

**Technical Development and Sociological Analysis for a Higher Cotton
Fibre Quality in Ginning**

**Technische Weiterentwicklung und soziologische Betrachtung zur
Erhöhung der Baumwollfaserqualität in der Entkörnung**

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Justin Kühn

Berichter: Univ.-Prof. Prof. h. c. (MGU) Dr.-Ing. Dipl.-Wirt. Ing. Thomas Gries
Univ.-Prof. Dr. phil. Roger Häußling

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Diese Dissertation ist auf den Internetseiten der Universitätsbibliothek online
verfügbar.

Teile dieser Arbeit basieren auf den Ergebnissen der von mir betreuten studentischen Arbeiten. Eine bibliographische Auflistung befindet sich am Ende des Literaturverzeichnis. Zusätzlich wurde RWTHgpt und DeepL zur Unterstützung verwendet.

Parts of this work are based on the results of the student thesis I supervised. A bibliographical list can be found at the end of the Literature overview. In addition, RWTHgpt and DeepL were used for support.

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Short Summary

This thesis addresses the issue of shortened cotton fibres during ginning, which hampers mechanical recycling and reduces overall recycling rates. Long and strong fibres are crucial for multiple recycling cycles. Otherwise, short fibres lead to waste. The ginning process faces challenges such as poor machine settings, wrong moisture management in processing, storage in dusty surroundings and a lack of practical knowledge among workers. The hypothesis posits that better moisture management and structured knowledge transfer (e. g. in a Train the Trainer program) can help reduce fibre length losses in ginning.

The research combines literature reviews, expert interviews and on-site investigations in India and Egypt with lab developments at RWTH Aachen University. It focuses on reliable moisture measurement techniques to preserve fibre length. Direct methods like the oven standard are accurate but slow, while indirect methods, including near-infrared spectroscopy (NIR) and electrical resistance measurement, offer quicker alternatives. Resistance measurement proves most viable for on-line control due to its low cost and robustness. Therefore, this system is further developed and used as a 50 \$ cheap approach for ginner trusted operation. Additional moisturisation system enable fibre gentle processing. Operationally, maintaining optimal moisture levels is critical. Peak fibre strength occurs at around 15% moisture content, while storage above 12% risks quality degradation. The study emphasizes the importance of effective training for ginning mill operators regarding moisture control and machine maintenance.

From an economic perspective, bale pricing is sensitive to quality differences. Quality preservation better preserves prices than increases above standard traded qualities. Implementing a moisture-management system can yield significant financial returns by preserving fibre quality. A cooperative model like Raiffeisen or farmer cooperatives as used in the USA involving farmers as co-owners of ginning mills can enhance focus on premium cotton attributes while fostering continuous improvement through reinvestment in training. Overall, this thesis advocates for simple yet robust measurement tools combined with effective operator training strategies to improve cotton quality sustainably while enhancing economic viability in production environments.

Kurzzusammenfassung

Diese Arbeit behandelt das Problem der Einkürzung von Baumwollfasern während des Entkörnungsprozesses. Dies verringert die Primärqualität und schränkt die Möglichkeit von mechanischem Recycling signifikant ein. Lange und reißfeste Fasern sind die Grundlage für die Erhöhung der Recyclingzyklen. Der Entkörnungsprozess leidet unter schlechten Maschineneinstellungen, Wartungen, Lagerung in staubiger Umgebung und Verarbeitung bei falschen Feuchtigkeitsgehalten. Auch Mangelt es an praktischem Wissen seitens der Maschinenbediener oder dem Vertrauen in technische Lösungen. Die Arbeitshypothese ist, dass ein besseres Feuchtigkeitsmanagement und ein strukturierter Wissensaustausch dazu beitragen, die Fasereinkürzung in der Baumwollentkörnung zu reduzieren. Dies kann durch konsortiale Entkörnungsbetriebe geschehen. Der wirtschaftliche Ansatz legt dies nahe, da Qualitätsdegradationen deutlich stärker (2-3 mal) gewertet werden, als Qualitätssteigerungen.

Die Forschung kombiniert Literaturrecherchen, Experteninterviews und vor Ort Untersuchungen in Indien und Ägypten mit Laborentwicklungen an der RWTH Aachen. Der Fokus liegt auf zuverlässigen Verfahren zur Feuchtigkeitsmessung und dem Feuchtigkeitsmanagement, um die Faserlänge zu erhalten. Direkte Messmethoden wie die Ofentrocknung sind genau, jedoch langsam. Indirekte Messmethoden, wie die Nahinfrarotspektroskopie (NIR) und die elektrischen Widerstandsmessung bieten schnellere Alternativen. Die Widerstandsmessung erweist sich als die praktikabelste Lösung für die prozessnahe Regelung. Sie ist günstig und robust. Daher wird dieses System weiterentwickelt und als vertrauenswürdiger Ansatz für rd. 50 € empfohlen. Zusätzliche Befeuchtungssysteme ermöglichen eine eigenschaftsoptimierte Verarbeitung der Baumwollfasern.

Im Betrieb ist es entscheidend, optimale Feuchtigkeitsniveaus der Fasern zu erzielen, um die Fasereigenschaften anzupassen. Die maximale Faserfestigkeit tritt bei etwa 15 % Feuchtigkeitsgehalt auf. Für die Lagerung von Baumwolle sollten 12 % nicht überschritten werden. Um diese und weitere Faktoren einzuhalten, werden effektive Schulung für Betreiber und Arbeiter hinsichtlich des Feuchtigkeitsmanagements und der Maschinenwartung empfohlen. Idealerweise nach dem Wissensmultiplikator-Prinzip.

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1 Introduction

This Thesis provides solutions for higher cotton qualities after the ginning process. On behalf of increasing recycling quotes, higher virgin fibre length is required. Fibre length preservation plays a major role in fulfilling even two or three cycles of mechanical fibre recycling. Otherwise, short fibre content (SFC) will increase significantly and most fibres will be taken out of the production cycle, which doesn't increase real recycling quotes. Therefore, the goal of ginning fibre length preservation helps to support the Global Sustainable Development Goals (SDG).

An overview of current practices of ginning will be given, based on literature as well as from on-site investigations. Moisturization systems as well as moisture measurement units are investigated and developed to improve the processing conditions of cotton. First, developments are made and checked in lab conditions. Afterwards they are validated on-site in the production facility. The validation for measurements takes place according to the standard moisture measurement method, the oven drying method. The moisture management is validated according to the fibre length distribution after ginning.

This first Chapter will give a short overview about the current situation and the scope and motivation for this research work is provided in Chapter 1.1. This includes the state of the art and specialties. Chapter 1.2 focuses on the occurring deficits of the state of the art and resulting work packages to overcome these downsides. The Approach and procedure to achieve the objectives is displayed afterwards (Chapter 1.3). For a better understanding the content of this thesis, a definition of frequently used phrases which might be unknown or unclear, is given. With this, everybody has the same understanding of the written words. These can be found in Chapter 1.4.

1.1 Current situation and motivation

Cotton is the most important natural fibre and generally one of the most important fibres overall. 26 million tons of cotton are processed every year [Vei22].

To visualize the importance of cotton, Fig. 1.1 shows the production distribution of common fibres.

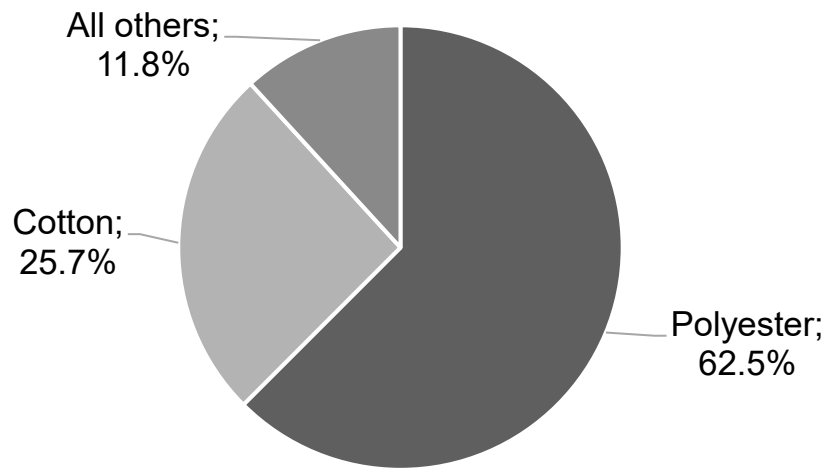


Fig. 1.1: Fibre production share in percentage [Vei22]

Humans are historically used to or by touch of cotton fibres and its properties. Each and every processing step has a significant influence to the fibre quality, properties and therefore the final product specifications. To increase the usability and durability of fibres, long and strong fibres are required. If this is not attained in the virgin fibres, there is no possibility to preserve these properties and fibres can not be recycled and will be downcycled. The influence is shown below:

1. Every processing step influences the fibre quality, especially fibre length and strength, according to compromises of productivity and efficiency
2. At the end of a virgin fibres product lifecycle, in mechanical recycling high fibre length and strength are required to preserve the usability for a second, third and more cycles
3. To achieve reasonable yarn qualities even with recycled fibres, blends of recycled and virgin fibres are made
4. Reduced virgin fibres are required, the higher the still existing quality of recycling fibres is

Another issue comes due to the processors knowledge. Worldwide, there are many illiterate, poor, small scale farmers. In low-wage countries in particular,

cotton is usually harvested by hand on family farms. In India, for example, family businesses own between two and four hectares of cultivated land. Cotton cultivation provides the bare minimum with difficulty and hardship. This usually goes hand in hand with a low level of education. Solely in high wage countries, cotton is machine harvested on huge areas and it is well established e. g. in the USA or Australia.

Farmers are dependent on quick payment in order to be able to make a living and buy food. For this reason, cotton is sold to intermediaries in around 70 % of cases. They offer a significantly lower price than the ginners, but the farmers get paid when the goods are handed over. Ginners usually pay after two or three months, when the processing season is over and the revenue from seed processing has been generated. [KFS22] Ginning is the agricultural necessary process step after harvesting to separate fibres from the seeds and bring out the cotton fibres quality.

Ginning is a low margin and invest sector, as it represents the transition between agricultural production and textile processing [Küh24]. The ginner is interested in high fibre output and the processing of the seeds and oil quality. The farmer and all other processors are interested in good fibre quality. In particular, mass throughput and fibre quality are in most cases negatively correlated. [KFS22] The motivation is to present simple measures to create a high impact on cotton quality. This addresses mostly but not only cotton lint, fabrics and garments.

Contamination is another big issue in cotton processing. Plastic bags are often used for mechanical harvesting. This mechanical processing often leads to plastic and trash contamination. Sometimes, shoes (during pre-compressing by feet) or other personal objects remain in the bales and get pressed. Partly, extra weight is gained by adding earlier planted vegetables or stones in the seed cotton bags. This leads to an enormous cleaning effort in the mills. This comes along with machine investments, personnel, maintenance and quality monitoring costs. Thus, high processing costs occur.

This thesis is intended to contribute to improve the situation of old-fashioned processing techniques, which are still continued due to lack of knowledge of any

better processes. Simple measures of process adjustments and low budget solutions shall be provided. Training concepts should help to ensure that the technologies are also applied and implemented. After experiencing the first deficits, these are further worked out with solutions in the following Chapter.

1.2 Deficits and resulting work packages

The current situation leads to three main deficits, which are worked out as:

1. More fibre shortening in ginning than necessary: due to bad maintenance and setting of the machines, seed cotton fibre experiences more fibre shortening than necessary. In hand ginning trials it can be shown, that more than 10 % fibre length increase could be achieved while performing proper ginning. Meanwhile, neps can be reduced and other properties can be improved for value addition. [KG24]
2. Quality decrease due to wrong storage: cotton fibres have a high ability to change their physical properties according to the surrounding moisture content. If it is stored for too long time in too high relative Humidity, fibre quality decreases.
3. Missing knowledge about proper processing: in some parts of the world and in some levels of the company's hierarchy, information is missing on proper machine settings, maintenance practices and processing conditions.

➔ Therefore, the working hypothesis is: **Losses in fibre length could be decreased with proper moisture- and knowledge management in ginning**

The objective is to overcome the lack of technology and knowledge distribution.

The resulting work packages include an investigation of:

1. machine operations and processing conditions: technological solutions are investigated and approved.
2. knowledge management: which knowledge is missing in different parts of the world and why it is missing. It is investigated as well, why existing techniques are not used.

As a result, this shall lead to higher wages for longer, more uniform fibres, stronger and thinner yarns as well as more resistant products. More detailed approaches to this are delivered below.

1.3 Approach and procedure to achieve the objectives

A first situational overview is provided by expert interviews. Therefore, different ginning locations in different countries are visited. Consultants are addressed as well, who have a standing in the ginning sector. Their knowledge and experience while having visited several ginning mills is very valuable for this investigation. On-site investigations of the ginning mills are helpful for first-hand information, direct insights and documentation. Eight interviews are held in India, supported by Raina Consulting and Associates Pvt. Ltd., Mumbai, India. These are held in October 2021 during the Corona Pandemic. Additionally, all participants in this investigation preferred to speak in Hindi or Marathi (local language in the state Maharashtra). Afterwards, in December 2021 additional four ginning mill visits took place for a personal on-site investigation of the situation, focusing on the visual findings, while having conversations during the visits. In the end of 2023, two transcribed interviews, three ginning mill visits, two cotton weighing centre visits and two field visits took place in Egypt. In the meantime, five expert interviews with internationally respected consultants as well as many talks to spinning mill owners are performed.

The technical developments started after the first investigations in India, in 2022. These are refined as per the ongoing findings in the laboratory of the Institut für Textiltechnik of RWTH Aachen University (ITA) and the on-site investigations in short and agile cycles. The technical developments are described in detail in Chapter 7. To use a common definition of phrases, the following Chapter shows the used definitions in this thesis. The overall procedure can be seen in Fig. 1.2 below.

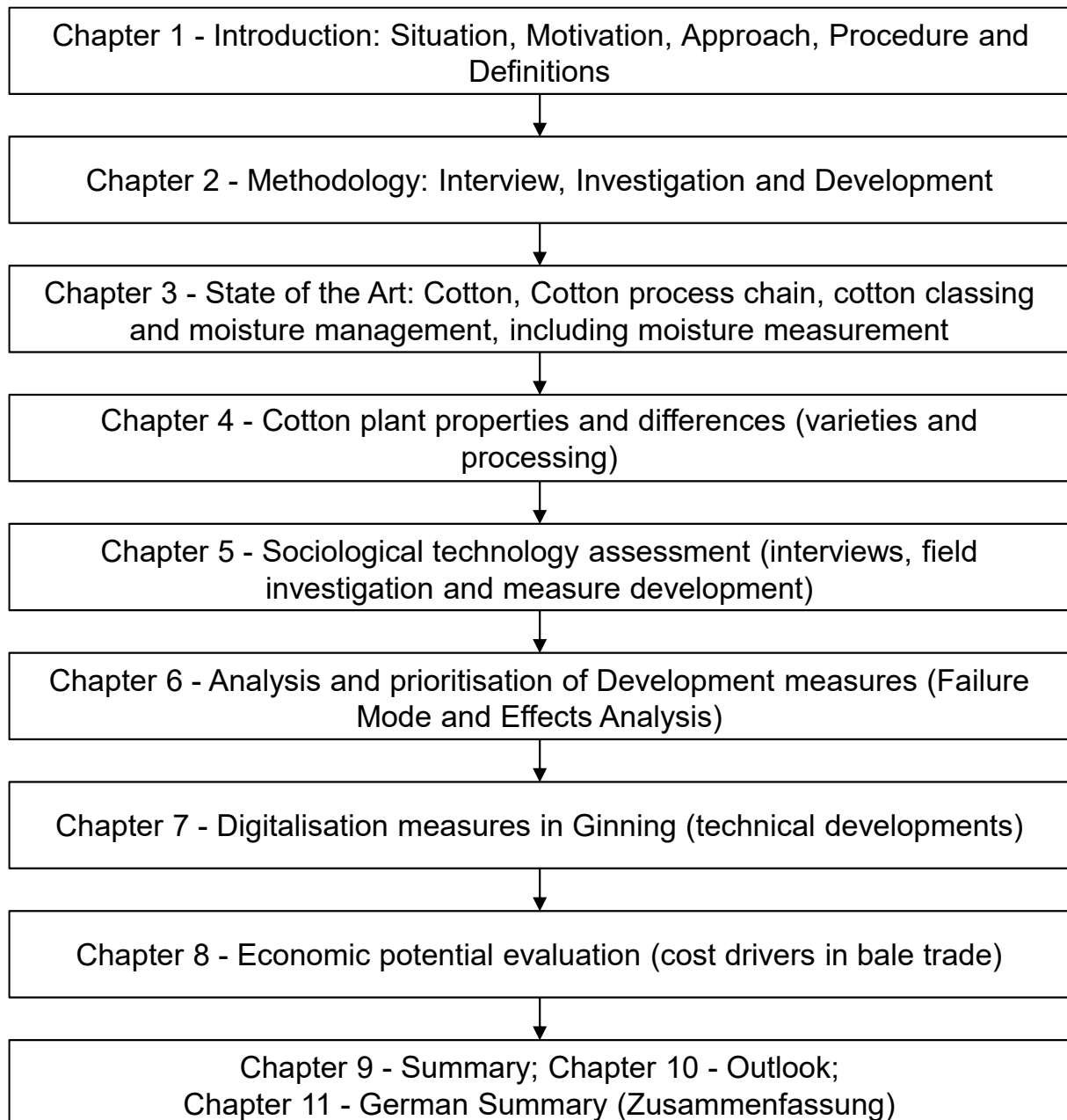


Fig. 1.2: Chapter structure of this thesis

Before diving in the content, it should be stated that methods to be used are literature and patent research, field investigations as well as engineering developments. The procedure of developments is based on engineering standards, which are further described in Chapter 2. Before this, Chapter 1.4 provides a common language understanding for reading this thesis by providing the most important definitions which are partly used different in professional context.

1.4 Word definitions to know

For the definitions of a common word understanding, Tab. 1.1 shows the most important expressions of this thesis and provides a brief description of the author's understanding. Following, all executions refer to this sense.

Tab. 1.1: Expression definition part 1

Expression	Description	Source
Raw seed cotton	Cotton with seeds and uncleaned amount of trash	Acc. To [AM94]
Seed cotton	Cleaned cotton, remaining the seeds	[AM94]
Lint	Long parts of the ginned cotton fibres	[AM94]
Linters	Short parts of the ginned cotton fibres	[AM94]
Roller / Washer	Synonyms for the cylinder in roller ginning machines, as heart of the machine	[PAS10]
Trash	Unintended organic matter in cotton	
Contamination	Unintended plastic parts in cotton	
On-Line	Within the production process	
At-Line	Beside the production process with minimal time losses	
Off-Line	Testing in laboratories (usually with significant time losses)	
On-Site	Visiting the relevant places in person by the author	
Radical Innovation	"Innovation with a high degree of change"	[ISO20]

Tab. 1.2: Expression definition part 2

Expression	Description	Source
Disruptive Innovations	“Innovation initially addressing less demanding needs, displacing established offerings”	[ISO20]
Incremental Innovations	Incremental innovation is at the other end of the continuum to Radical innovation	[ISO20]
GMO	Genetic modified organisms “are organisms (apart from human beings) whose genetic material has been altered in a way that does not occur naturally by mating and/or natural recombination”	[Eur24]
Recycling	“the process of treating things that have already been used so that they can be used again”	[Oxf24]
Downcycling	Using things, that have been used, for lower quality products than before	

After having a common sense of the words used, the methodology used in this thesis is described in the following Chapter.

2 Methodology

This Chapter is divided into the three parts: methods of interviews (Chapter 2.1), investigations (Chapter 2.2) and developments (Chapter 2.3). Interviews and on-site investigations are used for the first analysis of the overall requirements, like lack of trainings and development potentials. The social assessment needs to be examined with locally respected and knowledgeable people. Especially due to the language barrier in many developing countries, interviews with the support of local persons seem to be very promising to get the required information. Within the scope of the technical developments, new results and information shall be actively involved in the ongoing research. Therefore, the development methods show promising perspectives according to the earlier findings. As it is chronological beneficial as well, the description below begins with the interview methodology.

2.1 Interview methodology

Interviews are a helpful and considerable step for understanding the need of technical developments and transferring them, to be used. In social science, there are several steps required to come to the final research method and practice [BB22]. DIEKMANN defines the following four different typologies of research goals [Die08]:

1. Exploratory investigation
2. Descriptive investigation
3. Validation of hypotheses and theories
4. Evaluation studies

Exploratory investigations are used, if there is big uncertainty or lack of knowledge in the area of interest. Then a general knowledge generation is required. In these situations, qualitative methods are likely to be used. For instance, these could be qualitative interviews and unstructured observations. Unstructured means not following a questionnaire to steer the direction of explanation. In general, it is possible to generate research hypotheses out of those investigations. [Die08]

Descriptive investigations are made to quantify expectations instead of analysing the social interconnections. It is mainly used for values like frequency, proportions and average values. Especially in the context of social activities and views, like in case of elections. [Die08]

Validation of hypothesis and theories as well as evaluation studies are made with a given framework and expectations. This should reduce the given uncertainty of qualitative analyses and reduce failures in research operations. [Die08]

These can be called up with more or less structured approaches. The more structured the guideline interview is planned, the less the interviewer is allowed to adjust questions according to the course of the conversation. [Hel11, Fli10]

According to the given parameters, a semi-structured interview is selected as the preferred way of interview set-up. A comparing overview and selection of interviews is described in a following paragraph. After selecting the method, data handling is required. Data technology can be divided in five divisions of handling [Häu19]:

1. Production
2. Structuring
3. Distribution
4. Visualization
5. Data based or even-induced drive of social processes

These steps do not necessarily happen in chronological order or needs to be passed through completely. Some of them could take place more than once, some could be left out, according to the specific situation. Important factors across all of these points are, how the data are presented, who has access to it and how are they understood and by whom. This is the responsibility of the researchers and developers, who generate the data and prepare them for public access. In detail, it is a matter of “[...] appropriateness, low-threshold and manipulation.” [Häu19] To gain a better understanding of the different methods on data creation, a comparison of interview techniques is provided in Tab. 2.1 below.

Tab. 2.1: Guideline-Interview method overview part 1 [Fli10]

Interview-Method & Description	Pros	Cons
Focused interview – for media investigation, criteria are: 1. Not influencing candidates 2. Specific views and situations 3. Wide spectrum of stimulus feedback 4. Personal reference frame	Open, not influencing technique for distortion-free results; wide spectrum of results; deep and personal information	No “right” interview procedure; strong dependence of interviewer’s skills
Half standardized interview – specific development of the guideline-interview; well informed interviewee with concrete answers to open questions	Concrete answers, out of open questions	Potential of biased interviewees, if there is no good introduction
Problem-centered interview – big attention in psychology; Questionnaire with interview stimuli; Marking criteria are: 1. Focussing on a socially relevant obstacle 2. Method developed or oriented according to this obstacle 3. Process oriented in research process and obstacle investigation	Time efficient with short questionnaire	Mixture of description and questions, which might influence interviewee

Tab. 2.2: Guideline-Interview method overview part 2 [Fli10]

Interview-Method & Description	Pros	Cons
Expert interview – Compact interviews, due to time pressure in availability and focussed answers. Three typos of expert interviews: 1. Explorative 2. Systematization of results Theory generation	Very flexible in use; quick answers; good tool in combination with other methods; comparison between different parties and several insights	Very strong guidance necessary for reliable results; switch between expert and private person answering; difficult to find the “right” experts
Ethnographical interview – to be seen as friendly talks on field observations with two aspects: 1. Explicit reason for the conversation 2. Description of the project and reason of those questions to gain understanding and hope for long answers	Very helpful situational answers on occurring questions	High risk of being blocked or non-proper answers, careful opening; short dialogues; hard to plan

In summary, while each interview has its strengths and weaknesses, the expert interview stands out as particularly suited for mechanical developments with limited data bases due to its flexibility, quick response capability and structured approach when guided properly. However, addressing language barriers remains crucial across all methodologies to ensure accurate and reliable data collection.

