaften (von TEXTECHNO FAVIMAT+) es ermöglicht, Fasereigenschaften für kommerzielle Ballen ziemlich genau vorherzusagen.

Die entwickelten multiplen Regressionsmodelle zeigen die Faser-Garn-Beziehungen. Die Eigenschaften der Bündelfaserqualität wurden unter Verwendung eines einzigen umfassenden Testsystems (TEXTECHNO CCS Version 5) gemessen, während die Garnqualitätseigenschaften unter Verwendung des Zugprüfgeräts TEXTECHNO STATIMAT ME + für ein einzelnes Garn gemessen wurden. Diese Modelle sagen die Zugeigenschaften von Ring- und Rotorspinngarnen mit der Anzahl Ne 24 und Ne 36 genau voraus.

Eine Anfangsspannung von 5 cN/tex wurde verwendet, um die Kräuselung in den Fasern während der Messung der absoluten Reißfestigkeitsdehnung des Bündels zu entfernen, und es wurde eine positive Korrelation zwischen Reißfestigkeit und Dehnung mit R2 = 0,091 gefunden [7]. Der Befund veranlasst möglicherweise die Baumwollzüchter und -kultivatoren, eine Baumwolle mit besserer Faserdehnung zu kultivieren. In dieser Forschungsarbeit wird auch beobachtet, dass die Genotypen mit höheren mittleren Einzelfaser-Zugeigenschaften tendenziell eine höhere Dehnung aufweisen, wodurch sie weniger von der Schlagwirkung von Sägezahnschlägern der Entkörnungsmaschine beeinflusst werden.

Gegenwärtig verwenden die meisten Fabriken in Äthiopien DP-90, eine im Handel erhältliche Hochlandsorte (Gossypium hirsutum L.), die in großen landwirtschaftlichen Betrieben in bewässerten Niederungen und in wärmeren Mittelgebieten in kleinen landwirtschaftlichen Betrieben weit verbreitet ist , um grobe bis mittlere Fadenzahlen zu spinnen, und es werden überhaupt keine feinen Fadenzahlen erzeugt. Diese Studie ergab, dass es einige Sorten gibt, die unterschiedliche Merkmale aufweisen (z. B. Sille 1 (Stoneville), Bulk 202, BPA). Die Fabriken verwenden diese Sorten nicht, da sie nicht in ausreichender Menge im Handel erhältlich sind. Spinner benötigen jedoch einen viel breiteren Faserbereich, um eine geeignete Mischung herzustellen, die erforderlich ist, um die gewünschte Garnanzahl durch Minimieren der Endbruchraten und Maximieren der Effizienz zu spinnen.

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Abbreviations

Acala SJ-2	Name of cotton genotype/variety[1] grown in Ethiopia
AFIS	Advanced Fibre Information System (USTER® AFIS PRO 2)
AHP	Analytical Hierarchy Process
Alber 637	Name of cotton genotype/variety grown in Ethiopia
ANOVA	Analysis of Variance
Arba	Name of cotton genotype/variety grown in Ethiopia
ASTM D 1577	American Society for Testing and Materials: "Standard Test Methods for Linear Density of Textile Fibers"
ASTM D 1776	American Society for Testing and Materials: "Standard Practice for Conditioning and Testing Textiles. For cotton testing"
AT	Absolute Tenacity (measured by CCS version 5')
BE	Bundle Elongation (measured by CCS version 5)
BF	Bundle Force (measured by CCS version 5)
BPA	Name of cotton genotype/variety grown in Ethiopia
BTH	Bundle tenacity measured by 'USTER® HVI 1000')
Bulk 202	Name of cotton genotype/variety grown in Ethiopia
+b	Unit used for yellowness measurement of cotton
CCS version 5	Cotton Classifying System (Textechno CCS version 5 Bundle fibres testing instrument)
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CSITC	Commercial Standardisation of Instrument Testing of Cotton
Cucrova 1518	Name of cotton genotype/variety grown in Ethiopia
Cu-ok-ra	Name of cotton genotype/variety grown in Ethiopia
C.V %	Coefficient of variation percent
Deltapine 50	Name of cotton genotype/variety grown in USA
DP-90	Name of cotton genotype/variety grown in Ethiopia
EL_M	Single fibre elongation measured by FAVIMAT+
Estamble	Name of cotton genotype/variety grown in Ethiopia
€/kg	Cotton market price, Euro per kilogram
FAVIGRAPH	TEXTECHNO 'FAVIGRAPH': Single fibre linear density (fineness) and tensile tester
FAVIMAT+	TEXTECHNO 'FAVIMAT+': Automatic linear density, crimp and tensile tester for single fibres
FE	Bundle Fibres Elongation (measured by 'USTER® HVI 1000')
FIBRE	Faserinstitut Bremen e.V.
FQI	Fibre Quality Index

[1]Genotypes and variety have similar meaning in this research work and can be interchangeably used throughout the dissertation.

FQI_{HVI}	Fibre Quality Index (measured by 'USTER® HVI 1000')
FT	Bundle Fibres Tenacity (measured by 'TEXTECHNO CCS version 5')
GIZA 87	Name of cotton genotype/variety grown in Egypt
HM	High Moisture
LM	Low Moisture
USTER® HVI 1000	High Volume Instrument: For bundle fibres testing (USTER® HVI 1000)
USTER® HVI 910	High Volume Instrument: For bundle fibres testing (USTER® HVI 910)
ICA Bremen	ICA Bremen International Quality Testing and Research Center
ICAC	International Cotton Advisory Committee
ICCTM	International Committee on Cotton Testing Methods
ITMF	International Textile Manufacturers Federation
Lao Cara	Name of cotton variety grown in Ethiopia
LD	Linear Density (measured by 'TEXTECHNO CCS version 5')
LP	Linear Programming
Mantis	Single fibre laboratory testing equipment (Zellweger-USTER®)
MCDM	Multi-Criteria-Decision-Making
MFQI	Modified Fibre Quality Index
MIC	Micronaire (A unit used to measure cotton fibre fineness by air flow method)
Max	Maximum value
Mean	Mean value
Min	Minimum value
MIC_H	Micronaire (measured by USTER® HVI 1000)
ML_n	Mean length by number
ML_w	Mean length by weight
MV	Maturity Value (measured by 'TEXTECHNO CCS version 5')
Neps	Amount of neps (measure by CCS V-5 or AFIS PRO 2)
PROMETHEE	A method used for the purpose of decision making
PROMETHEE II	Used for complete ranking of the candidate alternatives
PROMETHEE rainbow	Used as a visualization tool to show property profile of the candidate alternatives
GAIA plane	Used as visualization tool for investigating the results derived from the multi-criteria analysis
PROMETHEE V	Used for decision-making problems where several options need to be selected while satisfying a given set of constraints
R	Range
R-36	Name of cotton variety grown in Ethiopia
Rd	Unit used for light reflectance measurement of cotton
RHS	Right hand constraint value
RiS	Ring Spinning
RoS	Rotor Spinning

SCN	Seed Coat Neps
S.D	Standard Deviation
S. E	Standard Error
SFC	Shot Fibre Content
SFC_n	Short Fibre Content by number
SFC_w	Short Fibre Content by weight
SFI_H	Short Fibre Index (measured by USTER® HVI 1000)
SFS_M	Single Fibre Strength (measured by FAVIMAT+)
Sille1 (Stoneville)	Name of cotton variety grown in Ethiopia
ST	Single yarn Tenacity (measured by TEXTECHNO STATIMAT ME+
TEXTECHNO	Textechno Herbert Stein GmbH & Co. KG
TN	Total Neps
UHML	Upper Half Mean Length
$UHML_H$	Upper Half Mean Length (measured by USTER® HVI 1000)
UI	Uniformity Index
UIH	Uniformity Index (measured by USTER® HVI 1000)
W	Work of Rupture (measured by 'TEXTECHNO CCS version 5')
UR	Uniformity Ratio
US PIMA PHY 881 RF	Name of cotton variety grown in USA
US UPLAND	United States upland cotton
USDA	United States Department of Agriculture

Symbols

ε_0	Measured elongation
ε_{cr}	De-crimping elongation
χij	Relative performance of ith alternative against jth crite rion
ε_m	Material elongation
F_v	Pre-tension
L^2	Test fibre section length
T_t	Fibre linear density
f^2	Resonance frequency
$\varphi^-(a)$	Negative outranking flow
$\varphi^+(a)$	Positive outranking flow
°C	Degree Centigrade
°F	Degree Fahrenheit
a_a, a_r, a_d	Proportions of Acala-SJ-2, Arba and DP-90, respectively
a_i	Proportion by weight of the ith component cotton in the mix/blend
C_i	Cost of the ith component in the mix/blend
cN/tex	Centinewton per tex, unit of fibre tenacity (direct method)
g/den	Gram per denier, unit of fibre tenacity (indirect method)

k	Number of mix/blend components
m	Number of Xi cottons
pj (a, b)	A number between 0 and 1
R^2	Correlation coefficient
RH %	Relative Humidity percent
t	Symbol used for parametric analysis
t	Thickness of the cotton sheet
V	Volume of the cotton sheet
v	Rate of feeding
w	Width of the cotton
W_{cr}	De-crimping work
w_j	Priority weight allocated to jth criterion
$W_{overall}$	Overall breaking work
w_{wi}	Percentage yield of returns and waste from the ith component in the blend
W_{yi}	Percentage yield of yarn from the ith component
X_i	cotton fibre constraints considered for cotton mix ing/blending
Z_t	Transformation cost of raw material
π (a, b), π (b, a)	Preferences indices
$Minimize: Z\ (cost)$	Cost objective function
$\varphi(a)$	Net outranking flow

1 Introduction to research

Cotton occupies a unique position in Ethiopia's agrarian economy. Ethiopia has enormous potential for the production of cotton. Ethiopia has a conducive weather and topography for the cultivation and production of cotton. Currently, cotton (Gossypium hirsutum L.) is widely grown in the irrigated low lands on large-scale farms and in warmer mid altitudes on small-scale farms under rain-fed conditions.

A recent study of the Ethiopian Investment Agency [1] indicates that there is 3,000,810 ha of land suitable for cotton production, which is 81.5 percent the sum of main cotton producing countries in Africa, namely Burkina, Mali, Cote d'ivoire, Cameroon, Benin, Chad, Togo, Senegal, Egypt, Zimbabwe, Nigeria. These African countries have a 2018/19 forecast harvested areas of 3,690,000ha [2].

Out of the total 3,000,810 million ha of land suitable for cotton production in Ethiopia, 1.9 million ha or 63.3% is found in 38 high potential cotton producing areas and the remaining 1.1 million ha or 36.7% is in 79 medium potential districts (see figure 5.1 and table 5.1). Despite this immense potential, Ethiopia currently (2018/19) produces about 38,000 metric tons of lint cotton from a total cotton area of 65,000 ha land which is only 2.17 % of the total area favorable for cotton cultivation [2].

Many textile industries in Ethiopia are equipped both with ring and rotor spinning systems. Some of them have also both carding and combing systems in their aggregating cotton processing lines. The initiation to this research was the researcher observation during the industrial internship mentoring program follow-up of his students. He observed the challenge of textile mills in Ethiopia when they were processing domestically cultivated cotton. They were practically faced many end breakages relatively higher than expected by a spinner.

Based on this initiation, the present study, wished to estimate any contribution of genotypes being grown in different cultivation regions of the country, if they appeared to contribute to tenacity, elongation, length distribution, short fibre content, neps level and including the HVI mean fibre properties.

A new pure genotype intense characterization of hand-ginned raw cotton and commercial machine ginned lint cotton was made. Genotype/ varietal differences when subjected to the ginning and spinning process was studied. Based on the new characterization, a model used for the optimization of cotton mixing/blending was developed.

In the study, after the production of selected yarn counts, fibre-yarn quality relations were investigated. Single fibre (tested by FAVIMAT+, FAVIGRAPH, AFIS) and bundle fibre (tested by HVI, CCS) quality properties was correlated with STATIMAT ME+ and USTER TESTER 5 tested yarn quality properties.

A new modified fibre quality index which is suitable to the studied commercial cotton varieties was developed and its applicability to other internationally known cotton varieties was evaluated. Improved multiple linear regression models used for correlating important fibre properties (tenacity, elongation, work-to-break, etc.) to the quality of yarn were developed.

Since, this research was initiated to study and find results on the relation of genotypes with ginning and spinning processes as well as various important fibre and yarn quality properties, the result would help the breeders in determining the more accurate cultivars used for the desired end products requirement and for the spinners to select cottons based upon their suitability for textile processing with acceptable quality and spinning efficiency (e.g. low number of ends down).

1.1 Problem Statement

Effect of genotype on cotton ginning and processability and quality of fibre and yarn is unknown.

1.2 Research Question

- What effects does the cotton genotype have on the fibre qualities such as tenacity, elongation, fineness, length distribution by number, length distribution by weight, short fibre content, neps level etc.?
- What relation exists between bundle "absolute tenacity" fibres property and spinnability of commercial cotton genotype?
- What effect does the cotton genotype have on fibre properties required for the optimization of cotton mixing for the production of carded ring and rotor spun yarns with the count Ne 24 and Ne 36?
- If the fibre properties required for the optimization of cotton mixing for the production of carded ring and rotor spun yarns with the count of Ne 24 and Ne 36 are genotype dependent, can a mathematical model be developed that can describe the cotton mixing?

1.3 General Hypotheses

- The cotton genotypes affect fibre qualities such as tenacity, elongation, fineness, length distribution by number, length distribution by weight, short fibre content, neps level etc.
- Relation exists between bundle "absolute tenacity" fibre property and spinnability of commercial cotton bales.
- Cotton genotypes affect fibre quality properties required for the optimization of cotton mixing designed for the production of carded ring and rotor spun yarns with the count Ne 24 and Ne 36.

1.4 Research Purpose

The purpose of this research is to investigate the ginning and spinning performance of available genotypes and provide a suitable cotton mixing/blending optimization and fibre-yarn quality correlation models which can be used in the practical application of spinning mills. And also, for better understanding of the effect of genotype on the quality of fibres which determine the cotton ginning behavior, cotton spinning performance and quality of intermediate (e.g. sliver, roving) and final products (e.g. knitted and woven yarns).

1.5 Research Objective

The objective of this research is to investigate the relation of cotton genotype with the ginning and spinning process and fibre qualities such as tenacity, elongation, fineness, length distribution by number, length distribution by weight, short fibre content, level of neps, etc. as well as yarn qualities such as tenacity, elongation, thin places, thick places and level of neps and then to provide suitable models which can help the cotton breeders, producers, and spinners.

2 Review of the literature

Keywords:
Genotype effect, fibre quality, ginning, spinning, product quality, optimum mixing, fibre tenacity, fibre elongation

In this section reviewing of the previous works showing the relation between cotton processability and fibre and yarn quality with genotypes is presented. Particularly, the effect of genotypes to the ginning, cleaning and spinning processes are the focus areas. The relation between quality of fibres measured with single (FAVIMAT, FAVIGRAPH, AFIS) and bundle (HVI, CCS) fibre testing instruments and genotypes will be reviewed. Previous scholarly models introduced for the optimization of mixing is discussed.

2.1 Introduction

Cotton fibre characteristics are determined by complex interactions among inherent fibre quality differences related to: genotype [3], environmental [4] and processing conditions such as: harvesting and ginning machines which can contribute to fibre variability by altering short fibre content (percent of fibres less than 12.7 mm in length) and level of neps [5]. Because of these interactions, fibre properties vary significantly at multiple levels, that is between cotton cultivation fields, between individual plants within fields, and even within single plants and on the same seed. The major challenge in cotton processing is to convert a highly variable raw material into uniform product with quality that remains consistent over long production cycles.

Great advances are continually occurring with ginning and textile processing machines (spinning preparation, spinning, weaving and knitting) as well as high performance textiles. In order to determine optimal fibre properties for a modern spinning system; processing efficiency and yarn product quality must be studied concurrently with cotton fibre properties.

The invention of current fast and high volume textile testing instrument (HVI), leads to the widespread adoption of fibre quality measurement and classification technology. The availability of fibre information, cotton bale selection and laydown arrangement systems have evolved from the reliance on skills and experience of spinners to highly sophisticated information management and engineered decision-making tools [6].

Despite intensive research and development efforts, classing fibre quality data for optimal bale mixing/blending still fails to include meaningful and reliable measurements of significant fibre properties now at the forefront of concerns for spinners, namely, elongation [7], neps [8] and short fibre [9] or more generally fibre length distribution. To evaluate short fibre content and level of neps, spinners depend on measurement methods with testing speeds not compatible with those of HVIs. The advanced Fibre Information System, or USTER AFIS, is one such method used to determine these important fibre quality determining parameters [10, 11].

The present study adopts a new approach of using fibre quality data from a single comprehensive fibre quality measurement system (CCS version 5: Textechno, Mönchengladbach, Germany). This approach helps to alleviate the discrepancy resulted from using two fibre quality properties measuring systems whose testing speeds not compatible. The fibre quality data obtained from a single comprehensive measurement system could also provide the proper selection of bales to be optimized for the required quality of end products.

2.2 Cotton genotypes

Cotton fibres, a viscoelastic material, are the fundamental building blocks used to form more complex structure of yarn and ultimately fabric. Fibre characteristics (e.g. geometric, mechanical and chemical properties) influence yarn characteristics (e.g. strength, extensibility, friction, stiffness and resilience). The resultant strength, evenness, hairiness and nepiness of yarn are some of the important aspects of yarn quality so that spinners select cotton genotypes based upon their suitability for textile processing with acceptable quality and spinning efficiency (e.g. low number of end breaks).

One of the primary decisions when planning a cotton cultivation year is the determination of the cotton genotype/variety. Many cotton growers in different countries of the world have started to choose cotton genotypes not only on the yield potential merits, but on the adoptability and stability of genotype to wide environmental ranges by assessing a varieties performance in a number of local and international wide tests both for yield and quality trends.

United States Department of Agriculture (USDA) can be categorized to globally recognized cotton classifier of commercial cotton bales and ICA Bremen testing center for testing quality of commercial cotton bales.

To better compete, the surviving textile mills have modernized their operations by introducing new spinning, knitting and weaving equipment that operates much faster than the textile operations of a decade ago. This new equipment together with consumer’s demand for higher quality textiles has combined for the need of higher quality fibre. The textile industry recognized that an essential component in producing high quality products is to have high fibre quality cotton genotypes/varieties.

2.3 Effect of Genotype on the ginning performance of cotton

Cotton is a natural fibre having several heterogeneous physical properties influenced by the region where it is cultivated as well as its variety types and variability in the climatic conditions. These variable properties of cotton fibre ultimately affect the quality characteristics of the final products. The main technological challenge in any textile process thus lies in normalizing the high variability in the physical properties of the input cotton fibres while converting them into a desired uniform end product.

Bragg et al. [12] investigated the effect of cotton genotype and ginning conditions on the quality of fibre and textile products. They used eleven major varieties of California cotton which later ginned in US southwestern cotton ginning research laboratory and then tested by HVI instrument. They found that genotype is the major contributor to overall variation.

While many research studies and current commercial classifications examine the mean values of fibre quality, recent research approach has demonstrated the importance of evaluating the distribution of fibre qualities. For example, the length distribution data available with the AFIS appears to contain information that is useful to both the cotton breeders and the spinners. Since the length distribution clearly appears to be variety related, it may provide a new tool for cotton breeders in their efforts to reduce short fibre content [13].

Considering both the usual method of commercial cotton classification by evaluating the fibre mean quality properties and the new distribution-based quality and processability studies approaches, the present study needs to show the performance of genotypes under study, when processed with the modern fast ginning machines.

2.4 Impact of mechanical ginning to the quality of cotton

One of the important fibre properties of raw cotton is the short fibre content (SFC). High levels of SFC result in large amounts of waste in processing, high concentrations of fly in working atmosphere (particularly at the opening and cleaning stage), high end breakage rates in spinning, lower yarn strength, and inferior yarn quality as a whole [14, 15, 16]. The SFC of carefully hand-ginned cotton is very low [17, 18, 19, 20] but it is increased by fibre breakage that occurs during the mechanical handling and cleaning involved in the ginning process [21, 22, 23].

Lord, [24] observes the fibre breakage in the ginning of cotton by producing six comb-sorter diagrams made by different operators on fibres removed carefully by hand from a sample of seed cotton in order to measures the unginned fibre length and a further set of six sorter diagrams made on the commercially ginned lint. The researcher was able to produce the following average length frequency distributions obtained from the two sets of tests (the fibre lengths are given in units of 1/32 inch):

Table. 2.1 Percentage frequency distributions of fibre length

Group lengths	Hand-removed	Machine-ginned
48-52	1	1
44-48	3	2
40-44	9	5

36-40	21	13
32-36	18	14
28-32	10	10
24-28	8	9
20-24	7	9
16-20	6	9
12-16	5	10
8-12	5	9
4-8	4	6
0-4	3	3

He found that the mean length of the cotton removed from the seed by hand was 29.0 (0.91 inch) and 24.9 (0.78 inch) for the machine ginned cotton. Here we can observe that there is a 14.14 % mean fibre length decrease because of degradation by the action of ginning and lint cleaning.

Saw-type cotton gin together with saw-type lint cleaners have been the center of attention regarding fibre damage in the ginning process for decades. It is generally agreed that the vast majority of fibre damage (change in the length distribution pattern by creating short fibre content and neps) occurs within saw type ginneries.

Marinus HJ van der Sluijs [25] investigated the impact of saw and roller ginning process on fibre quality properties and textile processing performance of long staple upland cotton and found a significance difference between the two ginning methods in some of the average fibre results, with the roller ginned fibre longer and more uniform with fewer short fibre and fibrous neps, as well as stronger with higher elongation.

Even though the saw type lint cleaner improves the appearance of ginned lint by eliminating foreign matter, motes, cottonseed, and other undesirable materials. Unfortunately, it also removes limited amount of good fibres as it does undesirable materials.

Short fibre content can be influenced by vigorous mechanical processing, especially at the gin. That seems one of the reasons for many textile researchers to be focused at ginneries as means for controlling short fibre content and nep levels. Controlling the level and amount of short fibres and neps at the starting point can have tremendous benefit for all parties in the cotton value chain. Reportedly, about 85% of total cotton in the world is ginned on saw-type gins [26].

To top this off the textile mills would like the gins to take this widely varying product and produce a uniform, homogeneous product. This allows the mills to operate at faster and faster spinning speeds with less labour, higher accuracy and dependability to successfully compete with synthetic fibres particularly with polyester.

The approach demonstrated in the present study is sampling of hand-ginned and machine-ginned lint cotton to investigate the effect of genotype on the fibre quality parameters which determine the ginning performance of cotton. Using these two types of important samples, the tenacity, elongation, short fibre content, length distribution by number, length distribution by weight and level of neps were studied.

Influence of machine ginning to the quality of products

Various research workers have studied the effect of roller-gin and saw-gin machines on the quality of intermediate products (e.g. sliver, roving) and yarn. Cocke, et al. [27] had stated that roller-ginned cotton fibres generally have a greater mean length and fewer short fibres and neps than saw-ginned cotton but have more dust. Griffin [28] has studied the effect of ginning rate on short fibre content and reported that the higher ginning rate than the recommended, increased the short fibre content of the ginning lint. This is higher still when processing seed cotton with at low moisture content.

Hughs et al. [29] in their experiments found that fabrics made from saw ginned cotton had more neps (23.4 neps/58 cm^2) than fabrics made from roller-ginned cotton (17.1 neps/58 cm^2).

2.5 Instrumental testing and optimization of mixing/blending

Over the years, developments in fibre quality testing and blending techniques have been largely hindered by insufficient fibre information resulting from a lack of capable and efficient testing methods. Accordingly, art and experience have been the primary tools.

One of the common approaches was massive blending, in which vast quantities of bales were mixed by grade (color, trash content and preparation) or growth area to reduce variability. This mixed cotton was then rebaled and fed to the opening and cleaning process line in random order to further enhance the mixing effect.

Of late, researchers [30] pointed out that the quality pricing priorities for cotton growers are different than the textile industry priorities.

For example, while the grade is the major factor for pricing for the growers' view, while fibre tenacity and elongation is the most important factor for the textile mill. Mogahzy, et al. [31], commented the current cotton classifying system as heavily weighted to the quality parameters that are not inherent characteristics of cotton, such as trash and preparation. Authors stated that, under this system, many cotton growers will take excessive lint cleanings at the ginning process, to improve the appearance of cotton and eventually get higher values in the market, which could hurt the quality of fibres by increasing the amount of short fibre contents and level of neps. This in its turn, could result in reduced quality of end products and spinning efficiency by introducing more fibre breakages during processing.

To include meaningful and reliable measurements of significant fibre properties, used for mixing/blending optimization, the modern cotton classification system needs to have a single comprehensive instrumental testing method which can satisfy all the players in the cotton value chain.

2.6 Tenacity and elongation properties of cotton fibre

Fibre tenacity/elongation are important fibre properties determining the amount of energy required to break either a fibre or a yarn. Work-to-break (energy) is critically important to processing performance of spinning, sizing/slashing, weaving and knitting machinery [32].

The productivity and efficiency of modern high speed weaving machines is affected by yarn type, quality and yarn preparation. Yarn stresses optimization is a major task in minimizing the weaving machine stoppage rate because of warp ends down. During the weaving process, warp is subjected to both static tension and frictional stresses, along with cyclic elongation that create tension peaks in the yarn. This implies that yarn elasticity or elongation, in addition to tenacity, is a contributing property in the textile manufacturing processes.

Louis, Fiori, and Sands [33] reported that the tenacity and elongation properties of single yarns are related directly to the fibre elongation of the cottons from which they are spun. Furthermore, in cotton products, where flexibility and elongation properties are needed, cotton fibre elongation becomes an extremely important property.

Fiori and Grant [34], from forty-three sample cottons latter spun to Ne 15/1, 30/1, 40/1, 60/1, 80/1, 100/1 found that yarn elongation was linearly and directly related to fibre bundle elongation for all studied yarn numbers. The importance of the fibre elongation for textile products has also been demonstrated by detailed research work based on a number of spinning trials [35]. It is not only the mean fibre breaking elongation that is important, but also its variation. Variation in elongation is important both at the single fibre level, within a sample, and also at the level of between-bale variance of HVI breaking elongation [36, 37].

Hequet et al. [38] stated that a bundle with a large variation in elongation from fibre to fibre will not behave the same as a perfect bundle where all fibres are identical even if the elongation averages are identical (all other fibre properties being constant). The bundle with a large variability in elongation is expected to be weaker because the stress applied to the bundle doesn’t affect all the fibres equally (assuming all the fibres are clamped on both ends). The low elongation fibres break first, and the resistance of the remaining fibres to the applied force decreases and due to the cascading effect, the bundle breaks.

Benzina, et al. [39] reported the effect of fibre bundle elongation in the work of rupture of fibre bundles, which is critically important to improve the processing performance of textile machinery. Authors also showed the importance of using fibre bundle elongation to improve the genetic screening in cotton breeding programs. In their experiment they were used a modified load-elongation testing instrument instead of HVI. This was because of that, even though, fibre bundle elongation can be measured by HVI systems, but, due to a lack of calibration standards, the results are not comparable between systems.

Yang and Gordon [40] carried out a research at the Commonwealth Scientific and Industrial Research Organisation (CSIRO). In their study, 20 international cotton samples were tested for elongation using the Favimat instrument (Textechno, Mönchengladbach, Germany) and two bundle testing methods; the CSIRO Sirolan-Tensor [41, 42], a fibre bundle tensile testing instrument developed by CSIRO, and the HVI 1000 (Uster Technologies, Knoxville TN, USA). They found that there was a positive correlation between Favimat single fibre and Tensor bundle elongation. But no correlation between Favimat single fibre elongation and HVI bundle elongation, which indicates some issues with the HVI elongation measurement.

Even though, there are available elongation measuring instruments, the central pre-requisite for the utility of methods for measuring elongation, however is, the ability to deliver precise results within a commercially acceptable time and cost. The Cotton Classifying System (Textechno, Mönchengladbach, Germany) is one of the methods designed to achieve more precise elongation measurement [43]. The Cotton Classifying System (CCS), in addition to the usual relative method of tensile testing which is commonly used by the HVI instrument, uses the absolute tenacity testing mode. It is important to note that CCS gives the Force-elongation data as well as the work-to-break (energy) which are important fibre properties used to assess the performance of cotton when processed with the modern fast and efficient spinning machinery [44].

Other important elongation-related properties are the breaking energy and the modulus. The breaking energy, based on the force and elongation measurement, can be ascertained using the mathematical integration of the area beneath the force-elongation curve. The breaking energy is important for studying the performance of fibres and yarns during their usage, and their behaviour during spinning and weaving processes.

The modulus describes the slope of the fineness-related force-elongation graph and is, therefore, a measurement of the fibre rigidity or the resistance against elastic deformation. Because the force-elongation behavior of cotton fibres is not exactly linear due to the visco-elasticity nature of the material, the modulus depends on which section of the curve is used for the measurement [45].

Therefore, it can be understood that the elongation characteristics associated with fibre tenacity are critically important in textile processing, namely: opening, carding, spinning and weaving as well as for breeding new cultivars that can withstand the mechanical action of modern high-speed ginning and textile machinery.

May and Taylor [46] reported the requirement of breeding cottons with higher tenacity to overcome the greater strain on cotton yarns introduced as a result of the increase in manufacturing speeds on the knitting and weaving machinery.

2.7 Raw material and spinning

The influence of raw material is important both from the technological as well as economic point of view. In cotton spinning system, raw material costs up to 50 – 70% of the total production cost of short-staple yarn. This fact alone is sufficient to indicate the significance of raw material for the yarn producer. The influence becomes still more apparent when the easy in processing one type of fibre material is compared with the difficulties, annoyance, additional effort and the decline in productivity and quality associated with another similar material.

Hardly can any spinner afford to use a problem-free raw material, because it would normally be too expensive. Optimal conditions can be obtained only through mastery of raw material. A good spinner achieves an acceptable yarn quality with trouble-free processing from a less expensive fibre which increases considerably the profitability and competitiveness of a spinning plant. Admittedly, however, the best theoretical knowledge will not help much if the material is already at the limits of spinnability or beyond. Excessive economy in relation to raw material usually does not reduce costs, rather increases them owing to deterioration of processability in the spinning plant.

Therefore, it is very important to have a thorough understanding of the quality parameters of the fibres and their influence on the spinning process and yarn quality so that the most appropriate fibre mix can be decided. It is also important to know about fibre parameters for setting machines and adjusting all important process parameters.

The relative importance of different fibre properties depends also upon the type of spinning technology. For example, to produce high-quality ring spun yarn textiles, fibres must be fine and have sufficient strength to endure processing (spinning preparation, spinning, and weaving or knitting). Fibre length and fineness affect the forces between fibres that dictate the “count,” of fineness, of the final yarn. Fibre maturity and strength affect a fibre’s ability to withstand the forces placed upon it during opening and blending, carding, drafting and spinning [47].

The spinning limit (i.e. the finest yarn number that can be spun satisfactorily from a specified lot of fibre under specified conditions) of a cotton is dependent on fibre properties and spinning method [48]. Longer, stronger fibres are better able to withstand the large forces placed on them during spinning and have more contact surface between fibres, thus increasing inter-fibre friction. These fibres are therefore able to be spun in finer yarns. Therefore, for a given fibre fineness, the longer the fibre, the smaller the minimum number of fibres required in the yarn cross section.

While fibre length, strength and fineness are most frequently correlated to yarn properties, [49], the trash content of cotton can also affect the maximum achievable yarn count. Due to the high angular speeds encountered by fibres during rotor spinning, trash particles can cause fibres breaks by exerting centrifugal force on the forming yarn. Foreign matter and neps increase yarn unevenness and ends down (i.e. breaks) in spinning, which decrease production efficiency and increase imperfections in the yarn and fabrics. For ring spinning, finer yarns are particularly susceptible to end breaks due to the presence of trash in the roving.

Accordingly, raw material classification is an important tool to identify and assign required raw material types designed for the specified end products properties. In a continuous effort to provide the best quality measurement data to the textile industry, USDA in 1991, began utilizing the HVI classification of cotton by providing the measured properties of strength, length, uniformity index, micronaire, color and trash. Given the international acceptance of HVI testing, in 1996 the Universal Cotton Standards Agreement was amended to recognize USDA-produced HVI Calibration Cotton Standards for strength, length and uniformity index. These new standards were named Universal HVI Calibration Cotton Standards and continue to serve today as the most recognized standards for HVI calibration.

3 Instrumental testing methods

Keywords:
Single fibre testing, bundle fibre testing, tenacity, crimp variation, elongation

3.1 Single and bundle testing of cotton fibre properties:

In this research work, the physical properties of competitor cotton fibres have been measured using both single and bundle fibre testing methods. The first method is used more for research purposes and do not belong in laboratory routines, but the fibre property assessed by the individual fibre method characterizes fibres from the material engineering point of view, and for this reason its value is tremendous.

3.1.1 Single fibre properties and testing methods

Among other single fibre properties, single fibre tenacity and elongation are very important properties used to evaluate processing efficiency of cotton during its conversion into textile products and the quality of these products. Textile testing instruments manufacturers introduce several single fibre laboratory testing equipment (e.g. Instron Universal Tensile Tester, Mantis by Zellweger-Uster, Favimat and Favigraph by Textechno) to evaluate the important fibre quality properties (e.g. linear density, crimp, tenacity, elongation, work-to-break, etc.) of cotton and other manmade fibres.

Uster AFIS can be also categorized from single fibre testing instruments but doesn't measure single fibre tenacity and elongation. Instead, it measures other important single fibre properties, such as fineness, maturity, length, short fibre content, level of neps, etc.

Even though, we have all these types of single fibre testing instruments, the central pre-requisite for the utility of available testing instruments is their ability to deliver precise results within a commercially acceptable time and cost.

Brief about testing instruments:

Instron have upper and lower jaws, where the upper jaw linked with load cell is remained stationary and the lower jaw moves downward at constant rate. Fibres to be tested are attached with special frame by adhesive and mounted on the machine for tensile testing.

The Mantis single fibre testing instrument consists of two measurement modes, mechanical and optical. The fibre is mounted automatically, i.e., the operator places a fibre across the jaw faces and the fibre is straightened by a vacuum pipe. Mantis provides information almost instantaneously (no chart reading) [50].

The FAVIMAT+ automatically determines the linear density of single fibres using the vibration method, e.g. according to ASTM D 1577. With this testing method the resonance frequency of the sample is measured at constant gauge length and known pre-tension; the data obtained is then used for calculating the linear density according to the following formula:

$$T_t = F_v /(4 \times f^2 \times L^2)$$

Where, T_t = fibre linear density; F_v = pre-tension force; f^2 = resonance frequency; L^2 = test fibre section length.

A possible influence of bending stiffness and fibre cross-section can be analysed by means of an automated pre-test and can in general be eliminated for series testing.

A further measuring system with opto-electronic sensor integrated in the FAVIMAT+ enables the creation of a digital image of the crimped fibre, which is held between the two clamps, and the subsequent evaluation of the crimp geometry regarding crimp number and crimp amplitude.

As applicable to mechanical crimp properties, size, shape and regularity of the crimp geometry supply adequate information on further processing of the fibres and the properties that can be expected from the intermediate and finished products.

Then, the tensile testing of single fibre which is one of the most important quality parameters used to assess the performance of a given commercial variety/bale during cotton processing, is measured. In addition to the (linear density-related) breaking force and breaking elongation, other parameters such as modulus, intermediate values of the force/elongation curve, e.g. force values at specified elongations and work to rupture, can be obtained.

The actual test section comprises the measuring- and draw-off clamps, which open and close automatically. The clamp jaws are tightened by spiral springs, and the clamping force can be sleeplessly and reproducibly adjusted over a wide range. The gauge length between the clamps can be varied between 0 and 100 mm.

Single fibre testing via instruments such as the FAVIMAT+ may also prove of use to breeders and researchers with limited testing material available or in areas where the detailed data which can be obtained is able to justify the investment in time and effort. As single fibre testing is performed the distribution of properties in a sample may be readily obtained.

FAVIGRAPH determines the linear density of single fibres using vibration method. FAVIGRAPH linear-density measuring head, which is situated adjacent to the tensile test section, is based on the FAVIMAT+ technology.

The tensile test section of FAVIGRAPH comprising the measuring clamp and the draw-off clamp, mechanical design for tensile forces up to 100 N. The pretension weight is used for straightening the fibres (for removing the crimps in the fibre) during the insertion into the clamps for the tensile testing. The pretension is realized automatically by the software. The pretension input is made in the form XX g/den. This makes the pretension (and therefore also the elongation) to be dependent on the linear density LD of individual fibres. For example, if we measure fibres with higher linear density (these are course fibres in the denier system), the pretension automatically becomes higher and thus resulted with a lower value of elongation.

The AFIS method is based on aeromechanical fibre processing, similar to opening and carding, followed by electro-optical sensing and then by high speed microprocessor-based computing and data reporting. A fibre sample formed like a small size sliver strand (0.5g) is introduced into the system and processed through a fibre individualizer which automatically separates the sample into fibre-neps and trash-dust components. Individualized fibres are transported pneumatically from the fibre individualizer by an air-stream. The fibres penetrated a collimated beam of light and scatter and block that infrared light in proportion to their optical diameter and in direct relation to their time of flight through the sampling volume. From the wave forms, which are microseconds in deviation, the pertinent data are acquired, analyzed and stored in the host computer. Distributions based on length, size and diameter are being generated.

In order to measure the single fibre length, fibres are separated by high speed rollers with pins on the AFIS fibre individualizer. There is some chance of fibre breakages then. The study shows that the average fibre becomes 0.01 to 0.04 inch shorter after AFIS testing [51].

3.1.2 Bundle fibre properties and testing methods

Tenacity and elongation are among the important bundle properties which determine the quality and processability of cotton fibre. But even though, both bundle tenacity and elongation are very important fibre properties, much effort is made for studying fibre tenacity than elongation.

The importance of tenacity and elongation property is presented in section 2.6. The present section gives emphasis on the comparisons between the bundle elongation testing methods of the Fibrotest and those of other testing instruments such as HVI.

It is well documented that with HVI bundle tests, the relationship between tenacity and elongation-at-break is quite weak and/or negative. This negative relationship is one of the reasons why the cotton breeders do not work on elongation. They concerned that improving elongation will result in lower tenacity and possibly discounts [52].

The reason for the negative correlation is not well documented, although a number of factors that affect the HVI tensile strength result have been investigated. These include pre-crimp tension, fibre length and rates of extension by

Taylor [53] and the effect of fibre length distribution, the size of the fibre beard and the subsequent position of the HVI jaw clamp more recently by Naylor and Naylor *et al* [54, 55]. In particular, it was observed by Naylor *et al* [55] that reported HVI elongation values displayed both a significant bias due to fibre length and also a dependence on the size of individual beards tested. A brief examination of the relationship between HVI length and bundle tensile properties which offers some insight into the reason for the negative correlation was also studied by Yang and Gordon [40]. They reported that these negative correlations are believed to be caused by a fibre length bias and variable jaw positioning in HVI fibre tenacity and elongation measurements.

The other possible reason is the difficulty in crimp removal during the bundle testing of fibres. The crimp exists, both within the fibre and between the fibres in the bundle. So that, during the tensile-elongation testing, it is important also to consider the crimp variation between the fibres in the bundle. The presence of crimp and crimp variation in the cotton may introduce undefined errors in the measurement of tensile-elongation properties when the bundle is inserted into the clamps of testing instrument with an unknown degree of stretching (initial tensioning) to remove crimping. So that, proper definition and measurement of crimp removal in the sample cotton should help to minimize or even eliminate such errors. One of the attempts performed to obtain readings with improved reproducibility on the basis of the HVI measurement, were various modifications made on HVI 910 module in the Faserinstitut Bremen [56, 57]. The modification includes:

1. The original regulation and control mechanism were removed and replaced by a specially developed mechanism.
2. The transducer was lowered and the lever arm stiffened in order to be able to record an undistorted force-elongation curve; furthermore, an extensometer was used for determining the elongation.
3. After clamping the fibre bundle, the movable clamp was driven a short distance in reverse, so as to record the force-elongation curve starting from zero force and to make clear observations on the de-crimping behavior of a cotton bundle.
4. Based on the complete force-elongation graph the bundle work can be calculated and the de-crimping work determined separately (the new characteristics are shown in Figure 1.
5. The measured elongation is divided into a de-crimping elongation (ε_{cr}) and a material elongation (ε_m) by constructing a tangent to the slope of the bundle force-elongation graph.
6. With further measures it was possible to keep the instrument at a constant level without the need for calibration using natural fibre standards, and therefore to reduce further systematic influences.

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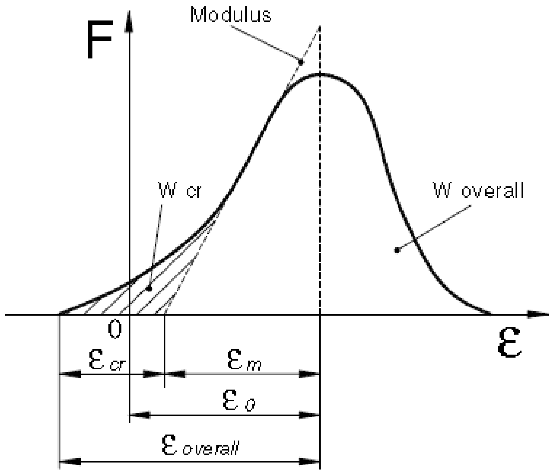


Figure 1. Splitting up of the measured elongation ε_0 with the modified HVI to the de-crimping elongation ε_{cr} and the material elongation ε_m up to the maximum force [57].

Accordingly, the de-crimping work can be subtracted from the overall breaking work.

On the basis of analysis of limitations in the present measurement of bundle elongation, various methods were developed (e.g. Fibrotest of Textechno Mönchengladbach, Germany) to achieve more precise measurement. In Fibrotest the length calibration is by use of both a 10 kg weight (the test results are referred as „Absolute Mode “values and on top of „absolute “calibration, the Fibrotest allows users to test calibration cottons to set up „relative mode “values. This process does not change the instrument calibration, but to provide an additional set of data that match the calibration cottons. The HVI corrects measured strength by micronaire values since the micronaire affects the optical measurement of the linear density of the beard between the clamps. The Fibrotest does not correct strength by micronaire values since the linear density of the beard between the clamps is determined gravimetrically [58].

4 Effect of ginning on commercial genotypes

Keywords:
Ginning, genotypes, tenacity; elongation, short fibre content, neps level

4.1 Experimental design

In this study, the first experiment is done for evaluating the fibre properties of seed cotton and the second experiment of the study was done to assess the effect of ginning on cotton fibre properties by evaluating the fibre properties of lint cotton after ginning and comparing with the values found prior to ginning. For all the experiments samples were tested by single fibre testing instruments (FAVIMAT+, FAVIGRAPH, AFIS) and bundle fibres testing instruments (HVI, and CCS).

Experiment 1: For evaluating the fibre properties of seed cotton, among twelve different Ethiopian cotton varieties [59], samples representing three commercial varieties, namely, Acala SJ-2, Arba and Deltapine 90 (DP-90) were collected from 3 plantation zones. The major cotton plantation zones covered are: North Ethiopia (Tigray, Amhara & Benishangul Gumuz); North-Central Ethiopia (Upper Awash, Middle Awash & Lower Awash) and South Ethiopia (Oromia, Arba Minch & Gambelia)[2]. The reason why these three varieties selected was because of that they were well known commercially available upland varieties (Gossypium hirsutum L.) widely grown in the irrigated low lands on large-scale farms and in warmer mid altitudes on small-scale farms. Other varieties usually found at research centers and because of agronomic or economic deficiencies not commercially available in sufficient amount.

Seed cotton samples were collected from the harvested modules in the field and/or warehouses to avoid any mixing between the varieties/genotypes. Fibres from the seed cotton were later removed by careful hand ginning for conducting the experiments. Three commercial cotton varieties with three hundred replications for 5 seed cotton samples randomly collected from each variety were used for the FAVIMAT+ and FAVIGRAPH single fibre testing (3 varieties × 3 zones × 5 samples × 300 tests replications). Excellent correlation (0.942) (see fig. 4.4) were found between mean single fibre quality parameters measured by Favimat+ and Favigraph. In this part of the study, it was preferred to use the results found by using the Favigraph single fibre testing instrument.

The same subset of samples was used to investigate the AFIS, HVI and CCS fibre properties. The AFIS fibre properties was tested with 30 replications of 3,000 fibres (i.e. 3 varieties × 3 zones × 5 samples × 30 tests of 3000 fibres replications),

[2] The clustering of Regions in the North, North-Central and South Ethiopia is used only for the purpose of categorizing cotton cultivation areas where samples are collected in this research.

The HVI and CCS fibre properties was tested with (3 varieties × 3 zones × 5 samples × 100 tests replications) for each instrument. One technician per every instrument was used throughout the testing days.

Experiment 2: It was conducted to assess effect of ginning on the cotton fibre properties. From the same varieties used to evaluate seed cotton properties, the amount required for ginning was transported using module trucks to the ginnery found in Addis Ababa. Samples were ginned under standard commercial conditions at the full-scale gin (7 bales/hr.) of 217 kg bale. The ginning machinery sequence consisted of a master feed controller, tower drier with ambient air, 6-cylinder cleaner, stick and leaf remover, tower drier, 6-cylinder cleaner, extractor feeder, gin stand and two stages of saw cylinder lint cleaning. The same ginning rate of 7 bales per hour were used throughout the experiment. Moisture content, room temperature and relative humidity were not different between varieties and averaged 6.4%, 26°C, and 55%, respectively. To maintain confidentiality for the gin participating in this study, the local name of the ginnery is not mentioned. The commercial varieties were Acala SJ-2, Arba and DP-90 harvested in all plantation zones, in 2017.

The procedure of testing is similar to the previous, which was for the FAVIMAT+ and FAVIGRAPH single fibre testing (3 varieties × 3 zones × 1 ginnery × 5 samples × 300 tests replications). The AFIS fibre properties was tested with 30 replications of 3,000 fibres (3 varieties × 3 zones × 1 ginnery × 5 samples × 30 tests of each 3000 fibres replications), the HVI and CCS fibre properties was tested with (3 varieties × 3 zones × 1 ginnery × 5 samples × 100 tests replications).

4.2 Seed and lint cotton assessment

Seed cotton is the cotton prior to hand or machine ginning (i.e. before the removal of fibres from the seed). Cotton after careful removal of the seed by hand ginning is termed 'raw cotton' in this study. Whereas cotton after the removal of the seed by the ginning machine is termed 'lint cotton'.

Assessment of cotton before ginning allows to evaluate the mechanical action of beaters on fibre properties and also helps to evaluate the variation in length distribution. The length distribution by weight of carefully hand-ginned cotton follows a normal distribution with a low short fibre content, or proportionately low short fibre content. However, this proportion is increased by fibre breakage that occurs during mechanical processing followed by non-normal length distribution by weight [60].

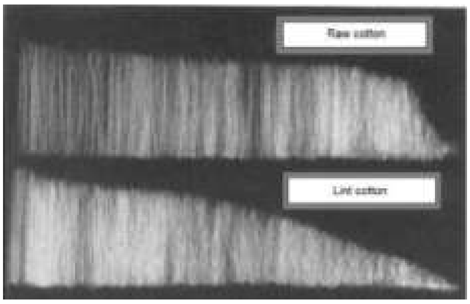


Fig. 4.1 Hand (upper) and machine (lower) ginned cotton distributions. (H. Wakeham: Text Res. J; 1955, p.422 [17])

4.3 Sampling methods and ginning

Seed cotton samples were collected from all the three plantation zones. Cotton samples were collected from the harvested modules in the field and/or warehouses to avoid any mixing between the varieties/genotypes. That means, samples at random were picked up from harvested modules in the fields and/or warehouses according to their varieties/genotypes. The samples used for raw cotton evaluation were later removed by careful hand ginning. Whereas the samples used to evaluate the effect of mechanical action was processed under standard commercial conditions at the full-scale gin (7 bales/h) of 217 kg bale. The same genotypes used to evaluate the seed cotton were used to assess the effect of ginning on the lint cotton fibre properties.

The AFIS mean maturity ratio for the studied commercial varieties were within the range 0.87-0.89.

Sample preparation for lint (bale) cotton testing is performed to represent the original source variety. To determine whether the cotton is suitable for obtaining a required quality of mix, the laboratory testing procedures was performed according to the internationally harmonized rules for defining sampling, sample handling and testing of cotton in the laboratory as well as the use of Standardized Instruments for Testing Cotton, High Volume Instrument (HVI) [61]. These procedures for taking a lot sample of cotton fibres, from a bale, and reducing the lot sample through a series of steps to produce test specimens that are representative of the source variety and suitable for the determination of fibre properties according to established procedures are also used for all the testing instruments used in this study.

For laboratory sample testing, two portion of sample per bale is drawn from both sides of each bale. An example of laboratory sampling to evaluate within and between bale variation is given by Gourlot and Drieling [62] (see fig. 4.2).

Fig. 4.2 Within-bale (left) and between bale (right) variability sampling. (Gourlot J.-P. and Drieling A., ISBN: 978-2-87614-686-0. EAN: 9782876146860 [62])

Fig. 4.3 Lint cotton sampling from opened bales

All the samples were conditioned before and during testing. As shown in the guidelines of International Cotton Advisory Committee (ICAC) Task Force on Commercial Standardization of Instrument Testing of Cotton (CSITC), International Textile Manufacturers Federation (ITMF) and International Committee on Cotton Testing Methods (ICCTM), For cotton testing the allowed temperature range is fixed at 21 +/- 1°C (70 +/- 2°F) and humidity range is fixed at 65 +/- 2% RH. The relevant ASTM Standard Practice is ASTM D 1776 "Standard Practice for Conditioning and Testing Textiles. For cotton testing".

The AFIS mean maturity ratio for the studied commercial varieties were within the range 0.87-0.89 (Acala SJ-2 = 0.89, Arba = 0.89 and DP-90 = 0.87)

The samples collected before and after ginning were tested with:

1. FAVIMAT+ and FAVIGRAPH single fibre testing instrument using the following testing parameters: gauge length = 3.0 mm, pre-tension = 1 cN/tex, and testing speed = 100 mm/min.
2. Advanced Fibre Information System (USTER AFIS PRO 2), with 30 replications of 3,000 fibres.
3. High Volume Instrument (USTER HVI 1000). With the following testing parameters: gauge length 3.175 mm, unknown pretension. The HVI testing speed, from literatures is 100 - 140 mm/min.
4. TEXTECHNO CCS V-5 bundle testing instrument using the following testing parameters: gauge length 3.175 mm, pretension 5 cN/tex, and testing speed = 100 mm/min

All single fibre and bundle testing was conducted under standard testing conditions of 21 +/-1^{0}C and 65 +/- 2% relative humidity.

As it was mentioned in experiments 1 and 2, fibre properties of the representative samples from seed cotton (before ginning) and lint cotton (after the ginning treatment) were evaluated using three single fibre (FAVIMAT+, FAVIGRAPH, AFIS) and two bundle fibres testing instruments (HVI, CCS).

Correlations were demonstrated to study the relations between the testing instruments used in the study.

Providing similar calibration and perfect clamping system for both the FAVIMAT+ and FAVIGRAPH laboratory testing instruments, a good correlation (R^2 = 0.942) is found between the tested average single fibre tenacities, for the cotton sample having linear density of 1.60 tex (see Fig. 4.4).

These laboratory testing instruments could also be used to provide the distributions of fibre properties which are very useful to the cotton breeders and researchers.

The distributions of fibre properties, can also be served as an additional information to strengthen the current cotton classification system. Currently, the available cotton bundle testing methods (such as, high volume instrument) commonly provide, only the average result of the tested samples.

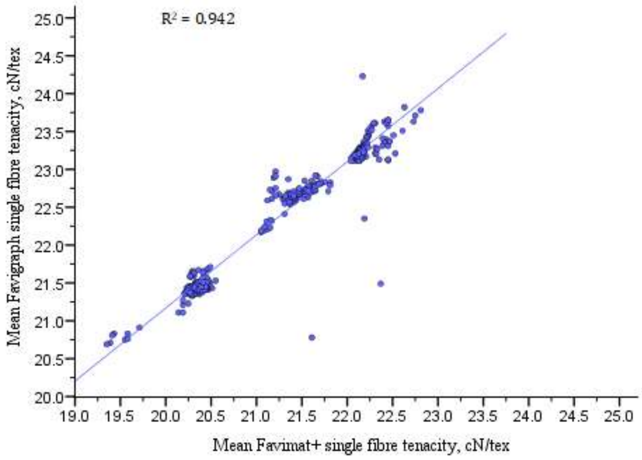


Figure 4.4 Average FAVIMAT+ Vs. FAVIGRAPH single fibre tenacities.

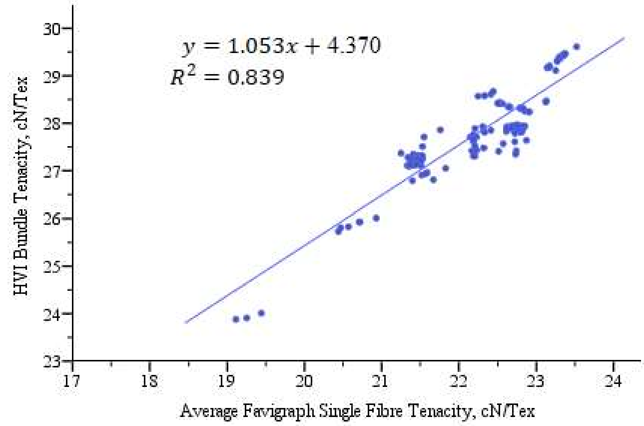


Fig. 4.5 HVI bundle tenacity Vs. average FAVIGRAPH single fibre tenacity

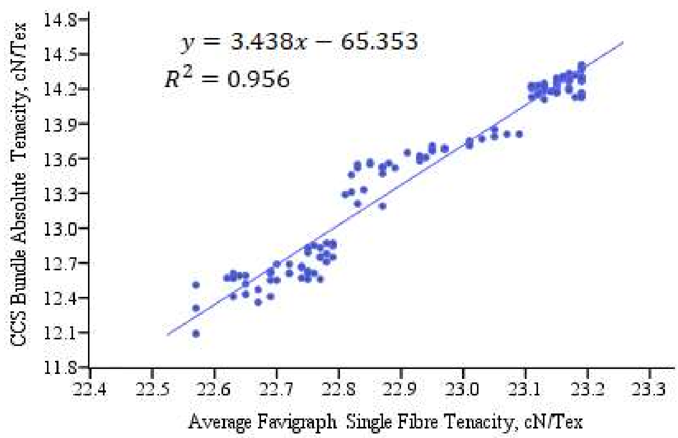


Fig. 4.6 CCS absolute bundle tenacity Vs. average FAVIGRAPH single fibre tenacity

Figure 4.5 shows the correlation between average FAVIGRAPH single fibre and HVI bundle tenacities. While figure 4.6 shows the correlation between average FAVIGRAPH single fibre and CCS absolute bundle tenacities.

The total work-to-break of the bundle is a function of both the load required to break and the elongation before rupture. This relationship for any bundle is represented by a unique stress-strain curve. While the stress-strain curve is commonly unavailable from HVI, the total work-to-break should be proportional to the product tenacity × elongation. Figure 4.7 shows that there is good correlation ($R^2 = 0.890$) between the HVI product tenacity × elongation and CCS work-to-break [7].

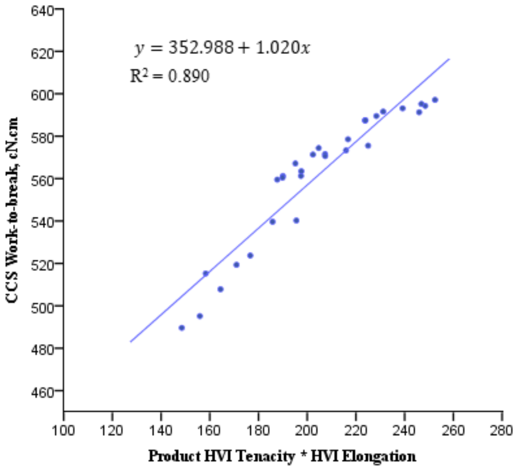
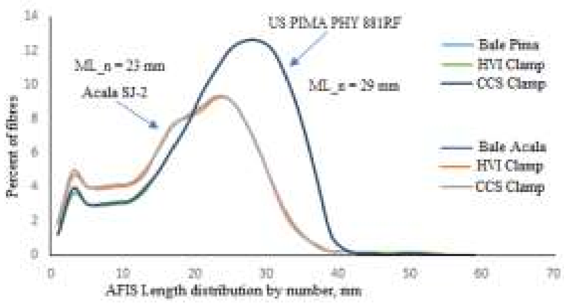


Fig. 4.7 CCS Work-to-break vs. product HVI Tenacity × HVI Elongation for commercial DP-90

In this research work assessment on fibre length from HVI clamp and CCS magazine were performed to evaluate whether they perfectly represent the original sample length distribution or not. In both HVI and CCS procedures of sample preparation the fibres picked by the clamp are combed, brushed and then tested for length/strength properties. In HVI these procedures are performed automatically while in CCS they are performed manually. Both methods of sample preparation, combed away the fibres which are not held by the clamp, seemed to be in favor of longer fibres. In AFIS testing, 0.5 gram of fibres were taken by hand directly from the sample, and a sample which looks like a small length sliver strand is prepared. This procedure of sample preparation assumed to introduce no bias of the length distribution.

Accordingly, to evaluate for their capability to represent the length distribution of the original sample, the fibres clamped by HVI and CCS fibres were carefully removed from their clamps, formed in to a small sliver strand and tested on USTER® AFIS PRO 2. From the studied cottons, Acala SJ-2 variety which is upland type used for short and medium cotton spinning and from US PIMA, PHY 881RF which is fine, long and strong variety were used in this test:

The AFIS length distributions by number and weight results are shown in the following figures.



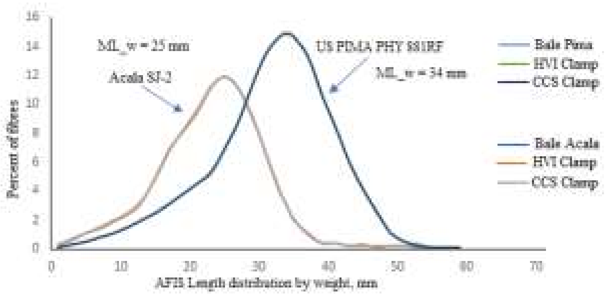


Fig. 4.8 AFIS length distribution by number Fig.4.9 AFIS length distribution by weight

As shown in figures 4.8 and 4.9 above, there were no obvious length distribution difference observed when both HVI and CCS clamps evaluated for their relations to the AFIS bale length by number and weight properties.

The calculated harmonic mean shows also that there was no extreme observation found. Total harmonic mean (For Acala SJ-2, Bale = 0.351, HVI clamp = 0.352, CCS clamp = 0.351), (For US PIMA PHY 881RF, Bale 0.597, HVI clamp = 0.597, CCS clamp = 0.596).

In other words, the clamps of HVI and CCS both represents the original bale length distribution.

The test results obtained from FAVIGRAPH, AFIS, HVI and CCS instruments are presented in Tables 4.2, 4.4, 4.6, 4.7 and 4.8. Short fibre contents and level of neps of lint cotton ginned: at different ginning rates of gin stand, at one or two levels of lint cleaning and high and low levels of moisture content are measured by CCS version 5 and presented in tables 4.9 and 4.10, respectively.

4.4 Results and Discussion

4.4.1 Fibre Linear Density

It is documented that the elongation values of fibres are linear density and maturity dependent, i.e. the finer and more mature the fibre, the greater the elongation [40]. During the textile processing, cotton with finer, more mature fibre will have higher work-to-break value than cotton which is coarser and less mature. On the studied commercial varieties, fibre linear density variation before and after the ginning treatment and the percentage difference were evaluated using FAVIGRAPH.

From the ANOVA table 4.1, it is observed that the ginning treatment brings small linear density variation but not significant at 0.01 level, where, Acala SJ-2 (0.337), Arba (0.577) and DP-90 (0.242) (i.e., p value > 0.01).

Table 4.1. ANOVA Analysis – Linear Density vs Ginning

		Sum of Squares	df	Mean Square	F	Sig.
LD_Acala	Between Groups	.011	1	.011	.925	.337
	Within Groups	3.559	298	.012		
LD_Arba	Between Groups	.004	1	.004	.312	.577
	Within Groups	4.065	298	.014		
LD_DP90	Between Groups	.014	1	.014	1.374	.242
	Within Groups	3.129	298	.010		

Table 4.2. FAVIGRAPH tenacity test results before and after ginning

			Statistical parameters						
Genotype	Fibre property	Ginning Status	Mean	S. D	Min	Max	S.E.	R	CV (%)
Acala SJ-2	Tenacity	Before Ginning	28.54	1.15	24.73	30.90	0.09	6.17	3.99
		After Ginning	27.24	1.18	23.45	29.87	0.10	6.42	4.19
		Mean Difference	1.30						
Arba		Before Ginning	28.32	1.17	25.65	31.67	0.10	6.02	4.25
		After Ginning	26.97	1.19	24.28	30.30	0.10	6.02	4.34
		Mean Difference	1.35						
DP-90		Before Ginning	27.72	1.21	25.12	32.60	0.10	7.48	4.37
		After Ginning	26.34	1.17	24.11	29.59	0.10	5.48	4.44
		Mean Difference	1.38						

Min (Minimum), Max (Maximum), S.E (standard error), C.V % (coefficient of variation), S.D (standard deviation), R (range)

Table 4.3. ANOVA Analysis – Effect of Ginning on Tenacity

		Sum of Squares	df	Mean Square	F	Sig.
Acala SJ-2	Between Groups	2701.812	1	2701.812	3975.053	.000
	Within Groups	202.548	298	.680		
	Total	2904.361	299			
Arba	Between Groups	1989.960	1	1989.960	2661.117	.000
	Within Groups	222.842	298	.748		
	Total	2212.802	299			
DP-90	Between Groups	3606.651	1	3606.651	7219.377	.000
	Within Groups	148.875	298	.500		
	Total	3755.525	299			

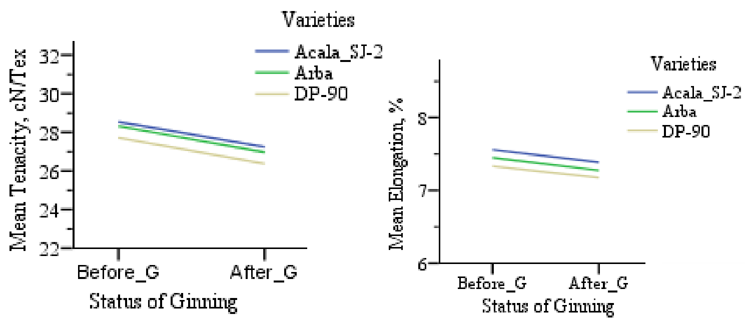


Fig. 4.10 FAVIGRAPH mean tenacity (left) and elongation (right) changes after the action of saw ginning

Table 4.4. FAVIGRAPH elongation test results before and after ginning

			Statistical parameters						
Genotype	Fibre property	Ginning Status	Mean	S. D	Min	Max	S.E.	R	CV (%)
Acala SJ-2	Elongation	Before Ginning	7.06	0.51	5.75	7.96	0.04	2.21	7.22
		After Ginning	6.89	0.42	5.75	7.85	0.03	2.10	6.10
		Mean Difference	0.17						
Arba		Before Ginning	6.95	0.82	4.51	8.10	0.07	3.59	11.80

	After Ginning	6.78	0.79	4.14	7.85	0.06	3.71	11.65
	Mean Difference	0.17						
DP-90	Before Ginning	6.83	1.24	3.77	8.27	0.10	4.50	18.16
	After Ginning	6.68	0.98	4.01	7.89	0.08	3.88	14.67
	Mean Difference	0.15						

Min (Minimum), Max (Maximum), S.E (standard error), C.V % (coefficient of variation), S.D (standard deviation), R (range)

Table 4.5. ANOVA Analysis –Effect of Ginning on Elongation

Variety		Sum of Squares	df	Mean Square	F	Sig.
Acala SJ-2	Between Groups	2.159	1	2.159	9.912	.002
	Within Groups	64.908	298	.218		
	Total	67.067	299			
Arba	Between Groups	2.246	1	2.246	3.432	.065
	Within Groups	195.033	298	.654		
	Total	197.280	299			
DP-90	Between Groups	1.833	1	1.833	1.465	.227
	Within Groups	372.977	298	1.252		
	Total	374.810	299			

Based on the estimated marginal means the mean difference resulted as a result of effect of ginning on Acala SJ-2 is significant at the .01 level

4.4.2 Tenacity and Elongation

In the studied samples the mean FAVIGRAPH tenacity difference before and after ginning treatment fall in the range (1.30, 1.35, 1.38) for Acala SJ-2, Arba and DP-90, respectively. In ANOVA tables 4.3 and 4.5, the F tests shows the effect of ginning on tenacity and elongation based on the linearity of independent pairwise comparisons among the estimated marginal means. Significant tenacity differences by the effect of ginning treatment were observed on all studied genotypes and favoured for Acala SJ-2, which after ginning treatment had mean FAVIGRAPH single fibre tenacity and coefficient of variation in tenacity values (27.24 cN/tex, 4.19%) than Arba and DP-90. After similar ginning treatment, Arba and DP-90 had lower mean FAVIGRAPH single fibre tenacity with higher coefficient of variation in tenacity values (26.97 cN/tex, 4.34%), (26.34, 4.44%), respectively than Acala SJ-2.

Acala SJ-2 which had greater mean tenacity and elongation value before ginning affected less than the other two studied varieties (see fig. 4.10). One of the reasons for variation in tenacity and elongation values, after ginning treatment, between the studied samples is assumed to be the genotype differences which has effect on the quality and variability of fibre quality properties grown under the same environment with similar cultural practices. Bel, et al. [63] also studied the effect of ginning treatments on two US varieties, Stoneville 506 (a hairy leaf variety) and Deltapine 50 (smooth leaf variety) grown in the Mississippi Delta by the same producer under similar cultural practices. They found ginning treatment and variety affected strength more severely Deltapine 50 which was significantly weaker (26.1 cN/tex) than Stoneville 506 (28.6 cN/tex).

The elongation differences by the effect of ginning treatment were not significant for varieties Arba and DP-90 (see table 4.5) at 0.01 level. But it was significant on Acala SJ-2, even though it remains with higher mean FAVIGRAPH single fibre elongation (6.89 %) and lower elongation coefficient of variation (6.10 %) than Arba and DP-90 varieties. It is important to mention here that the cotton breeders and spinners are suggested to consider both the mean tenacity and elongation as well as variations in tenacity and elongation values during the selection of varieties for the targeted end product quality requirements.

Therefore, it can be understood that the elongation characteristics associated with fibre tenacity are critically important in textile processing, namely: opening, carding, spinning, knitting and weaving as well as for breeding new cultivars that can withstand the mechanical action of modern high-speed textile and ginning machines. Stronger fibres tend to have higher elongation which results in better work-to-break. This could lead to lower fibre breakage during ginning process.

This fact is observed in the studied samples where Acala SJ-2 which had stronger mean FAVIGRAPH single fibre tenacity 28.81 cN/tex (table 4.2) and mean FAVIGRAPH single fibre elongation 7.22 (table 4.4) as well as higher mean HVI bundle tenacity 28.28 cN/tex (table 4.6) favoured by having less short fibre content by weight 10.5 % after the ginning treatment against Arba 10.9 % (table 4.7) and DP-90 11.7 % (table 4.8).

Tenacity and Elongation with CCS absolute mode

During the tenacity measurement the HVI corrects the measured tenacity by micronaire values. This is because of that the micronaire affects the optical measurement of the linear density of the bundle between the clamps. The CCS Fibrotest does not correct strength by micronaire values since the mass of the bundle, after the breakage, is determined gravimetrically by the high-resolution balance. This sample mass is used to calculate the linear density of the fibre bundle, which was used during tenacity testing, on which the absolute tenacity is based.

Due to the increasing manufacturing speed of modern textile machinery, the strain introduced on cotton by a highly rotating machine parts is becoming more severe. Because of this the cotton mills demand an accurate test results data which assists to control process performance of their machinery.