The flexibility and quick responses in expert interviews fit well within constraints, typically found in engineering. It allows systematic exploration (Explorative),

organization (Systematization) and theory generation which are essential when dealing with limited initial data but requiring structured development pathways. Moreover, social, cultural and other difficulties get reduced, due to the worldwide experience of the experts.

The interviews are conducted to find out the technological needs. Expert interviews are considered as an appropriate instrument for knowledge generation. A technical review is developed in this thesis which is based on a systematic literature research on the state of the art.

Expert interview descriptions in literature always begin with a definition of the status of an expert. For this thesis, experts are the available consultants and mill managers in the cotton sector. Those contacted for this thesis have 35+ years' experience in ginning and processing.

The corresponding interviews for this thesis shall be carried out as semi-structured guideline interviews. Guideline interview means, there is a questionnaire which gives an orientation and to keep the interview likewise and comparable. Semi structured means that there is a flexible part in it which could be described as *go with the flow*. If there are specific aspects the experts want to mention or a specific subject area the persons refer to, it is accepted to dive deeper into this. Moreover, questions will likely be added in this field as well. The method of expert interviews seems to be most promising due to the knowledge and structure in the ginning sector. Further information can be found in the corresponding literature. [Hel11, Fli10]

The counterpart is the interviewer himself and how he is recognised during the interview. This is very important for the behaviour of the interviewee, how he talks and how deep he dives into technical details.

Moreover, the cultural background, social status, experience and all those things influence the interview as well as the content and outcome. Even the setting and the location of the meeting influences the outcome of an interview a lot. [Hel11] One can only see, what he expects. That means, humans recognize signals and

actions, they expect, others will be dismissed. The schematic procedure of an interview is [Die08]:

1. Preparation of a questionnaire and intention analysis
2. Meeting organisation
3. Meeting processing, including recordings or taking notes
4. Minutes the meeting
5. Evaluation and interpretation

In the notes, subjective findings within the interview situation about the atmosphere, way of talking and development of the interaction should be covered. Self-speaking should be edited by the date, time and place of the meeting. The interpretation can be divided in coarse- and fine analysis, shown in Tab. 2.3 [LD04].

Tab. 2.3: Key points coarse and fine analysis of interviews, based on [LD04]

Coarse analysis	Fine analysis
Division into interview segments	Word for word analysis
Thematic and sequential structure	Pragmatic-rhetorical aspects of interpretative reality production
Cross-sequence phenomena	Text-local phenomena

Due to the different possibilities of interpretation and way of thinking according to the collected data, it is very subjective. This data evaluation has a strong tendency to the person working on it. Researcher interprets what other people already interpreted and wrote down, that there is always subjectivity in seemingly objective topics and facts. Just by pointing out key areas while leaving out not that important seeming areas. [Häu19] Therefore, the scientists, researchers and developers have to be aware of their responsibility and power. It needs to be sensitively considered, whether and how to bring in their own thinking to the content of on-site experts and former research. As this is similar for technical developments, methodical procedures are very important. The investigation methodology is explained and selected in the following sub-Chapter.

2.2 Investigation methodology

As in interviews, in investigation methodologies, there are several methods available for the investigation itself, comparison and evaluation of the most urgent tasks. This thesis focusses on the methods of *Industrie 4.0 Maturity Index* from *acatech*, digitalisation Guidelines from *Verband Deutscher Maschinen- und Anlagenbauer - VDMA* (English: *German Engineering Federation*), *Digital Now* by *Bundesministerium für Wirtschaft und Klima - BMWK* (English: *Federal Ministry of Economic Affairs and Climate Action*), *Smart Factory Guide* by *Mittelstand Digital Zentrum - MDZ* (English: *SME digital centre*), *Platform Industry 4.0* by BMW and BMFT. For the selection of most urgent topics, Failure Mode and Effects Analysis (FMEA), Fault Tree Analysis (FTA), Event Tree Analysis (ETA) and Hazard and Operability Study (HAZOP) is described, compared and selected.

The *acatech Industrie 4.0 Maturity Index*, developed by the German Academy of Science and Engineering, provides a structured framework for assessing and advancing digital transformation in manufacturing enterprises. The model systematically evaluates multiple dimensions, including information technology infrastructure, organizational structure and workforce competencies. With this, *acatech* generates a comprehensive picture of a company's readiness for Industry 4.0. By applying this index, companies can identify deficiencies in their digital capabilities and obtain targeted recommendations for improvement. The framework is particularly valuable for small and medium-sized enterprises (SMEs), as it outlines pragmatic pathways for progressing from initial stages of digitization to fully integrated and autonomous production systems. [SAD+17]

The VDMA, Germany's Mechanical Engineering Industry Association, publishes a series of guidelines, like the **Digitalization Guideline**, intended to facilitate digital transformation in the sectors of mechanical and plant engineering. These publications address key technological and organizational themes, including data management, artificial intelligence applications and process optimization in manufacturing environments and are designed as practice-oriented instruments to support the effective implementation of digital technologies. By incorporating

case studies, checklists and best practices drawn from leading industrial companies. The guidelines provide empirically grounded and actionable insights that are relevant to both SMEs and larger organizations. Their structured recommendations enable companies to mitigate risks associated with digitalization projects, enhance implementation efficiency and ultimately strengthen competitiveness within increasingly globalized and digitally integrated markets. [AF16]

The SME Digital network provides similar publications, designed for SMEs in advancing their digital transformation, as the **Smart Factory Guide** for example. These resources include thematic brochures on IT security in production environments, cloud solutions for SMEs and introductory applications of artificial intelligence, among other topics. The materials are deliberately formulated in accessible language and supplemented with practical examples, ensuring their relevance to the specific requirements and constraints of SMEs. By engaging with these publications, companies are able to develop a clearer understanding of complex digital technologies and to translate this knowledge into concrete, firm-level applications without the necessity of prior in-depth expertise. [RJG22]

Platform Industry 4.0 is a national collaborative initiative that unites stakeholders from industry, research and government in Germany with the aim of advancing smart manufacturing and the broader digital transformation of production systems. Among its outputs are a series of practice guides that provide actionable insights into the application of standards. This covers empirical case studies demonstrating the successful deployment of Industry 4.0 solutions. These documents enable companies to draw upon established implementation approaches while ensuring alignment with national regulatory frameworks and international standards governing the integration of automation technologies. Consequently, the practice guides function as authoritative instruments that reduce uncertainty in digitalization projects and accelerate the dissemination of innovative practices across diverse segments in manufacturing. [FF25] Tab. 2.4 shows a detailed comparison of those four methods.

Tab. 2.4: Digitalisation development method comparison [AF16, SAD+17, RJG22, FF25]

Method	Advantages	Disadvantages
acatech Industry 4.0 Maturity Index	Comprehensive, structured assessment of digital readiness at multiple dimensions; clear roadmaps to higher maturity levels; made for all enterprise sizes	Application can be resource-intensive & time-consuming, requiring significant data collection and analysis; may overwhelm SME with limited expertise or capacity
VDMA Digitalization guideline	Practical, industry-specific recommendations and case-based best practices; written with strong applicability to manufacturing contexts; useful for risk mitigation and process optimization	Content too general or broad for highly specialized industries; relies on companies to adapt recommendations to their own contexts without much prescriptive detail
SME Digital Network Smart Factory Guide	Offers accessible, easy-to-understand guides tailored to SMEs; includes practical examples and introductory materials on complex topics (e.g., AI, IT security, cloud computing); low entry barriers for non-experts	Technical depth is limited compared to academic or specialist literature; may not provide sufficient detail for advanced digitalization strategies in larger or highly digitalized companies
Platform Industry 4.0 Practice Guides	Presents real-world use cases aligned with established frameworks such as RAMI 4.0; supports standardization and compliance with international norms; reduces uncertainty through concrete implementation examples.	Strong focus on the German context, which may reduce transferability to other regulatory or industrial environments; sometimes emphasizes conceptual frameworks over operational details.

According to those presentations, advantages and disadvantages, the Smart Factory Guide is the most promising tool for ginning mills. The guide is made for SMEs, what ginning mills, especially in low wage countries, are. The Smart Factory Guide promises high efficiency, as it is particularly developed for this target group. It enables early stages in digitalization measures, while considering the mental change for employees as well.

The Smart Factory Guide supports companies in preventing quality-related failures, thereby increasing both effectiveness and efficiency. This approach uses analytical complexity management to identify the causes and effects of problems within production systems. The guideline is divided into eight phases. It starts with the requirements analysis phase, which provides an overview of known issues as well as potential optimization and solution strategies for the company. Next, the process modelling phase offers a detailed description of the production system, enabling root cause analysis for production failures and allowing for the creation of a process data model. [RJG22] The Smart Factory Guide represents the overall structure, in which this thesis is structured. Therefore, the content of the procedure can be found in those different Chapters:

- Requirements in Chapter 3 and 4
- Process modelling in Chapter 5
- FMEA and critical path analysis in Chapter 6
- Concept overview, selection, implementation and validation in Chapter 7

For the evaluation, **Fault Tree Analysis** (FTA) is a systematic, deductive method used to analyse the causes of system failures. The process begins with defining a "top event," which is usually an undesired failure or accident in the system. For the analysis, logic symbols, such as AND and OR gates, connect different events that could lead to this top event. Each branch of the tree represents a possible combination of failures or errors that could cause the main problem. Therefore, it is a logical, mathematical approach. The construction of the fault tree involves breaking down complex systems into smaller parts and identifying how failures in these parts can combine to produce larger issues. By mapping out all possible failures and their combinations, FTA helps identify

weak points in the design or operation. One advantage of FTA is its ability to visualize complex relationships between different causes of failure. It also supports decision-making by highlighting critical components where improvements would reduce risk most effectively. [VGR+81, RBH20]

Event Tree Analysis (ETA) is an inductive method used primarily for safety studies in engineering fields, like nuclear energy or chemical processing. Unlike FTA, ETA starts with one initiating event, such as equipment failure or human error and systematically explores all possible outcomes that might follow. Both are selected, as these branches like chemistry and nuclear energy have a great failure management. In ETA, analysts create a tree diagram that branches at every point where a safety function or barrier could succeed or fail after the initial event. Each path through the tree represents one possible sequence of successes or failures leading to different consequences, from safe recovery to severe accidents. For example, if there is a fire in a factory, ETA would look at whether fire alarms work properly. If not, whether sprinklers activate; if not, whether evacuation succeeds and so on. Each outcome can then be analysed for probability and severity. ETA helps identify weaknesses in safety barriers by showing how their failure can escalate problems. It also assists in prioritizing improvements based on which paths lead most often to serious consequences. ETA requires accurate information about how often each barrier fails and may miss rare but important scenarios if not carefully constructed. [RBH20]

Failure Mode and Effects Analysis (FMEA) is a proactive tool used during product design or process development stages across many industries such as automotive manufacturing, aerospace engineering, healthcare and electronics production. The FMEA process starts by listing all components or steps within a system or process. [RBH20] For each item listed [RBH20]:

- Possible failure path ways (*failure modes*) are identified
- The effect of each failure is described
- Causes for each failure mode are considered
- Current controls that might prevent detection are reviewed

After finding those failures, they get evaluated and rated. Three scores are assigned: Severity (how bad is the effect?), Occurrence (how likely is it?), Detection (how likely will we notice before harm?). Each of those scores is rated between one and ten. Multiplied with each other, they form a Risk Priority Number (RPN). [RBH20] A comparison of these mechanisms is shown in Tab. 2.5.

Tab. 2.5: Failure evaluation method comparison [RBH20]

Method	Advantages	Disadvantages
Fault Tree Analysis (FTA)	Visual representation; effective for complex systems; supports quantitative risk assessment.	Requires detailed system knowledge; can become complex quickly; less effective for identifying unknown failures.
Event Tree Analysis (ETA)	Good for analyzing accident scenarios; identifies success/failure paths; supports quantitative analysis.	Can result in very large trees with many branches; relies on accurate probability estimates.
FMEA	Structured approach; helps prioritize risks; widely used in automotive, manufacturing, healthcare.	RPN calculation can be subjective; may overlook complex interdependencies; time-consuming for large systems.

FMEA has several strengths, mentioned before. Additionally, FMEA focus on single failure influences while considering the mechanisms which lead to those failures. It is more easy to apply, as most failures do not interact with each other in ginning, as in more complex industries like aerospace. FMEA serves as a preventive risk assessment tool widely used across industries to detect, analyse and mitigate potential problems early in product or process development [Pfe21, Bel25]. To dive into details of comparison and urgency of further developments, failure modes and effects analysis (FMEA) together with the risk priority number (RPN) are selected. The FMEA promises a general and overarching comparison and selection according to the highest impacts and risks, visualized by the RPN.

FMEA can be divided into Design FMEA (DFMEA), for system functions and Processes (PFMEA) and for manufacturing steps. In PFMEA, the type of occurring failures and causes are addressed. Moreover, defect components are investigated according to arise, likelihood and reliability of detection. The PFMEA

process involves seven structured steps beginning with structural analysis, mapping relationships between processes and continues through functional analysis to failure identification. Each failure is rated by occurrence (O), severity (S) and detection probability (D) on a scale from 1-10. By multiplying those numbers, their product is the RPN value. The higher the RPN (0 to 1,000), the more severe or likely the risk. For ginning specifically, even minor process failures can significantly affect fibre quality. Therefore, FMEA helps highlight critical influences on fibre properties so that effective preventive measures can be proposed. [HS19, Pfe21] For the next step of development, the methods described below can be used.

2.3 Development methodology

The development methodologies mentioned here shall provide a structured procedure for gaining fundamental developments. *TRIZ*, *Scrum* and *Design Thinking* are examples for creative techniques, requiring different knowledge and effort. Experience has shown *Scrum* to be a promising approach in software development. Starting with Scrum, these methods are described below.

TRIZ is the theory of inventive problem solving (originally Russian: *teorija razreshenija izobretatelskih zadach*, short TRIZ). [IPP13] TRIZ is based on the paradigms of [EN19]:

- Contradiction
- Perfection
- Functionality
- Using resources

These paradigms lead to a four-step process, which is described below [EN19]:

1. Problem description
2. Matching and comparing of the general problem to TRIZ problems
3. Finding TRIZ solutions
4. Development of ideal solutions for issues

In Fig. 2.1 the TRIZ process is shown schematically, in comparison to other problem solving practices which do not dive deeper into problem investigations.

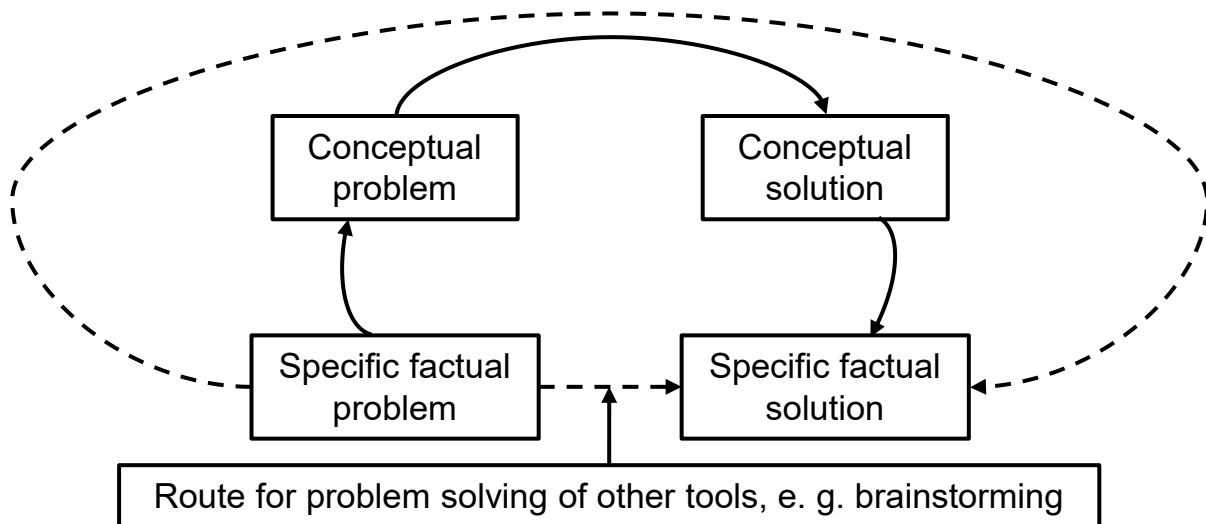


Fig. 2.1: TRIZ approach of problem solving, based on [IPP13]

From an analysis of around 200,000 patents, it was derived that the same problems were solved with solutions from a set of 40 fundamental solution principles. The specific problem to be solved, which is described in step one, is generalized into a conceptual (generic) TRIZ problem during the second step of the TRIZ process. The generic TRIZ problem is then matched with one of 76 TRIZ standard solutions. From this solution, one can be derived a specific solution for the problem to be solved, with the help of the effect database. [IPP13]

Scrum is a framework which helps to gain value through adaptive solutions. The name is inspired from a Scrum in football. The environment inside this framework is characterized by [SS20]:

- Product owner: complex problem and orders work into a product backlog
- During a sprint: Scrum teams turn a part of work into an increment of value
- Scrum team & stakeholders: evaluate results & adjust them for next sprint
- Repeat

The framework defines the parts required for implementation of the theory but is defined by the user. It is an iterative and incremental approach for optimization and risk control. It is built on transparency, inspection and adaption. [SS20]

The Scrum team consists of one Scrum Master, who manages the process, one Product Owner, who defines technical requirements and prioritizes them and Developers, who are responsible for developing a product (cf. Tab. 2.6) [SS20].

Tab. 2.6: Scrum team members [SS20]

Team member	Accountabilities
Developers	Creating Sprint Backlogs, a plan for the sprint; Definition of task completion; Daily plan adaption towards Sprint Goal; Hold each other accountable
Product Owner	Communication and development of Product Goals Creating, ordering and communicating Product Backlog items; Ensuring transparency, visibility and understanding
Scrum Master	Coaching team members in self-management and cross-functionality; Help with creation of high-value increments; Removing impediments; Ensuring that events are productive, on time and positive

It is a small team of maximum ten professionals without sub-teams or hierarchies. It is responsible for all product-related activities, like stakeholder collaboration, research and development, verification and all other product related activities. [SS20] The most important part of *Scrum* are Sprints (cf. Fig. 2.2).

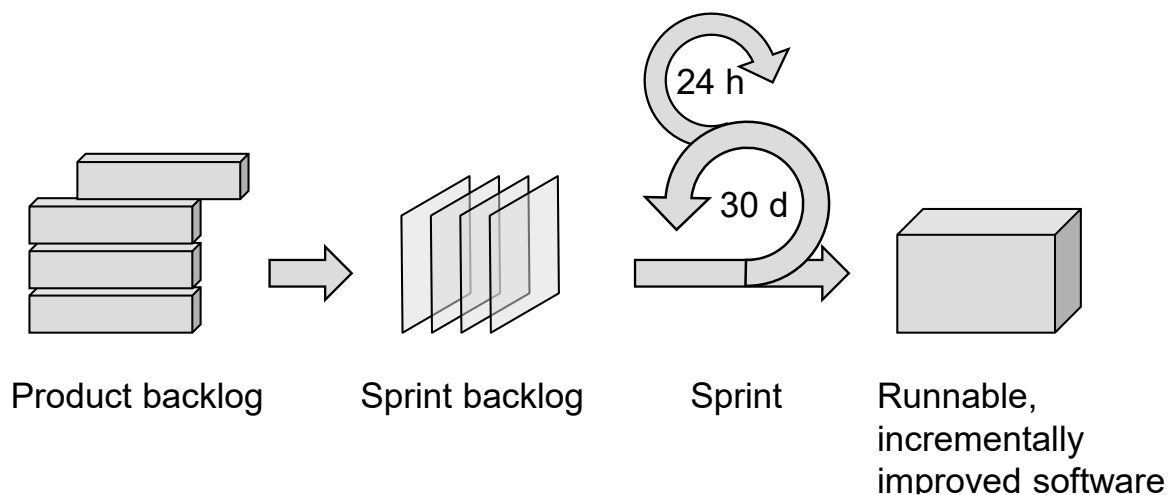


Fig. 2.2: Scrum sprint cycle [Sei17]

Sprints have a fixed length of up to one month and are followed immediately by the next Sprint. The outcome of every sprint is a usable product. During a Sprint all the work to achieve the product goal is done and there are no changes made, which endanger the sprint goal or quality. They enable predictability by the possibility of adaption once a month. The sprint review is to evaluate the outcome of the sprint to adapt. The team presents their progress to stakeholders and

discuss what was accomplished and what to do next. Further evaluation is done during the Sprint Retrospective to increase quality and effectiveness. [SS20]

VDI 2221 guideline is published by the Association of German Engineers (German: *Verein Deutscher Ingenieure*, short VDI) in 1986. VDI 2221 has a fixed structure, shown in Fig. 2.3.

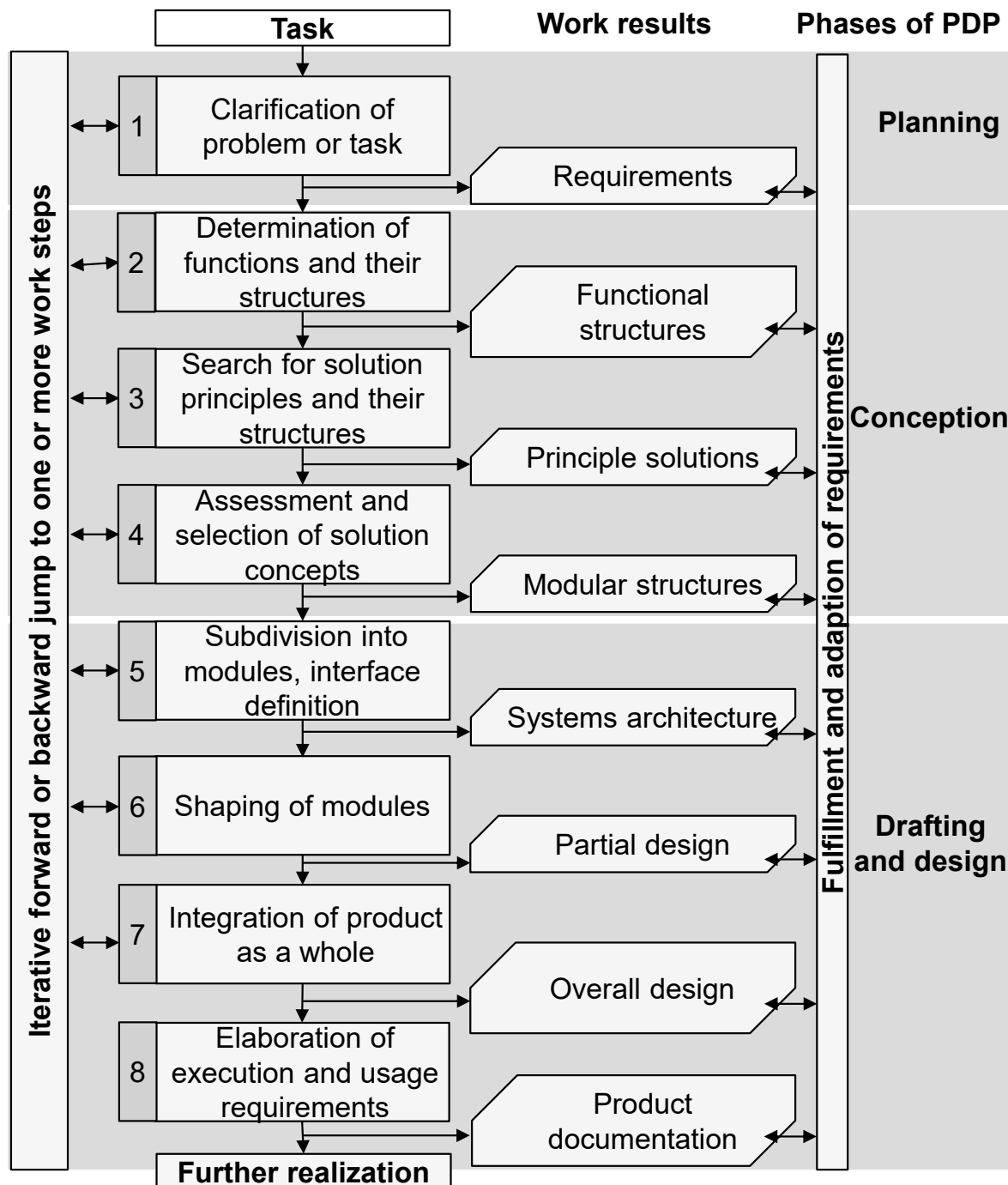


Fig. 2.3: Process overview of VDI 2221, based on [VDI19a, GEH+20]

The VDI procedure describes the methodology for developing and designing technical systems. The core idea behind VDI 2221 is that successful product development requires a logical sequence of steps. The guideline divides the engineering design process into distinct phases, each with specific objectives, tasks and results. This systematic approach supports teams in documentation of their progress, make informed decisions and communicate effectively. In this framework, it is constantly updated to stay up to date. Updates are especially influenced by practical use, science and teaching. [VDI19a] Therefore, agile concepts are slowly being introduced. It consists of a static procedure to generate design solutions.