In this study the CCS absolute tenacity is used to evaluate the effect of ginning treatment on tenacity properties of the commercial varieties and the result is presented in tables 4.6-4.8. Accordingly, the effect of ginning treatment on absolute tenacity is favoured to Acala SJ-2, with a value, (13.66 cN/tex, 13.16 cN/tex) against the two studied varieties Arba (12.23 cN/tex, 12.07 cN/tex) and DP-90 (11.70 cN/tex, 11.41 cN/tex).

The effect of ginning treatment on CCS elongation is also favoured to Acala SJ-2, with a value, (7.54 %, 7.51 %) than the two studied varieties Arba (7.14 %, 7.07 %) and DP-90 (6.28 %, 6.23 %).

The absolute tenacity with corresponding elongation values are important parameters to predict the spinnability of cotton for a desired yarn count. Higher tenacity with increased fibre elongation results in increased yarn strength and elongation. The cotton with higher elongation spin with fewer ends down than the lower elongation cotton [64].

4.4.3 Short fibre content and Neps

The negative effect of a high percentage of short fibres is usually associated with: extreme drafting difficulties, increased yarn irregularity and ends down.

Wang, et al. [65], after their experiment in a worsted Toenniessen ring spinning frame, stated that in the spinning triangle (yarn formation zone), short fibres can easily subject to the formation of trailing hairs similar to the edge fibres. Because, they have insufficient fibre length to build up the tension in them required for competing for the core position in the yarn body.

Haleem and Wang [66], after their comprehensive review of recent developments provide suggestion that fibre structure, length, fineness, uniformity ratio and short fibre content are the material based parameters that must be considered before spinning a yarn in order to yield better hairiness values.

It is documented that fibre length degradation resulting from breakage during lint cleaning is less severe in cotton with greater mean individual fibre tenacity [tenacity (cN/tex) × fineness (millitex) [67]. In the present study Acala SJ-2 with greater value of mean FAVIGRAPH single fibre tenacity (28.81 cN/tex × 164 millitex) was subjected to relatively less length breakage during the ginning treatment when compared against Arba (27.55 cN/tex × 160 millitex) and DP-90 (27.11 cN/tex × 156 millitex).

Neps are small entanglements of cotton fibres created during boll development, machine harvesting, handling, ginning, and mill processing. They are highly undesirable because they decrease mill processing efficiency, dye improperly, and detract the appearance of fabric. In this study, raw seed cottons of all the varieties which were composed of few neps, resulted with high level of neps after the process of ginning: Acala SJ-2 (75 count/g, 188 count/g) (table 4.6), Arba (87 count/g, 203 count/g) (table 4.7) and DP-90 (90 count/g, 221 count/g) (table 4.8). Varietal differences were significant with maximum difference 17%, which is similar to the 19% difference found by Miravalle, et al. [68].

Mangialardi [69] reported a possible increase in neps level potential as micronaire decreased, it is found a similar trend in this study, but micronaire differences were too small to draw valid inferences.

Table 4.6 Cotton fibre properties and their statistical parameters by varieties - Acala SJ-2

		Statistical parameters			
		Before Ginning		After Ginning	
Varieties	Fibre properties	Mean	S. D	Mean	S. D
Acala SJ-2	Micronaire, MIC	4.40H	0.39	4.41	0.53
	Fineness, mtex	164A	9.16	165A	11.32
	Maturity ratio,	0.85A	0.02	0.84A	0.05
	Upper half mean length, mm	30.37C	0.61	30.29C	0.93
		28.30H	0.65	28.21H	0.85
	Length by weight, mm	23.7A	0.83	23.1A	1.13
	Length by weight CV, %	33.6A	1.08	34.3A	3.23
	Length by number, mm	19.2A	0.75	17.9	1.03
	Length by number CV, %	48.5A	2.19	49.67	3.06
	Short fibre content (n), %	24.5A	2.66	28.84	5.37
	Total neps, count/g	75A	1.83	188A	26
	Seed coat neps, count/g	15A	12.78	14A	9.53
	Visible foreign matter, %	1.35A	0.52	1.12A	0.34
	Short fibre content (w), %	8.02A	0.47	12.45A	0.59
	Uniformity Index	86.56C	0.55	86.23C	1.35
		82.25H	2.15	81.91H	3.71
	Elongation at maximum force, %	7.54C	0.29	7.51C	1.32
		4.72H	0.09	4.68H	1.53
	Absolute Tenacity, cN/tex	13.66C	0.43	13.55C	1.24
	Relative Tenacity, cN/tex	31.03C	0.87	30.13C	1.39
		28.28H	0.72	27.78H	1.53
	Non-lint content, %	2.43C	0.34	1.23C	0.14

A (AFIS), C (CCS), H (HVI)

Table 4.7 Cotton fibre properties and their statistical parameters by varieties – Arba

		Statistical parameters			
		Before Ginning		After Ginning	
Varieties	Fibre properties	Mean	S. D	Mean	S. D
Arba	Micronaire, MIC	4.30H	0.10	4.31	0.71
	Fineness, mtex	160A	7.43	161A	11.32
	Maturity ratio,	0.85A	0.02	0.85A	0.05
	Upper half mean length, mm	27.82C	0.34	27.76C	0.60
		27.26H	0.69	27.21H	0.97
	Length by weight, mm	23.1A	0.61	22.81A	1.17
	Length by weight CV, %	34.1A	1.48	35.5A	3.59
	Length by number, mm	18.8A	0.76	17.1	1.34
	Length by number CV, %	47.9A	2.39	49.81	3.51
	Short fibre content (n), %	24.6A	3.04	29.13	7.41
	Total neps, count/g	87A	1.83	203A	27.00

Seed coat neps, count/g	16[A]	13.21	15[A]	10.24
Visible foreign matter, %	1.62[A]	0.79	1.12[A]	0.53
Short fibre content (w), %	8.36[A]	0.49	12.68[A]	0.67
Uniformity Index	84.51[C]	2.15	84.14[C]	1.72
	81.13[H]	1.28	80.56[H]	3.83
Elongation at maximum force, %	7.14[C]	0.32	7.07[C]	2.41
	5.14[H]	0.32	5.11[H]	2.74
Absolute Tenacity, cN/tex	12.23[C]	0.59	12.02[C]	1.56
Relative Tenacity, cN/tex	28.22[C]	0.50	27.12[C]	1.63
	27.89[H]	0.18	27.19[H]	1.81
Non-lint content, %	3.17[C]	0.39	1.87[C]	0.17

A (AFIS), C (CCS), H (HVI)

Table 4.8. Cotton fibre properties and their statistical parameters by varieties – DP-90

		Statistical parameters			
		Before Ginning		After Ginning	
Varieties	Fibre properties	Mean	S. D	Mean	S. D
DP-90	Micronaire, MIC	4.14[H]	0.06	4.11	0.92
	Fineness, mtex	156[A]	7.43	157[A]	11.51
	Maturity ratio,	0.84[A]	0.04	0.83[A]	0.07
	Upper half mean length, mm	28.06[C]	0.71	28.01[C]	0.71
		27.48[H]	0.71	27.41[H]	1.05
	Length by weight, mm	23.1[A]	1.20	22.42	1.19
	Length by weight CV, %	34.7[A]	3.44	35.9[A]	3.74
	Length by number, mm	18.7[A]	1.82	16.93	1.85
	Length by number CV, %	49.0[A]	6.66	49.92	3.65
	Short fibre content (n), %	25.7[A]	7.97	29.55	7.64
	Total neps, count/g	90[A]	2.21	221[A]	29.00
	Seed coat neps, count/g	27[A]	15.56	25[A]	11.74
	Visible foreign matter, %	2.71[A]	1.52	2.41[A]	0.59
	Short fibre content (w), %	8.49[A]	0.49	12.76[A]	0.78
	Uniformity Index	82.74[C]	1.48	82.39[C]	1.84
		80.66[H]	0.82	80.33[H]	4.11
	Elongation at maximum force, %	6.28[C]	0.44	6.23[C]	2.52
		4.28[H]	0.44	4.25[H]	2.81
	Absolute Tenacity, cN/tex	11.70[C]	0.99	11.41[C]	1.61
	Relative Tenacity, cN/tex	28.13[C]	1.30	26.83[C]	1.87
		26.94[H]	0.74	26.04[H]	1.93
	Non-lint content, %	2.84[C]	0.42	1.74[C]	0.19

A (AFIS), C (CCS), H (HVI)

4.4.4 Optimization of Ginning

Short fibre content

Short fibres do not contribute to yarn strength, tend to build neps during processing, reduce yarn evenness, and lead to fibre fly on the processing machines in the spinning mill and in downstream processing. They practically mean a loss for the spinning mill and a quality reduction to the yarn.

It is observed that the percentage of short fibre content is significantly increased after the ginning process. Cotton fibres normally break only when an applied tensile force exceeds their breaking strength at the moment of mechanical striking action. Tensile forces are normally applied to cotton during ginning: in the gin stand, when each fibre is pulled from the seed, and in the lint cleaner, when fibres are partially restrained during feeding to the saw cylinder and as they are striked against the cleaning grid bars.

It is reasonable to assume that processing rates higher than normal would affect the fibre-holding force at the lint cleaner feed plate. A higher than the normal fibre flow rate means a thicker batt at the feed plate, which, in turn, means greater restraint, on the fibres as they are presented to the saw tooth cylinder.

$$V = v \times t \times w$$

Where, V is the volume of cotton fed into the gin stand in unit of times; v is the rate of feeding the ginned cotton to the lint cleaner; t is the thickness of the cotton sheet and w it its width.

As the width of the sheet does not change for a given setup of machine, the formula given above can be written simpler $v \times t$ = constant, i.e. the rate of feeding must be inversely proportional to the thickness of the ginned cotton fed.

When gins are reloaded to increase the capacity of their gin stands, but do not increase lint-cleaning capacity, this thicker than normal batt flow may result. It is also likely that this would occur when lint cleaning capacity is normally only marginally sufficient and gin stands are overfed in an effort to decrease cotton trailer turnaround time at the gin. In such an event the driers would likely be used with heat to insure smooth operation of the gin. Maximum production ginning rate in combination with two stages of lint cleaning at low fibre moisture levels caused the greatest SFC (table 4.9). The ginning production rate is a factor, that may be controlled by gin operators. When they are fully informed on the effects of gin operation on fibre breakage, they should adjust ginning rates accordingly to produce a quality product. The fibre moisture problem is more difficult to control. Due to the long field exposure of hand harvested cotton, the bulk of Ethiopian cotton can be ginned, in most year, without the need for heat in the driers. It is not uncommon in many Ethiopian cotton cultivation areas for cotton to arrive at the gin with a fibre moisture content less than 5%. Indeed, much of Ethiopian cotton needs moisture restoration, rather than moisture removal, for best retention of inherent fibre length distribution during ginning.

Again, education and experience in the quality of lint ginned should go a long way in controlling the level of SFC at 11% or below.

Table 4.9 Short fibre content (%) of lint ginned at different rates of gin stands, at one level and two levels of lint cleaning and at two levels of moisture content, crop of 2017

Genotype and ginning rates	With one stage lint cleaning		With two stages lint cleaning	
	HM	LM	HM	LM
Acala SJ-2				
7 bales per hour	8.7	10.3	9.3	11.6
9 bales per hour	9.1	11.5	9.8	11.8
Arba				
7 bales per hour	8.9	10.6	9.7	11.9
9 bales per hour	9.3	11.8	10.3	12.1
DP-90				
7 bales per hour	9.1	10.7	9.9	12.2
9 bales per hour	9.5	11.9	10.6	12.5

HM = High moisture, LW = Low moisture

Level of neps

Cotton neps are created when fibres become tangled during the ginning operation. They are considered as a source of trouble in manufacturing and finishing, and they detract the appearance of yarn and fabric.

Before investigating the impact of ginning on the level of neps, it was required to evaluate the moisture level of the varieties subjected to the study. In many of the studied ginneries, there were no online moisture content control. Therefore, moisture content values should have been held constant because they have an influence on the cleanability of the cotton. In this study, the lint moisture content by variety effect was not significant, indicating that the trend was the same for all the studied varieties for nearly all the variables.

For the treatments studied, the gin stand and saw-toothed cylinder lint cleaners were the major contributors to the formation of neps at gins.

One lint cleaner produced the lowest SFC and nep values for all varieties; two lint cleaners produced the highest SFC and nep level values for all the varieties (see table 4.10). Therefore, for optimizing short fibre and nep content, using one lint cleaner is best for all the studied varieties. As mechanical manipulation (additional lint cleaners) on the lint cotton increased, there was an increase of short fibre content and neps. Nep levels also increases as short fibre content increases. Both neps and short fibres cause problems in yarn and fabric quality.

Table 4.10 Neps measurements results of lint ginned at different rates of gin stands, utilizing one level and two levels of saw-type lint cleaning, crop of 2017

Genotype and ginning rates	With one stage lint cleaning		With two stages lint cleaning	
	TN counts/g	SCN counts/g	TN counts/g	SCN counts/g
Acala SJ-2				
7 bales per hour	123	15	188	14
9 bales per hour	138	17	207	15
Arba				
7 bales per hour	136	16	203	15
9 bales per hour	157	19	225	18
DP-90				
7 bales per hour	153	27	221	25
9 bales per hour	178	29	246	26

TN=Total neps, SCN = Seed coat neps

4.5 Conclusions

A commercially grown cotton varieties that was approximately midrange in staple length and strength was subjected to the standard ginning treatment. The effect of gin processing on tenacity, elongation, length distribution and neps level was investigated. Some conclusions that can be drawn from this study are:

1. In comparing the quality properties of seed cotton (before ginning) with lint cotton (after ginning), a statistically significant FAVIGRAPH single fibre tenacity decrease was observed on all studied varieties. Acala SJ-2 with greater mean tenacity and less coefficient of variation in tenacity before ginning affected less than the other two studied varieties. The mean FAVIGRAPH single fibre tenacity difference in cN/tex, before and after ginning treatment fall in the range (1.30, 1.35, 1.38) for Acala SJ-2, Arba and DP-90, respectively. The HVI and CCS relative bundle tenacity results are also in favour of Acala SJ-2 (see tables 4.6-4.8).

2. The mean CCS absolute bundle tenacity difference in cN/tex, before and after ginning treatment fall in the range (0.11, 0.16, 0.29) for Acala SJ-2, Arba and DP-90, respectively.

The absolute tenacity with corresponding elongation values are important parameters to predict the spinnability of cotton for a desired yarn count. Higher tenacity with increased fibre elongation results in increased yarn strength and elongation.

3. The cotton with higher elongation spin with fewer ends down than the lower elongation cotton.

   In this study, Acala SJ-2 with greater value of mean FAVIGRAPH single fibre tenacity (28.81 cN/tex × 164 millitex) and elongation (7.06 %) was subjected to relatively less length breakage during the ginning treatment when compared against Arba (27.55 cN/tex × 160 millitex) and elongation (6.95 %), DP-90 (27.11 cN/tex × 156 millitex) and elongation (6.83 %).

   AFIS short fibre content by number and by weight after the ginning treatment for Acala SJ-2 was (SFC_n = 28.84 %, SFC_w = 12.45 %) against Arba (SFC_n = 29.13 %, SFC_w = 12.68) and DP-90 (SFC_n = 29.55 %, SFC_w = 12.76 %).

   There was a significant shift in the length distribution after ginning treatment (see Appendix A.1 and A.2).

   Raw seed cottons of all the varieties which were composed of few neps, resulted with high level of neps after the process of ginning: Acala SJ-2 (75 count/g, 188 count/g (table 4.6), Arba (87 count/g, 203 count/g) (table 4.7) and DP-90 (90 count/g, 221 count/g) (table 4.8). Varietal differences were significant with maximum difference 17%.

   As mechanical manipulation (additional lint cleaners) on the lint cotton increased, there was an increase of short fibre content and neps. Therefore, for the optimum short fibre and nep content, using one lint cleaner is best for all the studied varieties.

   In addition, in this study, ginning at 9 bales/h rate increases the short fibre and neps level as compared against ginning at 7 bales/h. Therefore, the practical means of controlling fibre breakage and short fibre content, for the studied varieties are ginning at 7 bales/h and keeping the ginning rate within recommended limits.

5 MCDM and LP support optimum mixing/blending

Keywords:

PROMETHEE-GAIA, AHP, Genotypes, Fibre quality, LP, Mixing/blending

5.1 Experimental design

This experiment presents a multi-criteria-decision-making (MCDM) and linear programming (LP) support approaches to determine the quality value of cotton fibre used for the optimization of mixing/blending.

Twelve different Genotypes of most widely used cottons in Ethiopia used in this study are DP-90, Cu-ok-ra, SJ-2, Arba, Lao Cara, Alber 637, BPA, Cucrova 1518, Bulk 202, Sille 1 (Stoneville), Estamble, R-36 [59].

The same cotton plantation zones covered during experimental design 4.1 are used for this study, namely: North Ethiopia - (Tigray, Amhara & Benishangul Gumuz); North-Central Ethiopia (Upper Awash, Middle Awash & Lower Awash) and South Ethiopia (Oromia, Arba Minch & Gambella).

Figure 5.1 Map showing areas of cotton production in Ethiopia (Blue marks are the areas of cotton producing regions in Ethiopia)

<u>Geographical Regions</u>

Table 5.1 shows different regions of Ethiopia with their altitude from where the cotton samples were collected for the study.

Regions	Farms/ Places	Irrigation/ Rain fed	Approximate Altitude
North Ethiopia	Hiwot farm in Humera	Rain Feed	700-1000 m
	Small & Large farms in Metama		
	Zeleke farm in Benishangul		
North-Central Ethiopia	Tendaho Agricultural Development Agency	Irrigated	300 m
	Middle Awash State Farm, Amibara Farm,	Irrigated	700 m
	Bonta Farm		
South Ethiopia	Arba Minch State Farm, Small farms in	Irrigated	1000 m
	Malayata Sodo, Birala Agricultural farm in	except in	
	Jinka	Sodo	

Twelve cotton varieties with 3 lint cotton samples randomly collected from each variety were used for the AFIS, HVI and CCS fibre properties. The AFIS fibre properties was tested with 30 replications of 3,000 fibres (i.e. 12 varieties × 3 zones × 3 samples × 30 tests of 3000 fibres replications), The HVI and CCS fibre properties was tested with (12 varieties × 3 zones × 3 samples × 100 tests replications) for each instrument. One technician per every instrument was used throughout the testing days.

5.2 Treatment of Data

In this section, PROMETHEE II method is applied to rank the considered twelve genotypes of cotton fibres from the best to the worst based on their HVI, AFIS and CCS measured fibre quality properties. The developed GAIA plane helps in segregating those genotypes into different groups/clusters with almost similar fibre properties profiles.

5.3 PROMETHEE-GAIA method

Using PROMETHEE-GAIA method researchers attempt to compare the fibre quality of varieties tested by HVI instrument. Though the quality of U-V plane indicates that cotton fibre selection was difficult problem to solve (Chakraborty et al., 2018) [70].

Amongst various multi criteria decision making (MCDM) tools, the PROMETHEE method (Brans and Vincke, 1985) [71] has become quite popular within the decision-making community because it has a clear computation procedure and can easily be interpreted for the purpose decision-making. It is also one of the most employed outranking methods in practice. The PROMETHEE family of methods has several versions, such as PROMETHEE I, II, III, IV, V and VI. The PROMETHEE I method provides a partial ranking of the candidate alternatives, PROMETHEE II allows a complete ranking, PROMETHEE III provides an interval order emphasizing indifference, PROMETHEE IV deals with continuous sets of possible alternatives, PROMETHEE V includes segmentation constraints and PROMETHEE VI is adopted when precise weights are not allocated. The Promethee method can also be combined together with the principal component analysis approach in the form of GAIA plane which acts as visualization tool for investigating the results derived from the multi-criteria analysis (Brans and Mareschal, 1994 [72]; Mareschal and Brans, 1988 [73]). The Promethee II is a non-parametric MCDM method used to evaluate and rank a number of candidate alternatives with respect to some predefined criteria/attributes [74]. It is primarily based on the outranking principle aimed to determine the degree of dominance of one alternative over another within a set of feasible options A ($a_i \in A$, for i = 1, 2…, m) with respect to jth criterion (for j = 1, 2…, n). The dominance degree is estimated while comparing pairs of alternatives from a set of alternatives A, and is based on the value χij which denotes the relative performance of ith alternative against jth criterion. A preference function is usually associated with each criterion for each pair of alternatives in order to reflect the perception of the decision-maker. Thus, for each criterion, the following preference function is considered:

$$p_j(a,b) = F_j\left[d_j(a,b)\right] \quad \forall a,b \in A$$

where, $d_j(a,b) = [f_j(a) - f_j(b)], \quad 0 \le p_j(a,b) \le 1$ .... (5.1)

When the deviations are negative, this preference becomes zero. The value of p_j (a, b) is a number between 0 and 1, it signifies the degree of preference that the decision-maker expresses for a over b with respect to jth criterion. Now, the aggregated preference indices are expressed as below:

$$\begin{cases} \pi(a,b) = \sum_{j=1}^{n} p_j\,(a,b) w_j \\ \pi(b,a) = \sum_{j=1}^{n} p_j\,(b,a) w_j \end{cases} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5.2)$$

where π (a, b) is the degree with which alternative a is preferred to b, π (b, a) is the degree with which alternative b is preferred to a and wj is the relative importance or priority weight allocated to jth criterion. These criteria weights can be determined while employing analytic hierarchy process (AHP) (subjective assessment based on pair-wise comparison of the criteria values) (Saaty, 1980) [75] or Shannon's entropy method (Rao, 2007) [76] (objective assessment considering the degree of disorder in a system). From these aggregated preference indices, two outranking flows can be defined. The positive outranking flow (leaving flow), as given in Equation (5.3), is the measure of strength of an alternative a with respect to the others. On the other hand, the negative outranking flow (entering flow) estimates the weakness of alternative a with respect to others, as expressed in Equation (5.4).

$$\text{Positive outranking flow } \varphi^{+}(a) = \frac{1}{m-1}\sum_{x \epsilon A} \pi(a,x) \ldots\ldots\ldots\ldots (5.3)$$

$$\text{Negative outranking flow } \varphi^{-}(a) = \frac{1}{m-1}\sum_{x \epsilon A} \pi(x,a) \ldots\ldots\ldots\ldots (5.4)$$

The net outranking flow is finally calculated while balancing between these two outranking flows:

$$\varphi(a) = \varphi^{+}(a) - \varphi^{-}(a) \ldots\ldots\ldots\ldots\ldots\ldots (5.5)$$

A higher value of φ(a) always signifies a better course of action or option. Thus, the PROMETHEE II method ranks the alternatives on the basis of their net outranking flows. Behzadian, Kazemzadeh, Albadvi, and Aghdasi (2010) [77] provided an excellent review of PROMETHEE II method and its applications in diverse decision-making domains.

The GAIA helps as a visualization tool to complement the complete ranking preorder as derived using PROMETHEE II method and provide guidance regarding the impact analysis of the most important criterion in the developed model.

Table 5.2 Values of the studied genotypes fibre properties and their statistical parameters

	Fibre properties						
Genotype	UHML	UR	FT	FE	MIC	SFC	Neps
DP-90 (G1)	29.25	41.55	24.7	5.73	4.35	8.6	213
Cu-ok-ra (G2)	29.13	41.43	23.48	5.63	4.37	12.1	264
Acala SJ-2 (G3)	29.73	43.24	25.88	6.08	4.17	8.2	188
Arba (G4)	29.55	41.95	25.68	5.95	4.29	9.2	202
LaoCara (G5)	27.58	41.41	22.25	5.6	4.13	10.1	275
Alber 637 (G6)	28.05	42.23	24.33	5.88	4.27	7.8	261
BPA (G7)	30.65	41.57	25.95	5.75	4.21	7.2	277
Cucrova 1518 (G8)	29.61	43.11	25.7	6.03	4.25	10.3	281
Bulk 202 (G9)	30.05	43.57	25.91	6.18	4.15	9.7	274
Sille1(Stoneville) (G10)	30.1	43.17	25.93	6.13	4.19	8.1	261
Estamble (G11)	26.58	41.91	22.14	5.93	4.31	9	280
R-36 (G12)	27.91	43.14	23	6.13	4.22	8.3	260
Mean	29.02	42.36	24.58	5.92	4.24	9.05	253
CV %	4.19	1.95	6.11	3.41	1.83	14.82	12.91

CCS-version 5 measured Fibre quality properties of the studies twelve genotypes are shown in table 5.2.

Before the application of PROMETHEE II method of genotypes ranking the correlation between the fibre properties was evaluated and presented in table 5.3. From this table we can observe that upper half mean length was positively correlated with fibre bundle tenacity and it was significant at the 0.01 level.

Uniformity ratio was negatively correlated with micronaire and it was significant at the 0.05 level. This was expected because of that a cotton with higher fineness value has a low micronaire value (MIC up to 3.1 very fine, MIC 3.1 – 3.9 fine, MIC 4.0 – 4.9 Medium, MIC 5.0 – 5.9 Slightly coarse and MIC > 6 coarse), because, micronaire is measured by Air flow through a mass of fibre (indirect method). Therefore, from the correlation it is deduced that fine fibres are positively correlated with uniformity ratio. All other factors being equal, fine fibres are long and have more surface area to volume ratio which provides a better distribution in the cotton improving its uniformity (evenness).

Uniformity ratio was positively correlated with bundle elongation and it was significant at 0.01 level. Uniformity of a bundle depends on the number of fibres present in the cross section. So, fine fibres produce more uniform cotton. Uniformity character of a cotton have influence on bundle elongation.

Fibre bundle tenacity was positively correlated (significant at 0.01 level) with upper half mean length. It is obvious that, long and fine fibres have high area/volume ratio which provides more surface contact and so low slippage during the bundle testing. This results in higher tenacity in the cotton. Fibre bundle tenacity was negatively correlated with short fibre content and level of neps. Fibre elongation was negatively correlated with micronaire.

Table 5.3 Coefficient of correlation between fibre properties of 12 genotypes

	UHML	UR	FT	FE	MIC	SFC	Neps
UHML		0.282	.918**	0.214	-0.185	-0.127	-0.248
UR			0.454	.940**	-0.506*	-0.186	-0.030
FT				0.437	-0.213	-0.304	-0.342
FE					-0.380	-0.320	-0.097
MIC						0.288	-0.148
SFC							0.212
Neps							

** Correlation is significant at the 0.01 level.

*Correlation is significant at the 0.05 level

5.3.1 Genotype ranking using PROMETHEE II

In the PROMETHEE II ranking, amongst the detailed fibre properties considered in table 5.2, upper half mean length (UHML), uniformity ratio (UR), fibre bundle tenacity (FT), fibre elongation (FE) are the higher-the-better type of quality characteristics. On the other hand, micronaire (MIC), percentage short fibre content by weight (SFC_w) and total level of neps (Neps) are the lower-the-better type of quality characteristics. The last two rows of this table respectively provide values of arithmetic mean and coefficient of variation (CV %) for the studied fibre properties. Now, in order to determine the relative importance of each genotype fibre quality properties for different spinning systems, four scenarios are considered and presented in table 5.4. The criteria weights are separately determined using a method of analytical hierarchy process (AHP) (see Appendix B).

Table 5.4 shows the priority order fibre properties used for the manufacturing of yarn in various spinning systems [78].

Table 5.4 Order of importance of fibre properties for different spinning systems

Order of importance	Type of spinning system			
	Ring spinning	Rotor spinning	Compact spinning	Air jet spinning
1	Fibre length	Fibre strength	Fibre length and length uniformity	Fibre fineness
2	Fibre strength	Fibre fineness	Fibre strength	Neps, trash and dust content
3	Fibre fineness	Fibre length and length uniformity	Fibre fineness	Fibre strength
4	Neps, trash and dust content	Neps, trash and dust content	Neps, trash and dust content	Fibre length and length uniformity

5.3.1.1 Ring spinning method scenario

After the AHP pairwise comparison method of criteria weighting the ranking of the studied genotypes is performed using the PROMETHEE-GAIA software. Accordingly, the computed negative outranking flow, positive outranking flow and the net outranking flow values for the ring spinning method scenario is provided in table 5.5.

Table 5.5 Ranking order of genotypes and net outranking flow under ring spinning scenario

Rank	Genotype	φ	φ^{+}	φ^{-}
1	Acala SJ-2 (G3)	0,2932	0,2932	0,0000
2	Sille1(Stoneville) (G10)	0,2764	0,2876	0,0113
3	Bulk 202 (G9)	0,2503	0,2935	0,0432
4	BPA (G7)	0,2088	0,2837	0,0749
5	Arba (G4)	0,1829	0,2153	0,0323
6	Cucrova 1518 (G8)	0,1477	0,2161	0,0683
7	DP-90 (G1)	0,0862	0,1647	0,0785
8	Alber 637 (G6)	-0,1342	0,0964	0,2306
9	Cu-ok-ra (G2)	-0,1474	0,0898	0,2372
10	R-36 (G12)	-0,2278	0,0858	0,3136
11	LaoCara (G5)	-0,4545	0,0161	0,4706
12	Estamble (G11)	-0,4817	0,0067	0,4885

From this table, it is observed that in the ring spinning scenario, Acala SJ-2 (G3) is identified as the most suitable genotype for short to medium staple ring spun yarns. In this scenario Acala SJ-2 (G3), Sille1(Stoneville) (G10), Bulk 202 (G9) are from the best performing group of genotypes whereas Estamble is the worst performing genotype in the studied Ethiopian cotton varieties.

A clear understanding about the fibre property profiles of studied genotypes under ring spinning scenario can be obtained from the PROMETHEE rainbow diagram, as given in figure 5.2.

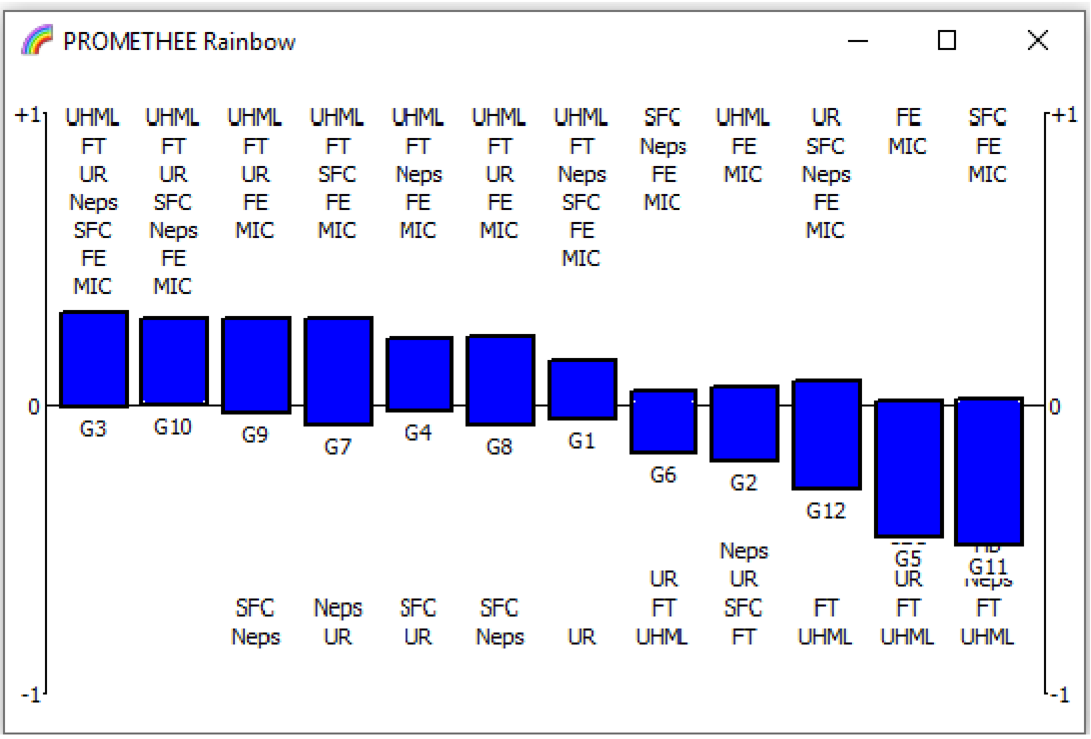


Fig. 5.2 PROMETHEE rainbow diagram for the studied genotypes under ring spinning scenario

From this figure it can be observed that Acala SJ-2 (G3) and Sille 1 (Stoneville) (G10) outperforms the other competitor genotype alternatives with respect to all the considered fibre quality properties. Bulk 202 (G9) and BPA (G7) genotypes have excellent values for fibre quality properties which are priority for ring spun yarns, namely upper half mean length (UHML), bundle tenacity (FT), and micronaire (MIC) except the level of neps.

The commercial varieties Arba (G4), Deltapine 90 (G1) and noncommercial variety Cucrova 1518 (G8) can be categorized in the same group and they satisfy the priority fibre quality properties required by the ring spinning system (except level of neps for G8).

For ring spinning scenario, the corresponding GAIA plane is developed using the PROMETHEE-GAIA software and presented in figure 5.3.

In this plane it is clearly shown that the commercial varieties Acala SJ-2 (G3), Arba (G4) and Deltapine 90 (G1) form a distinct cluster on satisfying the fibre quality properties required for the ring spinning scenario. Even though they have less upper half mean length value than Sille 1 (Stoneville) (G10), Bulk (G9) and BPA (G7), they have less level of neps and short fibre content that makes them suitable for the ring spinning scenario and they are clustered in the direction of the decision axis (a red line in the GAIA plane). It is also noticed that Estamble (G11), LaoCara (G5) and R-36 (G12) are almost outliers in the GAIA plane.

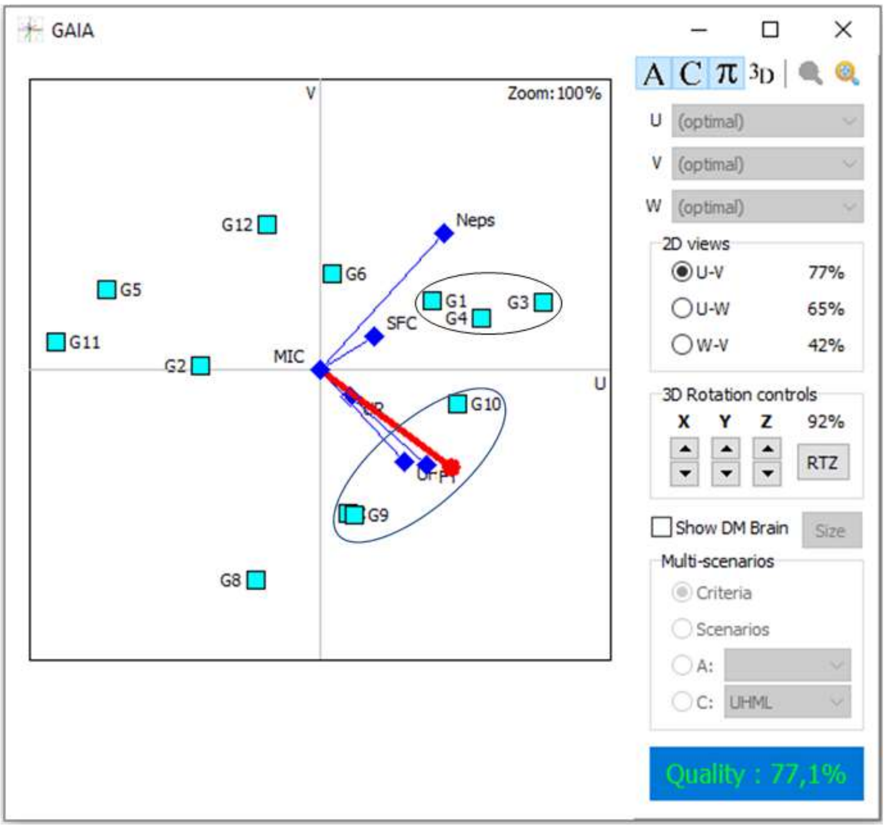


Fig. 5.3 GAIA plane for the studied genotypes under ring spinning scenario

5.3.1.2 Rotor spinning method scenario

The mechanism of yarn formation in rotor spinning system is completely different from that of ring spinning, and the yarn structure is somewhat different. Lack of effective drafting system in rotor spinning resulted with poorer fibre parallelization in the yarn structure than in ring yarns. Therefore, as it is presented in table 5.4, the fibre properties order of importance most suitable for rotor spinning can not necessarily be those most suitable for ring spinning.

As it was performed for ring spinning scenario, after the AHP pairwise comparison method of criteria weighting the ranking of the studied genotypes is performed using the PROMETHEE-GAIA software.

Accordingly, the computed negative outranking flow, positive outranking flow and the net outranking flow values for the rotor spinning method scenario is provided in table 5.6.

It is observed that (table 5.6) in rotor spinning scenario, as was the case with ring spinning scenario, Acala SJ-2 (G3) is identified as the most suitable commercial genotype for short to medium staple rotor spun yarns.

Table 5.6 Ranking order of genotypes and net outranking flow under rotor spinning scenario

Rank	Genotype	φ	φ^{+}	φ^{-}
1	Acala SJ-2 (G3)	0,3129	0,3129	0,0000
2	Sille1(Stoneville) (G10)	0,2902	0,3015	0,0112
3	Bulk 202 (G9)	0,2623	0,3052	0,0430
4	Arba (G4)	0,2052	0,2356	0,0304
5	BPA (G7)	0,2032	0,2778	0,0746
6	Cucrova 1518 (G8)	0,1668	0,2341	0,0673
7	DP-90 (G1)	0,0896	0,1761	0,0864
8	Alber 637 (G6)	-0,0659	0,1290	0,1949
9	R-36 (G12)	-0,2547	0,0794	0,3341
10	Cu-ok-ra (G2)	-0,2713	0,0661	0,3375
11	Estamble (G11)	-0,4692	0,0160	0,4852
12	LaoCara (G5)	-0,4692	0,0067	0,4759

In this scenario Acala SJ-2 (G3), Sille1(Stoneville) (G10), Bulk 202 (G9) are keep their ranking position as was the case with ring spinning scenario and they are from the best performing group of genotypes whereas Estamble shifts one position up because it has relatively better uniformity ratio (the 3rd order of importance for the rotor spinning) than LaoCara (G5). The worst performing genotype in the rotor spinning scenario is LaoCara (G5).

Similar to the ring spinning scenario, a clear understanding about the fibre quality property profiles of studied genotypes under rotor spinning scenario can be obtained from the PROMETHEE rainbow diagram, as shown in figure 5.4.

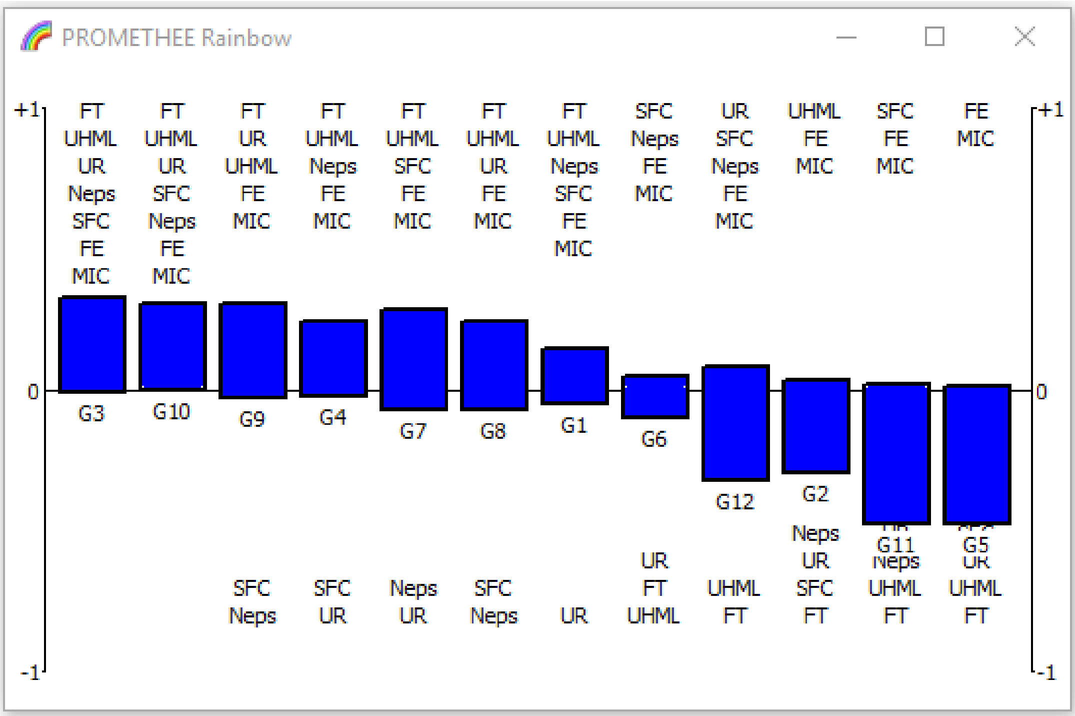


Fig. 5.4 PROMETHEE rainbow diagram for the studied genotypes under rotor spinning scenario

From this figure it can be observed that Acala SJ-2 (G3) and Sille 1 (Stoneville) (G10), as it was with ring spinning scenario, outperforms the other competitor genotype alternatives with respect to all the considered fibre quality properties. Bulk 202 (G9) keeps its ranking position as was with ring spinning scenario whereas BPA (G7) downs one position and placed after Arba (G4). The replacement of BPA (G7) by Arba (G4) can be explained by the fact that, Arba has relatively higher uniformity ratio and elongation than its competitor BPA.

For rotor spinning scenario, the corresponding GAIA plane is developed using the PROMETHEE-GAIA software and presented in figure 5.5.

In this plane it is clearly shown that the commercial varieties Acala SJ-2 (G3), Arba (G4) and Deltapine 90 (G1), as it was with ring spinning scenario, form a distinct cluster on satisfying the fibre quality properties required for the rotor spinning scenario.

Even though they have less upper half mean length value than Sille 1 (Stoneville) (G10), Bulk (G9) and BPA (G7), they have less level of neps and short fibre content that makes them suitable for the rotor spinning scenario and they are clustered in the direction of the decision axis (a red line in the GAIA plane).

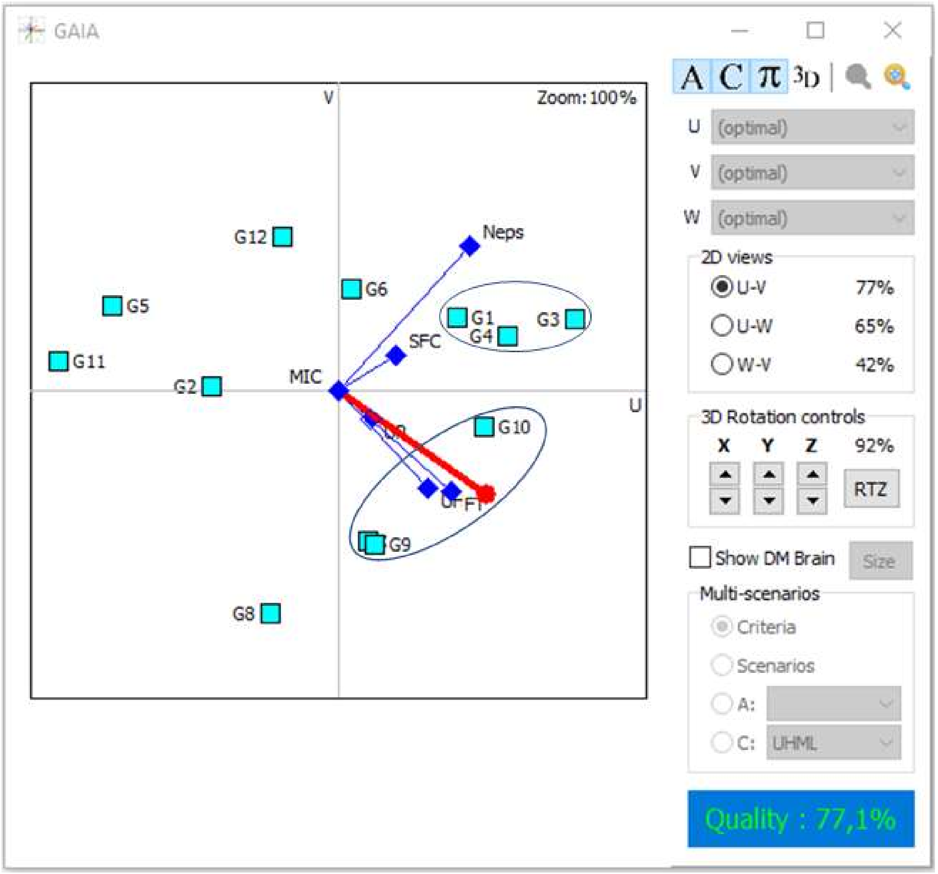


Fig. 5.5 GAIA plane for the studied genotypes under rotor spinning scenario

It is also noticed that Estamble (G11), LaoCara (G5) and R-36 (G12) are almost outliers in the GAIA plane.

5.3.1.3 Compact spinning method scenario

The mechanism of yarn formation in compact spinning system is essentially modification to the conventional ring spinning process with the aim of altering the geometry of the spinning triangle so as to improve the structure of the ring-spun yarn by more effective binding-in of surface fibres into the body of the yarn. This increases yarn strength along with marked reductions in CV %, defects and yarn hairiness. Compact ring-spun yarns can be up to 10% stronger than conventional ring-spun yarns. Therefore, as it is presented in table 5.4, the fibre properties order of importance most suitable for compact spinning is similar to those most suitable for ring spinning.

Table 5.7 Ranking order of genotypes and net outranking flow under compact spinning scenario

Rank	Genotype	φ	φ+	φ−
1	Acala SJ-2 (G3)	0,2917	0,2917	0,0000
2	Sille1(Stoneville) (G10)	0,2748	0,2857	0,0109
3	Bulk 202 (G9)	0,2535	0,2948	0,0414
4	BPA (G7)	0,1930	0,2718	0,0788
5	Arba (G4)	0,1762	0,2098	0,0336
6	Cucrova 1518 (G8)	0,1504	0,2156	0,0653
7	DP-90 (G1)	0,0766	0,1599	0,0833

8	Alber 637 (G6)	-0,1227	0,0966	0,2193
9	Cu-ok-ra (G2)	-0,1641	0,0835	0,2477
10	R-36 (G12)	-0,2169	0,0874	0,3044
11	LaoCara (G5)	-0,4468	0,0155	0,4622
12	Estamble (G11)	-0,4655	0,0064	0,4719

As it was with ring and rotor spinning scenarios, after the AHP pairwise comparison method of criteria weighting the ranking of the studied genotypes is performed using the PROMETHEE-GAIA software.

Accordingly, the computed negative outranking flow, positive outranking flow and the net outranking flow values for the compact spinning method scenario is provided in table 5.7.

As it is observed from table 5.7 in compact spinning scenario Acala SJ-2 (G3) is identified as the most suitable commercial genotype for compact spun yarns. In this scenario Acala SJ-2 (G3), Sille1(Stoneville) (G10) and Bulk 202 (G9) respectively, take the 1st to the 3rd order of rank and they are from the best performing group of genotypes whereas Estamble (G11) is the worst performing cotton for the studied samples as it was with ring spinning scenario.

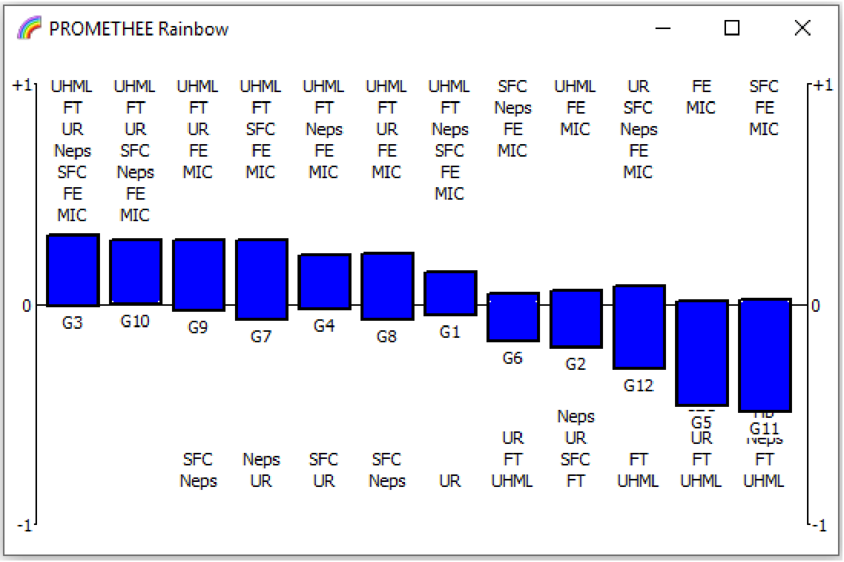


Fig. 5.6 PROMETHEE rainbow diagram for the studied genotypes under compact spinning scenario

A clear understanding about the fibre property profiles of studied genotypes under compact spinning scenario can be obtained from the PROMETHEE rainbow diagram, as given in figure 5.6. From this figure it can be observed that Acala SJ-2 (G3) and Sille 1 (Stoneville) (G10) outperforms the other competitor genotype alternatives with respect to all the important priority order fibre quality properties required for the compact spinning scenario. This ranking order in the compact spinning method scenario can be explained by the fact that both Acala SJ-2 (G3) and Sille 1 (Stoneville) (G10) are the candidates which best satisfied a higher length, length uniformity and tenacity properties requirement of the system. Acala SJ-2 (G3) has UHML (29.73 mm), UR (43.24) and FT

(25.88 cN/tex) and Sille 1 (Stoneville) (G8) has UHML (30.1 mm), UR (43.17) and FT (25.93 cN/tex).

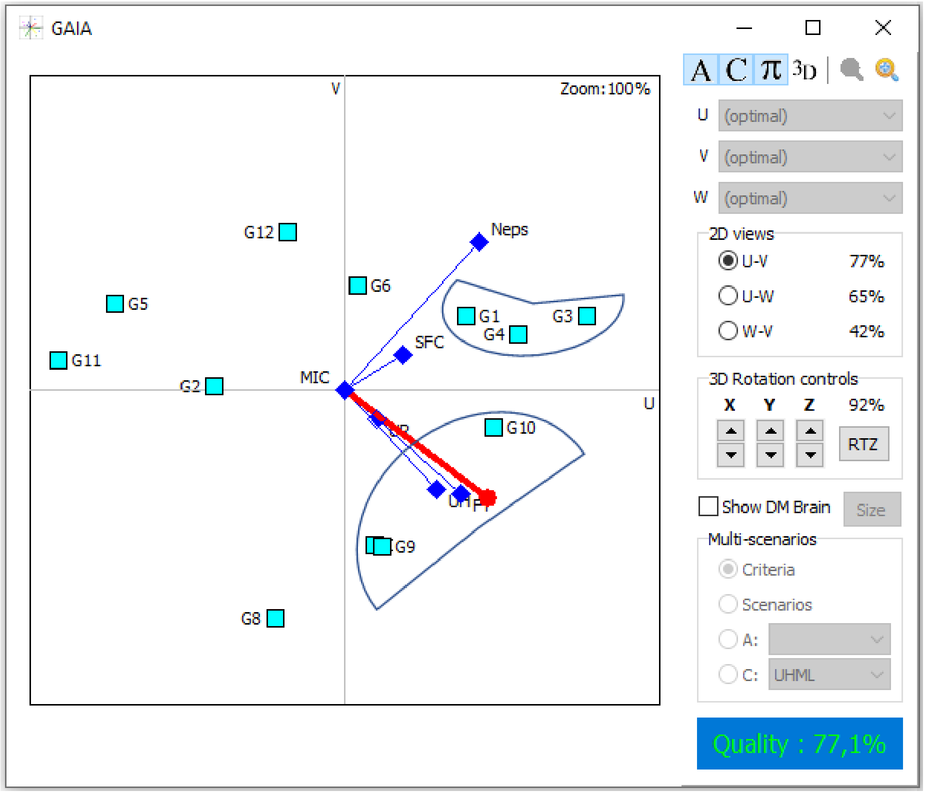


Fig. 5.7 GAIA plane for the studied genotypes under compact spinning scenario

As it was with ring and rotor spinning scenarios, the corresponding GAIA plane is developed using the PROMETHEE-GAIA software and presented in figure 5.7.

In this plane it is clearly shown that the three genotypes namely, Sille1(Stoneville) (G10), Bulk 202 (G9) and BPA (G7) form a distinct cluster on satisfying the fibre quality properties required for the compact spinning scenario. Similarly, from the GAIA plane for the compact spinning scenario, as portrayed in figure 5.7, the superiority of the three commercial cottons namely, Acala SJ-2 (G3), Arba (G4) and DP-90 (G1) is well noticed based on the direction of the decision axis towards them.

5.3.1.4 Air-jet spinning method scenario

The short staple air-jet yarns are generally made from 100% polyester, polyester-cotton or polyester-viscose blends. For the spinning of air-jet yarns, it is necessary to have a well combed cotton component in the blend and suitable number of drawing passages so as to utilize as much as possible of the fibre length in wrapping. The commercially successful air-jet spinning system is widely referred to as Murata jet spinning.
A high tenacity polyester staple-core/cotton yarn and fabrics produced with this new technology is strong, have low hairiness, clear appearance, high resistance to pilling and abrasion [79]. Besides improved durability and comfort

factor, a fabric made of such a yarn offers satisfactory levels of durable press and dimensional stability by simply heat setting for a minute or so [80, 81].

The mechanism of yarn formation in air-jet spinning system is completely different from those ring and rotor spinning, and the yarn structure is somewhat different. Unlike rotor system, this spinning system consists of a 3-over-3 high-speed roller drafting unit followed by two compressed-air twisting jets arranged in tandem. So that, the need of fineness and cleanness are important requirements for producing air-jet yarns. The fibre properties order of importance most suitable for air-jet spinning is presented in table (5.4).

As it was performed for ring, rotor and compact spinning scenarios, after the AHP pairwise comparison method of criteria weighting the ranking of the studied genotypes is performed using the PROMETHEE-GAIA software.

Accordingly, the computed negative outranking flow, positive outranking flow and the net outranking flow values for the air-jet spinning method scenario is provided in table 5.8.

Table 5.8 Ranking order of genotypes and net outranking flow under air-jet spinning scenario

Rank	Genotype	φ	φ+	φ–
1	Acala SJ-2 (G3)	0,2483	0,2483	0,0000
2	Sille1(Stoneville) (G10)	0,2210	0,2346	0,0136
3	BPA (G7)	0,1569	0,2316	0,0747
4	Bulk 202 (G9)	0,1452	0,2152	0,0700
5	Arba (G4)	0,1331	0,1705	0,0374
6	DP-90 (G1)	0,0772	0,1440	0,0668
7	Cucrova 1518 (G8)	0,0403	0,1530	0,1127
8	Alber 637 (G6)	-0,0295	0,1163	0,1457
9	R-36 (G12)	-0,1113	0,0981	0,2094
10	Cu-ok-ra (G2)	-0,2158	0,0625	0,2783
11	Estamble (G11)	-0,3236	0,0153	0,3389
12	LaoCara (G5)	-0,3417	0,0245	0,3663

As it is presented in table 5.8 in air jet spinning scenario, BPA (G7) comes to the 3rd position by replacing Bulk 202 (G9) which was the genotype keeping the 3rd position in all the previous three (ring, rotor and compact) spinning scenarios. This was expected, since the propriety order of fibre properties importance of air-jet spinning method is somewhat different from the mentioned three scenarios (see table 5.4). BPA (G7) is superior by upper half mean length, tenacity, fineness and short fibre content properties than its competitor, Bulk 202 (G9) and these properties are necessary requirements for satisfying the air-jet spinning method scenario. Here, it has to be emphasized that for the spinning of air-jet yarns, it is necessary to have a well combed component in the blend and a suitable number of drawing passages so as to utilize as much as possible of the fibre length in wrapping of the polyester core. For example, to produce a 50:50 polyester/cotton staple yarn the best suitable cotton type (from table

5.8) can be selected and separately processed so as to satisfy the component fibre requirement in the blend.

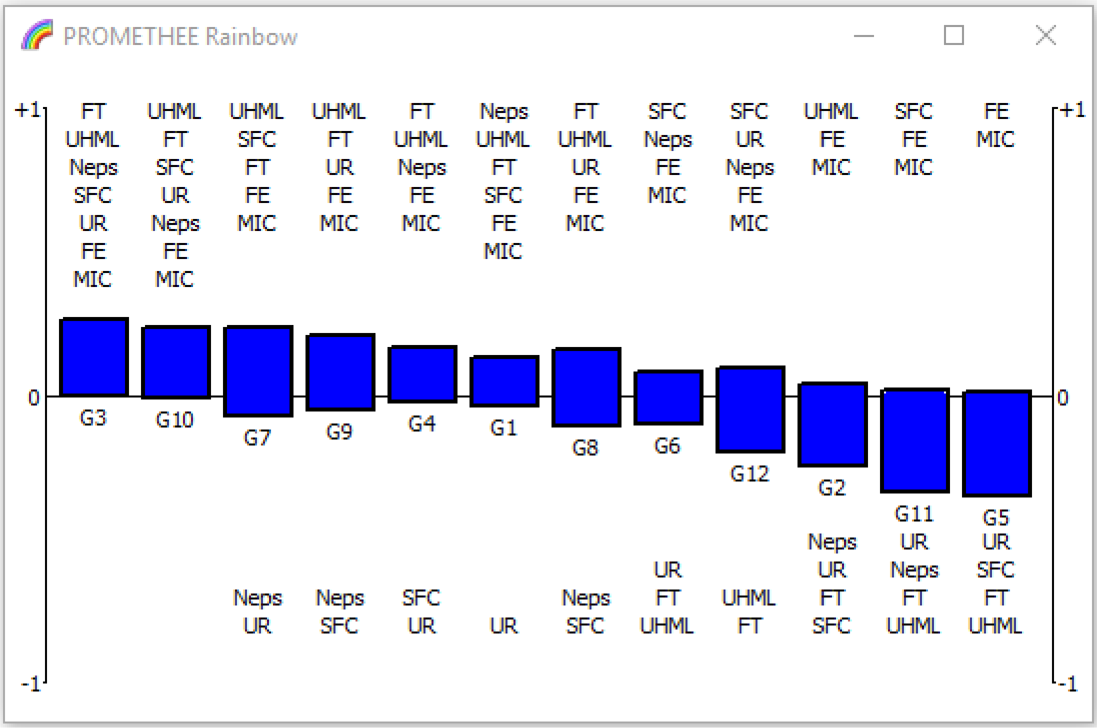


Fig. 5.8 PROMETHEE rainbow diagram for the studied genotypes under air-jet spinning scenario

A clear understanding about the fibre property profiles of studied genotypes under air-jet spinning scenario can be obtained from the PROMETHEE rainbow diagram, as given in figure 5.8. From this figure it can be observed that Acala SJ-2 (G3) and Sille 1 (Stoneville) (G10) outperforms the other competing genotype alternatives with respect to all the important priority order fibre quality properties required for the air-jet spinning scenario. This ranking order in the air-jet spinning method scenario can be explained by the fact that both Acala SJ-2 (G3) and Sille 1 (Stoneville) (G10) are the candidates which best satisfied a higher fineness, length, length uniformity, short fibre content and tenacity properties requirement of the system. Acala SJ-2 (G3) has MIC (4.19), UHML (29.73 mm), UR (43.24), SFC (8.2) and FT (25.88 cN/tex) and Sille 1 (Stoneville) (G8) has MIC (4.19), UHML (30.1 mm), UR (43.17), SFC (8.1) and FT (25.93 cN/tex).

As it was with all previous mentioned spinning scenarios, the corresponding GAIA plane is developed using the PROMETHEE-GAIA software and presented in figure 5.9.

In this plane it is clearly shown that the three genotypes namely, Sille1(Stoneville) (G10), Bulk 202 (G9) and BPA (G7) form a distinct cluster on satisfying the fibre quality properties required for the air-jet spinning scenario. Similarly, from the GAIA plane for the air-jet spinning scenario, as portrayed in figure 5.9, the superiority of the three commercial cottons namely, Acala SJ-2 (G3), Arba (G4) and DP-90 (G1) is well noticed based on the direction of the decision axis towards them.

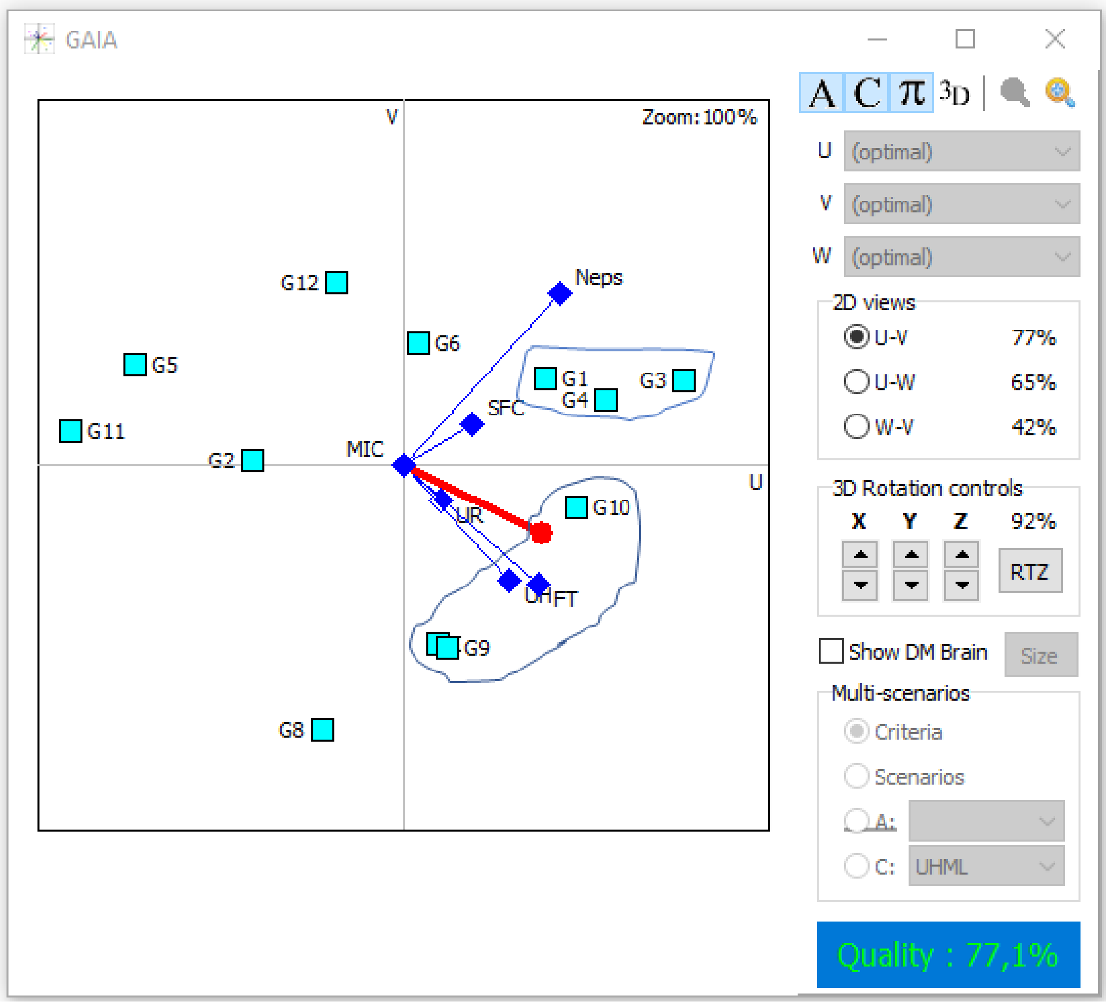


Fig. 5.9 GAIA plane for the studied genotypes under air-jet spinning scenario

5.3.2 Cotton mixing/blending optimization using PROMETHEE V

The implementation of PROMETHEE V approach extends the application scope of PROMETHEE II method [81]. The PROMETHEE II method usually provides a single compromise solution. On the other hand, PROMETHEE V method deals with those decision-making problems where several options need to be selected while satisfying a given set of constraints. It is particularly useful when the set of alternatives is segmented, and should be verified both between and within the cluster. In this research work, PROMETHEE method is adopted following the two steps as provided below:

Step 1: At first the net outranking flow is calculated for each genotype with considering priority order requirement of fibre quality parameters for the ring, rotor, compact and air-jet spinning scenarios using equation (5.5).

Step 2: The corresponding optimization model is then developed in the form of linear programing (LP) problem taking into consideration the net outranking flow values and predefined set of constraints on certain criteria. The objective function of this model is expressed as below [83, 84].

Table 5.9 Objective function and set of constraints in multi-criteria optimization model for ring spinning scenario

Objective and constraint functions
$Maximize\ Z = 0.0862X_1 - 0.1474X_2 + 0.2932X_3 + 0.1829X_4 - 0.4545X_5 - 0.1342X_6 + 0.2088X_7 + 0.1477X_8 + 0.2503X_9 + 0.2764X_{10} - 0.4817X_{11} - 0.2278X_{12}$
Subject to
$X_1 + X_2 + X_3 + X_4 + X_5 + X_6 + X_7 + X_8 + X_9 + X_{10} + X_{11} + X_{12} = 1$
$29.25X_1 + 29.13X_2 + 29.73X_3 + 29.55X_4 + 27.58X_5 + 28.05X_6 + 30.65X_7 + 29.61X_8 + 30.05X_9 + 30.1X_{10} + 26.58X_{11} + 27.91X_{12} \geq 29.02\ (UHML)$
$41.55X_1 + 41.43X_2 + 43.24X_3 + 41.95X_4 + 41.41X_5 + 42.23X_6 + 41.57X_7 + 43.11X_8 + 43.57X_9 + 43.17X_{10} + 41.91X_{11} + 43.14X_{12} \geq 42.36\ (UR)$
$24.7X_1 + 23.48X_2 + 25.88X_3 + 25.68X_4 + 22.25X_5 + 24.33X_6 + 25.95X_7 + 25.7X_8 + 25.91X_9 + 25.93X_{10} + 22.14X_{11} + 23X_{12} \geq 24.58\ (FT)$
$5.73X_1 + 5.63X_2 + 6.08X_3 + 5.95X_4 + 5.6X_5 + 5.88X_6 + 5.75X_7 + 6.03X_8 + 6.18X_9 + 6.13X_{10} + 5.93X_{11} + 6.13X_{12} \geq 5.92\ (FE)$
$4.1X_1 + 4.05X_2 + 4.19X_3 + 4.13X_4 + 3.63X_5 + 4.15X_6 + 4.11X_7 + 4.17X_8 + 4.2X_9 + 4.19X_{10} + 4.12X_{11} + 4.18X_{12} \leq 4.1\ (MIC)$
$8.6X_1 + 12.1X_2 + 8.2X_3 + 9.2X_4 + 10.1X_5 + 7.8X_6 + 7.2X_7 + 10.3X_8 + 9.7X_9 + 8.1X_{10} + 9X_{11} + 8.3X_{12} \leq 9.1\ (SFC)$
$213X_1 + 264X_2 + 188X_3 + 202X_4 + 275X_5 + 261X_6 + 277X_7 + 281X_8 + 274X_9 + 261X_{10} + 280X_{11} + 260X_{12} \leq 253\ (Neps)$

$$Maximize \sum_{i=1}^{m} \varphi(a_i)X_i \quad \text{...} (5.6)$$

where m is the number of X_i cotton fibre constraints considered for cotton mixing/blending.