In **Design Thinking** in particular, the diverging and converging approach (see Fig. 2.4) can be found in numerous literatures as well as in the ISO 56000 standard family for innovation management.

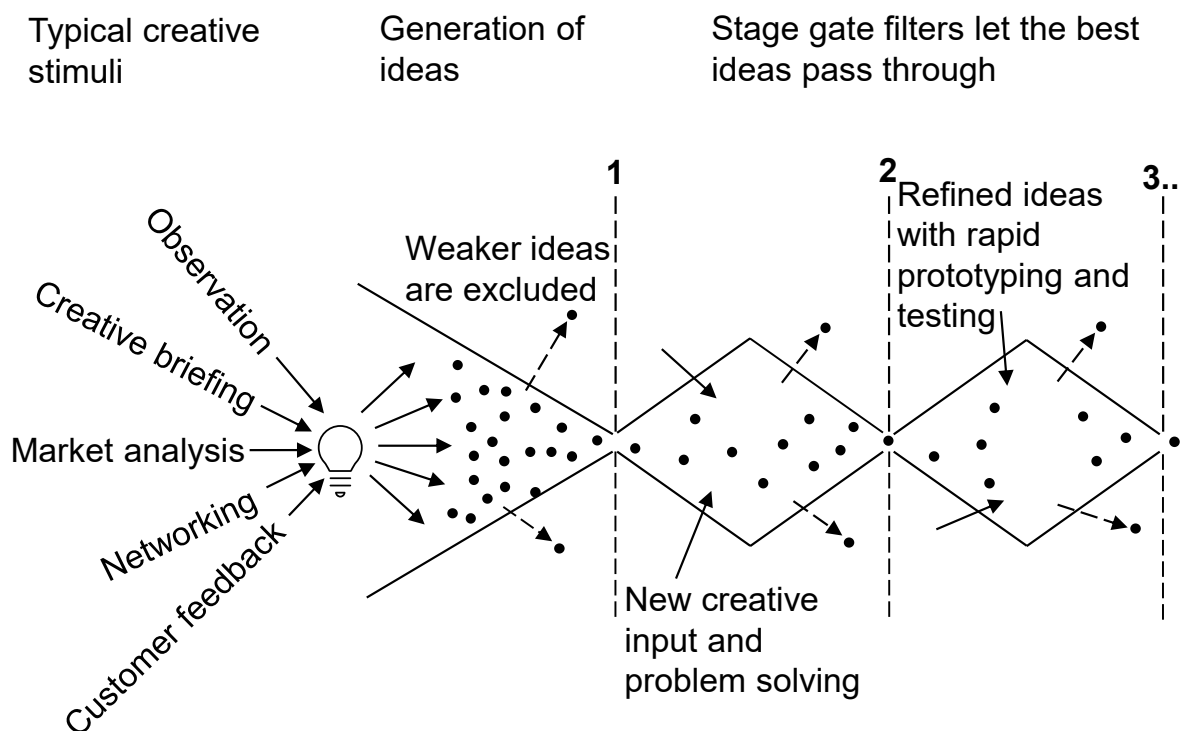


Fig. 2.4: Typical stage-gate idea refinement and selection process [Küh20]

Shown above is the start of an *idea management process* with subsequently applied divergent and convergent thinking. In addition, it becomes clear that

various creative stimuli can be decisive for the generation of ideas and that these have a significant influence. This is combined with intermediate filter stages. These are represented by the numbered, dashed lines. [Küh20]

This method represents a consolidation of existing practical approaches. It represents the latest findings from science and research in the fields of project management and psychology. Just as the naming and description of this method, the description of the idea management process is to be understood as a recommendation and guideline. These are intended to provide a sufficient approach, which allows for potential orientation. Neither the process nor the methods and techniques must necessarily be implemented stringently. Here the maxim applies: Everything that contributes to the radical innovation is allowed. It means that psychological effects of change management and human interaction is still too often underestimated. Just because there is a technical logical impact, it does not mean that the technique is widely and likely used. [Küh20] Nevertheless, Fig. 2.5 shows the procedure according to the *Design Thinking* method.

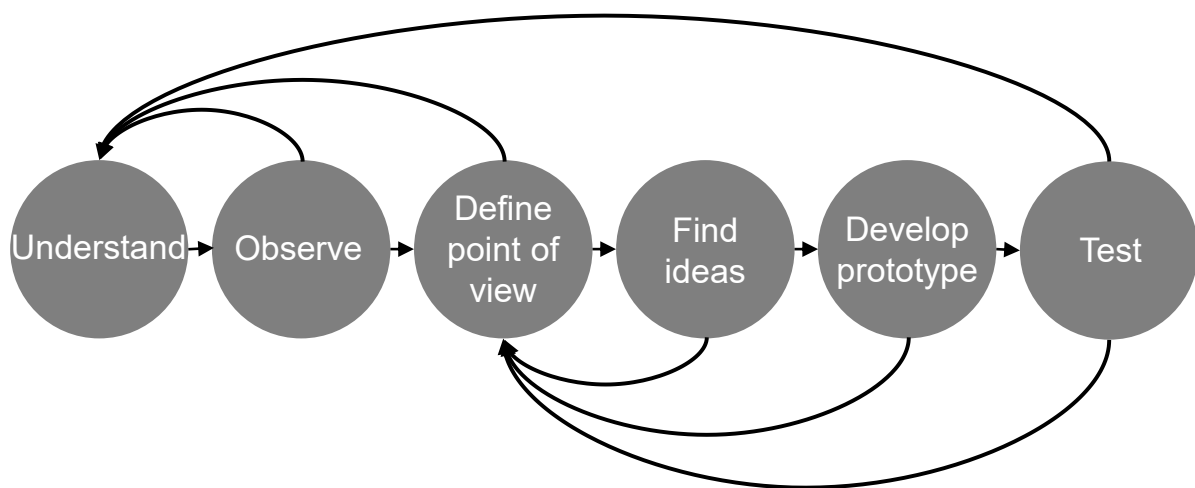


Fig. 2.5: Design Thinking micro cycle [LPL18]

The micro cycle of the *Design Thinking* method including the internal links can be seen. The macro process is characterised by the multiple execution of this micro process under the aspects of divergent and convergent consideration. It

is a practice-oriented approach, which is provided for prototyping on the basis of existing information. [UBP+15]

The latest findings in a *Design Thinking* process immediately influence the entire process, including prototype construction. In relation to SCHNITZLER's statement, the *yes, but* approach is replaced by a *yes and* approach. [UBP+15] This is intended to further promote communication and exchange, but to be less restrictive. This small difference in wording makes a huge psychological difference in willingness of the co-workers within the project.

The **set-based concurrent engineering** (SBCE) is a design principle, mainly driven by Toyota in its early developments. This principle begins with clear system targets and constraints that are translated into allowed parameter ranges for subsystems. Teams explore multiple design alternatives in parallel and keep feasible sets open instead of committing to a single concept early. Knowledge is made explicit through simple models and trade-off curves and it is shared across teams by communicating in ranges. System integration is achieved by finding the intersection of feasible sets across subsystems, followed by progressive narrowing as evidence grows. A single solution is selected at the last responsible moment, when feasibility and cross-system compatibility are proven and detailed design then proceeds quickly.

This process enables high concurrency with stable interfaces and reduces coupling between teams. Early analyses and tests provide evidence before commitment and link milestones to knowledge maturity rather than only to calendar dates. Suppliers are involved early under the same set-based logic to align interfaces and reduce late changes. Compared to point-based design, SBCE delays commitment while increasing shared understanding, which lowers rework and improves predictability. Validated trade-offs and design rules are captured and reused, strengthening organizational learning and accelerating future projects. To become a better overview between the different methods, a short overview is provided in Tab. 2.7.

Tab. 2.7: Method comparison for technical developments [VDI19a, VDI19b, EJK20, IPP13, LH19, CZS+21, SAP+23, MJ18]

Method	Advantages	Disadvantages
Scrum	Adaptability, transparency, frequent feedback, continuous improvement, motivation visibility empirical feedback, simple, promoting individual work, productivity and collaboration; Well defined roles and formal meeting structure, user centered	No description of project risk management difficulties with large projects and large scrum sprints (higher complexity), strong dependence of development team on team members
VDI 2221	Well established in technical developments; well-known from many participants	Based on existing technologies, therefore rather static and slow
TRIZ	Prevents erratic brainstorming, identification and clarification of problems, provides useful and novel solutions, generates more innovative ideas, provides breakthrough innovation, solutions are found fast due to clarifying process	Difficult to adapt to intuitive thinking styles, time needed to implement TRIZ, to many options to approach each system, Requires unusual commitment and enthusiasm, Lack of rigorous standards
Design Thinking	Good overview and suggestions for action; fast cycles and refining practice to adjust the projects outcome; high knowledge creation due to investigations	Might be used wrong by untrained user, no connection between paradigms and suggestions for action, lack of selecting, adapting and using guidance
Set-Based concurrent engineering	Reduces late changes and technical risk by exploring alternatives in parallel, making trade-offs explicit, integrating by intersecting feasible ranges and committing only when evidence is mature, which improves quality, predictability and learning	Can increase upfront cost and coordination effort, requires a disciplined culture and capable suppliers and, if sets stay too broad or decisions are delayed, may slow early phases or lead to indecision

Considering for the method selection, there is a dual-track approach in this project, to gain knowledge from interviews and field investigations, as well as doing technical developments. Due to its knowledge generation approach, combined with refining developments according to later insights, the *Design Thinking* approach is selected as the method to use. The following Tab. 2.8 also contains some techniques that can be used to process the steps.

Tab. 2.8: Suggestion of tools and methods per Design Thinking Phase [LPL18]

Phase	Shortcut to examples of tools & methods
Understand	• Create persona • Insert Hook Canvas • Apply Job-to-be-done • Create future user
Observe	• Fill in empathy map and define a lead user • Perform WH Questions to ask (What? How? Why?) • Check critical assumptions • Need finding conversation with open questions • Possess mindfulness • Use talking stick • Incorporating empathy into UX design
Define point of view	• Perform a 360-degree view • Use 9-window tool & daisy map • Use point of view questions, e.g. „How could we ...“
Find ideas	• Conduct brainstorming • Apply creativity techniques • Gain depth of ideas • Scamper • Structure ideas, clustering and documenting • Profile of ideas
Develop prototype	• Develop prototype • Use different types of prototypes • Boxing and Shelving • Conduct prototyping workshop
Test	• Feedback collection grid and structured testing • Conduct direct comparison testing • Experiment grid
Reflect	• Use retrospective board

It is common sense that the selection and attention to innovative ideas should be seen, appreciated and carried out from the top management. Moreover, they should engage in knowledge management to demonstrate its importance. For this overview, the state of the art is described in the following Chapter.

3 State of the Art

This Chapter provides a common understanding of the textile process, processing machines and influences of cotton processing. Every process step brings out a new commercial product. These commercial products are traded across the globe. Supply chains of textile products are often discussed in media nowadays in order to sustainability discussions. Due to the fact, that many companies are specialized to one step and only process from one product to another, a general overview helps understanding the different requirements and needs. Fig. 3.1 presents these commercial products which are traded along the textile chain, taking cotton as an example.

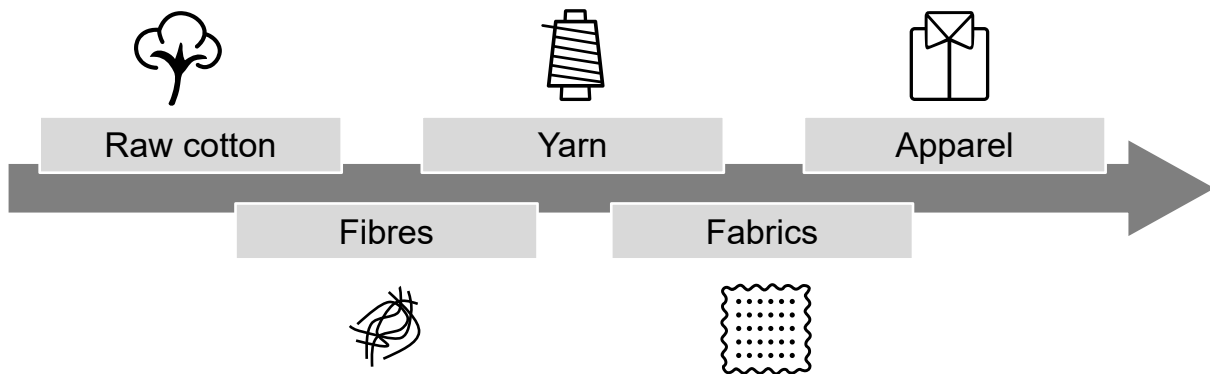


Fig. 3.1: Trading products of cotton [Küh22]

While solely doing one production step, the producing companies want to increase their own production capacity and throughput. This means ginning higher quantities of raw seed cotton per hour, spinning more kilogram yarn and so forth. The value of high-quality commercial products, far overreaching the requirements e. g. in strength or process stability, is often not valued and therefore not paid. These traded products could be called intermediate products, due to the fact that they are often sold by intermediate traders. As a result, the quality output is reduced to the accepted minimum while throughput is as high as possible. This is a result of the interviews and on-site investigations in ginning- and spinning mills worldwide. To gain a better understanding of these interrelationships, the quality factors and impacts are described below in each section, the process step is described. Chapter 3.1 dives into the cotton plant and properties for a general overview, cultivation practices, harvesting solutions and storage

requirements. Afterwards, the cotton is traded directly or, e. g. in India mostly via so called *intermediates*, to the ginning facility. What happens in the ginning facility is described in Chapter 3.2. This is then the main focus of this work because it has a very high impact on fibre quality. Furthermore, quality issues that come up here can never be fixed afterwards. This contains fibre shortening, seed coat fragments, neps, etc. This becomes an even bigger problem when cotton products shall be recycled for a second and third lifetime. While getting fibres out of garments, the fibre is shortened and damaged again. The impact of the fibre quality for further yarn production are described in Chapter 3.3 and for fabric production level in Chapter 3.4. After knowing how cotton is processed, Chapter 3.5 highlights the classification and valuation of cotton. The last one also includes the process steps of finishing and fabrication. Chapter 3.6 conclude the findings in this Chapter. But let's start in the beginning with Cultivation and Harvesting.

3.1 Cotton plants: Cultivation, Harvesting and Storage

Cotton is an annually recurring plant, which is commercially cultivated as a one-year crop for higher yields and therewith incomes. Cotton grows shrub- or tree-like, between 25 and more than 200 cm. It can be irrigated naturally and artificially. In general, cotton grows between 175 and 225 days. This depends on the variety, ground, climate and growing methods. A few days after sowing, the seedling sprouts. The plant develops in about 3 months until flowering. The ovary in the flower turns into a capsule after fertilisation. This reaches its full size in about 3 weeks and cotton bolls open 50 days after flowering. One cotton boll contains around 4 g of raw seed cotton, which is almost 1.5 g of lint fibres. [GVW19] The L. in the four main varieties of cotton is given from Carolus Linnaeus (latin name of Carl von Linné). He invented the binary taxonomy of biological organisms, which is applied until nowadays. Plenty varieties have been classified by Fryxell as well, but not had their breakthrough yet. Others than the named cotton cultivars are mainly used for special cultivation requirements likewise in Africa with very less water for personal consumption. [Fry84] An overview of the different cultivated cotton varieties is provided in Tab. 3.1.

Tab. 3.1: Cotton varieties description and occurrence [Fry84, Vei22]

Variety	Description	Occurrence
G. arboretum L. G. herbaceum L.	Developed in Persian regions; still grows wild in Africa and Asia; cultivated in Pakistan, India and China with low yields	3 % 2 %
G. barbadense L.	High quality long to Extra Long Staple cotton, like Pima	8 %
G. hirsutum L.	Standard medium to long staple cotton, like Upland	87 %

As there are huge differences in the usage of cotton varieties, the main difference is shortly displayed in the following Tab. 3.2.

Tab. 3.2: Cotton varieties, main differences, based on [Vei22, San19]

Class	Asian short staple	Upland	Pima	Egyptian	Sea Island
Variety	G. arboretum, herbaceum & hirsutum L.	G. hirsutum L.	G. barbadense L.	G. barbadense L.	G. barbadense L.
Quality	Low	Medium	High	Very high	Very high
Cultivation region	China, India, Pakistan	World-wide	USA, Peru, Israel	Egypt	Barbados, Jamaica
Market share [%]	10	80	5	< 5	0,004

As a lot of knowledge is required to cultivate different crops the best possible way for maximum value achievement, high wage countries tend to hire

consultants for cultivation. These consultants advise the crop selection, pest and fertilizer management, time of harvesting and everything related. They keep up to date with scientific findings and seed producers. One of those investigations are the irrigation types (cf. Fig. 3.2).

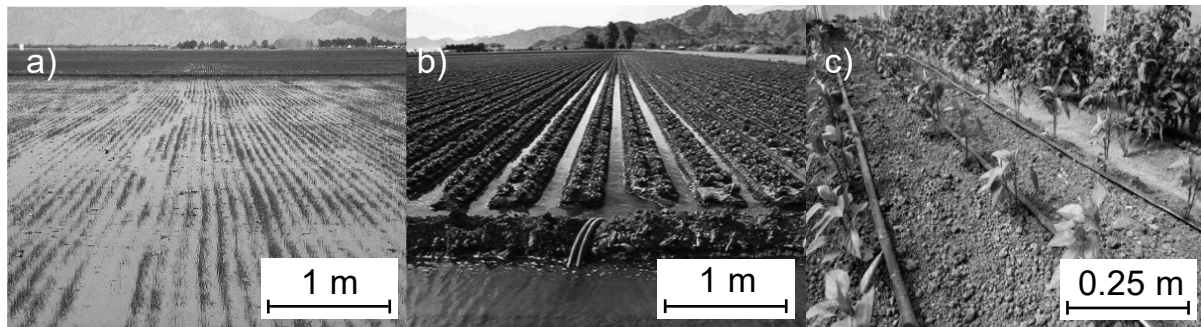


Fig. 3.2: Irrigation practices: a) flood b) furrow c) drip [KFS22]

In harvesting techniques, there is a huge difference according to the wealth of the country and farmer. High-wage countries as the USA and Australia 100 % of cotton is machine harvested. China for example has a mixed harvesting practice of hand and machine harvesting. Most developing countries instead harvest completely by hand. In general, hand harvested cotton could contain less contamination and foreign matters. This significantly refers to the workers knowledge and supervision as well. Due to unattendance at the monotony of harvesting and small plastic bags for the harvest it comes to increased trash and contamination. While storing the cotton in open bins on the ground, trash, foreign matters and soil particles contaminate the cotton. Even the fat and sweat of the hand contaminates the cotton. Therefore, harvesting with cotton gloves would be the best solution in terms of quality. Alternatively, machines could be used for those harvesting practices. [KFS22, GVW19] There are three kinds of cotton harvesting techniques [GVW19]:

- Spindle-Picker
- Stripper
- Hand picking

The spindle picker drills the raw seed cotton out of the open boll. The stripper needs the defoliation of the plant to strip up the whole plant while harvesting the cotton. The spindle picker is a selective tool, which only drills out mature cotton

out of chemically opened bolls. The stripper goes through the field once for harvesting and strips off everything which is remaining on the plants after some chemical treatment as defoliant with its brushes. This leads to a significantly higher amount of foreign matters in stripper harvested cotton. [WBB94, GVW19]

According to the type of harvesting, there is a different amount of trash, as mentioned before. In specific numbers it is approximately 35 to 70 kg of trash and dust for one bale machine picked cotton. For machine stripped cotton it is even 300 to 450 kg per bale. This relies on 680 kg harvested seed cotton per spindle picked 218 kg lint bale and 1020 kg stripper picked seed cotton. These quantities of trash needs to be managed and removed by the ginning mill. Trash could be sold for approximately 8 € per ton in 1994. It is usually used to enrich soil with nutrients. [PCM94] Soil quality is important for every cotton variety to be grown. This includes Genetic Modified Organisms (GMO), *Bacillus thuringiensis* bacteria modified cotton (Bt-cotton) and organic cotton, which is naturally evolved or a crossing of natural varieties.

Dated back to 2007, one third of the world cotton production is grown of genetic modified (GMO) cotton. Growing non-GMO cotton is more expensive than growing GMO cotton. This goes back on higher nutrient and pest amounts to be competitive in yield and quality. Therefore, it needs to be more closely considered whether organic cotton is more sustainable or environmentally friendly. [GH07]

According to other studies, drip irrigation combining a well-organized nutrient and pest management seems to be more sustainable. Moreover, many seed provider assure, that the seed growing in the plant is not re-plantable which brings additional dependencies of the farmer. Bt modified organisms are not allowed to be sold as organic as well. [WC07]

In cotton storage, PELLETIER and BYLER argue that such elevated moisture content is particularly detrimental to the colour of the cotton, resulting in a reduction in R_d and $+b$ values. Moreover, it can cause fibre decay and eventual dissolution. The degradation of cotton colour is illustrated in Fig. 3.3. [PB20]

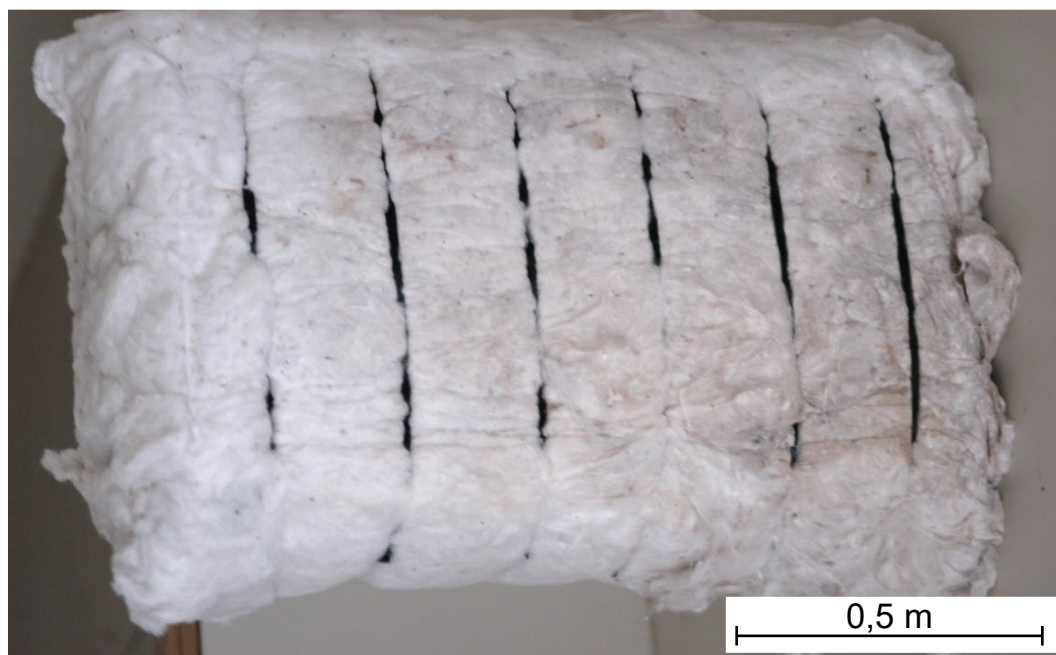


Fig. 3.3: Example of dust contamination in cotton bales [KFS22]

In storing cotton, colour degradation (e. g. yellowing or others) and mould might occur in very short time, see Tab. 3.3. [CLW84]

Tab. 3.3: Maximum storage duration, according to moisture content [CLW84]

Moisture content of seed (% wet basis)	Days storage
8 – 10	30
10 – 12	20
12 – 14	10
14 – 15	< 3

This value might be influenced, e. g. by the time of harvesting during the day. As cotton dries on the field during the day, this circumstance should be considered while harvesting in terms of the cotton quality.

Low wage countries tend to harvest 100 % of their cotton by hand, while high wage countries need to use machine harvesting to be economically competitive. The ITMF cotton contamination report shows, that the degree of contamination

and trash mostly depends on the general diligence. There are clean hand harvested cotton samples, as Egypt on rank 15 [Int16]. Oppositely, there are contaminated and trashy machine harvested varieties, like Greece which is 9th most contaminated cotton [Int16]. In general, the results show cleaner cotton in machine harvesting countries. Trash gets cleaned out in ginning and spinning. Thus, the following Chapter introduces those machines and techniques at gin.

3.2 Ginning

“Ginning mills today increasingly focus on productivity rather than quality.” [BDM+18] “A well-informed ginner can help growers make profitable production decisions and can improve the performance of textile mills.” [MOS94] The ginning mill has in general two functions [Ant94a]:

1. separating cotton lint from the seeds
2. cleaning the lint and delint the seed

The ginning process should preserve highest possible lint quality for the grower’s price. Meanwhile, the quality reduction should be hold on a minimum stage for the ongoing spinning process. [Ant94] It need to be considered, that this cleaning is always a compromise, shown in Fig. 3.4.

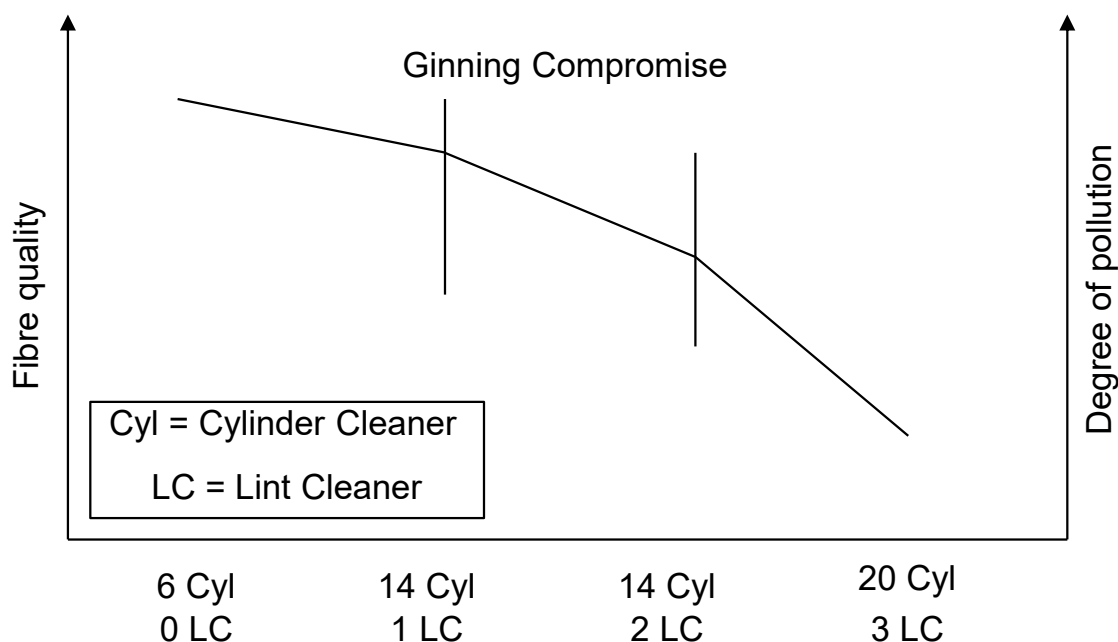


Fig. 3.4: Ginning compromise for cleaning stages in ginning mills [MAB+94]

As it is mentioned in the introduction, ginning has the highest impact on fibre quality. Gries et al. state that cotton classing is done according to purity, colour, staple length, fineness, strength and degree of maturity [GVW19]. This could be expanded to the following main quality factors as:

- Colour (Yellowness / degree of reflectance +b)
- Staple length
- Degree of mature fibres
- Contamination and trash free (e. g. plastics and dust)
- Neps

These are significantly influenced by the moisture content of cotton as well as the processing machines and settings. Important to mention is, that there are different machines used according to the harvesting and ginning method. Ginning machine add or take value from fibres and cotton seeds. Separating fibres started back in the early days with hand ginning. Until now, hand ginning is the most gentle and high qualitative ginning method. The principle of ginning is shown with hand ginning in Fig. 3.5.

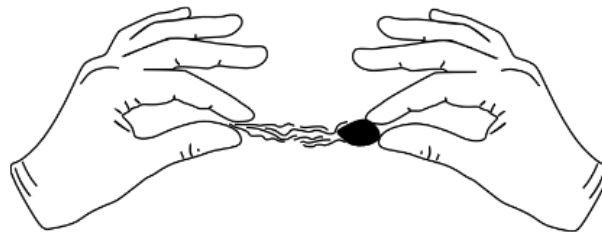


Fig. 3.5: Hand ginning and ginning principal visualisation

Hand ginning can achieve about 50 g per day and worker. To understand the historical development of ginning, milestones in ginning machine development are shown in Fig. 3.6. This should enable the understanding of ginning set-ups.

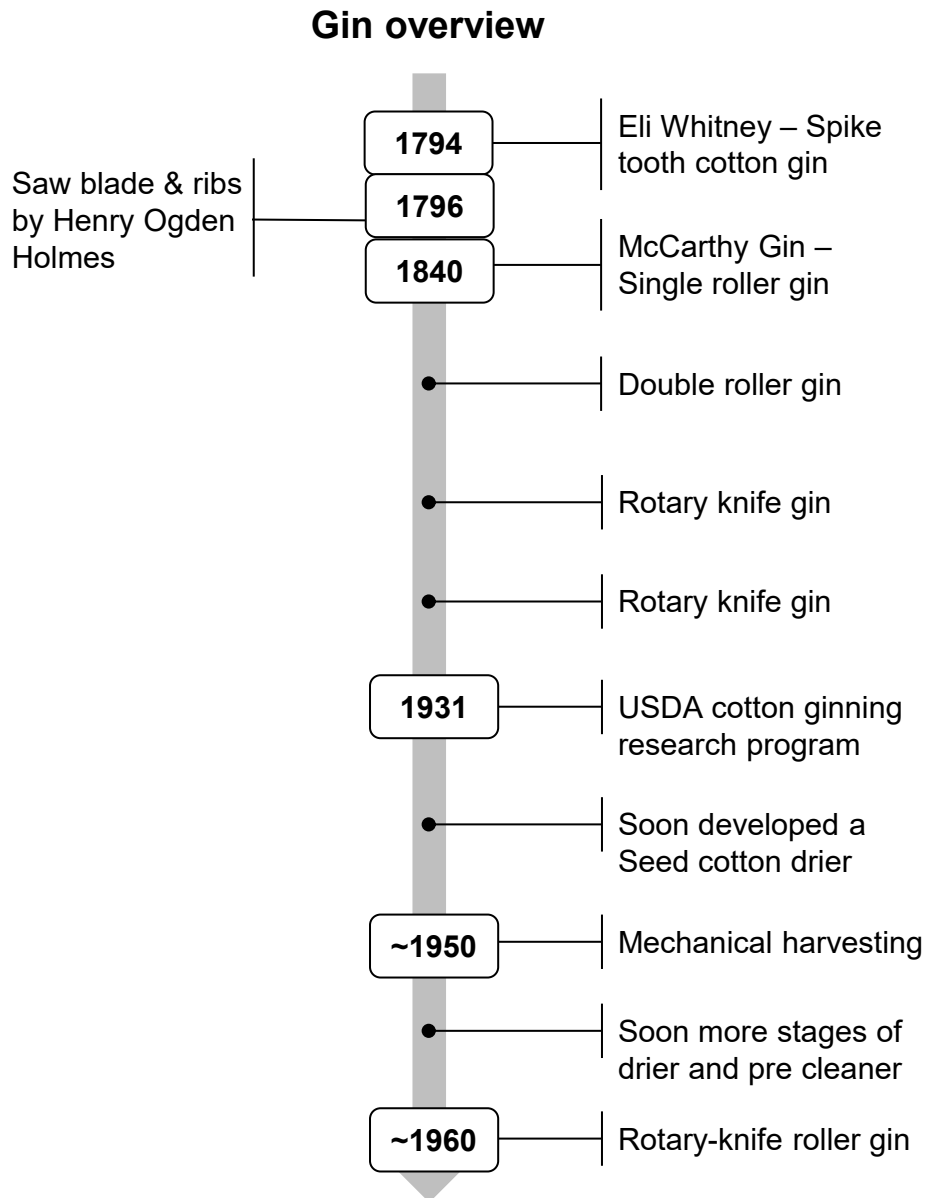


Fig. 3.6: Ginning timeline milestones, based on [AM94, Uni77]

This procedure of developments show, that evolution tries to fasten up separation of cotton fibres and seeds, while preserving the fibre quality. This can be seen from the fact, that roller ginning still preserves state of the art, even when saw ginning machines were developed at the same time as roller ginning was. A today exemplary literature-based machine installation for a roller ginning mill is provided with Fig. 3.7.

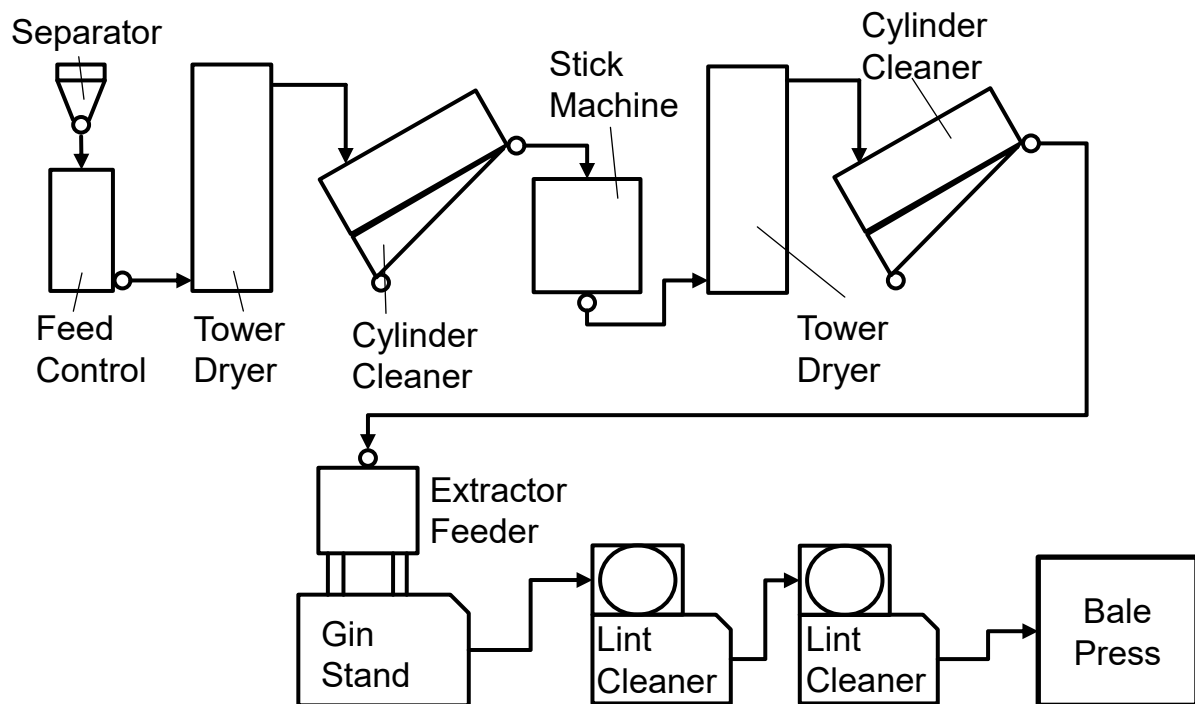


Fig. 3.7: North American (saw) ginning process chain, according to [AHM94]

“It is stated out, that there is solely an increase in whiteness and reduction of yellowness via pre-cleaning, without any adverse effects.” [PAS10] Limiting, in this study, there are no values for the fibre quality concerning staple length or fibre strength. Therefore, most important effects on fibres are not observed.

The outgoing product of a cotton gin, the lint bales, are used to easily deal with the extracted lint for further processing. Pressing the lint to compact packages of 200 kg (± 30 kg) carried out as a proper operation size. In general, this refers to the transportation medium size. International bales according to ISO 8115 have an optimal space usage in overseas containers. Long lasting research carried out that bales with a density of 500 kg/m³ to 650 kg/m³ are more difficult to open and have high expenditure of energy while pressing the bale. Even if it has an advantage in volume per unit and is easy to deal with on nowadays machines. Therefore, nowadays internationally 360 kg/m³ to 450 kg/m³ are recommended by ISO 8115. [PAS10] According to the lint amount required in a bale, the so called *Ginning Out Turn* (GOT) is an indication for the ginning efficiency and trash content. Roller ginning (cf. Fig. 3.8) has the highest mechanical GOT.

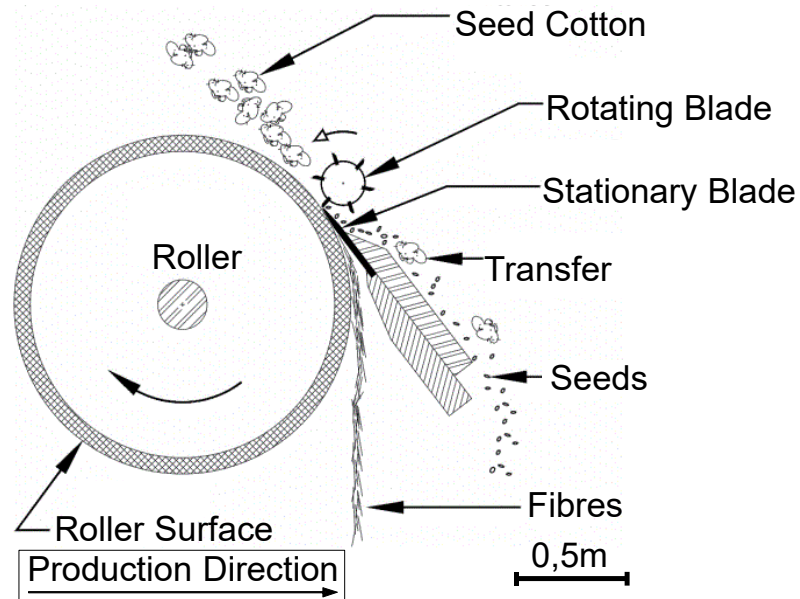


Fig. 3.8: Functional principle of roller gin stand [AWT+17]

Roller ginning is much slower than saw ginning but brings out 1 % to 3.5 % higher *Ginning Out Turn*. As roller ginning it is more fibre gentle, it is mostly used for long and extra long staple (ELS) cotton. Saw ginning is shown in Fig. 3.9.

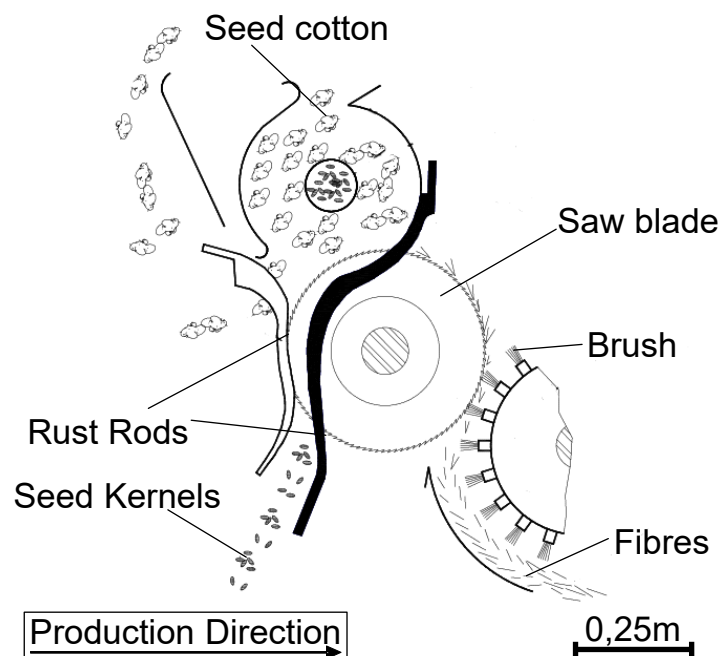


Fig. 3.9: Functional principle of saw gin stand [AWT+17]

Below, Tab. 3.4 shows the machines, described in literature for ginning mills.

Tab. 3.4: Ginning facility machine overview part 1 [KFS22, AM94]

Machine	Function	Comment
Green-Boll Trap	Removes green bolls, rocks and heavy foreign matter	Optional: Only used for machine harvested cotton, especially modules to prevent machine damages.
Automat. Feed-Control	Continuous and even seed cotton throughput	Mandatory: always used. Disperses cotton for better cleaning and drying due to less clumps.
Dryers	Dries wet cotton or in case of high moisture	Optional: not used in many low wage countries. Hot air streams for 10 to 15 s.; temperatures above 150 °C (300 °F) could over dry the cotton and cause permanent physical damages in cotton fibres
Cylinder Cleaners	remove small foreign matters, such as leaves, trash, dirt and plastics	Optional: not used in many low wage countries. Six or seven spiked cylinders at 400 to 500 rpm which scrub the cotton over grid rods. Drying continues at this stage. One cleaner process two bales per hour. Moisture is an important value due to its influence on fibre strength and therefore breakages or damages.
Stick Machines	Remove large foreign matters, such as burs and sticks	Optional: not used in many low wage countries. Principal is based on centrifugal forces. While the metal blades hold the seed cotton, heavier parts get removed automatically at 300 to 400 rpm. Moisture is again a relevant parameter.

Tab. 3.5: Ginning facility machine overview part 2 [KFS22, AM94]

Machine	Function	Comment
Coveyor-Distributor	Distributes cotton to the gin stand	Mandatory: different systems are available (see below in Fig. 3.10)
Extractor-Feeder	Buffering and continuous controlled seed cotton supply; cleans cotton as a secondary function	Mandatory: critical point, because seed cotton moisture must be in a proper range at this stage (e. g. 6 to 7 % for saw gin stands). Otherwise, uncontrolled breakages and damages could lead to weak or shortened fibres.
Gin Stand	Separation of lint and seed	Mandatory: heart of the process. Available in several specifications, described more in detail below. Production rates above the recommended throughput could cause fibre quality reduction, seed damages.
Lint Cleaner	Remove foreign matter to improve the cottons grade	Mandatory: the number of stages (1 to 3) is optional. Sometimes improves the colour grade of spotted cotton to light spotted or white lint. Always a compromise between cleaning and damaging the cotton, especially according to the moisture content
Water sprayer	Moisturization of cotton	Sprays water on lint while being carried on a belt, before sliding into the bale press
Bale Press	Pressing cotton in standardized bales	Mandatory: bales are the commercial product coming out of cotton gins. These are standardized formats and easier to handle.

The different raw materials need to be handled differently as well, due to their occurring properties. Seed cotton has a different behaviour than lint or seed itself. Therefore, a general overview of the different conveyor types and their usage should be present. These are shown in Fig. 3.10, which provides an overview about the different conveying systems and what it means for the different products (Seed cotton, lint and seeds) to be handled.