Accordingly, the objective function and set of constraints for the ring spinning scenario is given in table 5.9. We have the same constraint functions for all the remaining scenarios, and their objective functions is presented below:

1. Objective function of rotor spinning scenario:

$$Maximize\ Z = 0.0896X_1 - 0.2713X_2 + 0.3129X_3 + 0.2052X_4 - 0.4692X_5 - 0.0659X_6 + 0.2032X_7 + 0.1668X_8 + 0.2623X_9 + 0.2902X_{10} - 0.4692X_{11} - 0.2547X_{12}$$

Subject to

$$X_1 + X_2 + X_3 + X_4 + X_5 + X_6 + X_7 + X_8 + X_9 + X_{10} + X_{11} + X_{12} = 1$$

2. Objective function of compact spinning scenario:

$$Maximize\ Z = 0.0766X_1 - 0.1641X_2 + 0.2917X_3 + 0.1762X_4 - 0.4468X_5 - 0.1227X_6 + 0.1930X_7 + 0.1504X_8 + 0.2535X_9 + 0.2748X_{10} - 0.4655X_{11} - 0.2169X_{12}$$

Subject to

$$X_1 + X_2 + X_3 + X_4 + X_5 + X_6 + X_7 + X_8 + X_9 + X_{10} + X_{11} + X_{12} = 1$$

3. Objective function of air-jet spinning scenario:

$$Maximize\ Z = 0.0772X_1 + 0.2158X_2 + 0.2483X_3 + 0.1331X_4 - 0.3417X_5 - 0.0295X_6 + 0.1569X_7 + 0.0403X_8 + 0.1452X_9 + 0.2210X_{10} - 0.3236X_{11} - 0.1113X_{12}$$

Subject to

$$X_1 + X_2 + X_3 + X_4 + X_5 + X_6 + X_7 + X_8 + X_9 + X_{10} + X_{11} + X_{12} = 1$$

5.4 Mixing/blending optimization using LP method

Though there were limitations of using only few HVI fibre properties [85], a researcher successfully used linear programming method to optimize cotton mixing cost. Mathematical linear programming is a familiar technique used extensively in other industrial applications for optimizing cost and profits. Earlier, Ram et al. [86] and Bezdudnyi [87] suggested using linear programming for cotton cost optimization, but the practicality of this approach was hindered by a number of obstacles, including slow methods of fibre testing and the lack of powerful computing systems. In addition, linear programming has undergone several developments over the last few years to improve optimization procedures. The familiar simplex method has been mathematically stabilized Bland [88] and expanded to permit sensitivity and parametric analyses Murtagh [89], Ozan [90].

In this study the linear programing (LP) problem (table 5.9) is subsequently solved using simplex method and the derived optimal solution is given in tables 4.10-4.13. It is important to mention here that the constraint functions for all the scenarios is the same and presented in table 5.9. Whereas every individual scenario has its own coefficients of objective function.

Based on the result presented in table 5.10, it now becomes possible to establish the optimal proportions of the studied genotypes for subsequent mixing/blending to produce desired ring spun yarns.

Table 5.10 Optimum solution under ring spinning scenario for the studied genotypes

Genotype	Code	Optimized value
DP-90	G1	0
Cu-ok-ra	G2	0
Acala SJ-2	G3	0.3812
Arba	G4	0
LaoCara	G5	0.4071
Alber 637	G6	0
BPA	G7	0.2117
Cucrova 1518	G8	0
Bulk 202	G9	0
Sille1(Stone Vile)	G10	0
Estamble	G11	0
R-36	G12	0

From simplex optimization report (table 5.10), it can be observed that Acala SJ-2 (38.12%) and LaoCara (40.71%) are the two main constituents in the blend desired for the production of ring spun yarns, with a possible addition of BPA (21.17%). The most common objectives used to determine the number cottons in the mix are:

- Better economy: - The decrease of an expensive fibre by mixing with a cheaper one.

- Improved Durability: - The incorporation of a more durable fibre component will extend the useful life of a less durable one.
- Physical properties: - A compromise to take advantage of desirable performance characteristics contributed by both fibre components.
- Color: The ability to develop novel designs incorporating multi-color effects.

Thus, the inclusion of BPA in the final mix can be validated through its excellent fibre length (UHML) and bundle tenacity (FT) properties which would be responsible to satisfy the fibre quality requirements designed for the production of ring spun yarns. From table 5.4 it can be referred that these fibre constraints are in the first (UHML) and second (FT) priority order of importance for the production of ring spun yarns. Therefore, the limitations in the fibre length and tenacity quality properties of the main component cottons (Acala SJ-2 and LaoCara) can be compromised by the addition of BPA in the mix.

As it was with the ring spinning scenario the linear programing (LP) problem for rotor spinning scenario is subsequently solved using simplex method and the derived optimal solution is given in table 5.11. Based on this result, it now becomes possible to establish the optimal proportions of the studied genotypes for subsequent mixing/blending to produce desired rotor spun yarns.

Table 5.11 Optimum solution under rotor spinning scenario for the studied genotypes

Genotype	Code	Optimized value
DP-90	G1	0.5435
Cu-ok-ra	G2	0
Acala SJ-2	G3	0
Arba	G4	0
LaoCara	G5	0.2565
Alber 637	G6	0
BPA	G7	0
Cucrova 1518	G8	0
Bulk 202	G9	0
Sille1(Stone Vile)	G10	0.2000
Estamble	G11	0
R-36	G12	0

From simplex optimization report (table 5.11), it can be observed that the proportion of cottons in the mixing designed for rotor spun yarns is not the same with those designed for ring spun yarns. This is expected because of that in the case of rotor spinning system the order of importance of fibre quality parameters is different from ring spinning system (table 5.4). From table 5.11, we can refer that the DP-90 genotype which preferably can satisfy the priority order of rotor spun yarn fibre quality requirements (tenacity, fineness and length) comes to the solution. In this new optimum solution, we have the main component cottons of DP-90 (54.35 %) and LaoCara (25.65 %) with 20 % addition of Sille 1 (Stoneville).

Thus, the inclusion of Sille 1 (Stoneville) in the final mix can be validated through its excellent fibre tenacity, elongation, length and length uniformity properties which would be responsible to satisfy the fibre quality requirements designed for the production of rotor spun yarns. It very interesting to mention that LaoCara remains in both simplex solutions. This is explained because of the fact LaoCara can satisfy both the ring and rotor spinning systems fibre fineness requirements which is the third (ring) and the second (rotor) order of importance for the systems. LaoCara has excellent fineness (MIC = 4.13) property than all the genotypes in the study.

One important point to mention here also is that even though the commercial varieties DP-90, Acala SJ-2 and Arba appeared in a distinct cluster in the GAIA plane of PROMETHEE GAIA software the linear programing software of simplex make a strict selection of cottons to be used for the optimization of ring and rotor yarns.

The linear programing (LP) problem for compact spinning scenario is subsequently solved using simplex method and the derived optimal solution is given in table 5.12. Based on this result, it now becomes possible to establish the optimal proportions of the studied genotypes for subsequent mixing/blending to produce desired compact spun yarns.
From simplex optimization report (table 5.12), it can be observed that the proportion of cottons in the mixing designed for compact spun yarns is not the same with those designed for rotor spun yarns. It is because of that in the case of compact spinning system the order of importance of fibre quality parameters is different from rotor spinning systems (table 5.4). From table 5.12, we can observe that the Bulk 202 (G9) genotype comes to the solution since it preferably can satisfy the priority order of compact spun yarn fibre quality requirements (length, length uniformity, tenacity and fineness) than its competitor genotypes. In this new optimum solution, we have the main component cottons of Bulk 202 (62.28 %) and Acala SJ-2 (21.93 %) with 15.79 % addition of Arba.

Table 5.12 Optimum solution under compact spinning scenario for the studied genotypes

Genotype	Code	Optimized value
DP-90	G1	0
Cu-ok-ra	G2	0
Acala SJ-2	G3	0.2193
Arba	G4	0.1579
LaoCara	G5	0
Alber 637	G6	0
BPA	G7	0
Cucrova 1518	G8	0
Bulk 202	G9	0.6228
Sille1(Stone Vile)	G10	0

Estamble	G11	0
R-36	G12	0

Thus, the inclusion of Bulk 202 in the final mix can be validated through its excellent fibre length (UHML), length uniformity (UR) and bundle tenacity (FT) properties which would be responsible to satisfy the fibre quality requirements designed for the production of compact spun yarns. From table 5.4 it can be referred that these fibre constraints are in the first (UHML, UR) and second (FT) priority order of importance for the production of compact spun yarns. Bulk 202 has higher UR property than all its competitor genotypes used in the study.

The linear programing (LP) problem for air-jet spinning scenario is subsequently solved using simplex method and the derived optimal solution is given in table 5.13. Based on this result, it now becomes possible to select the appropriate cotton type for subsequent polyester/cotton blending to produce desired air-jet spun yarns.

Table 5.13 Optimum solution under air-jet spinning scenario for the studied genotypes

Genotype	Code	Optimized value
DP-90	G1	0
Cu-ok-ra	G2	0
Acala SJ-2	G3	0.6525
Arba	G4	0
LaoCara	G5	0.3475
Alber 637	G6	0
BPA	G7	0
Cucrova 1518	G8	0
Bulk 202	G9	0
Sille1(Stone Vile)	G10	0
Estamble	G11	0
R-36	G12	0

The simplex linear optimization report (table 5.13) presents a new mixing model used for the air-jet spinning scenario. In this optimization report only two cottons are coming to the solution namely, Acala SJ-2 (65.25%) and LaoCara (34.75%). As it was mentioned before, LaoCara has an excellent fineness property (MIC = 4.13) than all the genotypes in the study. The 'fineness' fibre property is the 1st priority in the order of importance required for producing air-jet spun yarns (see table 5.4). Therefore, combed Acala SJ-2 or LaoCara can be selected for the production of air-jet polyester/cotton blend yarns (for example, 50/50 or 65/35). So that, the function cotton as a wrapper fibre in the air-jet spun yarns can improve the comfort and aesthetic properties of fabrics (e.g. active wear, underwear, men's shirting and sheeting) which are considered the limitations of polyester fibre.

6 Statistical analysis and instrumental characterization

Keywords:

Commercial cotton, tenacity, elongation, modified fibre quality index

6.1 Experimental design

In this experiment, a subset of 32 bales from each variety of similar maturity group was selected to instrumentally characterize the commercial cotton varieties Acala SJ-2, Arba and Deltapine 90 (DP-90). For each bale a complete fibre quality profile was done. A cotton sample for each bale were tested with 100 number of measurements on High Volume Instrument (USTER HVI 1000). This procedure was used on 32 Bales (i.e. 1 sample x 100 tests x 32 Bales replications).

Definitions regarding sampling, sample handling and testing of cotton in the laboratory as well as the use of Standardized Instruments for Testing Cotton, High Volume Instrument (HVI) was performed according to the internationally harmonized rules [61].

They were also tested on the Advanced Fibre Information System (USTER AFIS PRO 2), with 15 replications of 3,000 fibres.

Single fibres were tested with the FAVIMAT+ (gauge length = 3.0 mm, pre-tension = 1 cN/tex, and testing speed = 100 mm/min).

The same subset of 32 bales was used to investigate the relationship between FAVIMAT+ individual fibre tenacity and HVI bundle tenacity. A total of 1,500 fibres (300 fibres x 5 replications) from each of the 32 bales were tested on a FAVIMAT+ tensile tester at a 3mm gauge length. FAVIMAT+ provides the force-to-break, elongation, and work-to-break of individual cotton fibres.

The HVI fibre properties along with statistical parameters of commercial cotton varieties, namely: Acala (SJ-2), Arba and Deltapine (DP-90), are shown in Table 6.1.

Table 6.1. HVI values of commercial cotton bundle fibre properties and their statistical parameters

		Statistical parameters						
Cotton Varieties	Fibre properties	Mean	S. D	Min	Max	S.E.	R	C.V (%)
Acala (SJ-2)	MIC	4.40	0.39	3.61	4.81	0.10	1.20	8.86
	UHML	28.30	0.60	27.46	29.36	0.16	1.90	2.12
	UI	82.25	2.15	77.58	85.37	0.55	7.79	2.61
	SFI	10.25	0.48	9.79	11.14	0.12	1.35	4.68
	FS	28.28	0.72	25.47	30.12	0.06	4.65	2.55
	FE	4.72	0.29	4.30	5.09	0.07	0.79	6.14
	Rd	79.85	1.36	77.42	81.67	0.35	4.25	1.70
	+b	8.77	0.55	7.57	9.44	0.14	1.87	6.27
Arba	MIC	4.14	0.06	3.99	4.23	0.22	0.24	1.45
	UHML	27.48	0.71	26.76	28.55	0.18	1.79	2.58

	UI	81.13	0.55	79.99	82.18	0.14	2.19	0.68
	SFI	12.63	1.93	10.31	15.40	0.50	5.09	15.28
	FS	27.89	0.18	27.31	28.57	0.01	1.26	0.65
	FE	4.28	0.44	3.67	5.12	0.11	1.45	10.28
	Rd	79.85	1.52	77.42	81.67	0.48	4.25	1.90
	+b	11.44	0.26	10.72	11.79	0.07	1.07	2.27
Deltapine (DP-90)	MIC	4.30	0.10	4.18	4.48	0.03	0.30	2.33
	UHML	27.26	0.60	26.42	28.32	0.16	1.90	2.20
	UI	80.66	0.82	79.20	82.10	0.21	2.90	1.01
	SFI	9.25	0.92	7.93	11.05	0.24	3.12	9.95
	FS	26.94	0.74	22.81	27.61	0.06	4.80	2.75
	FE	5.14	0.32	4.79	5.92	0.08	1.13	6.23
	Rd	71.33	4.41	61.33	74.51	1.14	13.18	6.18
	+b	8.14	0.14	7.76	8.28	0.04	0.52	1.72

Table 6.2 AFIS fibre properties and statistical parameters of Acala SJ-2 commercial variety

		Statistical parameters						
Cotton variety	Fibre properties	Mean	S. D	Min	Max	S. E	R	CV (%)
Acala (SJ-2)	Fineness, mtex	164	9.16	149	184	2.36	35	5.58
	Maturity ratio	0.85	0.02	0.81	0.91	0.01	0.10	2.80
	Length by weight, mm	23.7	0.83	21.9	25.2	0.22	3.3	3.51
	Length by weight CV, %	33.6	1.08	32.4	36.0	0.28	3.6	3.21
	Short fibre content by weight, %	8.2	1.17	6.4	10.9	0.30	4.5	14.26
	Upper quartile length by weight, mm	28.8	1.02	26.7	30.6	0.26	3.9	3.56
	Length by number, mm	19.2	0.75	17.8	20.5	0.19	2.7	3.89
	Length by number CV, %	48.5	2.19	44.7	52.7	0.57	8.0	4.52
	Short fibre content by number, %	24.5	2.66	19.7	30.3	0.69	10.6	10.84
	Immature fibre content, %	8.7	0.90	7.2	10.8	0.23	3.6	10.42
	Total neps, count/g	188	36.71	132	248	9.48	116	19.48
	Total neps mean size, mm	692	49.22	623	784	12.71	161	7.12
	Fibre neps, count/g	173	34.90	118	234	9.01	116	20.17
	Fibre neps mean size, mm	652	26.90	608	723	6.95	115	4.13
	Seed coat neps, count/g	15	12.78	4	44	3.30	40	83.32
	Seed coat neps mean size, mm	1179	315.33	742	1725	81.42	983	26.75
	Visible foreign matter, %	1.35	0.52	0.13	2.12	0.15	1.99	38.66

M (Mean), S.E (standard error), C.V % (coefficient of variation), S.D (standard deviation), R (range)

Table 6.3 AFIS fibre properties and statistical parameters of Arba commercial variety

		Statistical parameters						
Cotton variety	Fibre properties	Mean	S. D	Min	Max	S. E	R	CV (%)
Arba	Fineness, mtex	156	11.04	136	170	2.85	34	7.09
	Maturity ratio	0.84	0.04	0.77	0.91	0.01	0.14	5.16
	Length by weight, mm	23.1	1.20	20.3	24.9	0.31	4.6	5.18
	Length by weight CV, %	34.7	3.44	29.2	41.0	0.89	11.8	9.91

Short fibre content by weight, %	9.2	3.53	4.4	17.3	0.91	12.9	38.37
Upper quartile length by weight, mm	28.1	0.91	25.5	29.1	0.24	3.6	3.24
Length by number, mm	18.7	1.82	14.8	21.6	0.47	6.8	9.75
Length by number CV, %	49.0	6.66	39.2	66.4	1.72	27.2	13.60
Short fibre content by number, %	25.7	7.97	14.4	45.6	2.06	31.2	30.98
Immature fibre content, %	8.7	2.36	5.6	14.1	0.61	8.5	27.11
Total neps, count/g	213	46.95	122	280	12.12	158	22.08
Total neps mean size, mm	729	59.85	657	867	15.45	210	8.21
Fibre neps, count/g	186	52.93	92	270	13.67	178	28.50
Fibre neps mean size, mm	654	25.28	616	693	6.53	77	3.87
Seed coat neps, count/g	27	18.56	8	76	4.79	68	68.91
Seed coat neps mean size, mm	1175	108.24	964	1305	27.95	341	9.21
Visible foreign matter, %	2.71	1.52	0.50	5.66	0.39	5.16	56.28

M (Mean), S.E (standard error), C.V % (coefficient of variation), S.D (standard deviation), R (range)

Table 6.4. AFIS fibre properties and statistical parameters of DP-90 commercial variety

		Statistical parameters						
		Mean	S. D	Min	Max	S. E	R	CV (%)
Deltapine (DP-90)	Fineness, mtex	160	7.43	149	174	1.92	25	4.65
	Maturity ratio	0.85	0.03	0.82	0.91	0.01	0.09	3.06
	Length by weight, mm	23.1	0.61	21.8	24.4	0.16	2.6	2.63
	Length by weight CV, %	34.1	1.48	30.9	36.4	0.38	5.5	4.33
	Short fibre content by weight, %	8.6	1.40	5.6	10.4	0.36	4.8	16.15
	Upper quartile length by weight, mm	28.1	0.60	26.9	29.0	0.16	2.1	2.14
	Length by number, mm	18.8	0.76	17.4	20.5	0.20	3.1	4.04
	Length by number CV, %	47.9	2.39	42.9	50.9	0.62	8.0	4.98
	Short fibre content by number, %	24.6	3.04	18.0	28.4	0.78	10.4	12.35
	Immature fibre content, %	8.1	0.94	6.4	9.7	0.24	3.3	11.59
	Total neps, count/g	202	26.62	156	238	6.87	82	13.20
	Total neps mean size, mm	711	20.61	670	738	5.32	68	2.90
	Fibre neps, count/g	186	26.59	138	218	6.87	80	14.33
	Fibre neps mean size, mm	669	21.08	635	708	5.44	73	3.15
	Seed coat neps, count/g	16	4.47	6	22	1.15	16	27.95
	Seed coat neps mean size, mm	1189	155.08	992	1500	40.04	508	13.04
	Visible foreign matter, %	1.62	0.79	0.29	3.03	0.20	2.74	48.90

M (Mean), S.E (standard error), C.V % (coefficient of variation), S.D (standard deviation), R (range)

Table 6.5 ANOVA for AFIS length (L_n) distribution evaluation (Between commercial cotton varieties)

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.982	2	.991	.668	.518
Within Groups	62.303	42	1.483		
Total	64.284	44			

Table 6.6. Values of FAVIMAT+ single fibre properties and their statistical parameters

		Statistical parameters						
Cotton Varieties	Fibre properties	Mean	S. D	Min	Max	S.E.	R	CV (%)
Acala (SJ-2)	Linear Density, dtex	1.60	0.10	1.25	1.75	0.01	0.50	6.54

	Tenacity, cN/tex	23.28	0.17	22.35	23.82	0.01	1.47	0.71
	Elongation, %	7.01	0.98	4.80	9.42	0.08	4.62	14.00
Arba	Linear Density, dtex	1.62	0.12	1.25	1.78	0.01	0.53	7.34
	Tenacity, cN/Tex	22.67	0.20	22.17	24.23	0.02	2.06	0.90
	Elongation, %	6.63	0.88	4.11	8.24	0.07	4.13	13.28
Deltapine (DP-90)	Linear Density, dtex	1.64	0.11	1.27	1.77	0.01	0.50	6.86
	Tenacity, cN/Tex	21.41	0.19	20.69	21.71	0.02	1.02	0.87
	Elongation, %	6.41	0.78	0.93	7.94	0.06	7.01	12.24

6.2 Results and discussion

6.2.1 Instrumental characterization of commercial cotton

Among twelve different Ethiopian cotton varieties, widely used three commercial cotton varieties namely, Acala SJ-2, Arba and Deltapine (DP-90) were selected for instrumental characterization of Ethiopian cotton. The test results obtained from HVI, AFIS and FAVIMAT+ instruments are presented in Tables 6.1, 6.2, 6.3, 6.4 and 6.6.

1. Fibre Length and Length Distribution:

   AFIS test results on fibre length distributions are presented in tables 6.2-6.4 for varieties used in the study. From the ANOVA table 6.5 we can observe that no significant difference in the fibre length distribution is observed (i.e., p value > 0.05) between the varieties. Acala SJ-2 (Ln = 19.2, SFCn = 24.5); Arba (Ln = 18.7, SFCn = 25.7); DP 90 (Ln = 18.8, SFCn = 24.6). The result of ANOVA analysis with no significant difference in the fibre length distribution permits the spinners to classify the bales into the same categories during HVI fibre selection and laydowns arrangements.

2. Fibre Tenacity and Elongation

   This work, in addition to HVI bundle tenacity, uses the FAVIMAT+ single fibre tenacity/elongation results (FAVIMAT+ of TEXTECHNO, Germany). The relationships between average FAVIMAT+ Single fibre tensile properties and HVI bundle properties are all linear with a positive slope and a rather good coefficient of determination (R^2 = 0.839), (see fig. 6.2).

   The elongation characteristics associated with fibre tenacity are of critical important at textile processes, namely: Opening, Carding, Spinning and Weaving. Stronger fibres tend to have higher elongation which results in better work-to-break. This could lead to lower fibre breakage during textile and ginning processes. FAVIMAT+ elongation and work-to-break relationships are also all positive with a positive slope and good coefficient of determination (R^2 = 0.793), (see fig. 6.4).

   HVI tenacity values: Acala SJ-2 (28.28 cN/tex), Arba (27.89 cN/tex), DP-

90 (26.94 cN/tex) is quite narrow for the three commercial varieties. FAVIMA+ single fibre tenacity and elongation is also presented in table 6.6 with the value: Acala SJ-2 (Tenacity = 23.28 cN/tex, Elongation = 7.01 %), Arba (Tenacity = 22.67 cN/tex, Elongation = 6.63 %), DP-90 (Tenacity = 21.41 cN/tex, Elongation = 6.41 %).

HVI Tenacity in cN/tex of the three commercial varieties fall in the range 26.94-28.28. This HVI tenacity data of the representative samples for the studied three commercial varieties will be useful to the spinner while blending cotton with other varieties of cotton or manmade fibres and to the weaver and finisher for identifying suitable varieties which can stand sizing and chemical finishing treatments better.

Fibre elongation at break or the breaking elongation is an important cotton fibre property that directly affects yarn elongation and work-to-break values. It is reported that even though, Fibre bundle elongation can be measured by HVI systems, but, due to a lack of calibration standards, the results are not comparable between systems [39].

In the studied samples the FAVIMAT+ elongation in percent for the three commercial varieties fall in the range 6.41-7.01. According to literatures a level above 7% being desirable. Based on this information to prepare a cotton mix for relatively better yarn and greige fabric elongation the spinner has to increase the proportion of by weight of the Acala SJ-2 variety.

3. Fibre Fineness and Maturity

Typically, fibre fineness is reported by micronaire value. However, variation in micronaire value for any one variety usually indicates change in maturity rather than change in fineness because, micronaire value calculated by normal airflow instruments is influenced by fibre maturity. Therefore, the Advanced Fibre Information System (USTER AFIS PRO 2) were used to measure fineness in addition to HVI micronaire.

Micronaire values: Acala SJ-2 (4.40), Arba (4.14), DP-90 (4.30) is quite narrow for the three commercial varieties. This range is considered good for spinning. Differences in AFIS fineness between the three commercial varieties: Acala SJ-2 (164 mtex), Arba (156 mtex), DP-90 (160 mtex) is also very small.

Average Maturity Ratio range of the three commercial cotton varieties grown at different places/farms is Acala SJ-2 (0.85), Arba (0.84), DP-90 (0.85), which is considered satisfactory. Cotton fibre maturity greatly affects nep formation, dye uptake and dyed appearance. Variations in maturity within a yarn batch or fabric can lead to streakiness and barré due to differences in dyed appearance. The spinner has to understand, however, not only the average maturity which is important but also the distribution of maturity. A small percentage of immature or “dead” fibres may not significantly affect the average maturity but could affect the yarn and fabric appearance, notably in terms of nippiness and white flecks which can comprise only about 0.5% (by weight) of fibres.

4. Neps

   Number of neps per gm of fibres and also nep size are influencing factors in quality of yarn, particularly of finer count. AFIS is considered one of the most reliable process control instruments used to measure neps at different stages in processing. The AFIS measurements of neps in cotton samples are provided in tables 6.2-6.4. Since nep count is commonly used in spinning industry, we have: Acala SJ-2 (Neps = 188 Count/g); Arba (Neps = 213 Count/g); DP-90 (Neps = 202 Count/g). It is expected that neps are created at first place during ginning and nep count is influenced by fibre maturity which mostly varies from place to place and time to time within the same variety. Thus, nep count is likely to be influenced by ginning practices and sources of fibres. Therefore, further study is required for comparative analysis of nep counts between places/ginneries and also before and after machine ginning.

6.2.2 A modified cotton fibre quality index

It is documented that various studies associated with HVI systems may be divided into three categories: (a) evaluation of the precision and repeatability of HVI measurements, (b) engineered fibre selection and cotton bale management using HVI parameters, and (c) development of prediction equations of yarn quality and processing performance [91].

Fibre Quality Index (FQI) is one of the ad hoe curvilinear equations, in which the cotton fibre properties are combined into one integrated index. It was introduced on the basis of the following considerations: (i) the fibre properties used in the index should be selected from the theoretical considerations or from prior knowledge of their impact on yarn strength, or from a combination of both; (ii) the minimum number of properties should be used; (iii) the properties should be the usually measured ones, so as to ensure the applicability of this index in practice; (iv) the error of measurement of the fibre properties should be low; and (v) the form of the function and any parameters used in constructing the index should be invariant over different spinning conditions.

The currently used fibre quality index is based mainly on HVI measurements:

$$FQI_{HVI} = \frac{FS \times UHML \times UI}{FF} \quad \text{(6.1)}$$

FS is the fibre bundle tensile strength (cN/tex), UHML is the upper half mean length (mm), UI is uniformity index (%) and FF is fibre fineness (micronaire) [7].

The FQI_{HVI} equation doesn't consider the elongation property which is the main contributor to the work-to-break of cotton fibres.

It is documented that HVI bundle clamping units use a gauge length of 1/8 inch (3.175 mm) for tensile testing. The system of pre-tensioning as well as height of pre-tensioning are not known for these units. The speed of breaking according to literature is: 100…140 mm/min for the USTER HVI 1000.

In this experiment, a comparison was made between US upland cotton measured by FAVIMAT and the three studied commercial upland varieties measured by FAVIMAT+.

Single fibres were tested with similar testing conditions for both FAVIMAT and FAVIMAT+; gauge length = 3.0 mm, pre-tension = 1 cN/tex, and testing speed = 100 mm/min).

Accordingly, in arriving the choice of an appropriate modified fibre quality index equation for the studied three commercial cottons, the following correlation between FAVIMAT+ single fibre and HVI bundle tenacities is produced.

$$SFS_M = 0.926BT_H - 3.420$$

Where: SFS_M is the Favimat+ single fibre tenacity in cN/tex, BT_H is the HVI bundle tenacity in cN/tex (see fig. 6.2). Having similar calibration system and clamping system in perfect condition with equal clamping force for both the FAVIMAT+ and FAVIGRAPH laboratory testing instruments, the same result was found for the evaluated samples which have similar linear density values [103].

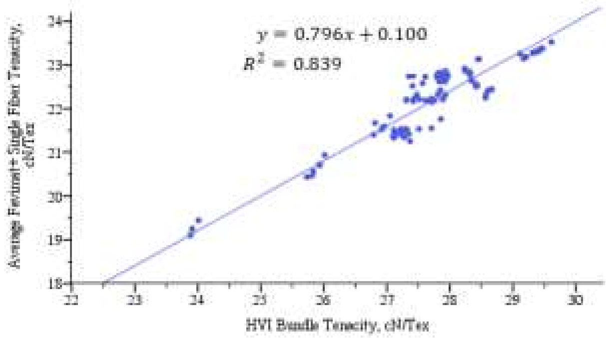


Fig. 6.2 HVI bundle tenacity Vs. average Favimat+ single fibre tenacity

The FAVIMAT+ single fibre test results were compared with the US upland cotton measured by FAVIMAT.

For the US Upland cotton, using Favimat researchers [38] evaluated the relationship between HVI bundle tenacity and Favimat average single fibre tenacity (see fig. 6.3).

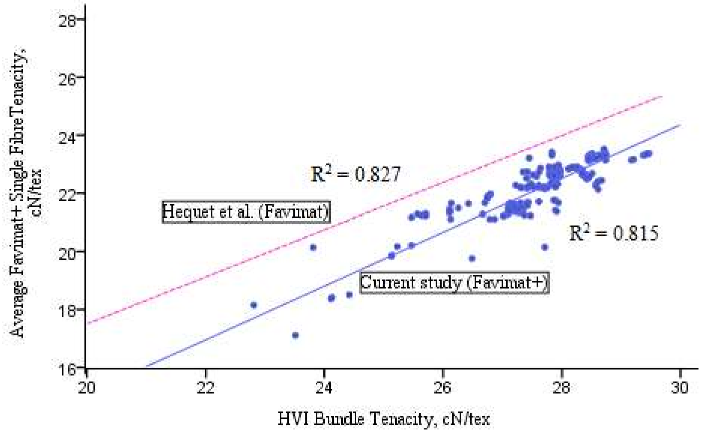


Fig. 6.3 HVI bundle tenacity Vs. average Favimat & Favimat+ single fibre tenacity

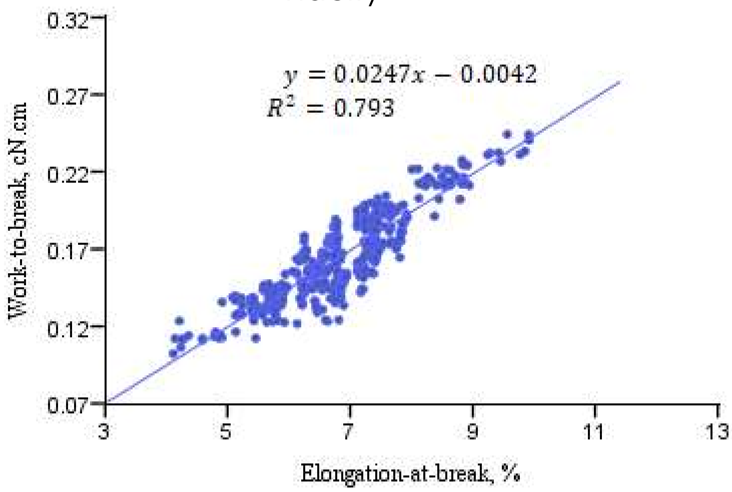


Fig. 6.4 Favimat+ elongation-at-break Vs. work-to-break

Using Favimat researchers [38] also evaluated the relationship between elongation-at-break and work-to break on the US upland cotton and the result of their studies is compared with Acala SJ-2 (upland cotton) measured with Favimat+ (see fig. 6.5).

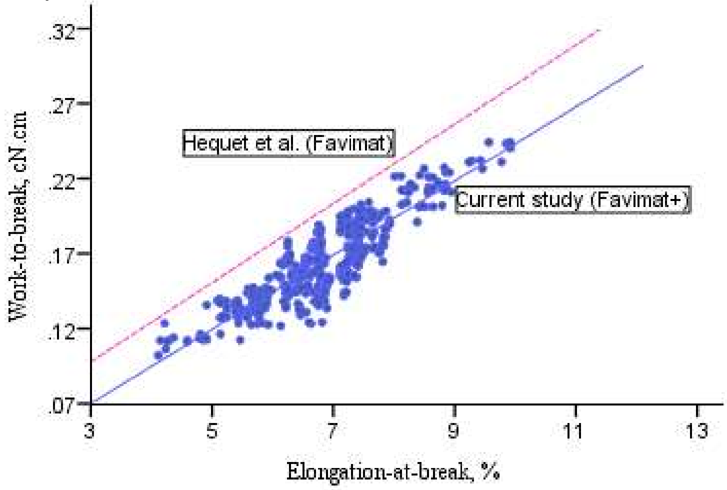


Fig. 6.5 Favimat elongation-at-break Vs. work-to-break

In order to compare different cottons, work of rupture should be evaluated so that it is possible to take account of the various masses of different varieties. Hence, specific work of rupture, which is the amount of energy needed to break a sample of unit mass, should be used.

Thus, the MFQI which considers both the single fibre tenacity and elongation is more consistent for the comparison between different cotton varieties. Accordingly, considering both the HVI and FAVIMAT+ main fibre properties and assuming the linear geometric properties, a modified fibre quality index formula is presented as follow:

$$MFQI = \frac{[UHML_H \times UI_H \times (1-SFI_H) \times SFS_M \times (1+EL_M)]}{MIC_H} \quad (6.2)$$

$UHML_H$ is the HVI upper half mean length (mm), UI_H is the HVI uniformity index (%), SFI_H is the HVI short fibre index (%), MIC_H is the HVI fibre fineness (micronaire), SFS_M is Favimat+ single fibre tenacity (cN/tex), EL_M Favimat+ single fibre elongation (%).

Table 6.7. Quality Index values for the three commercial cotton varieties

Cotton Varieties	Cotton Fibre Quality Indexes		
	FQI	SCI	MFQI
Acala (SJ-2)	149.6	126.0	130.9
Arba	150.2	121.4	113.7
DP-90	138.6	110.0	105.7

Table 6.8. Quality Index values for the US Upland, Pima & Egypt Giza 87

Cotton Varieties	Cotton Fibre Quality Indexes		
	FQI	SCI	MFQI
US PIMA	479.9	230.4	549.5
US UPLAND	170.2	134.3	145.4
Giza 87	472.2	228.0	516.9

6.3 Conclusions

In conclusion, the result of ANOVA analysis with no significant difference in distribution permits the spinners to classify the bales into the same categories during HVI fibre selection and laydowns arrangements. Classification of cotton bales with similar length distribution will minimize the undesirable laydown variability in critical properties such as short fibres contents which are the main sources of yarn unevenness.

In this study the HVI tenacity for the studied three commercial varieties fall within the range of 26.94-28.28. According to USDA system of cotton classification this range is categorized in the descriptive designation “average” strength group. In the studied samples the FAVIMAT+ elongation in percent for the three commercial varieties fall within the range 6.41-7.01. According to literatures a level above 7% being desirable. During preparation of a cotton mix desired for relatively better yarn and greige fabric elongation the spinner may increase the proportion by weight of the Acala SJ-2 variety.