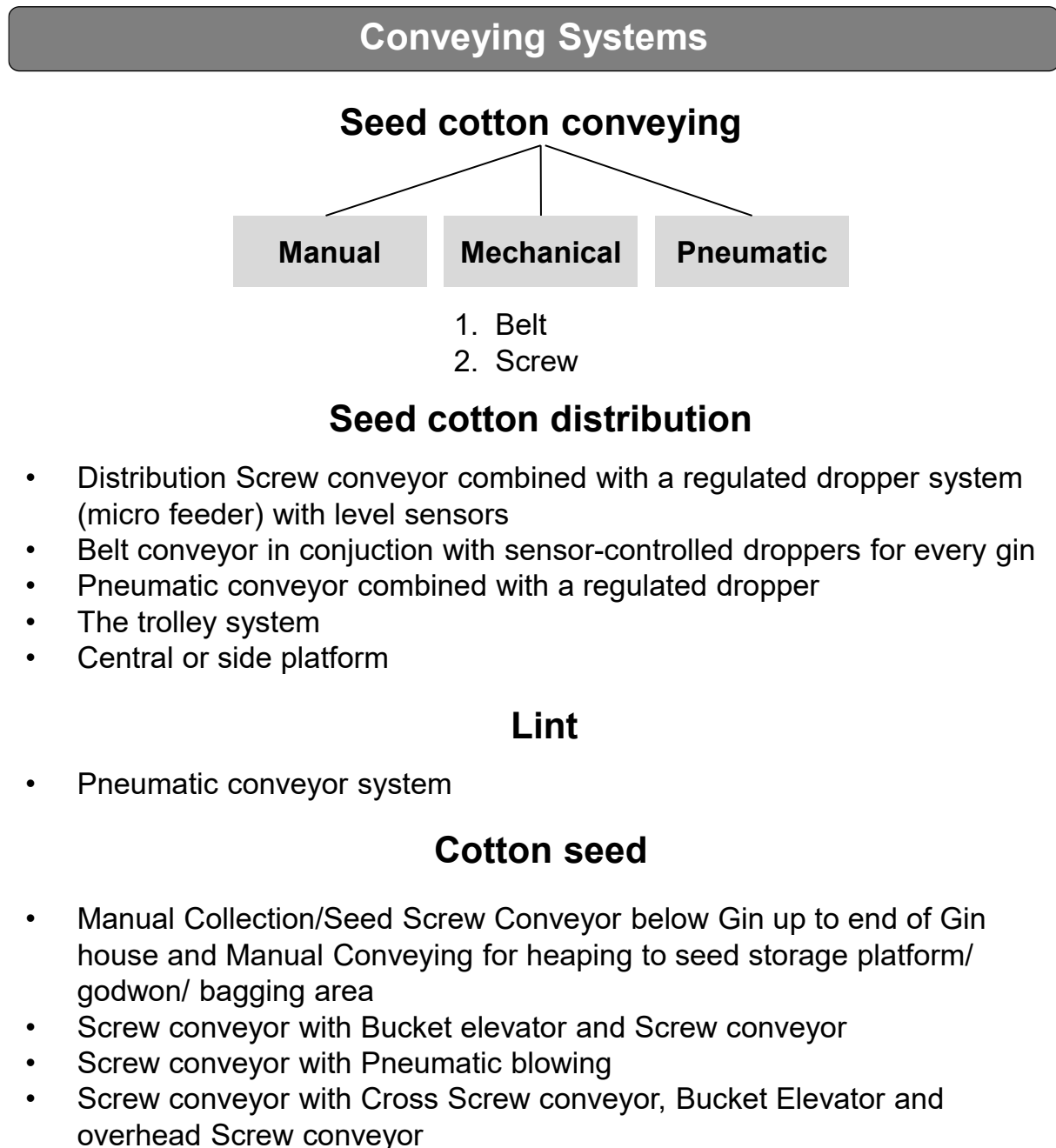


Fig. 3.10: Conveyor system overview and description

Partly, especially in low wage countries, hand sorting and cleaning stages are established to deliver cleaner cotton. This is observed in ELS cotton processing. As the conveying system has a high influence on the lint quality. Conveying affects the fibre quality, partly fulfils cleaning tasks while transporting but might lead to negative impacts as well. It requires high knowledge to properly set-up the conveying system and to ideally use it for the desired mill set-up. Therefore, some overview is provided below for a general knowledge and understanding. More detailed knowledge can be found in the according literature or should be discussed with the machine manufacturers for the particular requirements considering the whole mill set-up. According to cleaners: Seed cotton cleaning is often used in more than one sense in the ginning industry. Therefore, Patil et. al. recommends differing cleaning and extracting in use. Cleaning means the removal of small parts e. g. trash, leaving pieces and bracts. Extracting refers to bigger parts like sticks and burs. [PAS10]

The lint conveyor system requires an air speed of 8 to 11 m/s that the lint is properly transported. Belt conveyor systems instead usually run with 1 to 1.5 m/s. The rubber belt is 3 to 4 mm thick. [PAS10] In the whole air conveyor system of a ginning mill, different air velocities are required. These could be seen in the bullet points below. According to the use of different assemblies, huge losses might occur. In the whole air conveyor system of a ginning mill, different air velocities are required. According to the use of different assemblies, huge losses might occur. The list is led by vacuum droppers, where leakages up to 35 % frequently occur. Tower dryers, boll traps and cylinder cleaners are also well known for their air leakage. [BCE+94] In droppers, where leakages up to 35 % frequently occur. Tower dryers, boll traps and cylinder cleaners are also well known for their air leakage. [BCE+94] Commonly used systems for cotton handling are [BCE+94]:

- Centrifugal fans
- Axial flow fans
- Separators and Droppers
- Blow boxes
- Mechanical Conveyors (Belt- and screw conveyor)

Possibly used system for cotton gin trash handling and air pollution management are the following [PCM94]:

- High efficiency cyclones
- In-line filters
- Condenser drum conveyor
- Rotary drum collection system

Many ginner know that moisture is quite relevant. Nevertheless, ginner do not take much effort to measure the moisture content. Kühn et al. described, that one ginner promised to measure the 13 % moisturized cotton with his hand and therewith defines the right time of processing. [KFS22]

As most literature is from the USA and focuses on drying, this paragraph is followed by an overview of the main products in humidification. GULYAEV et al. developed a machine that loosens cotton with rollers and then let it fall through a chamber where it is moistened by fine water sprayed from a nozzle, achieving a theoretical capacity of 4,000 kg/h and increasing the cotton's moisture content by 1.11 % to 9.38 % in total. [GML19] Fig. 3.11 shows this machine.

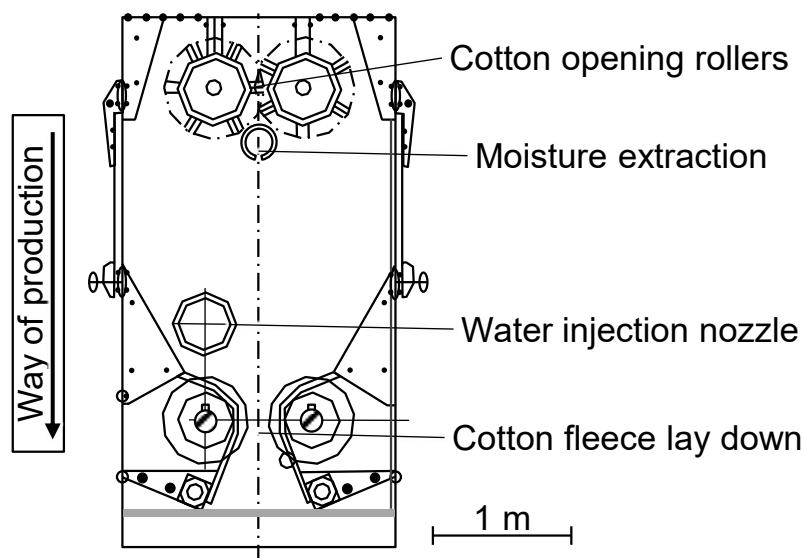


Fig. 3.11: Humidification unit, based on [GML19]

Samuel Jackson Inc., Lubbock, USA, is specializing in cotton moisture control. They offer machines like the conditioning hopper and "King Mesa" that uses moist air and a mix of moist air and water vapor to moisten the cotton before

entering the gin stand. Samuel Jackson Inc. states, that this is enhancing the cotton moisture content without sharing details of the working mechanism of the machines. [Sam23, Sam17] The humidifier is shown in Fig. 3.12.

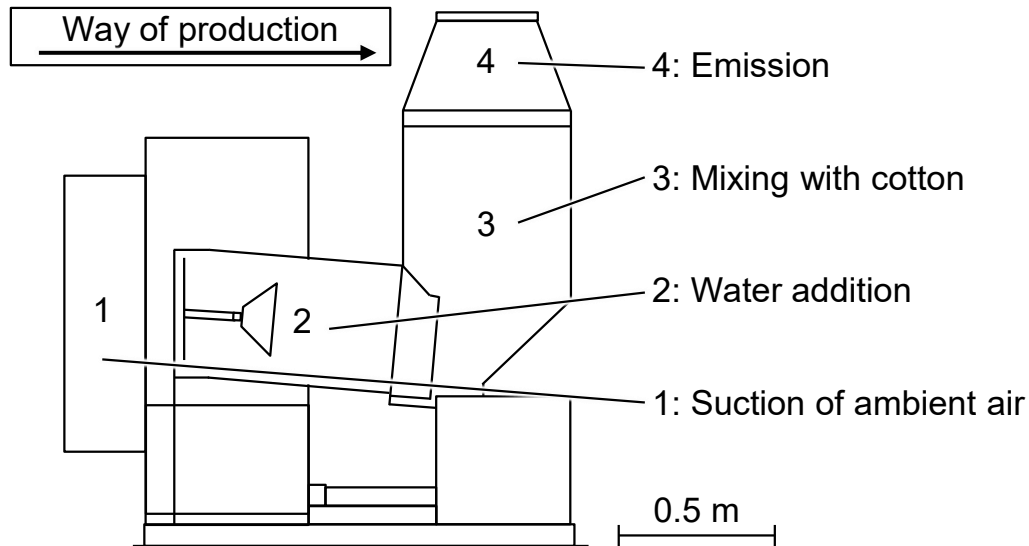


Fig. 3.12: King Mesa humidifier, Samuel Jackson Inc. [Sam17]

The moisture content needs to be regulated across the whole process chain, not only in the gin stand. Therefore, an understanding of the importance of the moisture content while processing seed and lint cotton needs to be further spread. These are further described in Chapter 4.2. Moreover, it is very important to understand, that the outgoing quality of the ginning mill significantly influences the best achievable quality of the spinning mill. Usually, those entities don't know each other and do not share knowledge. All those systems should be appropriately maintained and worn out parts should be replaced to achieve the highest possible fibre quality, especially in ginning machines. [Sha14] In low wage countries, energy cost is more important in terms of pricing the processing. Comprehensively, saw ginning is mostly used in high wage countries, as labour cost is a significant influence to the processing cost. To gain a common understanding and push any further dialogue, spinning procedures and machines are described below. This should be the case, even between different organisations and process steps.

3.3 Spinning

After the bale opening, lint cotton and all other materials in a spinning facility are processed by air conveyor systems. The basics are equivalently valid as described earlier. This Chapter provides a general overview on pre-spinning and spinning procedures. Processing steps in pre-spinning are [GVW19, Law07]:

1. Pre-opening & pre-mixing (bale opener)
2. Heavy particle detection and extraction (feeder)
3. Pre-cleaning
4. Blending / mixing
5. Intensive opening & cleaning, incl. foreign particle separation
6. Carding

There is a long-lasting discussion on how and where to clean cotton. “The overall carding system has a cleaning efficiency of 95 % [...] which is much higher than the 45 % for the opening and cleaning lines”. [Law07] This shows, that the effect of high cleaning efficiencies in carding and low cleaning effects in pre-cleaners are significant. For higher bale prices, cleaning is performed with pre-cleaners in ginning mills. VAN DER SLUIJS indicates the following aspects for saw gin units [Slu24]:

- Cleaning in the gin:
 - Higher (better) grades
 - Lower fibre quality
 - Lower lint turn out (or ginning out turn – short GOT)
 - Easier disposal of bigger trash parts
- Cleaning in the spinning mill
 - Increased bale weights
 - More-controlled cleaning conditions
 - Lower throughput while having a better cleaning
 - Less fibre stress
 - Increased fibre and yarn quality
 - Reduced productivity and increased waste percentage

LEIFELD recommends slow and non seed crushing cleaning to 4 % trash in the ginning mill. As (fine) opening is and will be required in spinning mills, additional cleaning in opening and carding leads to 0,04 % trash in the yarn. [Lei92]

To become a better understanding between the different steps of the textile process chain, exemplary cotton spinning requirements are further displayed. The steps and machines to be used after the carding machine are [GVW19, Hun07]:

- Spinning preparation
 - Draw frame (drafting and doubling for higher evenness)
 - Combing machine (increase average fibre length for yarn quality improvement)
- Spinning
 - Ring: roving frame (Flyer), ring spinning (cops), winding (package)
 - Rotor: sliver to package
 - Air Jet: sliver to package
- Twisting

Not all steps are mandatory. According to the yarn quality required, only selected steps might be used or further machines might be added. [Hun07] It is known, that the three important factors of yarn strength, yarn appearance and spinning yarn breakages are best preserved, if there is as less drying and cleaning as possible [Ant07]. This is shown as an overview in Tab. 3.6 below.

Tab. 3.6: Fibre property priority according to the spinning procedure [Gor07]

Rank	Ring	Rotor	Air-Jet
1	Length	Strength	Length
2	Strength	Fineness	Trash
3	Fineness	Length	Fineness
4		Trash	Strength

There is no further or deeper consideration of these steps in this thesis. It can be read in detail in corresponding literature, e. g. from HUNTER or GRIES et al.

3.4 Fabric production, finishing and fabrication

In the subsequent stage of processing, yarns are utilized for fabric and textile production. A fundamental differentiation exists between woven and knitted fabrics. As DIN 60000 standardizes, knitted fabrics are defined as fabrics formed from one or more yarns (or yarn systems) through the creation of loops, where initial loops are formed with the yarns into which subsequent loops are interlocked. Knitting or warp knitting machines are employed for this purpose. Conversely, fabrics are manufactured on weaving machines, where two yarns are vertically interwoven to create the fabric – the warp thread and the weft. Multiple layers of the warp thread are alternately opened in various directions, allowing a weft thread to be inserted through the gap. The yarn layers are then interchanged and the weft thread is shot back through the fabric. The weft thread can achieve speeds of up to 1570 m/min, potentially leading to yarn breakages. Consequently, weaving necessitates particularly robust yarns. Conversely, knitting machines are much gentler on yarns and fibres. [GVW19]

Subsequently, the woven or knitted sections undergo finishing processes, which involve altering the wear or care properties, with a primary focus on transforming the appearance, particularly the colour. Numerous methods are employed for this purpose. In instances where the fabric is intended to exhibit a uniform coloration, the presence of a significant proportion of impurities poses a substantial challenge. These minute, dark particles are particularly conspicuous in light-coloured textiles and can consequently diminish the perceived value of the product for the customer.

Research projects showed, that a minimum of 15 cN/tex should be archived for proper material handling within the fabric production. Knitting yarns require at least 13 cN/tex in most cases, while reducing the production speed or twisting the incoming yarn. Therefore, 15 cN/tex are recommended for both, knitting and weaving. Yarn quality is always based on the fibre quality. The according classification is described in the following Chapter.

3.5 Classification and valuation

As mentioned in Chapter 3.1, the most important fibre quality parameters are: colour, staple length, fineness, strength and degree of maturity [GVW19]. This could be expanded to the following main quality factors as [GVW19]:

- Colour (Yellowness / degree of reflectance +b)
- Staple length
- Fibre strength
- Degree of mature fibres
- Contamination and trash free (e. g. plastics and dust)
- Neps
- Leaf grade
- Trash

Mixing all of those quality categories to achieve the overall quality and trading price is a highly complex procedure. Moreover, additional parameter come across to set those overarching values into a frame of measurable and comparable results. These parameters are used to declare specific prices to cotton. Therefore, tables are established which mark base qualities and value-added makers and value dropping markers. Price differences are further described and investigated in Chapter 8. Cotton classification is divided in the following sections, adding the above mentioned factors by [Moo94]:

- Classer Determinations
- Preparation (“degree of roughness or smoothness of the ginned lint cotton” [Moo94])
- Extraneous Matter (“any substance that is not cotton fibre or leaf material and that is not discernible in the official cotton standards. Examples [...] are bark, grass, spindle twists, seed coat fragments, dust and oil.” [Moo94])
- HVI Determinations
- Length Uniformity
- Micronaire
- Colour (Yellowness / degree of reflectance +b)

This complexity could be shown by watching the yellowness and degree of reflectance correlations (cf. Fig. 3.13). It will not be further investigated in this Chapter. Otherwise, it requires too much space.

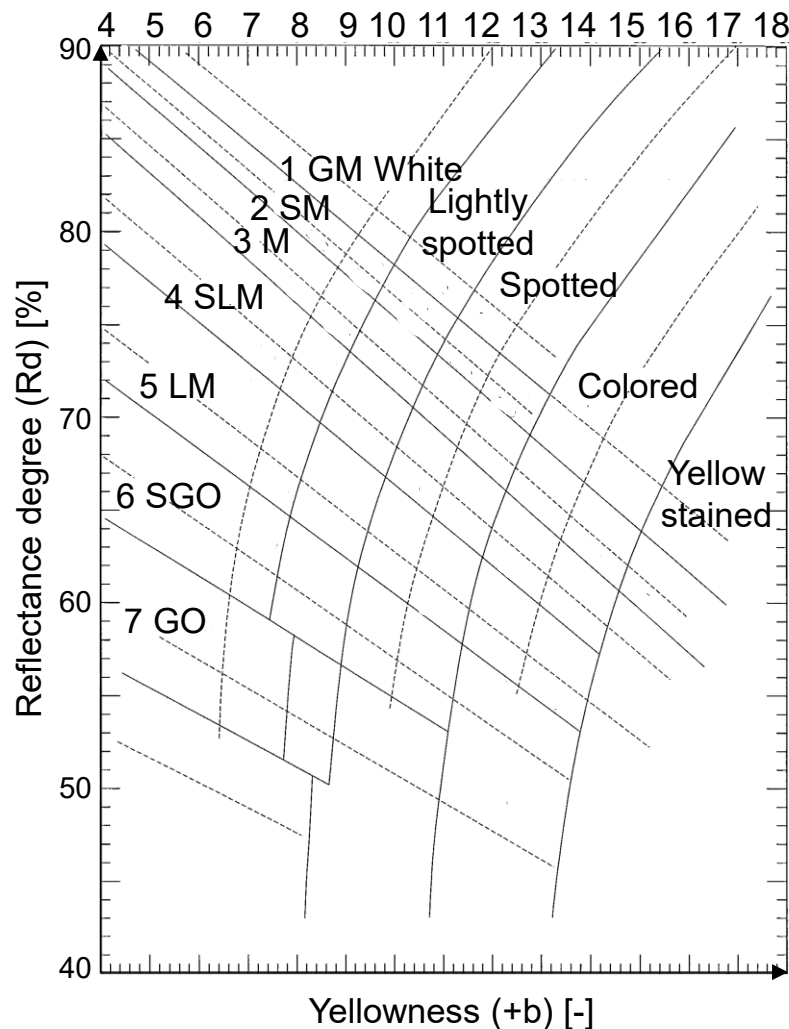


Fig. 3.13: Correlation of yellowness +b and Rd value to cotton quality [Cot24]

Other factors as well as the price sensitivity of those factors can be seen in Chapter 8. For those quality values, established Testing devices are [Tes21]:

- USTER-Tester
- Advances Fibre Information System (AFIS)
- Micro Dust and Trash Analyser (MDTA)
- FibroTest
- FibroLength

This list includes testing systems from other companies, based on their technology as well. Further information and descriptions can be found in [Tes21, Tex24, Ust24, GVW19]. The still valid length classification from 1918 is divided for Pima- (G. Barbadense L.) and Upland-Cotton (G. Hirsutum L.). The Upland length classes are from 20,64 mm up to 31,75 mm (13/16 inch to 1 1/4 inch). For Pima, the cotton length classes are from 33,34 mm up to 38,1 mm (1 5/16 inch to 1 1/2 inch). [PEB84] The staple conversions in mm according to the International Cotton Association (ICA) Bremen are shown in Tab. 3.7.

Tab. 3.7: Staple length classing [ICA18]

Length classification	Short	Medium	Long	ELS
Length [mm]	20,64 - 24,61	24,61 - 29,36	29,37 - 31,74	> 31,75

This length classification is standardly described with the Upper Half Mean Length (UHML) measurement. [Cot18] Additionally to this fibre length classification, the ICAC adopted the following classes in 1988 for yarns, while 1 s means NeB 1 [NS20]:

- “waste/padding
- coarse count (yarn count 1s through 19s)
- medium count (yarn count 20s through 30s)
- high-medium count (yarn counts 31s through 40s)
- fine count: (yarn count 41s through 50s)
- extra-fine count (yarn count 51s and higher)”

As cotton is a pure cash crop, it does not feed the farmer by itself in case of bad harvest. Cotton is solely financially viable for the farmer while having an appropriate yield. Food crops feed the farmer in a first row and let them earn money with high yields above the own usage over the year. Therefore, the financial output of cotton cultivation is the most important thing. Typical business models can be found for reference in the following Chapter.

3.6 Direct moisture measurement – thermogravimetric methods

Direct moisture measurement is based on the separation of water present in the sample from its dry substance, like cellulose in terms of cotton. These methods are primarily used for referencing, as continuous on-line measurements with direct methods are extremely difficult. Values are usually given as percentage. [HS12] The main direct measurement methods are summarized under the name of thermogravimetric methods. An overview is given below, before describing three methods in particular.

The aim of thermogravimetric measurement methods is to directly determine the moisture content of a material sample by heating and weighing. These are also known as the dry weighing method. For this purpose, the moisture is removed from the moist sample in a drying process by applying heat to the sample in an oven. The weight of the dry sample is compared to the weight of the moist sample. [PB20] The moisture content is calculated according to equation (3.1), formulated by [PB20]:

$$MC = \frac{OW - FW}{OW} \quad (3.1)$$

With: MC = moisture content (wet basis), OW = original (wet) weight, FW = final (dry) weight

Another parameter of these measurement methods is the moisture regain, relative to the dry weight, which is given in equation (2), defined in [PB20]:

$$MR = \frac{OW - FW}{FW} \quad (2)$$

With: MR = moisture regain (dry basis), OW = original (wet) weight, FW = final (dry) weight

Available methods include the oven drying method, the infrared drying process (IR drying process) and microwave drying [Kup99, KG10]. These methods are

carried out under certain conditions, such as a suitable drying time, temperature, sampling and sample preparation as well as material-specification [KG10, Kup99]. This ensures greater reproducibility [Kup99]. These conditions are internationally standardised, e. g. by the German Institute for Standardisation (German: Deutsches Institut für Normung – short DIN) and the American Society for Testing and Materials (ASTM) [MHC+10, KG10, PB20]. The various methods are based on the same principle of determining the weight of the moist sample before drying and the dried sample after oven drying [KG10]. However, they differ in the type of drying [KG10]. These measurement methods are often used to calibrate indirect measurement methods [Kup99]. Fig. 3.14 shows a schematic setup of the thermogravimetric measurement method.

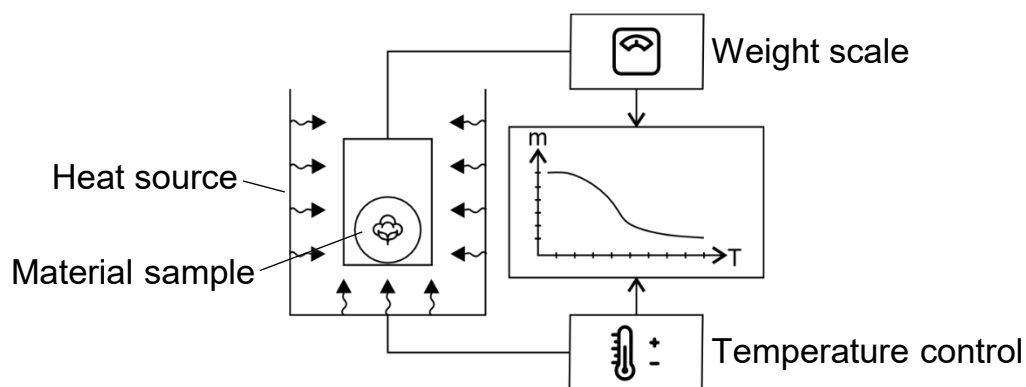


Fig. 3.14: Schematic setup of thermo-gravimetric measurement method [HS12]

The basic measurement setup generally includes an oven equipped with a fan and preferably an integrated balance. If this is not the case, a desiccator is also required. Furthermore, containers are required for sample storage and for subsequent weighing during the drying process. For example, glass jars or metal containers with a volume of approximately one litre that can be sealed airtight are used for sample storage. Metal baskets are used as containers for weighing during drying in the oven with integrated scales. For drying with a desiccator, metal bottles or cans that can be sealed airtight are used. A balance is also required to weigh the containers together with the sample. [AST19] Another standardized drying method, mentioned in ASTM D2495 is the oven drying, described in the following Chapter.

3.6.1 Oven Drying method

The oven drying method is the oldest and most widely used standard method of measuring the moisture content of cotton, while being very time-consuming [DR16, Kup99]. In this method, energy is supplied to the sample in an oven as heat by convection and heat conduction. The sample is dried until a state of equilibrium is reached. However, this equilibrium state does not necessarily correspond to the complete absence of water, but to an equilibrium between the vapour pressures in the sample and the atmosphere in the oven. [Kup99] This principle is shown in Fig. 3.15.