Micronaire values: Acala SJ-2 (4.40), Arba (4.14), DP-90 (4.30) is quite narrow for the three commercial varieties. This range is considered good for spinning. Differences in AFIS fineness between the three commercial varieties: Acala SJ-2

(164 mtex), Arba (156 mtex), DP-90 (160 mtex) is also very small. And their average Maturity Ratio range grown at different places/farms is Acala SJ-2 (0.85), Arba (0.84), DP-90 (0.85). The similarity in maturity ratio can be taken as an indication for the accuracy of micronaire readings.

Although neps are related to maturity, including maturity distribution and "dead" fibres, harvesting, ginning and mechanical treatment (processing) conditions in the spinning mill. The measured nep level of lint (ginned) cotton for the studied varieties, Acala SJ-2 (Neps = 188 Count/g); Arba (Neps = 213 Count/g); DP-90 (Neps = 202 Count/g) can be taken as an information for spinner to optimize the speed of beating rollers in the blow room. Optimizing a carding machine is particularly challenging since the card's ability to remove objectionable faults (neps, trash and seed coat fragments) and the degree of fibre damage are diametrically opposed.

Ranges of the three commercial fibre properties fall within a narrow range. Ethiopian textile factories are equipped with both ring as well as rotor spinning facilities and some of the factories have combing machines. However, spinners need much wider range of fibres to utilize fully and economically their plants. In order to compete in the international market for export as well as to cater to the needs of domestic markets and also to run the plants at the optimum capacities, wider range of products is essential. Cotton breeders and cultivators in Ethiopia should strive to cultivate long and strong fibres with a better elongation property.
In this research work a modified fibre quality index (MFQI) is formulated for the commercial Ethiopian cotton varieties and the results are given in Table 6.7. The values obtained are compared with the values of the usually used fibre quality index and spinning consistency index formulas which do not consider the fibre elongation property. For example, the performance of Acala SJ-2 is known to be better than that of Arba during the back-trace history spinning processes. This is clearly shown by the value of MFQI whereas the FQI which is based on only HVI measurements failed to predict it.

The results obtained show that the combination of HVI and FAVIMAT+ data predict quite accurately fibre properties for commercial bales.

7 Optimizing mixing/blending cost using MFQI and LP

Keywords:

Mixing/blending cost, objective function, fibre quality constraints, optimum Mixing/blending

7.1 Experimental design

In section five of this study, multi-criteria-decision-making (MCDM) and linear programming (LP) support approaches was used to determine the quality of cotton fibre required for the given blend optimization. There, the formulation of objective function was based on Analytical Hierarchy Process (AHP) weighting of cotton quality required for a given spinning system and the same set of quality constraints functions were used for all the systems.

The objective of this part of the study is to optimize the mixing/blending of the three commercial cottons (instrumentally characterized in section 6) with the application of linear programming method using: a cost objective function and combined effect of fibre quality characteristics using the previously discussed new modified fibre quality index formula (MFQI) as a constraint function. The name these three commercial cotton varieties instrumentally characterized in section 6 are: Acala SJ-2, Arba and DP-90.

Values of MFQI and their respective HVI and FAVIMAT+ fibre properties are shown in tables 6.1 and 6.6. Accordingly, the problem can be formulated as follows:

$$Minimize: Z\ (cost) = \sum_{i=1}^{i=3} (a_i)C_i \qquad \ldots\ldots (7.1)$$

$$= (a_a)C_a + (a_r)C_r + (a_d)C_d$$

where, a_a, a_r, a_d represent proportions of Acala-SJ-2, Arba and DP-90, respectively in the mix. C_a, C_r and C_d represent costs of Acala-SJ-2, Arba and DP-90 respectively in the mix.

7.2 Objective functions of cotton cost

The cost objective function has the advantage of being simple and linear in form. The cost of cotton may simply be expressed by its market price or as a function of all expenses related to raw material [85].

In material management [92], the total cost of raw material generally consists of ordering and setup costs (expediting and testing), carrying costs (handling, insurance, storage, and data processing costs), and purchase costs (price per pound, labor, and overhead charges).

Bezdudnyi, [93] suggested that the cost of cotton should be based on different cost elements involved in transforming fibre to yarn, including the cost of raw material (price of cotton, transportation, storage, and inventory), the amount of cost of return and waste per pound of each cotton type used in the blend, and the percent yield of yarn from each component in the blend. These factors are expressed in a cost function of the following form:

$$Z_t = (1/\sum_{1}^{k} a_i W_{yi})\,[100\sum_{1}^{k} a_i\,C_i - \bar{C}_w \sum_{1}^{k} a_i W_{wi}]\,,$$

where Z_t = the transformation cost of raw material, a_i = the proportion by weight of the i_{th} component cotton in the blend, k = the number of blend components, C_i = the cost of the i^{th} component in the blend, W_{yi} = the percentage yield of yarn from the i^{th} component, w_{wi} = the percentage yield of returns and waste from the i^{th} component in the blend, and $\bar{C}_w$ = the average cost of waste and returns. The complexity in using this equation to optimize cotton cost arises from Z_t = being non-linearly related to the proportions a_i.

The effect of percent waste and yam yield can alternatively be accounted for by considering the constraints related to these parameters, such as trash content and spinnability limits of each cotton component in the blend.

The assumption here is that if the proportion of cotton with relatively higher amount of trash content is added, then the cost of mixing will be linearly increased. Because trash content is directly and indirectly related to processing waste, the removal of trash being associated with fibre breakage and the removal of fibres as waste, as well as nep formation. These in turn can considerably affect spinning performance and yarn quality.

Accordingly, the trash content (non-lint content) and other fibre data used for spinning repeatability test of Acala SJ-2, Arba and DP-90 are measured using the Textechno CCS version 5 testing instrument with (3 varieties × 3 zones × 5 samples × 100 tests replications). One technician was used throughout the testing days and their results are given in table 7.1.

The CCS fibre property profiles with the addition of price criterion in the decision-making model for the studied commercial bales under AHP weighting scenario can be obtained from the PROMETHEE rainbow diagram, as given in figure 7.1.

The position of 14 measured fibre properties in the diagram clearly shows the performance of every cotton type with regard to its CCS fibre properties.

Table 7.1 CCS bundle fibre properties and their statistical parameters

		Statistical parameters						
Cotton Varieties	Fibre properties	Mean	S. D	Min	Max	S.E.	R	CV (%)
Acala SJ-2	Micronaire, MIC	3.98	0.39	3.19	4.39	0.1	1.2	9.82

	Linear Density, mtex	170.34	6.85	161.45	184.57	1.77	23.12	4.02
	Maturity value,	0.9	0.02	0.87	0.92	0	0.05	1.98
	Upper half mean length, mm	30.37	0.6	29.53	31.43	0.16	1.9	1.99
	Upper quartile mean length, mm	33.44	0.49	32.15	33.91	0.13	1.76	1.47
	Mean length, mm	25.31	0.48	24.54	26.43	0.12	1.89	1.88
	50% Spun length, mm	13.22	0.19	12.83	13.52	0.05	0.69	1.44
	2.5% Spun length, mm	30.39	0.58	29.57	31.27	0.15	1.7	1.9
	Short fibre content, %	10.69	0.53	10.13	11.91	0.14	1.78	4.94
	Short fibre Index, %	6.53	0.48	6.07	7.42	0.12	1.35	7.4
	Uniformity ratio	43.24	0.61	42.17	43.94	0.16	1.77	1.4
	Uniformity Index, %	86.56	0.55	85.42	87.61	0.14	2.19	0.63
	Elongation at maximum force, %	7.54	0.29	7.12	7.91	0.07	0.79	3.82
	Force at break, N	203.31	12.63	187.27	224.25	3.26	36.98	6.21
	Work, cN*cm	529.05	6.75	521.47	539.24	1.74	17.77	1.28
	Absolute Tenacity, cN/tex	13.66	0.43	13.11	14.52	0.11	1.41	3.14
	Relative Tenacity, cN/tex	31.03	0.87	29.12	32.54	0.22	3.42	2.8
	Light reflectance, Rd	86.46	0.94	85.14	87.61	0.24	2.47	1.09
	Yellowness, +b	9.94	0.55	8.74	10.61	0.14	1.87	5.55
	Non lint content, %	2.43	0.34	2.09	3.12	0.09	1.03	14.03
	Trash, pcs/gr	165	40.25	121	257	10.39	136	24.35
	Seed coat neps, pcs/gr	78	4.48	71	87	1.16	16	5.75
	Neps, pcs/gr	32	4.89	25	41	1.26	16	15.16
Arba	Micronaire, MIC	3.83	0.06	3.68	3.92	0.02	0.24	1.57
	Linear Density, mtex	195.45	13.66	184.54	241.21	3.53	56.67	6.99
	Maturity value,	0.87	0.02	0.81	0.91	0.01	0.1	2.3
	Upper half mean length, mm	28.06	0.71	27.34	29.13	0.18	1.79	2.53
	Upper quartile mean length, mm	32.39	0.79	29.68	32.65	0.2	2.97	2.44
	Mean length, mm	24.58	0.53	22.34	23.91	0.14	1.57	2.16
	50% Spun length, mm	13.03	0.28	11.65	12.72	0.07	1.07	2.15
	2.5% Spun length, mm	29.86	0.68	27.35	29.13	0.18	1.78	2.28
	Short fibre content, %	11.56	0.72	11.63	13.94	0.19	2.31	6.23
	Short fibre Index, %	7.74	1.93	7.12	12.21	0.5	5.09	24.94
	Uniformity ratio	41.95	0.5	41.02	42.36	0.13	1.34	1.19
	Uniformity Index	84.51	1.48	80.42	85.24	0.38	4.82	1.75
	Elongation at maximum force, %	7.14	0.44	5.67	7.12	0.11	1.45	6.16
	Force at break, N	197.72	1.93	180.64	187.62	0.5	6.98	0.98
	Work, cN*cm	525.59	2.51	511.23	519.81	0.65	8.58	0.48
	Absolute Tenacity, cN/tex	12.73	0.99	9.87	12.71	0.26	2.84	7.78
	Relative Tenacity, cN/tex	28.22	1.3	25.78	30.44	0.34	4.66	4.61
	Light reflectance, Rd	85.12	1.36	77.42	81.67	0.35	4.25	1.6
	Yellowness, +b	9.72	0.26	11.87	12.94	0.07	1.07	2.67
	Non lint content, %	2.84	0.42	2.14	3.53	0.11	1.39	14.79

	Trash, pcs/gr	215	24.24	175	271	6.26	96	11.27
	Seed coat neps, pcs/gr	87	5.604	77	94	1.447	17	6.44
	Neps, pcs/gr	27	3.11	27	39	0.8	12	11.52
DP-90	Micronaire, MIC	4.13	0.1	4.01	4.31	0.03	0.3	2.42
	Linear Density, mtex	198.32	2.41	191.64	198.75	0.62	7.11	1.22
	Maturity value,	0.85	0.02	0.85	0.91	0	0.06	2.35
	Upper half mean length, mm	27.82	0.34	27.35	28.35	0.09	1	1.22
	Upper quartile mean length, mm	31.53	0.77	31.42	33.75	0.2	2.33	2.44
	Mean length, mm	22.89	0.48	24.11	25.53	0.13	1.42	2.1
	50% Spun length, mm	12.07	0.53	12.15	13.74	0.14	1.59	4.39
	2.5% Spun length, mm	28.04	0.45	29.11	30.52	0.12	1.41	1.6
	Short fibre content, %	12.49	0.45	11.04	12.51	0.12	1.47	3.6
	Short fibre Index, %	9.44	0.92	6.42	9.54	0.24	3.12	9.75
	Uniformity ratio	41.55	0.74	41.12	43.46	0.19	2.34	1.78
	Uniformity Index	82.74	2.15	79.84	87.63	0.55	7.79	2.6
	Elongation at maximum force, %	6.28	0.32	6.79	7.92	0.08	1.13	5.1
	Force at break, N	183.37	8.94	181.65	211.12	2.31	29.47	4.88
	Work, cN*cm	513.89	7.75	513.01	539.65	2	26.64	1.51
	Absolute Tenacity, cN/tex	11.7	0.59	11.08	13.24	0.15	2.16	5.04
	Relative Tenacity, cN/tex	28.13	0.5	27.32	29.14	0.13	1.82	1.78
	Light reflectance, Rd	79.85	4.41	75.12	88.3	1.14	13.18	5.52
	Yellowness, +b	12.59	0.14	9.34	9.86	0.04	0.52	1.11
	Non lint content, %	3.17	0.39	2.35	3.71	0.1	1.36	12.3
	Trash, pcs/gr	225	33.55	109	254	8.66	145	14.91
	Seed coat neps, pcs/gr	92	2.789	87	97	0.72	10	3.03
	Neps, pcs/gr	31	2.76	23	33	0.71	10	8.9

M (Mean), S.E (standard error), C.V % (coefficient of variation), S.D (standard deviation), R (range)

In this PROMETHEE II (see Appendix C.1) ranking, amongst the detailed fibre properties considered in table 7.1, maturity value (MV), upper half mean length (UHML), uniformity ratio (UR), bundle elongation (BE), bundle force (BF), work of rupture (W), absolute tenacity (AT), light reflectance (Rd), are the higher-the-better type of quality characteristics.

On the other hand, linear density (LD), percentage short fibre content (SFC), yellowness (+b), trash content (TC), seed coat neps (SCN), total level of neps (Neps) and market price of cotton (€) are the lower-the-better type of quality characteristics.

Using all the data from a single comprehensive system (Textechno CCS version 5) is advantages for precise evaluation of commercial bales performance. Particularly measurement of trash content and fibre properties required to evaluate spinning performance of cotton needs to be reported from a single system. This will make the calculation of a given cotton cost of manufacturing easier.

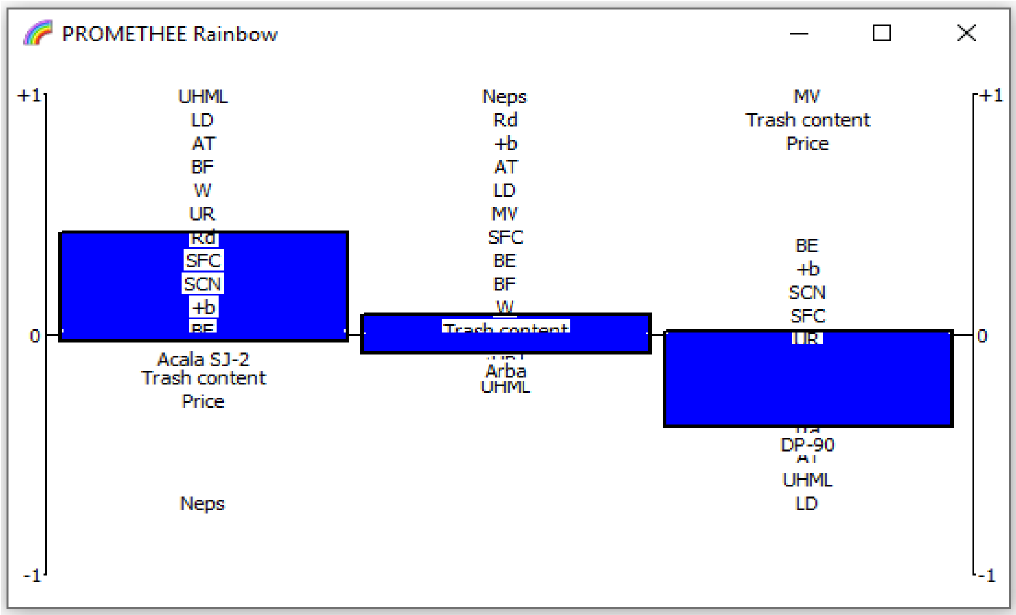


Fig. 7.1 PROMETHEE rainbow diagram for the studied commercial bales

From figure 7.1 it can be observed that Acala SJ-2 outperforms the other competitor alternatives with respect to many of the considered fibre quality properties except level of neps and its market price (€/kg). Arba outperforms DP-90 with respect to all the considered fibre quality properties except its market price (€/kg). DP-90 has relatively less market price (€/kg) than its competitor commercial cotton alternatives.

The corresponding GAIA plane is presented in figure 7.2. In this plane it is clearly shown that the commercial varieties Acala SJ-2 and Arba are placed to the direction of the decision axis while DP-90 against the direction of the decision axis.

It gives some picture for the spinner to consider the advantages of both quality and price during the procedure of mixing/blending optimization.

The quality of U-V plan being (100 %), in this result is an interesting feature of the GAIA plane. It can be considered as an indication for the advantage of using the fibre quality data from a single comprehensive system (CCS) do not mislead the analysis by excluding a potentially part of information contained in the multicriteria problem.

Recalling equation 7.1, we have

Minimize: $Z\ (cost) = 1.49 \times a_a + 1.37 \times a_r + 1.23 \times a_d$

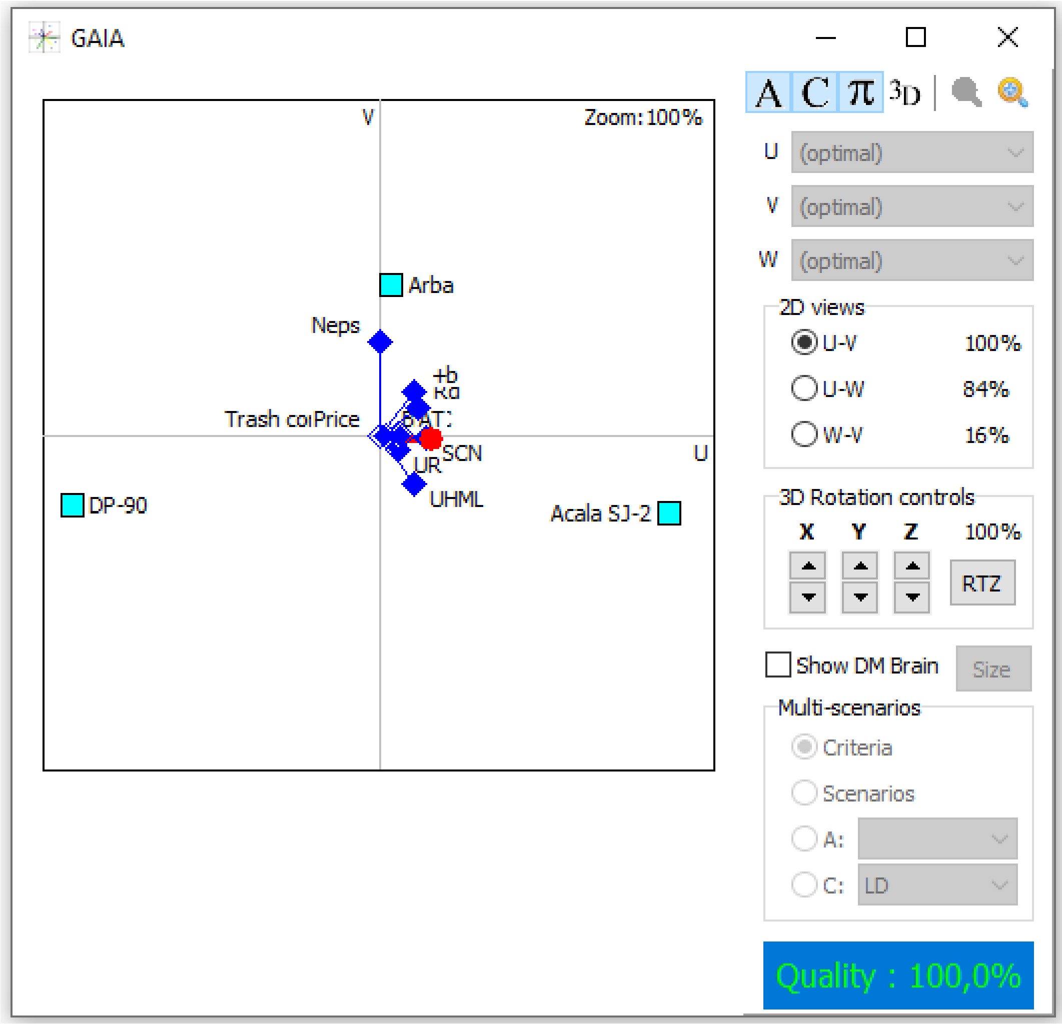


Fig. 7.2 GAIA plane for the studied commercial bales

7.3 MFQI as a constraint function

The value of combined fibre quality index is calculated using the found new modified fibre quality index values (see table 6.7 section 6), therefore we have:

MFQI: $130.9 \times a_a + 113.7 \times a_r + 105.7 \times a_d$

$a_a + a_r + a_d = 1, \; a_a \geq 0, \; a_r \geq 0, \; a_d \geq 0$ ....(7.2)

Application of the new modified fibre quality index to combine the effects of important HVI fibre properties, namely, upper half mean length, uniformity index, short fibre index and micronaire and FAVIMAT+ single fibre tenacity and elongation properties are very important to predict the achievable yarn quality or processing performance for a given mix.

The solution of this linear programing (LP) problem is subsequently solved using simplex method and the derived optimal solution is summarized in tables 7.2-7.5.

Table 7.2 Optimized cost of mixing = € 1.2671428

Variety	Price	Optimum mix ratio
Acala SJ-2	€ 1.49	0.1428571
Arba	€ 1.37	0
DP-90	€ 1.23	0.8571429

The optimum cost of the blend is € 1.27 per kilogram. Proportions of cottons Acala SJ-2, Arba and DP-90 in the blend, which satisfy the used fibre quality index value, are, 0.1429, 0 and 0.8571, respectively (table 7.2).

Table 7.3 Constraint summary

Name	Value	Shadow price
MFQI Used	109.3	0.0103175

Table 7.3 shows the value of the constraint function which is the optimum value of fibre quality index to be used in the blend. The shadow price indicates that, if there is an increment of MFQI beyond the value of 109.3, then this will add € 0.01 to the objective cost of mixing.

Table 7.4 Sensitivity analysis - cost

Variety	Optimum mix ratio	Objective coefficient	Allowable minimum	Allowable maximum
Acala SJ-2	0.1428571	€ 1.49	€ 0.26	€ 0.181000000000001
Arba	0	€ 1.37	€ 0.057460317460318	Infinity
DP-90	0.8571429	€ 1.23	Infinity	€ 0.084186046511629

Table 7.5 Sensitivity analysis - constraint

Name	Final value	Shadow price	RHS constraints	Allowable minimum	Allowable maximum
FQI	109.3	0.0103175	109.3	3.60	21.6

7.4 Sensitivity analysis

The sensitivity analysis yields the range over which values of a given parameter of the problem may vary, all else being held fixed, without altering the nature of the solution.

For example, as shown in table 7.4, the allowable minimum and allowable maximum of Acala SJ-2 was € 0.26 and € 0.18, respectively. The allowable minimum and allowable maximum of DP-90 was 'infinity' and 0.08, respectively. This means that over this range, varieties of Acala SJ-2 and DP-90 will remain in the solution. At a cost of varieties Acala SJ-2 and DP-90 outside their sensitivity ranges will result in a new variety (Arba) to come to the solution.

The sensitivity analysis for the righthand side (RHS) (table 7.5), shows the range over which a value of the righthand side can be varied without changing the set of variables that is part of the solution. For example, the allowable minimum and maximum for MFQI is 3.60 and 21.6, respectively. This means that the constraint righthand side (RHS value of MFQI) should remain in this range to keep the same decision variables in the solution. For example, if we increase the value of MFQI up to 21.6, then for every MFQI added, the objective cost of mixing will increase by the amount of the shadow price (i.e. € 0.01). Though their proportion in the mix is changed, Acala SJ-2 and DP-90 will remain in the solution. But if we vary the value of MFQI outside the sensitivity range, the simplex analysis will yield different varieties with different ratio as well as a new mixing cost (see table 7.6).

Table 7.6 Simplex analysis by varying cost of component cottons in the mix

cost		Mixing ratio			
Value	Shadow price	Acala SJ-2	Arba	DP-90	Mixing cost
Acala SJ-2					
1.24	0.000396825	0.142857	0	0.857143	1.23
1.68	0.0175	0	0.45	0.55	1.29
Arba					
1.31	0.01	0	0.45	0.55	1.27
DP-90					
1.32	0.00625	0	0.45	0.55	1.34

7.5 Parametric analysis

Parametric analysis reveals the way in which the optimal solution varies as a function of the righthand constraint value. Results of the parametric analysis for the modified fibre quality index are given in table 7.7. This analysis was performed based on formulating the index constraint as follows:

$$\text{MFQI: } 130.9 \times a_a + 113.7 \times a_r + 105.7 \times a_d \geq t; \quad 105.7 \leq t \leq 131$$

As shown in table 7.7, values of MFQI from 105.8 to 130.8 increase the cost of mixing from € 1.23 to € 1.49 Above 130.8 the solution becomes infeasible, which we expected because this value represents the marginal MFQI available.

Table 7.7 Parametric analysis of fibre quality index: RHS 109.3, lower limit = 105.8, upper limit = 130.8

RHS		Mixing ratio			
Value	Shadow price	Acala SJ-2	Arba	DP-90	Mixing cost
105.8	0.01031746	0.003968	0	0.996032	€ 1.23
110.8	0.01031746	0.202381	0	0.797619	€ 1.28
115.8	0.01031746	0.400794	0	0.599206	€ 1.33
120.8	0.01031746	0.599206	0	0.400794	€ 1.39
125.8	0.01031746	0.797619	0	0.202381	€ 1.44
130.8	0.01031746	0.996032	0	0.003968	€ 1.49
130.9		…infeasible…			

8 Commercial cotton variety spinning study

Keywords:
Fibre-yarn tenacity relation, fibre-yarn evenness relation, fibre-yarn imperfections relation, end breakage rate

8.1 Fibre-yarn relations

Cotton fibres, a viscoelastic material, are the fundamental building blocks used to form the more complex structure of yarn and ultimately fabric. Fibre quality properties (e.g. length, fineness, tenacity, elongation, length uniformity, short fibre content, light reflectance, non-lint content, level of neps,) influence yarn characteristics (e.g. strength, extensibility, friction, stiffness and resilience). The resultant strength of yarn is an important aspect of yarn quality so that spinners select cottons based upon their suitability for textile processing with acceptable quality and spinning efficiency (e.g. low number of ends down). Increasing micronaire tends to increase irregularity and frequencies of thin and thick places and decrease yarn strength [94]. Micronaire affects yarn appearance more than any other fibre property [95]. All other factors being constant, finer fibres produce more regular and stronger yarns, although the effect of fineness on strength is generally secondary to that of fibre length. Neps have been found to decrease rapidly and yarn strength slightly, with increasing micronaire.

A cotton bale is a bale of fibres with variability; however, as it was demonstrated in sections four and six, a multiple bale laydown is utilized to minimize the with in bale and between bale fibre variability for better yarn properties. It has been demonstrated with cotton yarns containing high yarn strength variability or low spinning strength would require low production rates or must be used in heavy yarns [96]. Graham and Taylor [96] further state that cotton yarns containing high spinning strength as well as low spinning strength variability could be processed at high production rates or used to produce fine yarn for quality products.

Establishing a relationship between yarn and fibre properties is necessary to better understand the resultant yarn structure. Correlations of yarn strength to fibre strength, fibre cohesion, and fibre regularity were first presented by Peirce in 1947 [97], Bogdan, 1956 [98], Bogdan 1967 [99]). Currently, fibre properties normally considered for fibre-to yarn research have included the common HVI™ properties such as micronaire, length, length uniformity, strength, elongation, light reflectance, yellowness and trash. These fibre quality properties are particularly important for the classification of cotton bales.

Whereas, the spinner's quality concerns at the output of the opening, cleaning and mixing line are increasingly geared toward parameters that cannot be measured using HVIs, namely neps, short fibre content or fibre length distribution [100, 101, 102].

In particular, despite intensive research and development efforts, classing data still fails to include meaningful and reliable measurements of some fibre properties now at the forefront of concerns for spinners, namely, neps [8], and short fibres or more generally fibre length distribution [9]. To evaluate those properties, spinners depend on measurement methods with testing speeds not compatible with those of HVIs. The Advanced Fibre Information System, or USTER AFIS, is one such method.

The aim of this part of the research is to evaluate and predict the impact of important fibre quality properties (measured with CCS version 5 of TEXTECHNO, Germany) on single yarn tenacity property (measured with STATIMAT ME+ of TEXTECHNO, Germany). Evaluation of all fibre quality properties from a single comprehensive system (e.g. CCS version 5) will help to minimize the problem which comes from using two non-compatible instruments. Other yarn quality parameters are measured by USTER tester 5. All testings are conducted under standard testing conditions.

8.2 Experimental design

The optimized mix for the commercial varieties derived from the simplex linear programming analysis (table 7.6, section 7) was 14% Acala SJ-2, 0% Arba and 86% DP-90). This mix was processed through : Rieter bale plucker (UNIfloc A 11), Rieter pre-cleaner UNIClean - B 11, Rieter uni-mixer-B 70, Rieter uni- flex B 60, Rieter vision shield, Rieter combo shield and condenser A 21, and carded with Rieter Carding machine (Card C 60-RSB) at a production rate of 32 kg/h to produce carded slivers with linear density of 4600tex. Carded slivers were blended and drawn to a linear density of 3900tex using Integrated Draw Frame (IDF). Second passage Reiter draw frame was used to draw samples to a final linear density of 4250tex. For the ring spun yarns roving samples were drawn to a linear density of 490tex, and a slight twist (0.51–0.63 turn/cm). The roving was spun into Ne 24 and Ne 36 yarns with a twist multiplier of 4.2 (weaving twist) on a Rieter G 35 Ring Spinning Frame. Ten bobbins of yarn were made from each sample using traveler speed of 32m/s and a spindle speed of 13,500 rpm.

For the rotor spun yarns (i.e. Ne 24 and Ne 36) second passage Rieter draw frame was used to draw samples to a final linear density of 4250tex, feed to BT/R 923 Rieter rotor machine spinning heads, with the draft of 114, opening roller speed 6000rpm and the number of teeth on the opening roller clothing 1035, a 50mm diameter of rotor and rotor speed of 100,000rpm. The twist multiplier used was 4.6.

8.3 Fibre-yarn tensile properties relations

STATIMAT ME+ with a testing speed of 5000 mm/min with test length of 50 cm was used for testing the tensile, elongation and work-to-break properties of the produced Ne 24 and Ne 36 ring and rotor spun yarns. The mean values of 100 tests was taken for tenacity and elongation evaluation of each system spun yarns.

8.4 Results and discussion **(Fibre properties-yarn tenacity relations)**

A regression equation is developed using a wide range of values of fibre characteristics (67 observations). For the yarn count Ne 24 of ring spinning, the regression equation takes the form (see table 8.1):

$$ST = -11.552 - 0.350MIC + 0.450UHML - 0.088SFC + 0.205UR + 0.072BE + 0.210ABT + 0.021Rd - 0.131NLC - 0.001NPs$$

Where, ST = Statimat tenacity (cN/tex); MIC = micronaire; UHML = upper half mean length (mm); SFC = short fibre content (%); UR = uniformity ratio; BE = bundle elongation; ABT = absolute bundle tenacity (cN/tex); Rd = light reflectance; NLC = non lint content (%); NPs = level of neps (count/g). All the fibre properties were measured using a single comprehensive system, namely TEXTECHNO CCS Version 5.

Table 8.1 Multiple regression equations for Ne 24 and 36 ring and rotor yarns.

Count of yarn and spinning system	Regression equation	R^2	F value
24's (RiS)	ST = -11.552 – 0.350MIC + 0.450UHML – 0.088SFC + 0.205UR + 0.072BE + 0.210ABT + 0.021Rd – 0.131NLC – 0.001NPs	0.835	78.693
36's (RiS)	ST = -11.576 – 0.350MIC + 0.450UHML – 0.088SFC + 0.206UR + 0.072BE + 0.210ABT + 0.021Rd – 0.131NLC – 0.001NPs	0.835	78.703
24's (RoS)	ST = -7.391 – 0.295MIC + 0.250UHML – 0.150SFC + 0.159UR + 0.130BE + 0.422ABT + 0.033Rd – 0.066NLC – 0.001NPs	0.749	46.336
36's (RoS)	ST = -6.071 – 0.432MIC + 0.232UHML – 0.158SFC + 0.177UR + 0.177BE + 0.398ABT + 0.029Rd – 0.286NLC – 0.001NPs	0.765	50.542

RiS = ring spinning and RoS = rotor spinning; ST = Statimat tenacity

Predicted values of Statimat tenacity factor for yarns produced from Acala SJ-2, Arba and DP-90 were 13.52179, 11.89283, 11.07987, respectively, which we obtained by substituting the CCS fibre properties (see table 7.1) for each component in regression equation above for the yarn count Ne 24. If the desirable minimum value of Statimat tenacity is 11. 89 cN/tex, the tenacity constraint will be:

$$ST: 13.52 \times a_a + 11.89 \times a_r + 11.08 \times a_d \geq 11.89$$

The desirable level of tenacity can be determined from yarn quality specifications for a targeted end product. Other basic constraints, which should be added before analysis, are proportions sum from equation 7.2:

$$a_a + a_r + a_d = 1, \quad a_a \geq 0, \; a_r \geq 0, \; a_d \geq 0$$

The results of the optimum mixing and sensitivity analysis for this problem are given in tables 8.2 and 8.3. As shown in table 8.3, the sensitivity range for the yarn tenacity is 11.08 cN/tex to 13.52 cN/tex, which means that the value of desirable yarn tenacity should remain in this range to keep the nature of the optimum solution unchanged.

Table 8.2 Optimized cost of mixing = € 1.3120492

Variety	Original value	Optimum mix ratio
Acala SJ-2	0	0.3155737
Arba	0	0
DP-90	0	0.6844262

Table 8.3 Sensitivity analysis-tenacity

Name	Final value	Shadow price	RHS constraints	Allowable minimum	Allowable maximum
ST	11.85	0.106557377	11.85	0.77	1.67

Results of the parametric analysis for the Statimat single yarn tenacity are given in table 8.4. This analysis was performed based on formulating the single yarn tenacity constraint as follows:

$$ST:\ 13.52\times a_a + 11.89\times a_r + 11.08\times a_d \geq t;\ 11.08 \leq t \leq 13.52$$

Table 8.4 Parametric analysis of Statimat single yarn tenacity: RHS 11.85cN/tex, lower limit = 11.08cN/tex, upper limit = 13.52cN/tex.

RHS		Mixing ratio			
Value	Shadow price	Acala SJ-2	Arba	DP-90	Mixing cost
11.09	0.10655737	0.004098	0	0.995901	€ 1.23
11.14	0.10655737	0.024590	0	0.975409	€ 1.24
11.19	0.10655737	0.045082	0	0.954918	€ 1.26
12.19	0.10655737	0.454918	0	0.545081	€ 1.35
13.19	0.10655737	0.864754	0	0.135245	€ 1.45
13.51	0.10655737	0.995901	0	0.004098	€ 1.49
13.52		…infeasible…			

As shown in table 8.4, increasing values of Statimat single yarn tenacity from 11.09cN/tex to 13.51cN/tex increase the cost of mixing from € 1.23 to € 1.49 Above 13.51cN/tex the solution becomes infeasible, which we expected because this value represents the marginal single yarn tenacity available.

Table 8.5 shows the sensitivity analysis for the cost of cottons in the mix. From the table the allowable minimum cost of Arba variety is 0.053, if we decrease the cost of Arba below this value, say for example by 0.06, this variety will come to the solution, while the expensive variety Acala SJ-2 will be excluded from the mixing solution.

Table 8.5 Sensitivity analysis - cost

Variety	Optimum mix ratio	Objective coefficient	Allowable minimum	Allowable maximum

Acala SJ-2	0.3155737	€ 1.49	€ 0.26	€ 0.16172839506173
Arba	0	€ 1.37	€ 0.05368852459016	Infinity
DP-90	0.6844262	€ 1.23	Infinity	€ 0.08036809815951

Table 8.6 shows the new sensitivity analysis with the variety Arba coming to the mixing solution.

Table 8.6 Sensitivity analysis – with variety Arba

Variety	Optimum mix ratio	Objective coefficient	Allowable minimum	Allowable maximum
Acala SJ-2	0	€ 1.49	€ 0.26	Infinity
Arba	0.9506172	€ 1.31	€ 0.08	Infinity
DP-90	0.0493827	€ 1.23	€ 0.00944785276073	€ 0.08

Using the presented multiple regression equations (table 8.1), it is possible to work out similar analysis for the remaining ring and rotor counts.

The result obtained showed that the successive multiple regression equations formulated using CCS fibre quality parameters and Statimat single yarn tenacity allows to predict quite accurately ring and rotor spun yarns of count Ne 24 and Ne 36.

The approach of using all the data of fibre properties from a single comprehensive system (e.g. CCS) can possibly minimize the errors introduced from using two different incompatible testing instruments.

8.5 Spinning performance and fibre-yarn properties relations

Textile mills efficiency is related to how well it is able keep the yarn processing with minimum number of yarn faults and tolerable level of ends down (number of yarn breaks). Yarn coefficient of variation of mass (CVm %), yarn count variation between packages (CVb), yarn thin places per 1000 meter, thick places per 1000 meter and neps per 1000 meter of yarn, for Ne 24 and Ne 36 ring and rotor yarns were measured with USTER tester 5. The testing speed was 400m/min.

All the testings were conducted under standard testing conditions. The mean values of 100 tests were taken for all yarn quality parameters evaluated. Individual yarn quality properties for Ne 36 ring and rotor spun yarns are given in table 8.7

The spinning performance and yarn properties were evaluated for the yarn count Ne 36 of ring and rotor spinning produced from the mix of commercial varieties derived from the simplex linear programming analysis (see table 7.6, section 7). Statimat yarn tensile properties are also presented for the purpose of comparison.

Table 8.7 Individual yarn quality properties for Ne 36 ring and rotor spun yarns

Variable	Ring	Rotor
Tenacity (cN/tex)	15.71	12.32
CVten	11.3	9.12
Elong	5.57	6.43
CVm (%)	19.27	17.15
CVb (%)	2.3	1.7
Thin places -40% (count/1000 mts)	563	413
Thick places +35% (count/1000 mts)	1117	811
Neps +200% (count/1000 mts)	1271	517
Hairiness	4.27	3.13
Ends down (count/1000 spindle/rotor hrs)	63	215

Cvten = coefficient of variation in tenacity

Yarn tenacity and imperfections estimation through knowledge of fibre characteristics is of considerable value to both the cotton breeder and the cotton spinner. As cotton is grown to be spun, it is a primary concern of the cotton breeder to know the relative importance of the different fibre characteristics contributing to yarn properties, so that he can select for such properties to achieve the desired strength and other qualities in the produced yarns. Yarn tenacity and imperfections measurement provides reliable evaluation of fibre spinnability. That is why the interrelationship between fibre tests and yarn strength and imperfections have occupied the attention of textile scientists for years.

In the present research, correlation study is performed between the modified fibre quality index (see equation 6.2) [103], and five important yarn quality parameters: tenacity, mass coefficient of variations and imperfections (thin places, thick places and neps) for the rotor spun yarn of Ne 36.

Excellent correlation (R^2 = 0.908, see Fig. 8.1) is found between Statimat yarn strength and the modified cotton fibre quality index which supports the previous research findings on the importance of cotton fibre qualities to determine the mechanical properties of spun yarns.

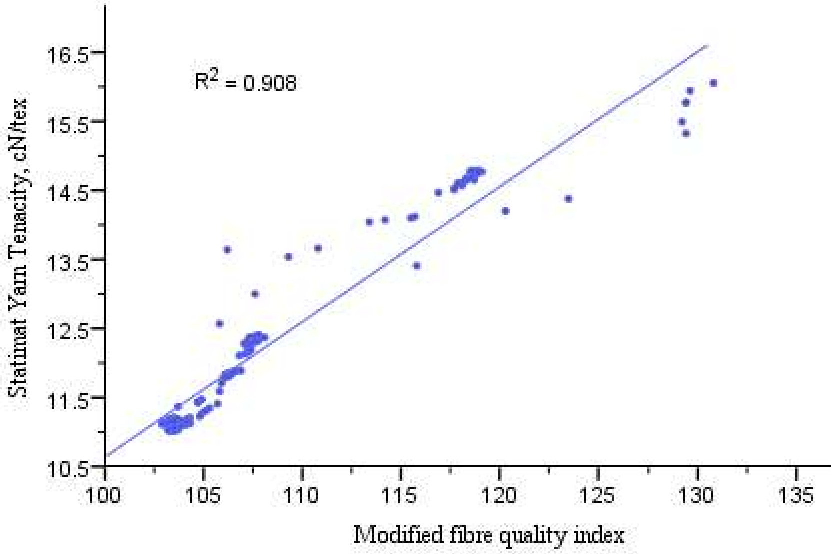


Fig. 8.1 Correlation between MFQI and yarn tenacity

Another important yarn quality parameter is the yarn mass coefficient of variation (CVm %). The CVm % influence the following fabric qualities: The visual appearance of the cloth, the dyeability of fabric and the fabric weight uniformity.

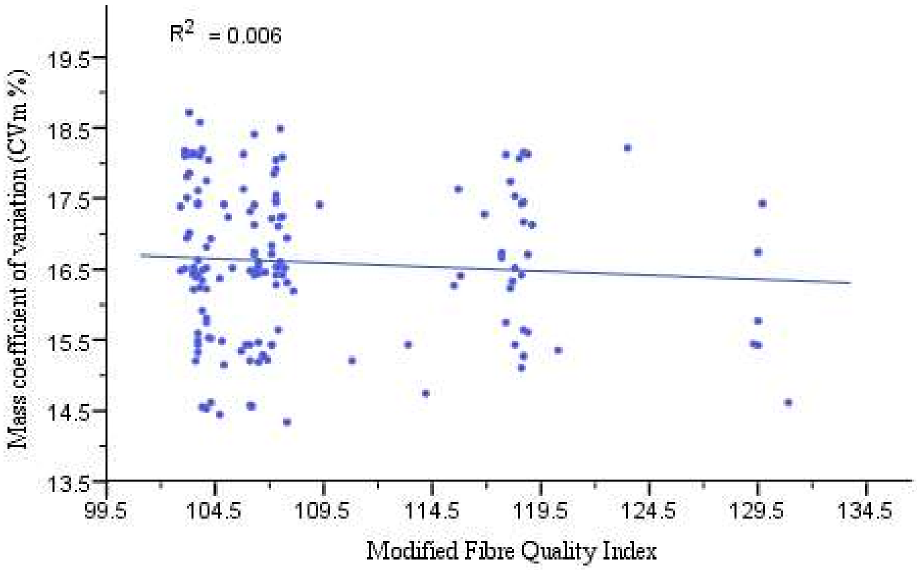


Fig. 8.2 Correlation between MFQI and yarn mass coefficient of variation

CVm % is more crucial in weft knitted fabrics. Stripiness is more difficult to distinguish in such type of fabrics particularly if they are patterned. Mass uniformity of fabric is also influenced by yarn CVm % which potentially of importance in applications (such as filter materials, paper making fabrics of thermally stablising structures) where thickness must be constant. Perhaps the most important effects of yarn CVm %, however arise when dyeing is carried out. The presence of colour can emphasise visible defects, and a fabric that is acceptable in the grey state can become totally undesirable once dyeing has taken place, purely as a result yarn irregularity in mass. The fabrics produced from the yarn with higher CVm % have inferior fabric appearance as compared to lower CVm %. This is more prominent in the case of knitted fabrics.

The imperfections which include the thin places, thick places and neps are termed as frequently occurring faults. It is not only their more or less frequent appearance which influences the quality of the finished product, but they can be also disturbing according to their size and number in subsequent processing. Thin and thick places in a yarn quite considerably affect the appearance of a woven or knitted fabric. Furthermore, an increase in the number of thin places and thick places refers to a particularly valuable indication that the raw material or the method of processing has become worse. Thin places usually exhibit a higher yarn twist in view of the fewer number of fibres in the yarn cross-section but with the thick place faults the contrary is the case.

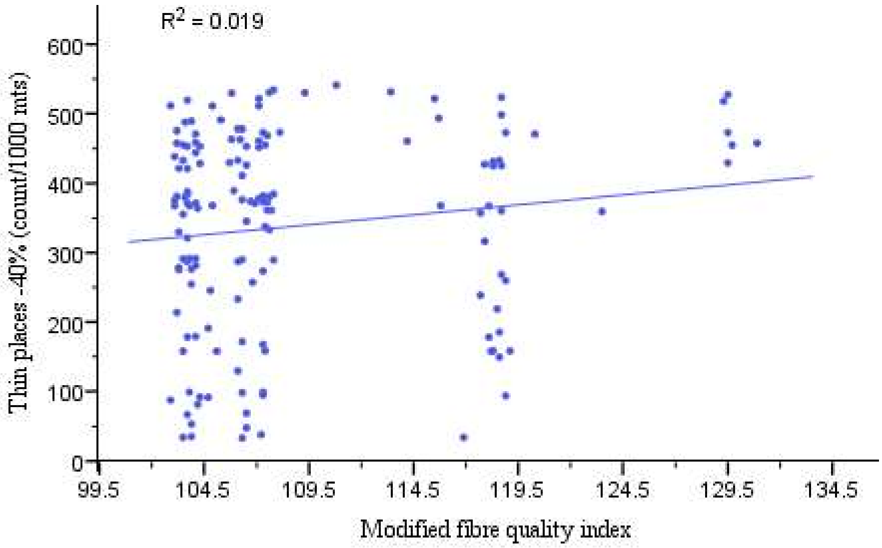


Fig. 8.3 Correlation between MFQI and yarn thin places

Neps: They can be defined as the entanglement of fibres either with trash particles as a nucleus or cluster of immature fibres. These neps quite considerably affect the appearance of woven or knitted fabric. Furthermore, they pose processing difficulties, particularly in the knitting machine sector of the industry. Neps can be divided into two categories: raw material neps and processing neps. Raw material neps in cotton are primarily the result of vegetable matter and immature fibres in the raw material. Processing neps are produced at ginning, opening and also in cotton carding. Their formation is influenced by beater rollers clothing, settings between the beater rollers and grid bars, production speeds, conditions of the machines etc.

In this study, no correlation is found between the modified fibre quality index and yarn imperfections (see figures 8.3, 8.4 and 8.5).

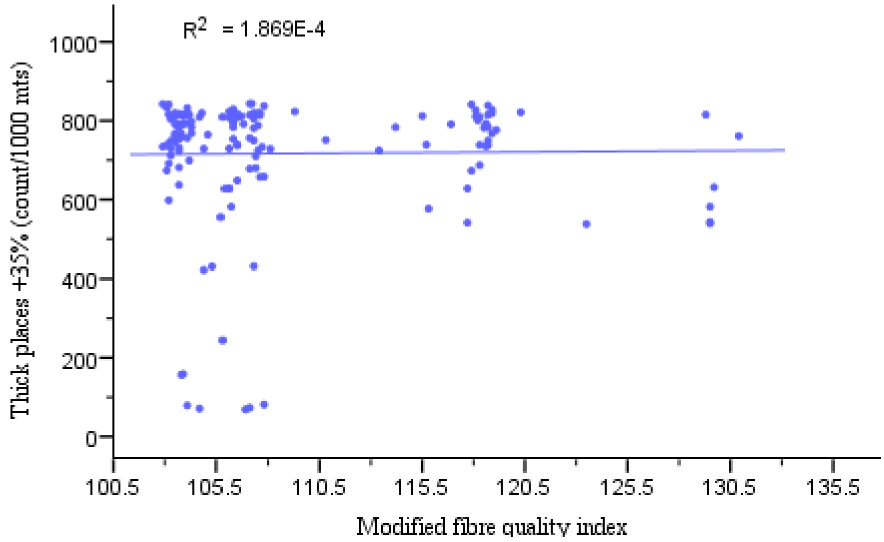


Fig. 8.4 Correlation between MFQI and yarn thick places

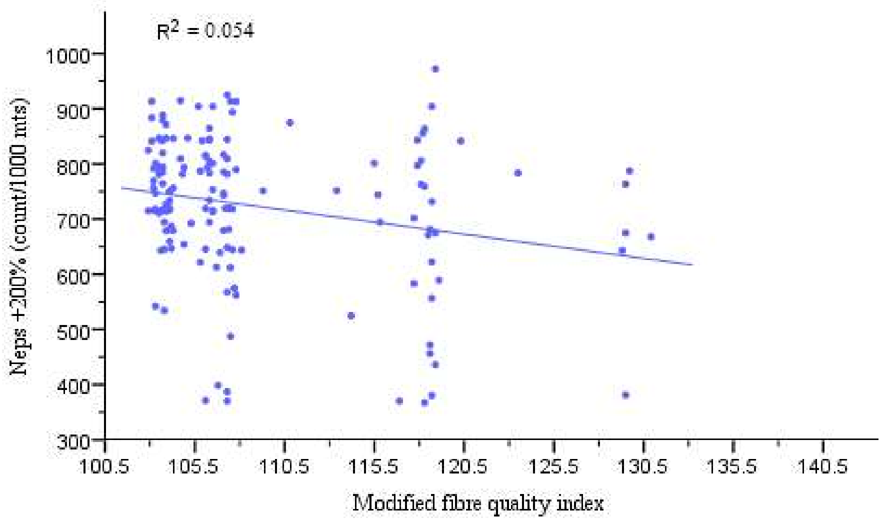


Fig. 8.5 Correlation between MFQI and yarn level of neps

As it can be clearly shown in the figures 8.2 – 8.5, in this study, no correlation is found between the modified fibre quality index and yarn CVm % as well as imperfections. The yarn mass coefficient of variation and imperfections characteristics were therefore influenced by the improper machine parameters during the yarn production and random variations. For example, the drafting roller eccentricity in the drafting system, results in the offset of the top roller from the axis of rotation, and this causes the radius of rotation to vary during each revolution of the roller. Consequently, roller eccentricity causes the nip of a roller pair to fluctuate, and this alternatively increases and shortens the drafting zones. In the case of the front rollers, the number of fibre-leading ends nipped by the rollers will vary in a regularly repeated manner, resulting in thick and thin places in the drafted material.

It is also required to maintain proper drafting in roller the drafting system. Because, the higher the single zone draft, the fewer the number of fibres in the cross section that will be drafted in the ideal way and therefore the more pronounced the thick and thin places and the greater the irregularity of drafted material.

Therefore, it is possible to improve the quality of yarns by the selection of proper technological machine parameters and correcting of defective machine parts, during the process of yarn production.

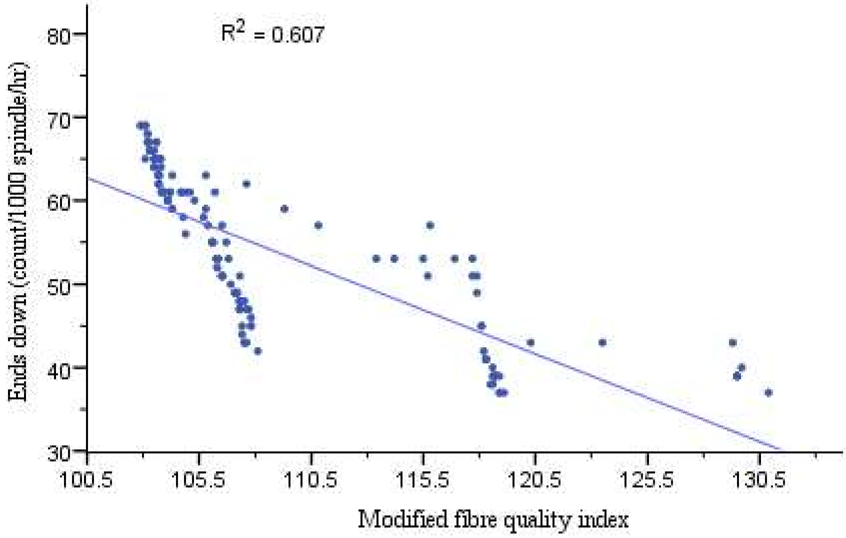


Fig. 8.6 Correlation between MFQI and ring yarn ends down

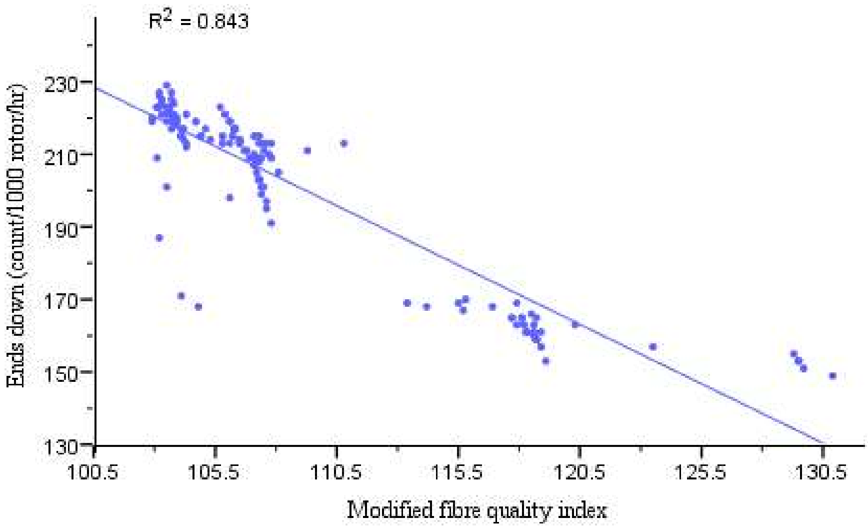


Fig. 8.7 Correlation between MFQI and rotor yarn ends down

In this study, ends down tests were also conducted to evaluate the application of the introduced modified fibre quality index for the preparation of a suitable cotton mix, so that to observe any significant difference in the rate of occurrence of ends down. Ends down was measured for ring and rotor spinning systems for the duration of 8hrs (a shift). The mean ring and rotor spinning ends down was recorded and calculated for 1000 spindle and rotor hours, respectively (see table 8.7).

Control of end breaks at various stages of processing is very vital in order to produce a yarn of good quality and maintain a high level of machine and labour productivity. Every end breaks apart from being a potential cause of a break in subsequent departments, results in a yarn defect, lower machine efficiency, higher waste and more work load for the tender. In ring spinning, yarn breaks occur generally at places that are too weak to withstand the tension imposed during spinning (spinning triangle). It could therefore be expected that increase in yarn strength should reduce end breakage rate. It has been found that for every 1% increase in yarn strength (due to the use of better performing cottons in the mix), end breaks in ring spinning are significantly reduced (see fig. 8.6). In this figure, it is presented that the correlation between end breaks and modified fibre quality index is, R^2=0.607.

Compared to ring spinning, in rotor spinning, a higher correlation is found between end breaks and modified fibre quality index, R^2=0.843 (see fig. 8.7). This mainly, can be explained by the fact that when the mixing is improved/optimized, then the amount, size and distribution of trash particles which comes with the feed sliver and are delivered to the rotor groove will be minimized. Therefore, their interference with the process of yarn formation will be controlled. This is one of the main causes for minimizing end breakage rate by improving the mixing of cottons in rotor spinning system.

9 Research conclusions

Keywords:
Genotype-fibre quality relation, genotype-ginning effect, optimum ginning, optimum mixing, yarn quality, end breakage rate

The main research question of this research was:

- What relation exists between cotton genotype/variety and ginning, spinning and quality of fibres?
- What relation exists between CCS measured bundle "absolute tenacity" fibres property and spinnability of commercial cotton genotype?
- What is the initial tensioning effect to the removal of crimp during the measurement of bundle elongation?
- Why the spinning mills in Ethiopia were facing many end breakages relatively higher than expected by a spinner, particularly, when they are processing local commercial genotypes/varieties?

9.1 Genotype-ginning effects

A commercially grown cotton varieties that was approximately midrange in staple length and strength was subjected to the standard ginning treatment. The effect of gin processing on tenacity, elongation, length distribution and neps level was investigated. Some of the conclusions drawn from this test are:

1. In comparing the quality properties of seed cotton (before ginning) with lint cotton (after ginning), a statistically significant FAVIGRAPH single fibre tenacity decrease was observed on all studied varieties. Acala SJ-2 with greater mean tenacity and less coefficient of variation in tenacity before ginning affected less than the other two studied varieties. The mean FAVIGRAPH single fibre tenacity difference in cN/tex, before and after ginning treatment fall in the range (1.30, 1.35, 1.38) for Acala SJ-2, Arba and DP-90, respectively. The HVI and CCS relative bundle tenacity results are also in favour of Acala SJ-2.

2. The mean CCS absolute bundle tenacity difference in cN/tex, before and after ginning treatment fall in the range (0.11, 0.16, 0.29) for Acala SJ-2, Arba and DP-90, respectively.

3. The absolute tenacity with corresponding elongation values are important parameters to predict the spinnability of cotton for a desired yarn count. Higher tenacity with increased fibre elongation results in increased yarn strength and elongation.

4. The cotton with higher elongation spin with fewer ends down than the lower elongation cotton.

   In this study, Acala SJ-2 with greater value of mean FAVIGRAPH single fibre tenacity (28.81 cN/tex × 164 millitex) and elongation (7.06 %) was subjected to relatively less length breakage during the ginning treatment when compared against Arba (27.55 cN/tex × 160 millitex) and elongation (6.95 %), DP-90 (27.11 cN/tex × 156 millitex) and elongation (6.83 %). AFIS short fibre content by number and by weight after the ginning treatment for Acala SJ-2 was (SFC_n = 28.84 %, SFC_w = 12.45 %) against Arba (SFC_n = 29.13 %, SFC_w = 12.68) and DP-90 (SFC_n = 29.55 %, SFC_w = 12.76 %).

There was a significant shift in the length distribution after ginning treatment.

Raw seed cottons of all the varieties which were composed of few neps, resulted with high level of neps after the process of ginning: Acala SJ-2 (75 count/g, 188 count/g (table 3.5), Arba (87 count/g, 203 count/g) (table 3.6) and DP-90 (90 count/g, 221 count/g) (table 3.7). Varietal differences were significant with maximum difference 17%.

9.2 Genotype-fibre quality relations

The applied PROMETHEE-GAIA method observation showed that there is a clear genotype difference with respect to their performance to the mixing/blending requirements.

The genotypes with outstanding fibre quality properties (for example: Acala SJ-2, Sille 1 (Stoneville), Bulk 202) have fulfilled the quality requirements for the ring, rotor, compact and air-jet spinning methods. The developed model using PROMETHEE II method clearly showed the performance of these genotypes against their competitors by positioning them from the first to the third order of ranking. The bad performing genotypes, on the studied samples, was also identified according to their fibre quality properties.

9.3 Absolute tenacity-spinning relations

Fibre-yarn multiple regression models are developed using the measured data from a single comprehensive bundle tenacity-elongation measurement system, namely, CCS, and Statimat single yarn tenacity tester. These models allowed to effectively predict the tenacity property of ring and rotor spun yarns of counts Ne 24 and Ne 36, from the measured bundle fibre quality parameters.

Five cN/tex initial tensioning is used to remove the crimp in the fibres during the measurement of absolute tenacity-elongation and found a positive correlation between tenacity and elongation with $R^2 = 0.091$ [7]. The finding can better motivate the cotton breeders and cultivators for avoiding the practice of ignoring for cultivating a cotton with better fibre elongation because of the usual practice of negative correlation between bundle tenacity and elongation. In this research work, it is also observed that the genotypes with higher mean FAVIGRAPH single fibre tensile properties tend to have higher elongation which provided them to be less affected by the striking action of saw-toothed beaters of the ginning machinery.

9.4 Fibre mix quality-yarn end breakage relations

Though, the mechanism of fibre breakage is a complex phenomenon, in this research work, a positive correlation is found between the fibre quality index and yarn end breakage rate for the produced Ne 24 and 36 counts of ring and rotor yarns. That means, by successively changing the proportion of component commercial variety in the mixing, it was possible to observe its contribution to the minimization of end breakages. Therefore, it is concluded that preparing a suitable mix, along with optimum machine parameters settings, allows the spinner to minimize the end breakage rate in both ring and rotor spinning systems.

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Appendix

Appendix A Effect of ginning on length distribution

APPENDIX A.1 Length distribution by number before and after the ginning treatment

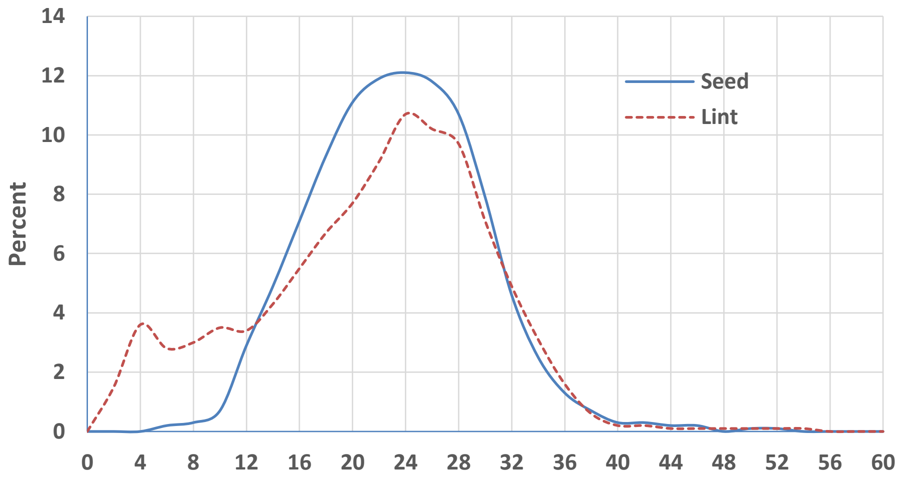


Fig. A.1.1 Acala SJ-2 length distribution by number, mm

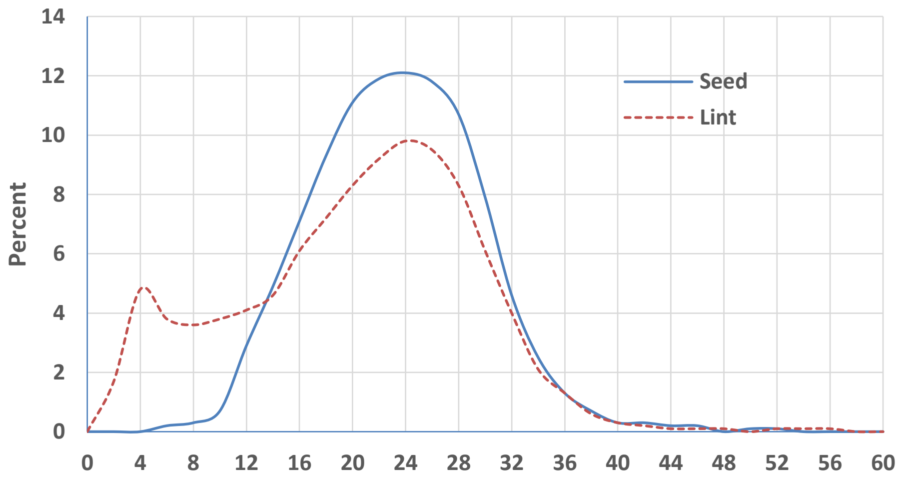


Fig. A.1.2 Arba Length distribution by number, mm

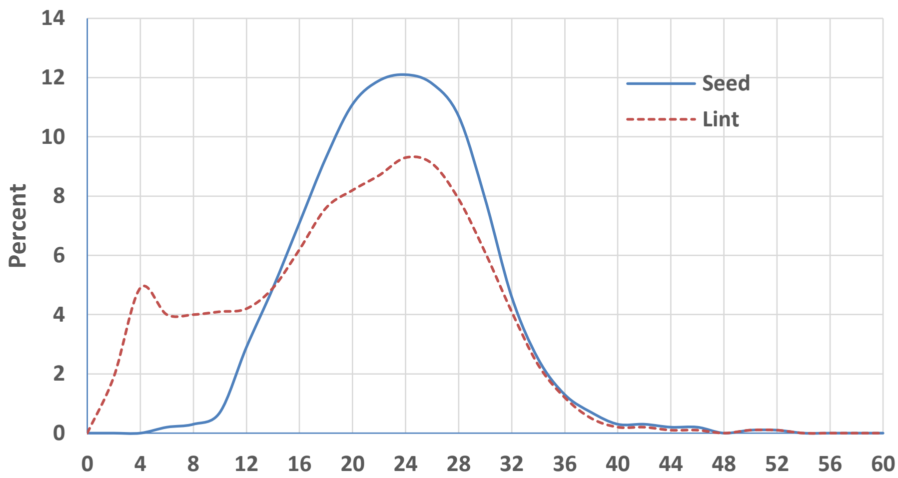


Fig. A.1.3 DP-90 length distribution by number, mm

APPENDIX A.2 Length distribution by weight before and after the ginning treatment

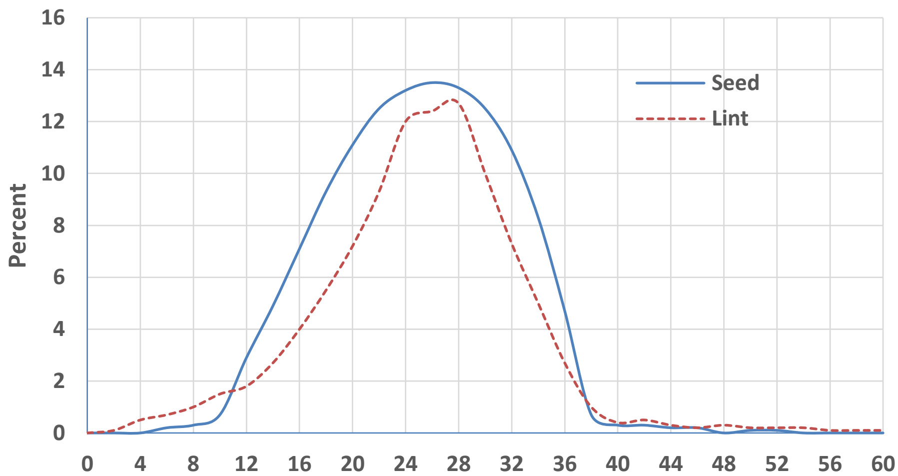


Fig. A.2.1 Acala SJ-2 length distribution by weight, mm

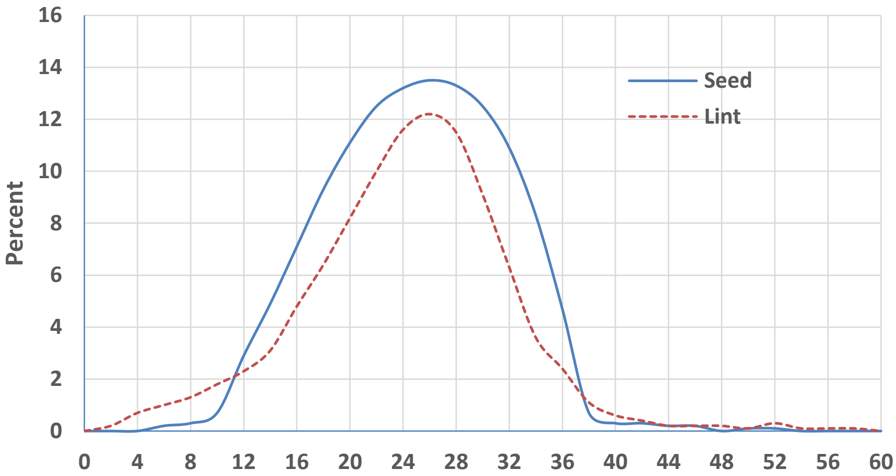


Fig. A.2.2 Arba length distribution by weight, mm

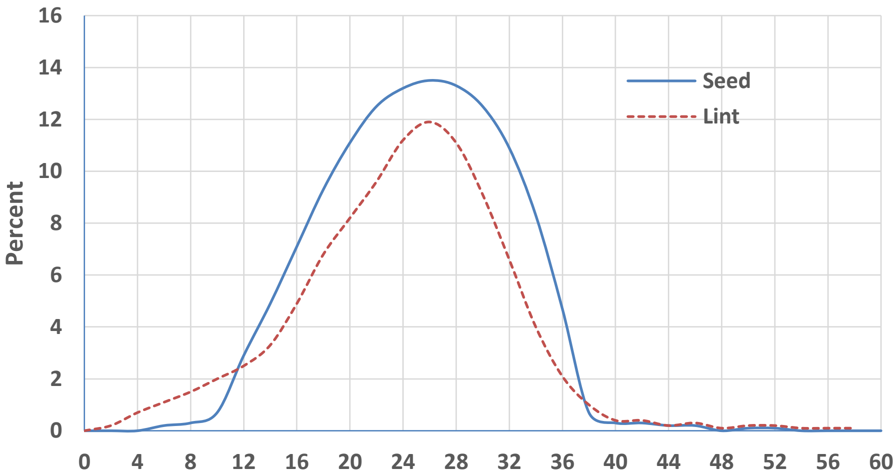


Fig. A.2.3 DP-90 length distribution by weight, mm

APPENDIX A.3 Length distribution by number after the ginning treatment directly taken from the AFIS data