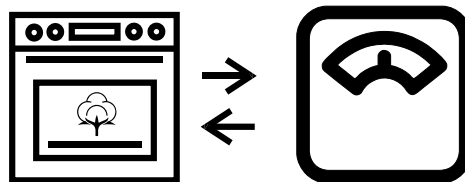


Fig. 3.15: Schematic drawing of the oven drying method principle

ASTM D2495 has standardised the oven drying method for use on cotton [MHC+10]. According to ASTM D2495, the oven provides a constant temperature of $105\text{ }^{\circ}\text{C} \pm 2\text{ }^{\circ}\text{C}$ and is ventilated with fresh air from standard atmosphere for textiles, by using a fan. The samples, e. g. removed from the bale as intended, are immediately stored untreated in an airtight container until drying. The size and number of samples are also specified. The weight of the sample should be 5 g or 10 g, depending on whether the proportion of cotton in a fibre blend is greater or lesser than 50 %. The number of samples is calculated on the basis of empirical values and allows a maximum deviation of 0.5 % from the theoretical average value. Depending on whether an oven with an integrated weighing system is used, different drying times are specified and are also dependent on the cotton content of the sample. For example, the drying process is generally completed when the change in mass after several weighing's with defined time intervals is less than 0.1 % of the sample mass or a specified minimum time has elapsed. If an oven with an integrated weighing system is used, this minimum time is 5 hours for seed cotton or waste containing less than 50 % lint cotton. The time intervals for termination via the change in mass are 1 h. For

lint cotton, blends or waste containing at least 50 % lint cotton, the minimum time is 1 h and the intervals are specified to 15 min. If no integrated weighing system is available, the dried sample is removed from the oven before each weighing and cooled to room temperature in a desiccator. [AST19] A desiccator is a glass container equipped with a tray for the samples to be dried, which is located slightly above the floor. The container can be sealed airtight and dries the samples with the help of an added solvent, which is then located below the tray. [Fak20] Here, the minimum drying time in the oven for seed cotton or waste containing at least 50 % lint cotton is 12 h and the time intervals for an earlier termination via the mass change is 1 h. For lint cotton or waste containing at least 50 % lint cotton, the minimum time in the oven is 8 h. For pre-weighing, the container and sample are weighed, the sample is transferred to the respective container for weighing during the drying process and the empty weight of the container is determined. The sample mass can be determined from this. [AST19] A usual alternative to the oven drying method is the infrared drying method, described below.

3.6.2 Infrared and microwave drying method

In contrast to the oven drying method, the moist sample is dried using a radiant heater (cf. Fig. 3.16) [KG10]. Different wavelength is used for infrared and microwave drying according to their specification described below.

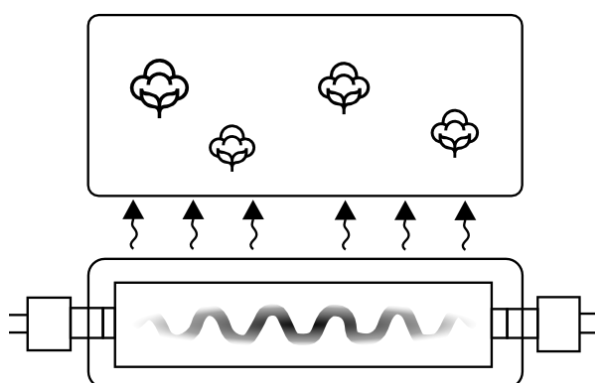


Fig. 3.16: Schematic setup of the infrared drying method

Main advantage of both of these methods is shorter drying duration. The radiant heater dries the sample by emitting radiation that hits the sample surface. Part

of the radiation is absorbed by the samples surface and further conducted inside the sample in the form of heat conduction. The emissivity of the radiant heater and the absorptivity of the sample material are wavelength-specific. The emission of the radiant heater is more pronounced in the infrared wavelength range than in the rest of the spectrum. Together with the absorption capacity of the sample material, this results in a drying process that is dependent on the radiation properties of these two components. The distribution of the radiation intensity of the radiant heater over the wavelength has significant influence as well. This measurement is temperature dependent, as all physical objects emit electromagnetic radiation, including infrared radiation. [KUP99]

For the set-up: the sample is placed on a balance. The radiant heater dries the sample directly on the balance so that the change in weight during the drying process can be analysed. Similar to the oven drying method, the measurement is terminated when the mass does not change at all or only slightly after a longer period of time or when a set time has elapsed. [Kup99] Fig. 3.17 shows the electromagnetic spectrum with the corresponding wavelengths and frequencies.

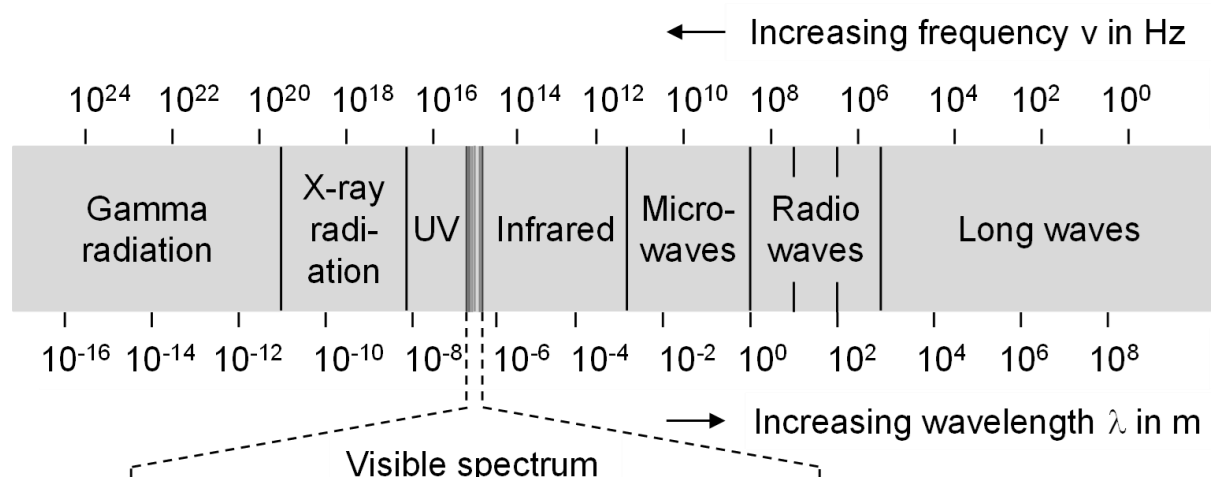


Fig. 3.17: Electromagnetic wavelength spectrum [Fre18]

This shows, that the drying wavelength is out of the human visibility. This leads to energy reduction, while not adding additional loads to the operator. Operators can still focus on their main activities and do not get disturbed by light emission. Alternatively, Microwave drying can be used. The same principle is used in microwave drying, described below.

The microwave drying method dries the sample using radiation in the microwave range [KG10]. Microwaves penetrate dielectric materials and can be reflected and transmitted at every grain boundary of the material. Microwaves used for drying usually have a wavelength of 122.5 mm and excite dipole molecules such as water molecules. This excites areas with high humidity and also heats up the inside of the sample. The heating of the water molecules leads to the evaporation of the moisture. [Foo22] Alternative measurement methods that do not require the separation of the water from the sample are presented below.

3.7 Indirect moisture measurement

The indirect measurement methods differ substantially from the direct methods described above. The water present in the sample is not removed and weighed, instead, physical properties of water are measured. These include the water's optical absorption and electrical resistance. By means of previously experimentally determined characteristic curves, which are generated from a signal assigned to the water content, conclusions are drawn about the moisture content. Indirect moisture sensors are suitable for on-line measurement. [HS12]

3.7.1 Near-infrared spectroscopy (NIR)

NIR spectroscopy relies on the varying absorption properties of molecules. The near-infrared spectrum encompasses wavelengths ranging from 0.9 μm to 2.5 μm . The absorption intensity of a molecule is influenced by both the wavelength of light and the molecular type. When a molecule is exposed to infrared light, it absorbs specific wavelengths while allowing others to pass through. In the near-infrared range, water exhibits strong absorption at particular wavelengths, indicated by peaks in its absorption spectrum. When a sample is irradiated with infrared light, its absorption spectrum can be recorded, reflecting a combination of the individual spectra of the molecules within the sample. A higher water content in the sample results in a greater resemblance between the absorption spectra of the sample and water. Water can precisely be measured between 0.4 μm and 2.5 μm . [DHQ+12] The schematic setup for this method is shown in Fig. 3.18.

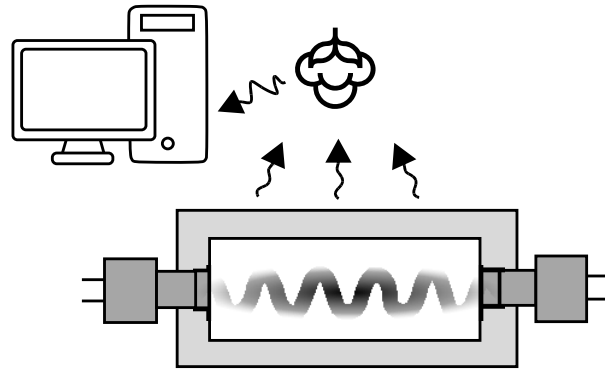


Fig. 3.18: Schematic setup of the near-infrared spectroscopy measurement

In contrast to the infrared drying, emitted waves from the testing material are measured. A computer then calculates the moisture content and different physical properties according to the absorbed wavelength. The procedure and behaviour of electric resistance measurement is described below.

3.7.2 Resistance method

Moisture measurement via the change in resistance of the material to be tested is one of the indirect measurement methods. The principle of moisture measurement using the resistance method is based on the low impedance of the water to allow electrons to flow through the test specimen. A high water content leads to a decrease in the resistance of the entire test specimen. [PB20] A schematic drawing of the measurement setup is shown in Fig. 3.19.

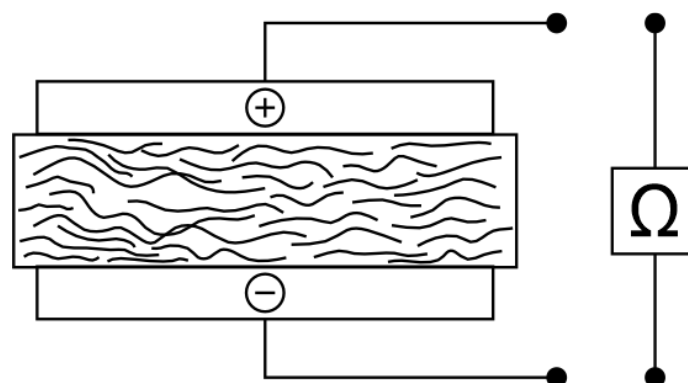


Fig. 3.19: Schematic setup of the resistance measurement, based on [FHN12]

The electric resistance (eq. (3.1)) can be described by Ohm's law [Byl98]:

$$U = R * I \quad (3.1)$$

With: U = voltage, R = ohmic resistance, I = amperage

Assuming that the resistor to be tested has the shape of a cylinder, the diameter is small compared to the length and the current flows continuously. The resistance can also be calculated as in equation (3.2) can also be represented as in equation (3.3) [Byl98]:

$$R = \rho_R * \frac{L}{A_R} \quad (3.2)$$

With: R = ohmic resistance, ρ_R = specific resistance, L = length of the resistor, A_R = cross-sectional area of the resistor

The specific resistance of cotton is made up of the specific resistances of dry cotton and water. Accordingly, the moisture content can be determined by measuring the resistivity of the cotton. [Byl98]

In practice, the above conditions for the measurement of moist cotton for equation (3.2) are only partially fulfilled. For this purpose, cotton samples are filled into a cylindrical test specimen and the resistance of the sample is measured. In particular, the measurement results of the samples showed no proportionality between the resistance and the reciprocal of the cross-sectional area. [Byl98] Instead, it is observed as in equation (3.3) a proportionality to the reciprocal of the circumference of the cotton sample is observed [Byl98]:

$$R \sim \frac{1}{C} \quad (3.3)$$

With: R = ohmic resistance, C = circumference of the cotton sample

Through further experimental investigations, the dependence of the resistance on the moisture content and the size of the sample can be determined as shown in equation (3.4) [Byl98].

$$R = \frac{P_1}{(M_C - P_2)C} \quad (3.4)$$

With: R = ohmic resistance, P_1 = parameter 1, P_2 = parameter 2, M_C = moisture content, C = circumference of the cotton sample

The parameter P_2 expresses the amount of bound water in the cotton. This water has no influence on the electrical resistance. [Byl98] Disregarding this parameter would lead to a systematic underestimation of the moisture content. It should be noted that equation (3.4) is not the only possible description of the problem [Byl98]. It is only an experimental solution [Byl98]. Therefore, these methods are systematically prepared in an evaluation scheme in Chapter 7.4. Nevertheless, before coming to the comparison, it is mandatory to understand possibilities of cotton humidification (Chapter 7.3) and implementation potential (Chapter 7.4). While not using the direct contact between the measured material and the circuit boards, capacitive testing might be used.

3.7.3 Capacitive method

The capacitive method is often also referred to as the dielectric method. It is based on the dielectric conductivity of a material, also known as permittivity. According to equation (3.5), this results from the absolute permittivity (electric field constant) and the material-specific relative permittivity. Capacitive testing appears similar to the resistance method, usually with air between the samples and the capacitors (cf. Fig. 3.20).

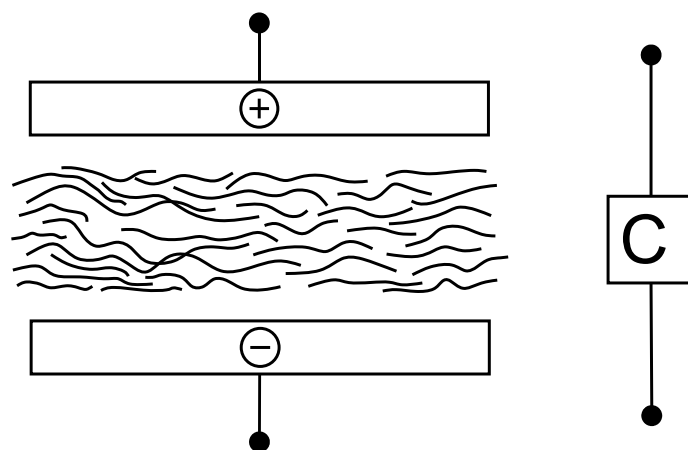


Fig. 3.20: Schematic setup of capacitive measurement, based on [FHN12]

At a temperature of 20 °C, water has a relative permittivity of 80 and therefore a significantly higher relative permittivity than air at 1.00059 [MM56]. As relative permittivity is a ratio of the dielectric displacement while placing a sample between the capacitor plates, it has no unit. Moreover, relative permittivity is practically independent of temperature and surrounding electric field strength. [FHN12] The materials for which the dielectric method is used also have significantly lower permittivity than water, meaning that the water content has a significant influence on the permittivity of the entire sample. Permittivity is calculated as followed [FHN12]:

$$\varepsilon = \varepsilon_0 \cdot \varepsilon_r \quad (3.5)$$

With: ε = permittivity, ε_0 = absolute permittivity. ε_r = relative permittivity

The measuring system consists of a capacitor in whose electric field the sample is placed. The following relationship applies to the capacitance of a plate capacitor [FHN12]:

$$C = \varepsilon_0 \cdot \varepsilon_r \cdot \frac{A}{d} \quad (3.6)$$

With: C = capacitance, ε_0 = absolute permittivity. ε_r = relative permittivity, A = electrode surface area, d = distance between the electrodes

This means that the capacitance of the capacitor is proportionally dependent on the permittivity of the dielectric, the material between the plates. By determining the capacitance of the capacitor with the sample between the electrodes, the absolute amount of water in the sample material can be determined. However, a statement about the humidity is only possible if the sample quantity is known. If the permittivity of the analysed material deviates significantly from the value 1.0, it is also necessary to know the permittivity of the analysed material. The capacitor capacity can be determined via the resonance frequency or the time course of a charge. These have significant influence on the interaction of cotton and the testing device. Therefore, all selections influence each other. The base of knowledge for this is provided in the following two Chapters, after a short interim conclusion of these described methods.

3.8 Interim Conclusion

As Chapter 3.6 and 3.7 show different methods for moisture measurement and not one specific one, these are shortly summarized and compared for the further elaboration. Moisture measurement is divided on first hand into direct and indirect measurement. Direct measurement means having a full value in Gram, which is the loss of water in a sample. Indirect measurement means having a helping value, like wavelength emission, which can be calculated into Gram of water, by examining specific tables or equations.

Many of those measurement principles rely on different wavelength, which are applied to the examined sample. This can be within the direct or indirect measurement principle. Direct measurement emits heat in the sample and dries all water out. For these principles, infrared and microwaves are applied. Indirect NIR measurement collects emitted infrared-signals and calculates a corresponding moisture content in the sample. The same principle is applied in capacitive measurement, but using electromagnetic fields and their deflection.

Concluding the direct measurement which is investigated here, is the oven method, which applies heat in a closed box to the sample and dries it. This method is still used as a reference method as it is the only standardized direct measurement method by now.

In indirect measurement, the last examined method is contact based, which is the resistance measurement. This method conducts electricity through the sample and measures the resistance. According to the specifics of this method, a minimum moisture content is required for being able to measure and reference values are required to set up a calculation to get out moisture contents.

Direct methods are not suitable for online or at-line testing, as they all require a certain duration for the absence of water. Therefore, indirect measurement methods are preferred as they allow results to be obtained quickly. All of those methods have their own requirements according to temperature-dependence, destructiveness, fibre properties, variety, origin or contamination. These methods are further investigated to be used in ginning mills in the following Chapters.

4 Cotton plant properties and differences

This Chapter provides a specific cotton fibre overview. Physical properties as well as differences between varieties are pointed out with regard to their influence on ginning optimisation. In particular, Indian and Egyptian cotton are displayed, which are mainly investigated during the execution of the relevant projects. Current literature mostly relies on data generated between the 1960th and 1980th. These data generalize all cotton varieties across the world to have similar physical properties. This Chapter begins with a cotton variety comparison (Chapter 4.1). Afterwards, moisture adhesion and influences are shown in Chapter 4.2. Out of this, particular recommendations for cotton handling are made in Chapter 4.3. Summarized in an interim conclusion in Chapter 4.4.

4.1 Cotton variety comparison in physical properties

Cotton literature state value ranges to cover most grown varieties in the world, without stating that it is for different varieties. But even within the same variety, depending on the cultivation conditions, different values are reached. The most significant physical values for cotton processing are shown in Tab. 4.1 below.

Tab. 4.1: Physical properties overview cotton [Den24]

Property	Value at Standard Climate	Wet Fibre in % to dry fibre
Fineness strength	25 - 50 cN/tex	100 - 110
Max- force elongation	6 - 10 %	100 - 110
Modul	300 - 600 MPa	-
Degree of Elasticity	75 %	-
Moisture content	7 - 11 % (21°C & 65 % rH) 14 - 18 % (24 °C & 95 % rH)	-

As in commercial cotton planting, there are more than 130 varieties, the overview below will only be a very small part of all existing types. Usually, plant cultivation relies on a couple of well operating and high-yielding plants. In India for example, many plant types rely on the variety ICS 105. The currently most often

cultivated plant is ICS-105 - LRA-5166. This variety is cultivated in five of nine cotton growing states in India. [ICA18] But depending on the state and its weather conditions, different physical properties are about to be expected.

Tab. 4.2: Indian cotton variety comparison on physical properties [ICA18]

Region (variety all RCH659-BGII)	Staple length [mm]	Micronaire	Bundle strength [g/tex]
Madhya Pradesh	25 - 27	3.5 - 4.9	24 - 27
Maharashtra	26 - 27	3.5 - 4.4	24 - 26
Karnataka	26 - 28	3.5 - 4.2	24 - 27
Andhra Pradesh	25 - 27	3.6 - 4.2	24 - 26
Tamil Nadu	25 - 27	3.8 - 4.5	24 - 26

In this table it can be seen, that even the same cotton variety brings up significant changes in fineness and fibre length. Bundle strength experiences less changes according to the region. Soil and growing conditions influence the physical properties which are measured on standard occasion. As most cotton varieties are not specified and investigated like this, it clearly shows as a starting point that further investigation on physical differences is required.

In Egypt, all cotton varieties rely on *Gossypium Barbadense* Linnaeus, brought from India. The breeding program strictly foresees, that Egyptian GIZA cotton is solely planted and breed in Egypt. Currently, there are nine mainly used GIZA types in Egypt. Five are expected to yield extra long staple (ELS) cotton, four are made for long staple cotton. ELS cotton is around 10 % of Egypt's total cultivation. The main properties are exemplary shown for GIZA 87 (5 % of cultivation area) and GIZA 86 (65 % of cultivation area). [ICA18] As values of the ICA Bremen are not precise in this regard, own samples are taken in Egypt and analyzed in a AFIS PRO 2. It relies on different locations within the season of 2023/24. The basis of correlation seems to be the degree of maturity shown in following Fig. 4.1.

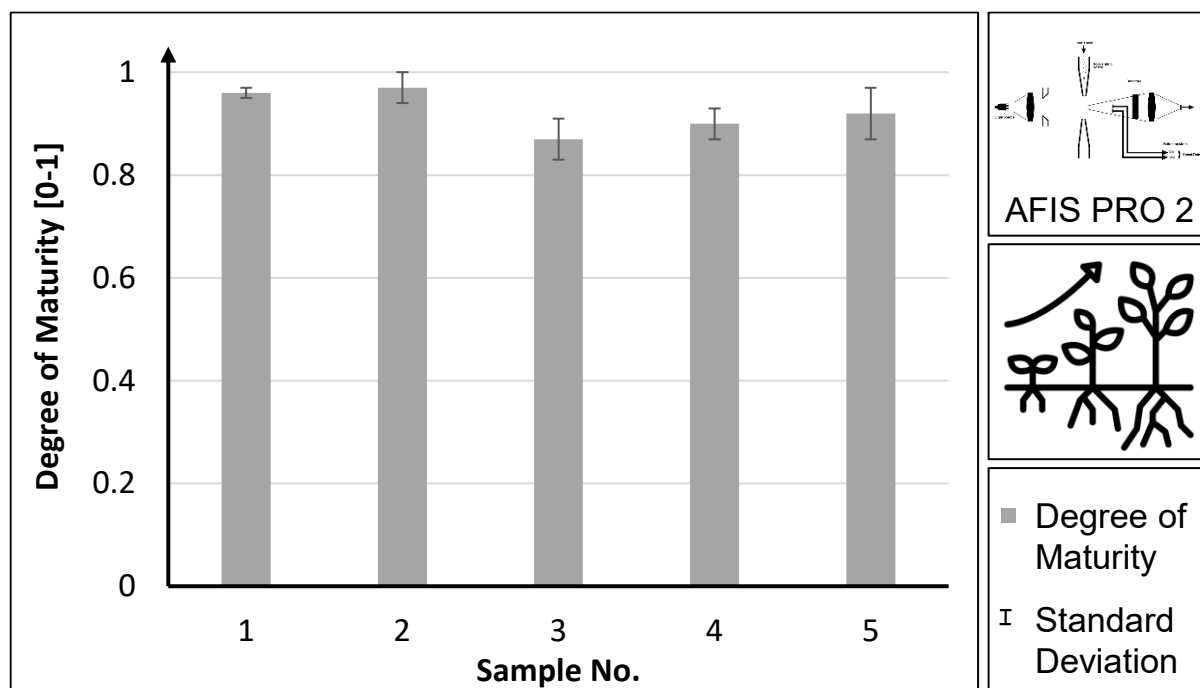


Fig. 4.1: Degree of Maturity GIZA 97 Season 2023/24

It can be seen, that sample 2 (97 % mature) and sample 3 (87 % mature) highly differ. One main question in this regard is, whether the degree of maturity is according to the skill of the cotton pickers or cultivation techniques. Both can't be investigated on a short track. It should be further investigated for higher knowledge creation for dealing with physical fibre and seed behaviour in ginning. The mutual influence within cotton lint can be seen in length, uniformity and fineness. Displaying those follows in Fig. 4.2 displaying the fibre length.

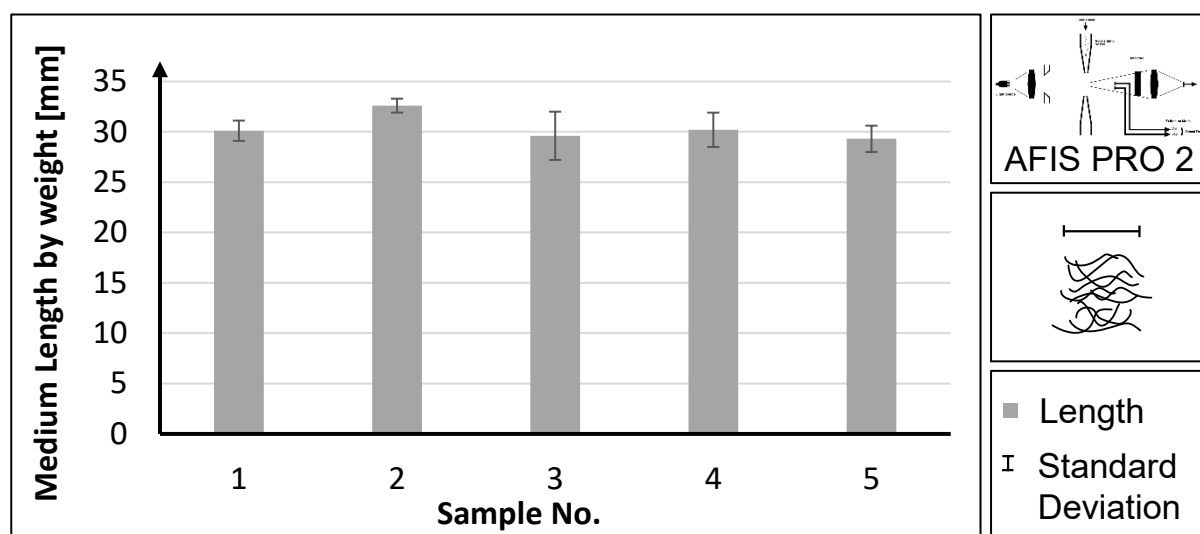


Fig. 4.2: Fibre Length GIZA 97 Season 2023/24

Fibre length average is displayed based on the weight of the fibres. That means, it is not to be compared with staple length, which would be Upper Half Mean Length (UHML), measured by HVI. Distribution and correlation can be seen between degree of maturity and length. Below, Fig. 4.3 shows Length Uniformity.

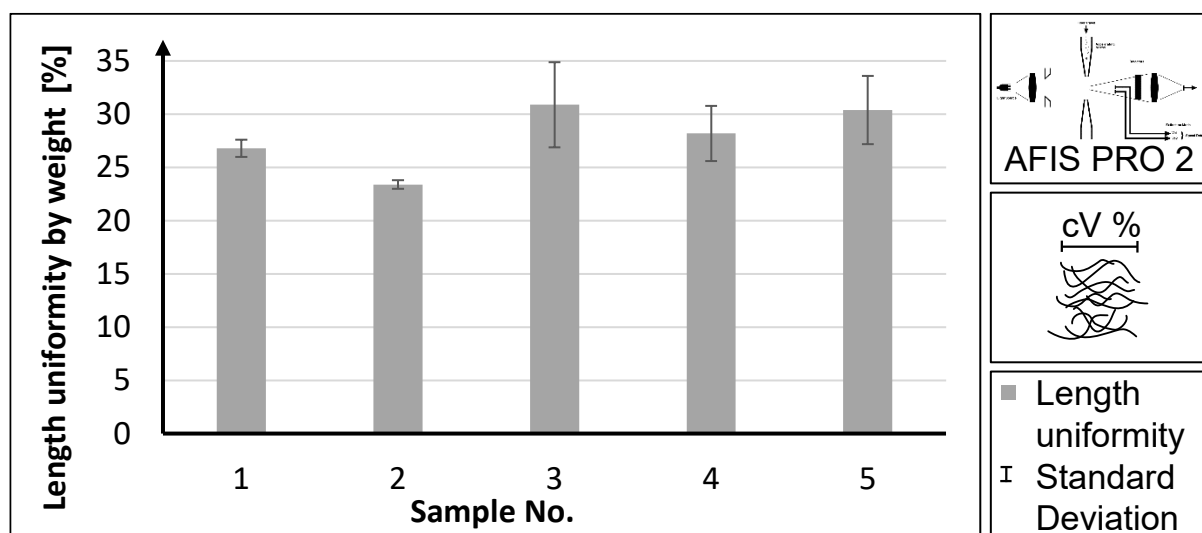


Fig. 4.3: Fibre Length Uniformity (cV%) GIZA 97 Season 2023/24

Uniformity is usually seen to negatively correlate with maturity. This means, mainly immature fibres lead to higher length distribution and therewith to higher coefficient of Variation (cV) of mass. A last clear indicator shown in Fig. 4.4 is the Cotton Fineness, measured by AFIS PRO 2 as well.

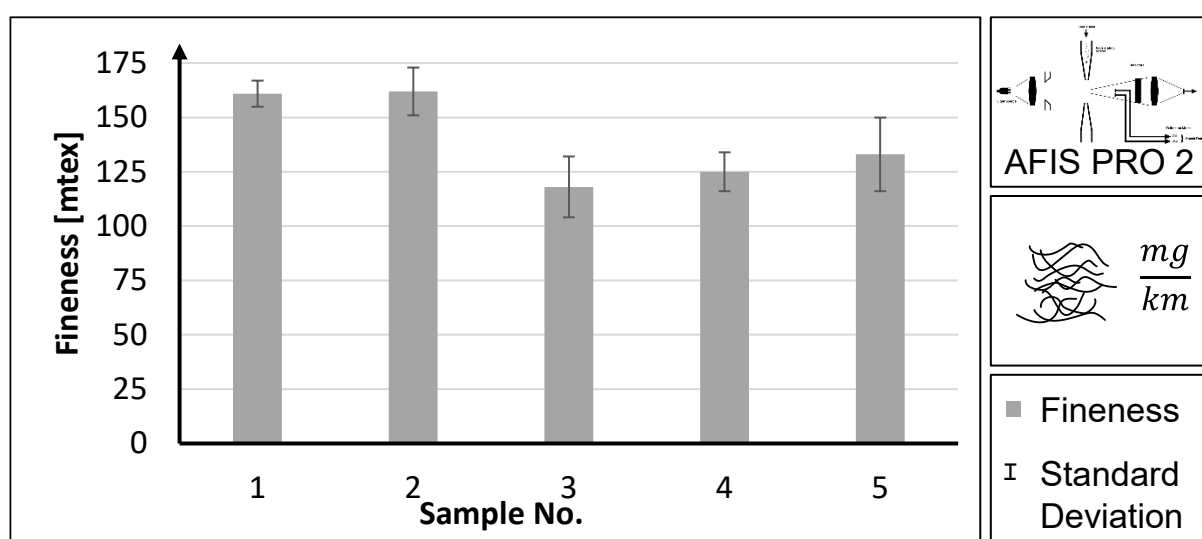


Fig. 4.4: Fibre Fineness GIZA 97 Season 2023/24

As cell walls and the thickness of the fibre increases while growing and maturing, this correlation is expected as well. The influence itself is significant, as we can see, that 10 % difference in maturity ratio between Sample No. 2 and 3 lead to an average loss in fineness of 27 %.

Even in lint producing ginning mills, seed recultivation is highly state wise monitored in Egypt. All cotton gins have an oven, which dries the cotton seed at announced temperatures. Fields or gins, which are selected for re-cultivation dry at a lower temperature to control pests but preserve the seeds recultivation properties. Selected seeds for oil production get dried at high temperatures to make seeds unusable for recultivation. Moreover, strong import and export control takes place, to preserve GIZA cotton from outside diseases or bringing Egypt's varieties into the world.

In cotton investigation and observation, physical differences between different varieties are commonly unviewed. In this investigation it was found out, that there is a different shell detachment behavior of different cotton varieties. The example of shell detachment behaviour of cotton seeds is shown in Fig. 4.5.

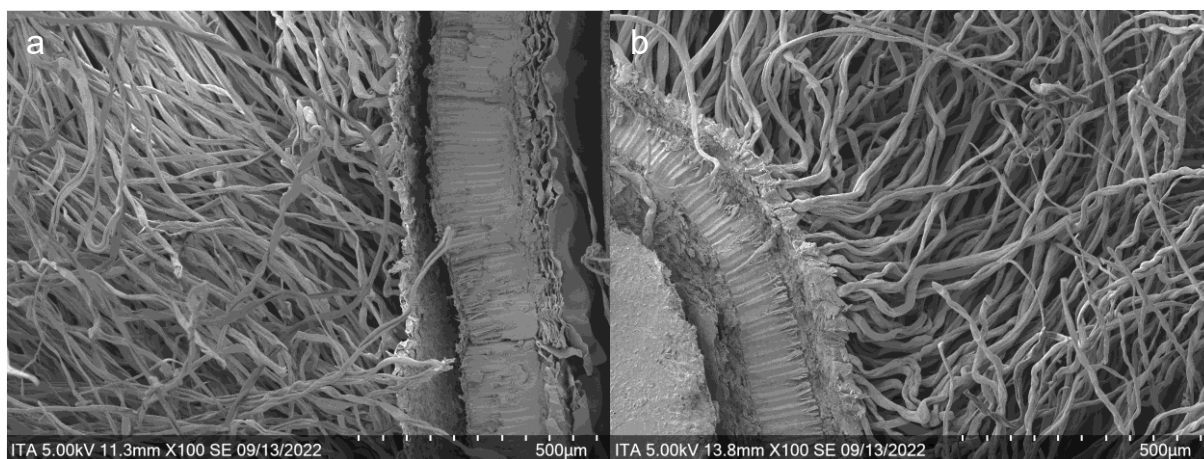


Fig. 4.5: Shell detachment behaviour of cotton from: a) Burkina-Faso b) India

It can be seen that cotton seeds from Burkina-Faso (left) tend to have higher ability of losing the outer shell. This shell is more likely to remain at the seeds and lead to connected fibre bundles instead of single fibres. In the Indian cotton seed, all layers of the seed strongly stick to each other, even after cutting for the scanning electrode microscope. This can be seen in the investigated machine

ginned cotton as well. Seed shell detachment leads to significant increase in seed coat fragments in the cotton. Further investigation needs to be done, whether it's by cultivation practices or behaviour of the variety.

ANTHONY and GRIFFIN JR. state out further reasons for fibre breakage at an unlikely higher place than directly at the seed. This might happen through prior wall weakening by microbial attacks, growing interruption or twists and loops which partly occurs in fibre manipulation. Moreover, shearing forces might occur, for which fibres have a lower resistance than axial forces or just uneven force application and therefore unlikely force peaks. [AG01]

In general, for cotton processing requirements remain stable across all different spinning technologies and products. There is a minimum fineness, strength and elongation needed in fibres and yarns. The buying decision of merchants and spinners is usually price driven. The lint cotton is bought to reach the minimum market requirements with the cheapest available cotton blend. In this regard, proper bale management is one of the crucial margin drivers. Therefore, achieving higher quality yarns with same production cost increases margins.

From literature it is clear, that the moisture content has the most significant influence to the cotton's physical properties and processing. Usually, no further in-depth investigations are made. Therefore, the following Chapter focuses on further displaying and investigating moisture correlations.

4.2 Moisture influence

This Chapter provides insights on moistening cotton and shows physical differences between the varieties Giza 86, 93, 94 and 95. Moreover, non-GMO as well as GMO cotton from Burkina Faso (BF) is analysed. Moisture contents can be calculated on wet basis and on dry basis as follows [AM94]:

- Wet basis: $\text{weight of moisture in sample} \times 100 / \text{weight of sample}$
- Dry basis: $(\text{Original weight} - \text{dry weight}) \times 100 / \text{dry weight}$

As we can see, during storage, the moisture content has a significant influence at different levels. Especially for re-cultivation and oil production, free fatty acids

and aflatoxin level degraded during long storing at high moisture content [Ant07]. Appropriate moisture levels are [Ant07]:

- 10 %: re-cultivation characteristics prevention limit
- 11 %: colour degradation (spotting) occurs
- 12 %: Oil quality prevention limit; long storage limit
- ≥ 13 %: yellowness will increase sharply, especially while storing for more than 45 days

MOORE and GRIFFIN found out, that overdrying leads to irreversible changes in the fibre. This leads to lower yarn strength for example. Therefore the cotton should only be stored until the ginning begins and not more dried than needed. The fibre lengths on the other hand is reversible. Moreover, moisture contents above 8 % led to difficulties in processing. [USDA64] This is quite controversial view and was further specified to some more dependencies. Cotton is often dried to about 4 or 5 % moisture content on the field. Cotton has it's highest strength at 15 % moisture content and is about 1.7 times stronger, compared to the 4 % moisturized cotton [MG64]. These low moisture contents lead to 1.4 times higher fibre breakages in the cleaning process, while applying two stages of lint cleaners [MG66]. It was confirmed once again, that the breaking force of the fibre increases almost linear with the increase of the moisture content by ANTHONY and GRIFFIN JR. They state 3.1 g to pull fibres apart from the seed at 3.6 % moisture to 5.0 g at 13.3 % moisture. [AG01] Concluding with the statement of Hughs et al. "overdrying" is a false term. The so called *overdrying* of cotton fibres comes from two main sources. First from too hot drying, secondly from too dry processing, while fibres are too brittle. This might occur in all stages, especially in cleaning and ginning. [HMJ94] Right procedure recommendations for cotton fibre processing will be made in the following Chapter 4.3.

Moisture should be divided in surface moisture (e. g. by rain) or moist air. Having a high surface moisture might lead to significant negative influences as rot or mould. The moist air leads to an increase or decrease of the moisture content of the hygroscopic seed and fibre. [HMJ94] Lint quality and moulding is less affected by higher moisture contents than seeds. Researcher in the US carried out, that moisture levels of 13 to 15 % lead to light spotting in seed cotton

storage. Moreover, moisture levels above 13 to 14 % sharply increase yellowness while storing for more than 45 days. This is due to the work of bacteria in the cotton. Therefore, moisture contents below 12 % are recommended for longer storage periods. [PAS10]

Temperature changes affects seed cotton less significant than moisture content. Studies shows that the average temperature and ambient during harvesting has moderate influence on the cotton's yellowness. Even after a temperature drop in the cotton seed module, the yellowness keeps increasing after being above 13 % of moisture once. [PAS10] Due to the fact, that high moisture contents lead to a loss in quality and price, the moisture content should be checked frequently and properly. This means having an average of two to three values taken with a clean and dry measurement system. [PAS10] Therefore, proper ongoing moisture monitoring is required instead of checking cotton moisture before storage.

The duration for moisture adjustment depends on the density of the textile structure. Fibres tend to adjust moisture faster than yarns or fabrics. This moisture adjustment is according to the surface, which is surrounded by ambient air. Moisture contents count to be in equilibrium, if weighing at intervals of 2 hours show less than 0.25 % change of mass [DIN11] REUMANN suggests the following durations for moisturization (cf. Fig. 4.6).

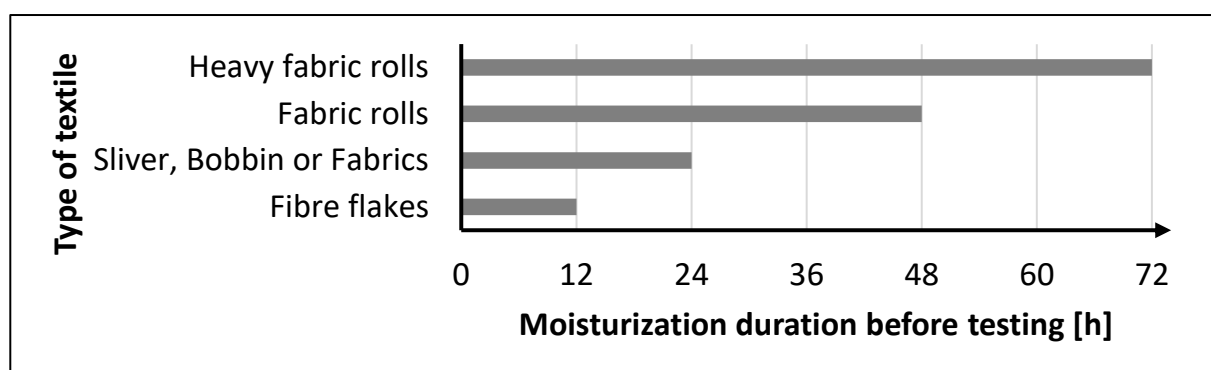


Fig. 4.6: Moisturization duration according to textile type [Reu00]

This shows, fibre flakes should be in moisture equilibrium after 12 hours. As this duration would require a massive amount of storage capacity in US cotton

classing strategy, a procedure is developed to moisturize cotton within 15 to 20 minutes [Ear17]. To make sure, how cotton reacts to heat stress even across different varieties, independent from moisturization duration, a test series is fulfilled with 24 hours of fibre flake moisturization. The expected result is moisture differences in moisturization and drying, as well as between the varieties. According to KLEINHANSL, expected cotton moisture contents are 7 to 11 % based on the Denkendorf Fibre board from 2024. [Reu00, Den24]

Own investigations show main differences. Each sample weighs 10 g of cotton, weighed at 20 °C and 60 % rH. Additional weight is gained, by weighing it with a Polypropylene (PP) plastic bag to preserve moisture content when the door of the climate chamber is opened. Those PP bags get closed immediately and the weighing procedure begins. Every variety is muddled out of 3 samples. Even between different Giza varieties, which are particularly close in genetic matters (cf. Fig. 4.7).

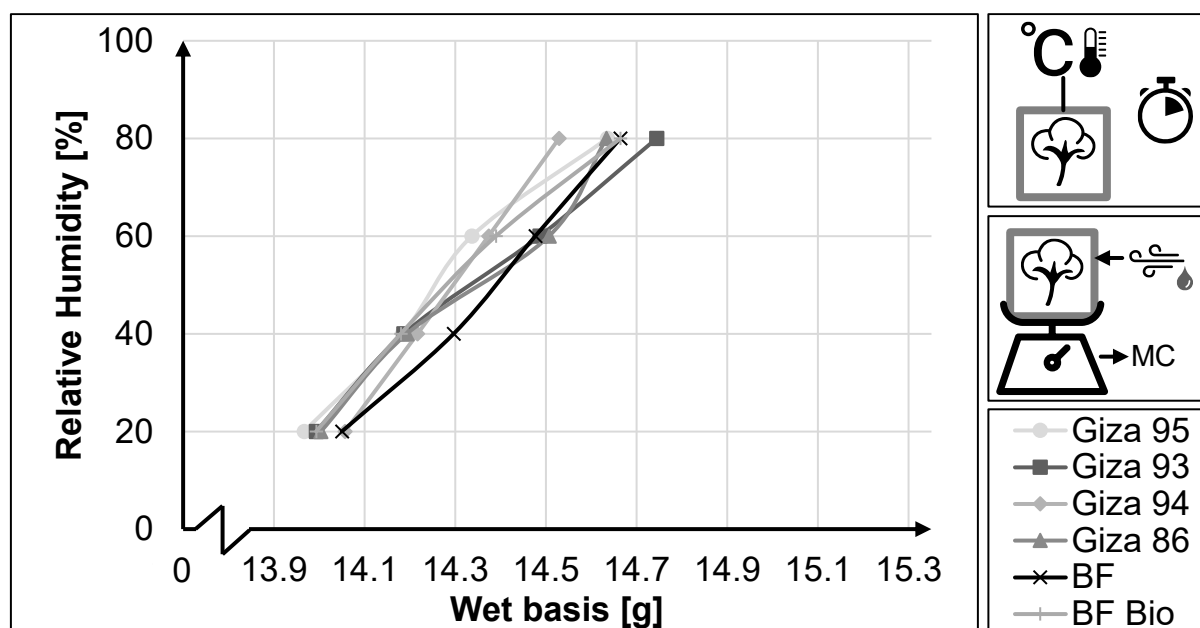


Fig. 4.7: Drying behaviour of different cotton varieties acc. to rH (35 °C)

It can be seen, that there are significant differences between the achievable weight, which is corresponding to the relative Humidity within the cotton. The maximum deviation is at 60 % rH with 0.17 g, which is 1.7 % lint moisture difference. The following Fig. 4.8 shows the moistening process.

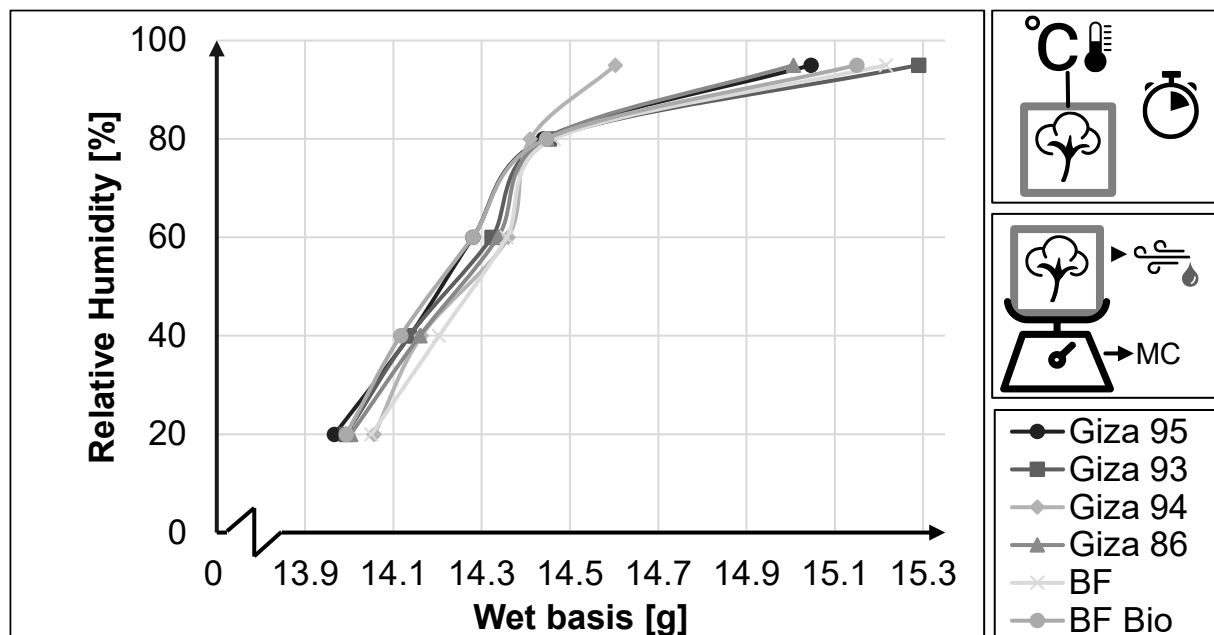


Fig. 4.8: Moistening behaviour of different cotton varieties acc. to rH (35 °C)

Unexpectedly, in moistening the fibres, this tendency is reduced, while the lowest difference is at 80 % rH with only 0.26 % deviation. Giza 94 results differ significantly at 95 % rH. Further examples focus on Giza 95 and 86 as findings are similar. Drying and moistening weights of Giza 95 are shown in Fig. 4.9.