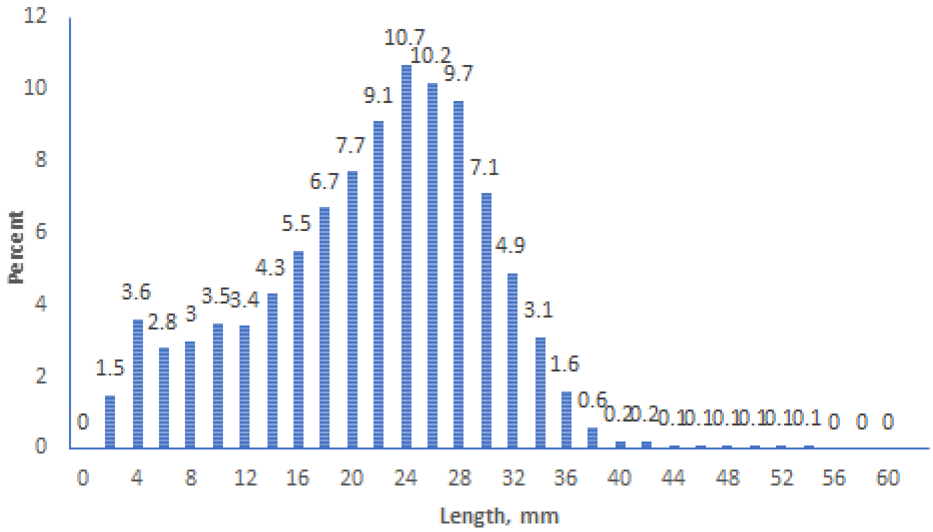


Fig. A.3.1Acala SJ-2 Length distribution by number

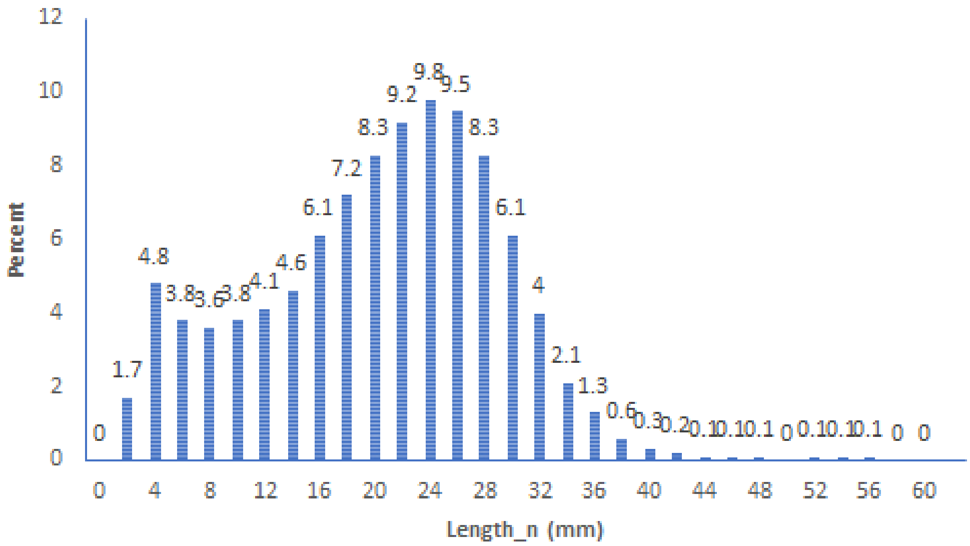


Fig. A.3.2 Arba Length distribution by number

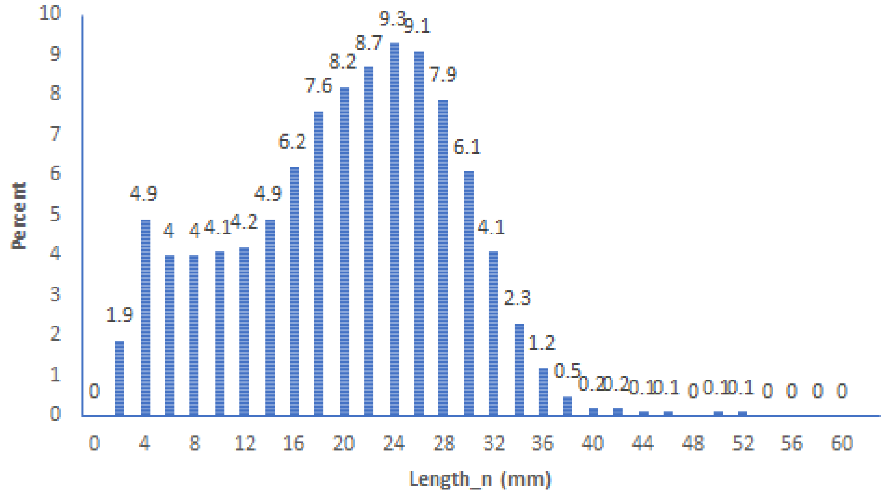


Fig. A.3.3 DP-90 Length distribution by number

APPENDIX A.4 Length distribution by weight after the ginning treatment directly taken from the AFIS data

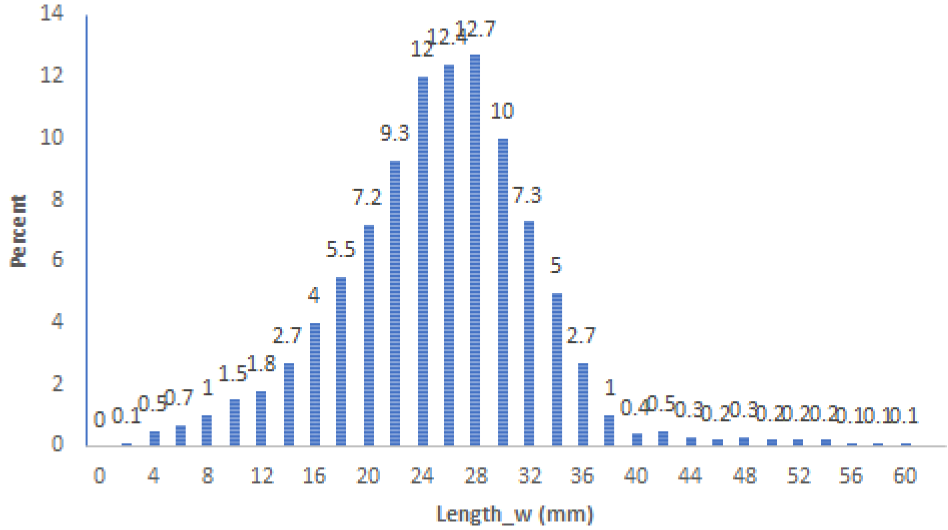


Fig. A.4.1 Acala SJ-2 Length distribution by weight

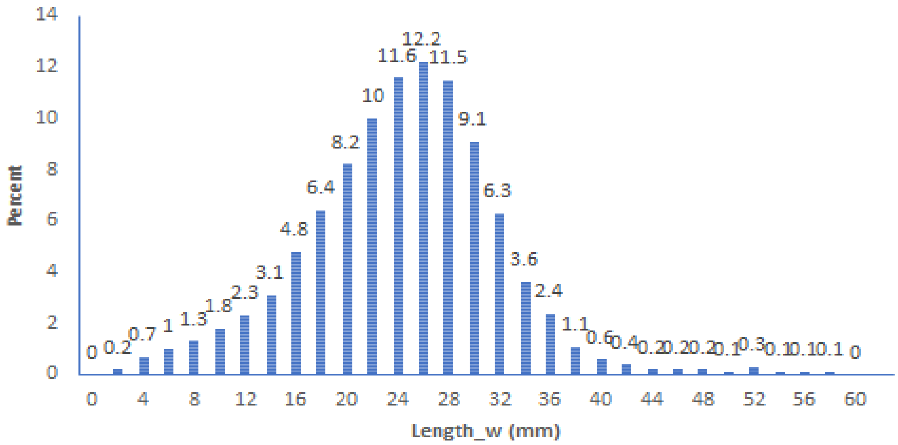
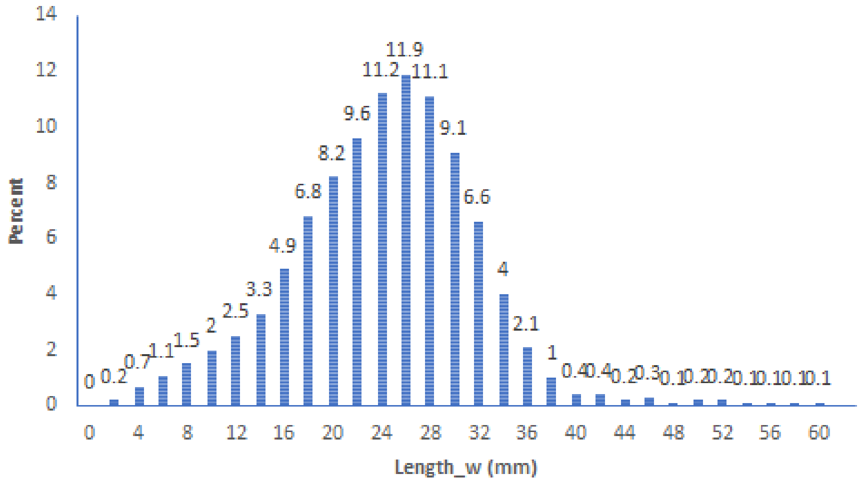


Fig. A.4.2 Arba Length distribution by weight



DP-90 Length distribution by weight

APPENDIX B Analytical hierarchy process (AHP) criteria weighting assigning

APPENDIX B.1 Developing a hierarchical structure

Procedures for fibre quality index measurement using AHP method:
Step 1: Developing a hierarchical structure with the goal at the top level, the attributes/criteria at the second level and the alternatives at the third level,

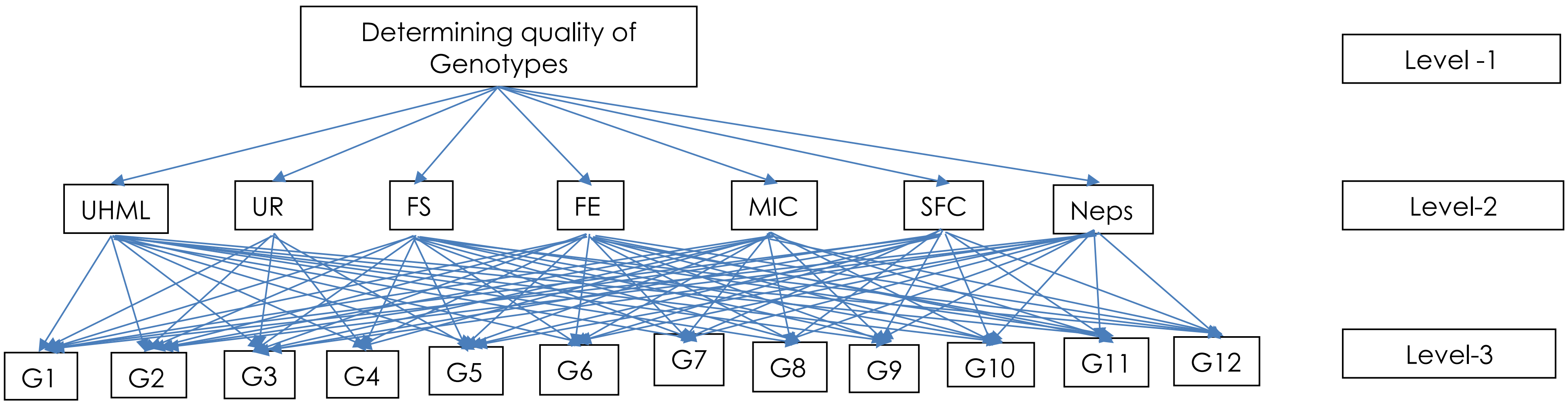


Fig. B.1 hierarchical structure

The method can be used to calculate weights of criteria of fibre quality parameters. Accordingly, we can have a decision Matrix with seven fibre quality criteria: upper half mean length (UHML), uniformity ratio (UR), fibre strength (FS), fibre elongation (FE), fibre fineness (MIC), short fibre content (SFC) and neps level (Neps). We have twelve alternative cotton Genotypes (varieties). Each alternative variety will have own value of criteria (fibre quality constraint) associated with it. For example, DP-90 genotype (G1) will have upper half mean length, uniformity ratio, fibre strength, fibre elongation, fibre fineness, short fibre content and level of neps associated with it, similarly, all other genotypes will have their fibre quality criteria associated with them.

APPENDIX B.2 Determining the relative attributes of criterion

Step 2: Determining the relative attributes of different criteria (fibre quality constraint) with respect to the goal (determining quality of genotypes).
The second step is to create a pair-wise comparison matrix. This pair-wise matrix gives the relative importance of each constraint with the goal. For example, how important is upper half mean length when compared to fibre strength/tenacity during the selection of commercial cotton varieties. This pair-wise comparison matrix can be created with the help of scale of relative importance. In which, 1 is for equal importance, 3 for moderate importance, 5 for strong importance, 7 for very strong importance, 9 for extreme importance. 2,4,6,8 are assigned for intermediate values. 1/3, 1/5, 1/7 and 1/9 are values for inverse comparison. Here we will have a seven cross seven matrix. Because, we have seven constraints. The Values in the pair-wise matrix depends on the importance of a given constraint against its competitor in contributing for the improvement of cotton variety performance during the ginning and further textile processing. The relative weight showing the importance of individual characteristics against its competitors are presented in figure B.2. These weights were obtained by consulting literatures and analyzing of the experts meaning.
The following important points were considered during the pair-wise weightage assignment between fibre constraints.

UHML

The fibre length and its variation play a major role both in the processing of for cotton as well as in the quality of yarn. With regard to yarn quality longer fibres provide greater overlap facilitating higher cohesion among fibres resulting in greater yarn strength. Also, the better overlap among fibres helps the yarn to be spun at a lower twist multiplier thus enabling higher production.

Fineness (Micronaire)

Fibre fineness influences both the strength and irregularity of yarns. For a particular count, as the fibre becomes finer, the number of fibres in the cross-section of the yarn increases. With increase in the number of fibres, the greater will be the surface area of contact among the fibres and higher will be their resistance to slippage during a tensile test.

Fibre strength/tenacity

Fibre tenacity is a major contributor to yarn tenacity. Theoretically, fibre strength makes its maximum contribution to yarn strength when the fibres lie parallel to the yarn axis, i.e. when the yarn contains no twist.

Strength is very often the dominating characteristic. This can be seen from the fact that nature produces countless fibres, most of which are not usable for textiles because of inadequate strength. The minimum strength for a textile fibre is approximately 6cN/tex (about 6 km breaking length). Since binding-in of the fibres into the yarn is achieved mainly by twisting, and thus can exploit at most 30 to 70% of the strength of the material, a lower limit of about 3 g/tex is finally obtained for the yarn strength, which varies linearly with the fibre strength.

Uniformity ratio

The uniformity ratio is used to provide information about the frequency distribution of fibre length. The UR gives an indication of short fibre content, since cottons of low length uniformity ratio are likely to contain a high percentage of short fibres and would be difficult to process and would produce lower yarn quality. Thus, the length uniformity ratio is important to yarn production efficiency as well as yarn strength and evenness.

Fibre elongation

The elastic elongation is of decisive importance since textile products without elasticity would hardly be usable. They must be able to deform (e.g. at knee or elbow) in order to withstand high loading (also during processing), but they must also return to shape. The fibre elongation should, therefore, be at least 1 – 2% (glass fibres), and preferably slightly more. The individual fibre's work-to-break is extremely important to prevent fibre breakage. Stronger fibres tend to have higher elongation which results in better work-to-break which could lead to lower fibre breakage during processing.

Short fibre content (SFC)

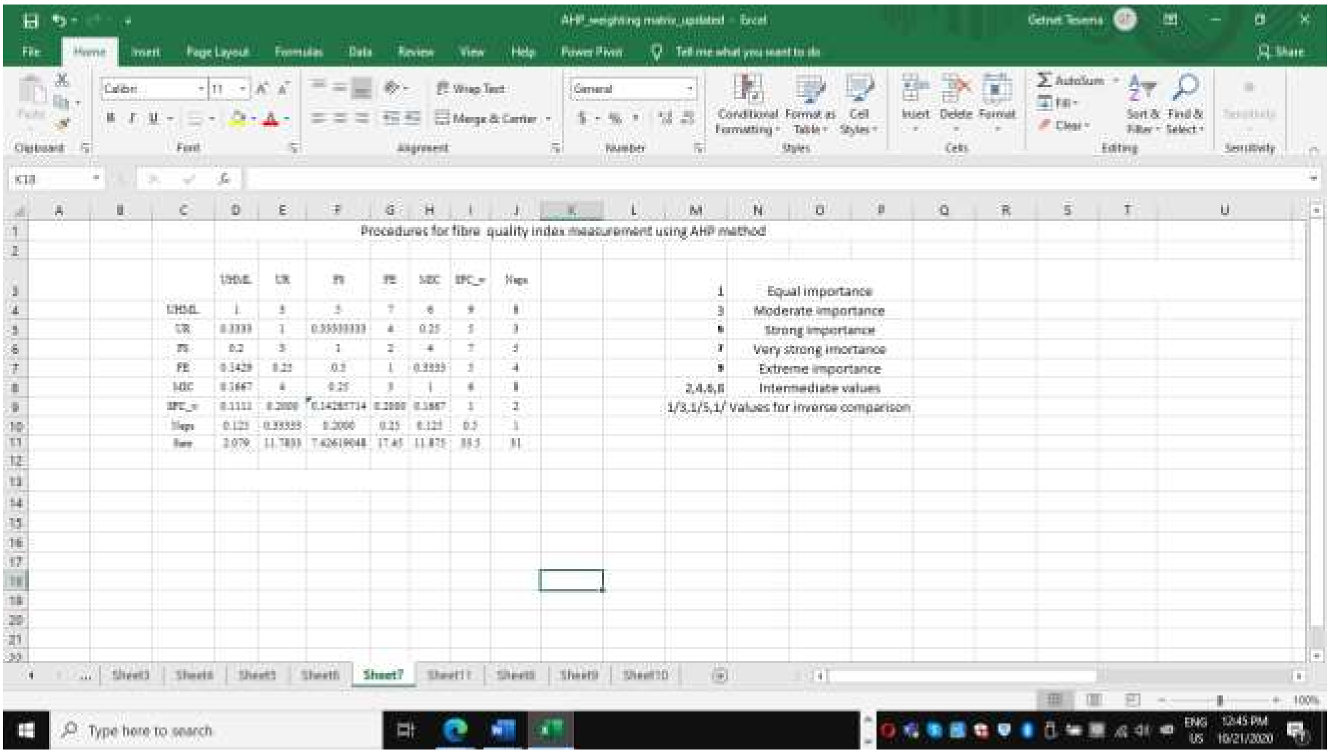
The negative effect of a high percentage of short fibres is usually associated with: Extreme drafting difficulties, Increased yarn irregularity and ends down which reduce quality and increase processing costs, increased number of neps and slubs which is detrimental to the yarn appearance, higher fly liberation and machine contamination in spinning, weaving and knitting operations, and higher wastage in combing and other operations.

Neps

Neps are small entanglements or knots of fibres. In general, two types of neps can be distinguished. They are: fibre neps which are small knots that consist only of fibres, and seed-coat neps which contain foreign particles such as husk, seed or leaf fragments.
Investigations indicate that fibre neps are predominant, particularly fibre neps having a core mainly of unripe and dead fibres. Thus, it is clear that there is a

relationship between neppiness and maturity index. Neppiness is also dependent, exponentially, on the fibre fineness because fine fibres have less longitudinal stiffness than coarser fibres.

A large proportion of neps in raw cotton is produced by the processing method via plucking and hard ginning, and the nep count is substantially increased in the blowroom. The card is the first machine to reduce the nep count to a usable level, and nep-reduction at the card is achieved primarily by disentanglement rather than by elimination. Neps not only create disturbance in themselves as thick places, but also dye differently from the rest of the yarn and thus become clearly visible in the finished fabric.


Procedures for fibre quality index measurement using AHP method

	UHML	UR	FS	FE	MIC	SFC_n	Neps
UHML	1	3	5	7	6	9	8
UR	0.3333	1	0.33333333	4	0.25	5	3
FS	0.2	3	1	2	4	7	5
FE	0.1429	0.25	0.5	1	0.3333	5	4
MIC	0.1667	4	0.25	3	1	6	8
SFC_n	0.1111	0.2000	0.14285714	0.2000	0.1667	1	2
Neps	0.125	0.33333	0.2000	0.25	0.125	0.5	1
Sum	2.079	11.7833	7.42619048	17.45	11.875	33.5	31

1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong imortance
9	Extreme importance
2,4,6,8	Intermediate values
1/3,1/5,1/	Values for inverse comparison

Fig. B.2 Pair-wise comparison matrix

APPENDIX B.3 Criteria weights

Step 3: Calculating the criteria weights

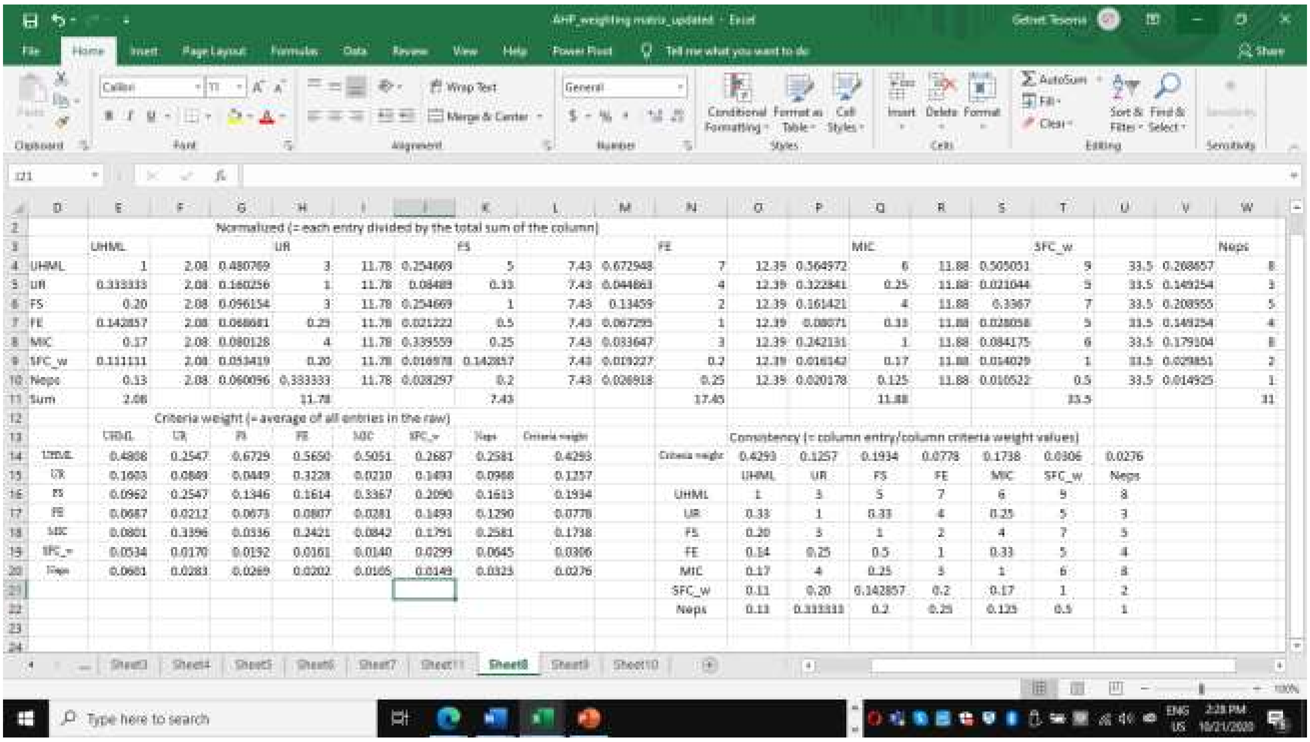


Fig. B.3 Normalized pair-wise comparison matrix and criteria weight calculation

APPENDIX B.4 Consistency index

Step 4: Consistency index calculation

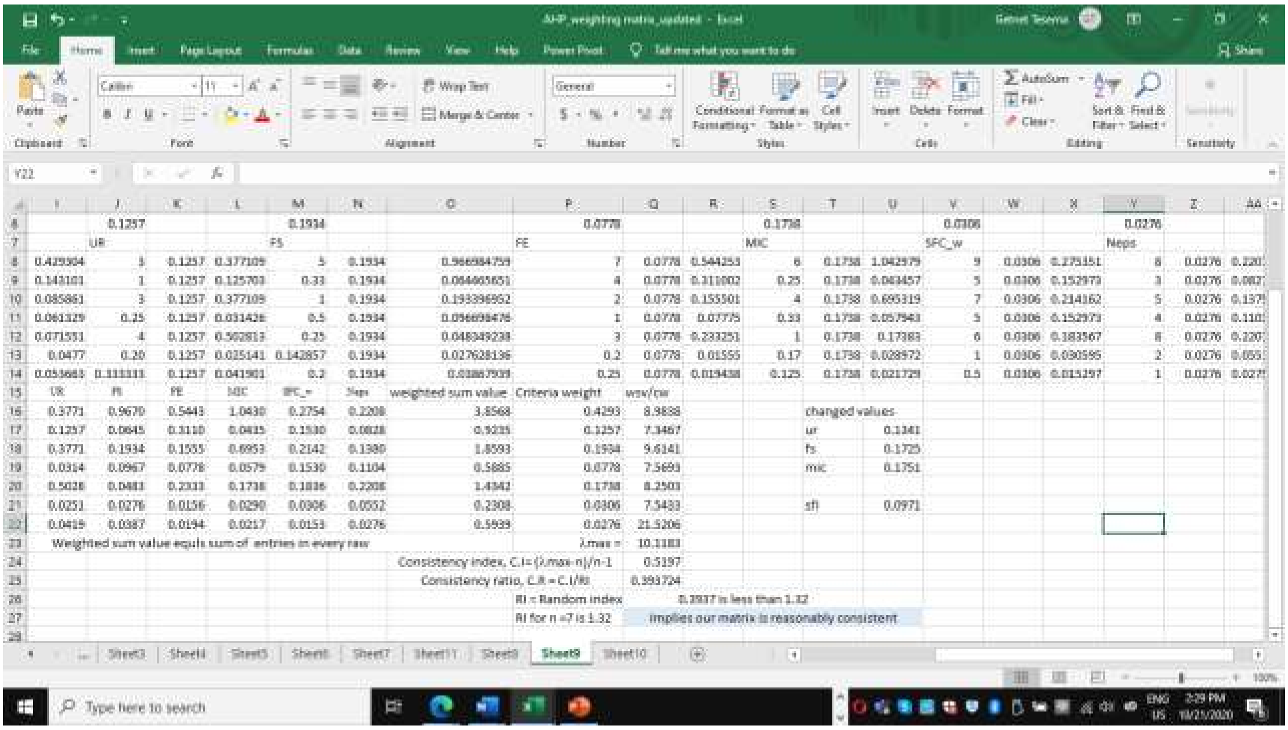


Fig. B.4 Consistency index evaluation

APPENDIX C Application of a single comprehensive testing system: CCS V-5

APPENDIX C.1 Commercial cottons fibre quality evaluation

(using PROMETHEE-GAIA software and 14 CCS (TEXTECHNO CCS VERSION 5, Germany) measured fibre data including absolute tenacity).

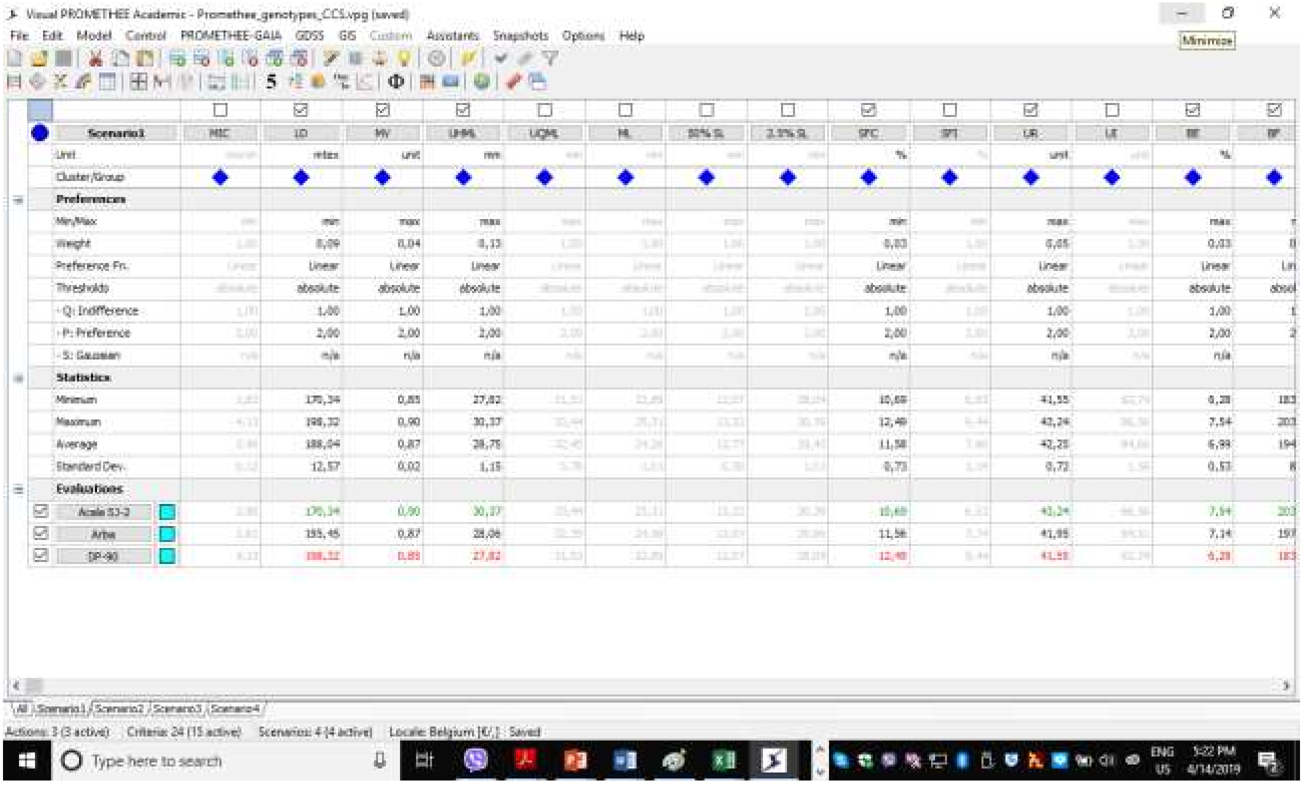


Fig. C.1 Commercial cottons fibre quality evaluation

APPENDIX C.2 CCS V-5 measured parameters and GAIA plane

(distances from UHML)

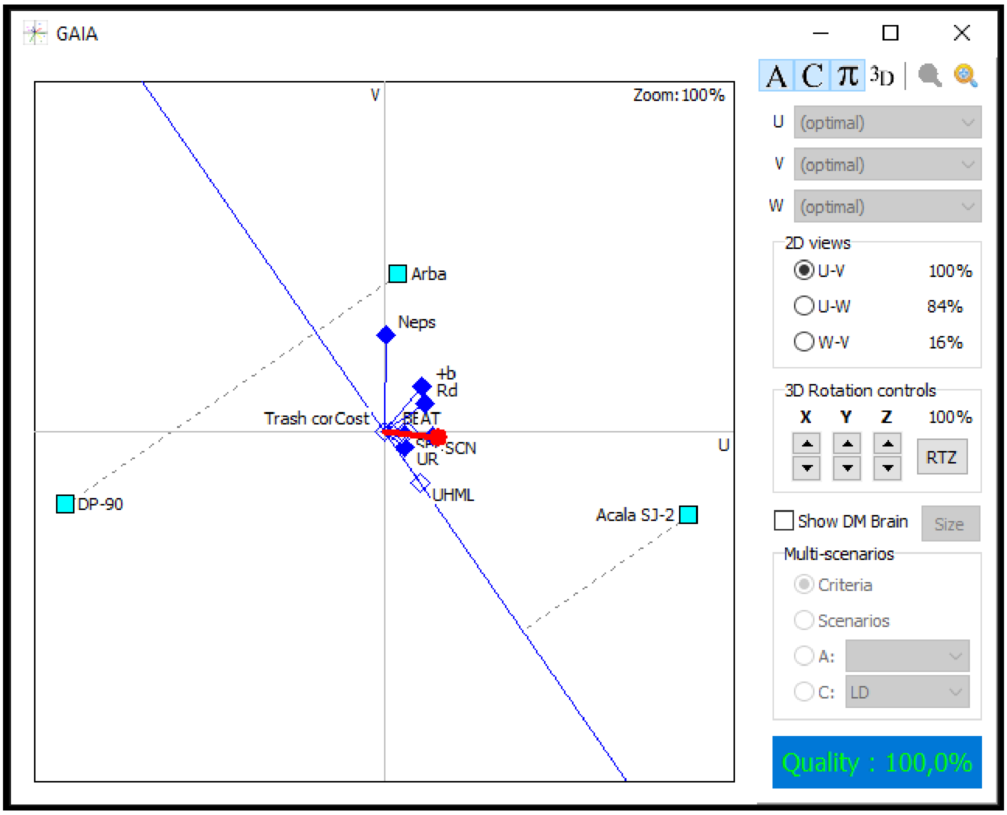


Fig. C.2 Distances from the CCS measured UHML axis (the blue line)