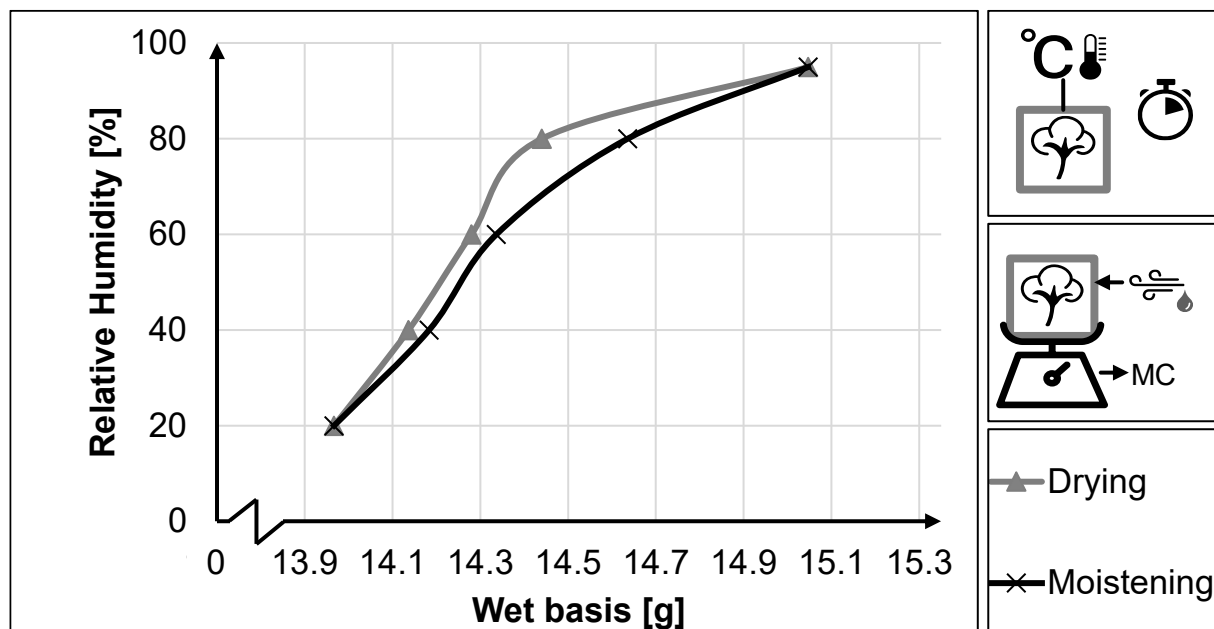


Fig. 4.9: Giza 95 drying and moistening behaviour at different rH (35 °C)

Giza 95 shows slight difference in water adaption according to drying and moistening. The biggest difference is at 80 % rH with 0.2 g change out of the 10 g fibres. 95 % rH and 20 % rH are all the same values, as there is only one value measured during the testing process. The equipment could not safely reach lower moisture contents than 20 % or higher than 95 % rH. To finalize this row of figures and proof the findings, Fig. 4.10 show the drying and moistening behaviour of Giza 86.

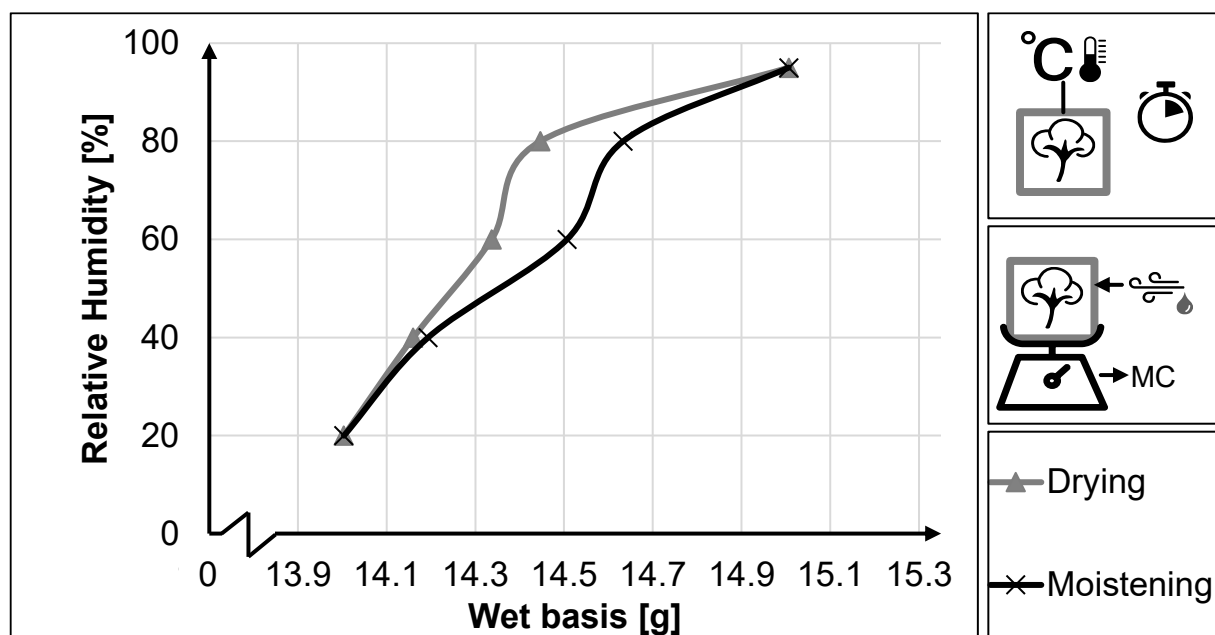


Fig. 4.10: Giza 86 drying and moistening behaviour at different rH (35 °C)

Giza 86 is the sample with highest value deviations. This deviation occurs at 60 % rH with 0.17 g. This means a change in weight of 1.7 %, solely on lint basis. These values align with given literature.

As lint was weighed and packed at 20 °C, basic values at 60 % rH across all different varieties differed by 0.04 g between 20 °C and 35 °C in the moistening process. This underlines the hypothesis, that rH is more important than temperature for testing. During drying, a weight hysteresis up to 0.18 g occurs, as visible in the Figures above already. Therefore, it should be considered that cotton or its products, like yarns and fabrics, should be tested all in the same way. As transportation usually takes place at low humidity and in hot containers, coming from dry state and moistening cotton is recommended.

To set a proper frame on the processing recommendations of cotton, it needs to be clarified that most research and publications come out of the US. This means, the main focus in cotton fibre extraction is on saw ginning. Nevertheless, in the following Chapter an attempt is made to address all cotton handling steps.

4.3 Cotton handling recommendations

In general, cotton handling recommendations should preserve existing quality. Cotton quality is affected by every treatment, handling and processing. All of those processes influence cotton quality negatively. Therefore, handling should be as less as possible to preserve fibre length, low damaging and colour. Fibre gentle means reduced rubbing of fibres against sieves for cleaning.

To set an appropriate moisture content, knowledge about moisture values and machine settings are most important factors. Therefore, it is good to know that most of the moisture coming out in conventional drying in gins is out of the fibre, not the seed [HMJ94]. Main factors to determine the drying rate are [HMJ94]:

- air temperature
- air to cotton weight ratio
- degree of boll openness
- exposure time
- air to cotton relative velocity
- entering cotton moisture content

An appropriate amount of seed cotton is required to archive a sufficient drying [HMJ94]. Typically used values and air volumes of seed cotton are [HMJ94]:

- 1,25 m³/kg in tower dryer systems at 450 to 600 m/min
- 2,5 to 3 m³/kg in towerless systems at 1200 to 1500 m/min (for pipes)

These air velocities are required to have a sufficient seed cotton movement [HMJ94]. At the same time, there should be a proper compromise between the duration of ambient heat around the cotton and the temperature itself. Previous investigation show, that drying at high temperatures should be done only at low durations (cf. Fig. 4.11).

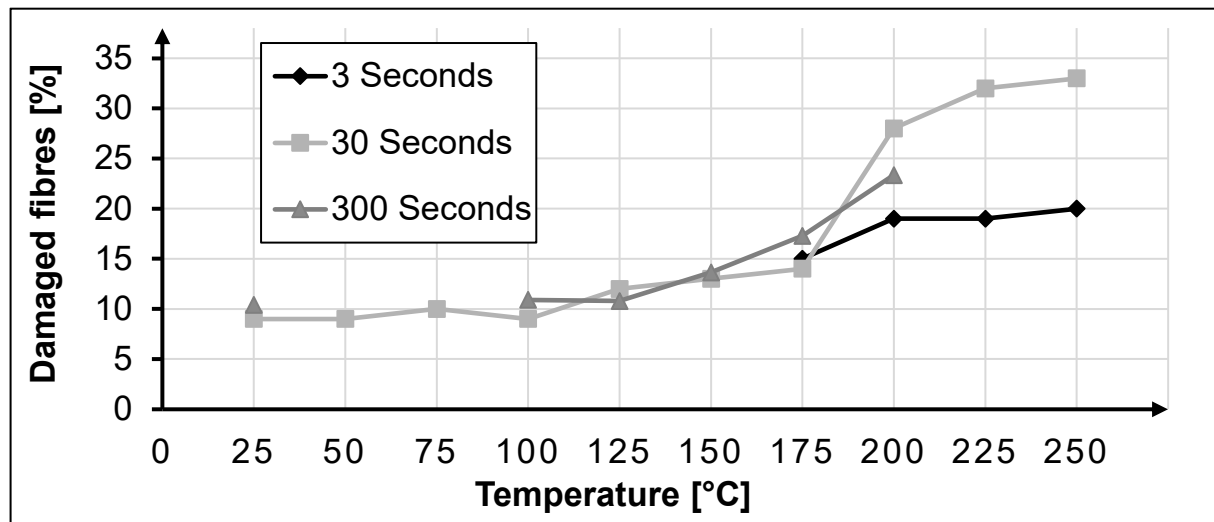


Fig. 4.11: Heating fibre damaging behaviour on duration [HMJ94]

The figure shows, that drying might be suitable even at high temperatures but with low duration, like 3 seconds. To see what happens if fibres get even more heated, consider the cotton fibre reactions on heat from Tab. 4.3.

Tab. 4.3: Cotton Fibre temperature reactions [ICAC01; Reu00; MG64; Reu24]

Temperature [°F]	Temperature [°C]	Cotton fibre reaction
200	93	Max. recommended temperature
250 - 300	120 - 150	Colour change
450 - 500	230 - 260	Scorching
750	400	Ignition / Flashing

Beside these well investigated temperature dependent reactions on fibres, mechanical stress during fibre processing leads to significant shortening, as well as damaging. Therefore, loads and friction should be reduced as much as possible, while optimizing the physical resistance of the cotton with different treatments. Specific recommendations for a reduction of loads can not be provided within this framework. It is taken into account to optimize fibre behaviour and properties, with setting optimized moisture contents, summarized below.

4.4 Interim conclusion

The same cotton variety cultivated in different regions of India exhibits significant variations in fibre length, fineness and micronaire values due to differing soil and weather conditions. These variations highlight the profound influence of geographical regions on cotton fibre properties and emphasize the importance of considering local environmental factors in cultivation practices.

Higher degrees of maturity correlate with increased fibre length, uniformity and fineness due to thicker cell walls. A study found that a 10 % difference in maturity can lead to a 27 % loss in fineness, underscoring the crucial role of optimal cultivation and harvesting practices in maintaining fibre quality.

Moisture content emerges as a critical factor affecting cotton's physical properties and processing behaviour. Cotton fibres exhibit maximum strength at a moisture content of around 15 %, being 1.7 times stronger than at 4 % moisture content. An overview about well-set moisturization duration, moisture contents and colour protection are provided in Fig. 4.12.

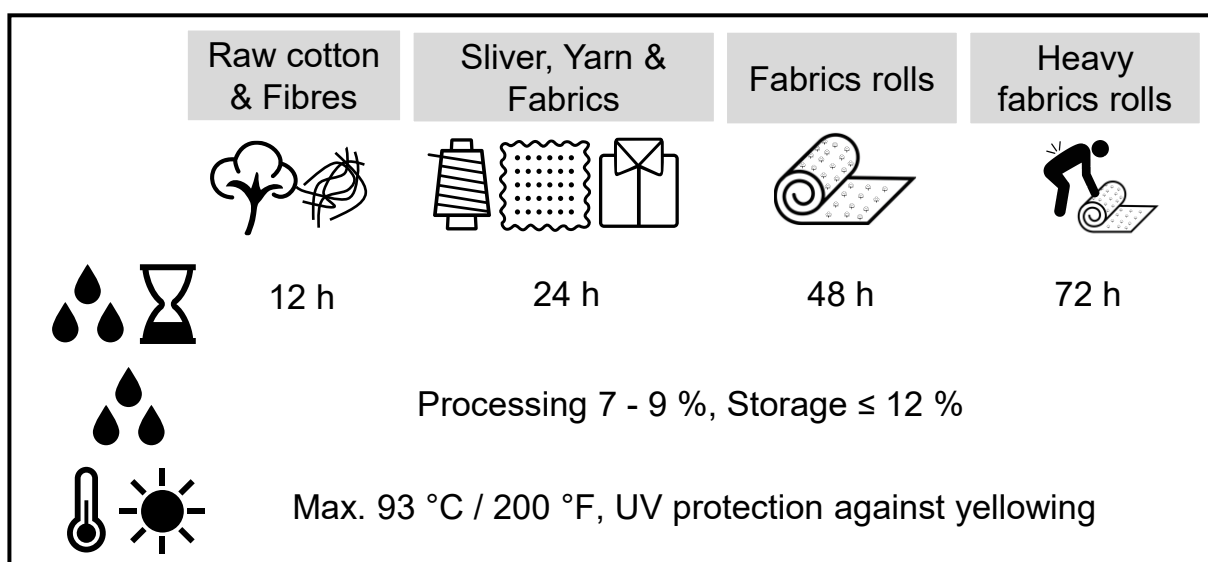


Fig. 4.12: Product specific moisture and colour protection recommendations

Based on that knowledge about moisture and cotton colour, typical processing practices are summarized in the Chapter below, based on interviews and on-site investigations.

5 On-site technology assessment

In this Chapter, an overview is provided, of ginning plant practices, expert interview results and derived tasks. There is a wide spread between communicated practices in ginning mills and those which are seen on-site. Therefore, investigations at the processing sites are mandatory to get a wider view on the ginning situation worldwide. The corresponding results for developing countries are collected in India and Egypt. Further discussions are examined with experts in particular from the USA, Australia and Germany.

Before describing the sociological investigation, it is important to know the stakeholders. As ginning is a national and local business, there are several different external and internal stakeholders to be considered. Those vary significantly, depending on the country and region. Externally, governmental actors involve themselves as deep as wished, on their own decision. For those external stakeholder, general recommendations for participation are written down later on. Internal stakeholder (cf. Fig. 5.1) remain similar across different regions and countries, as tasks are the same. Therefore, the main focus will be on internal stakeholders.

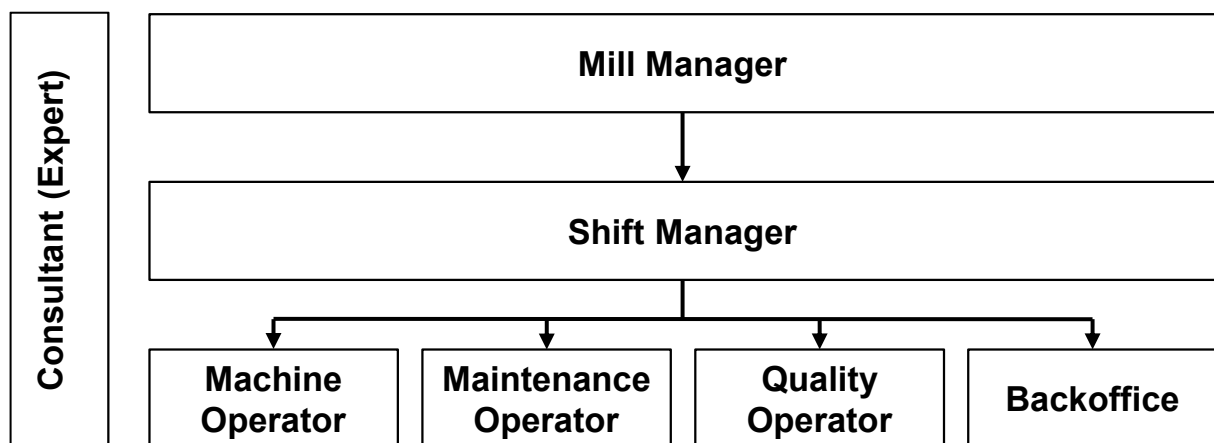


Fig. 5.1: Internal stakeholder in a ginning mill [KFS22]

Consultants are widely used in developing and developed countries. In the USA, farmers consult experts for every different crop they grow. Consultants are particular experts in one processed crop and interact with every hierarchical level in a mill. Experts get deep and overarching insights, learnable in interviews.

5.1 Expert interviews of mill representatives and consultants

On the one hand side, many low wage countries as India for example usually do not see or value the necessity of predictive maintenance. In direct discussions, most mill managers promise the importance of maintenance as well as predictive maintenance and quality assurance during production. While visiting the facility, from a German engineer's perspective, the practical implementation is missing. This is shown in interviews, held by Raina Consulting and Associates Pvt. Ltd., Mumbai, India, based on a questionnaire from KÜHN et al. [KFS22]. The interviews are held during the Covid 19 pandemic in October 2021. Due to the language barrier and level of education, the interviews are held in the mother tongue of the ginning mill manager and operator in-charge. This means interviews are held in the local language of Maharashtra, which is called Marathi. The according documentation can be found in Chapter 15. On the other side, Egypt for example still widely drives ginning machines which are built between 1880 and 1920. These machines are very well preserved and maintained. They usually operate with a much lower throughput, while preserving the fibre quality and length very well. Many interview partners here mention the maintenance strategy as well. Meanwhile, the surrounding infrastructure which is not value adding or does not bring money is widely neglected, too. This means buildings get cracks, the floor is full of mud puddles and the fire brigade (if applicable) has partly empty compartments in the fire truck.

As the interviews in India are carried out mostly during walking across the ginning facility, there is no transcript available. It is mostly held in short conversations, supported by a translator. As it is the starting point of this research, it is highly appreciated for orientation in the field of ginning research in Germany for developing countries. The expert interviews carried out in 2023 in Egypt are prepared with a guiding questionnaire and documented on a recording device. This procedure of clarifying the assumed content before preparing a whole questionnaire [Die08]. A transcript of these interviews including the situational observations of the interview setting can be found in Chapter 16. Displayed in an unsorted but clustered way, findings are:

- Small hold farmers, usually 100 % hand picking
- Given awareness for importance of cleaning and moisture management
 - India: 12 % moisture content is mentioned
 - Egypt: 6-7 % moisture content is mentioned (as in literature)
- Using High Volume Instrument (HVI) tests as a key for quality definition + Given awareness for fibre quality, as Colour and Length (not yet used)
- Awareness for quality preservation (e. g. degradation while touching or spoiling if being too contaminated/wet) → central trusted testing centres
- Low nep count required (causing too many neps in ginning)
- Awareness of shortening lint due to gins (even at higher productivity)
- Rotobar ginning as a future alternative (rotating knife in roller gins)
- From some farmers contamination is a big issue (fruits in cotton bags)
- Awareness for machine damages by contamination (especially stones)
- High skilled operators required (e. g. via ongoing working contracts)
- Good maintenance and good cleaning (each shift) required
- Trainings are available, by consultants or machine manufacturers
 - Mentioned: 7 days theory → Maintenance
 - Practical training while the machines are running at the beginning of the ginning season → General procedure and Troubleshooting
- Trust in (testing) devices
- Training for farmers required to inform about consequences of bad behaviour (e. g. putting stones or fruits in the bag, trash, contamination)
- Technology change brings mind change issues
- State wise control wished
- Increasing importance of organic or certified cotton (e. g. by *Better Cotton Initiative* (BCI))

After having those interviews, additional field visits are done for on-site investigations of the state of the art. This includes additional interviews, mostly supported by people within the visiting delegation who are able to translate the local language to English. The findings are described in detail below. After providing a full overview, the development of solution and conclusion is described.

5.2 Technical and Social on-site analysis in ginning mills

Due to the fact that there is significant deviation between the communicated procedure and the real situation at place, this Chapter displays the findings at

place. This is also called on-site, here. To give a best unbiased view on the situation, it is including pictures for documentation.

In Raw seed cotton Handling, contamination with trash and plastic parts is still a big issue. As cotton is handpicked in almost all low wage countries, it has the potential for very clean raw seed cotton. The raw seed cotton handling on the field is solely investigated in Egypt as it is too late for the harvesting season during the India visit. Farmer and process observer from universities promised, that there is no plastic used during cotton harvest in Egypt, as it is governmentally mandated. During the field visit, many day labourers used plastic bags as the state wise sold jute bags cover 280 kg raw seed cotton. The handling of those for weighing by four persons with sticks as tools are displayed in Fig. 5.2.



Fig. 5.2: 280 kg raw seed cotton bag handling with four persons and tools

The people left and right sided carry the bag. The tripod is the weighing system. After weighing, in Egypt cotton is sold on auctions. In India, the current raw cotton owner sells it to a ginning mill or commissions a ginning mill for separating seed and lint.

In each surveyed ginning facility (India and Egypt) the unloading of delivered raw seed cotton is performed manually. Smaller Indian gins receive seed cotton from smaller goods carriers, typically transporting approximately 4 t of seed cotton. Conversely, larger gins receive their cotton deliveries from heavier trucks, which carry around 30 t of raw seed cotton. Fig. 5.3 illustrates the typical types

of trucks used for transportation. The smaller truck depicted in the image carries 2.2 t cotton. Notably, the cotton is mostly transported uncovered, leaving it susceptible to dust and sand contamination during transit. [KFS22]



Fig. 5.3: Cotton delivery trucks in India [KFS22]

Not all deliveries are transferred without coverage. In certain instances, the raw seed cotton is packaged in jute bags, auctioned and delivered to the ginning mill. This presents a challenge, as the jute material, being a natural fibre itself, can become intermixed with cotton fibres during the feeding process at the ginning mill. The separation of jute fibres from cotton fibres proves to be a difficult task in the blowroom of a spinning mill. This may result in cotton ring spun yarn containing slight traces of jute fibre. The presence of jute fibre during the yarn and/or fabric dyeing process can lead to fabric defects. [KFS22]

The trucks undergo weighing procedures both before and after the discharge of raw seed cotton to ascertain the value of the delivered material. However, the primary challenge arises with regard to its storage. Improper moisture management may lead to mould growth if stored for extended periods. [KFS22] But, jute bags and -fibres in the cotton are much better in their behaviour than plastics. Afterwards, the cotton is typically stored under open roofs, leaving it vulnerable to environmental factors such as heavy rain or wind (cf. Fig. 5.4).



Fig. 5.4: Raw seed cotton storage in India [KFS22]

Another challenge is the absence of segregation of different batches in harvesting. Instead, the cotton is mixed together using an excavator, rendering it impossible to differentiate between deliveries from various farmers. This makes the traceability of cotton much more difficult. Moreover, while mixing up different harvests of one field, more contaminated cotton with dust and sand contaminates the cleaner cotton. As mixing is often fulfilled with tractors on sandy ground, this is even worse in terms of dust contamination. Indian ginners usually argue this with the excepted trading limits of contamination, which adds extra weight, without using cotton. The cotton quality significantly drops at this time and processing gets much more difficult. This refers to the following paragraph of a machine overview and the degree of automation.

Ginning machine set-up and the general flow of material is similar to the state of the art in Chapter 3.2. Though the visited Indian facilities purposely don't use pre-cleaning machines or drying machine. Therefore, the machine set-up is some shorter than expected from literature (cf. Fig. 5.5). The reason for this is, that the ginners do not earn (significantly) more money for cleaner cotton, so an investment in cleaning machines would not be profitable. [KFS22]

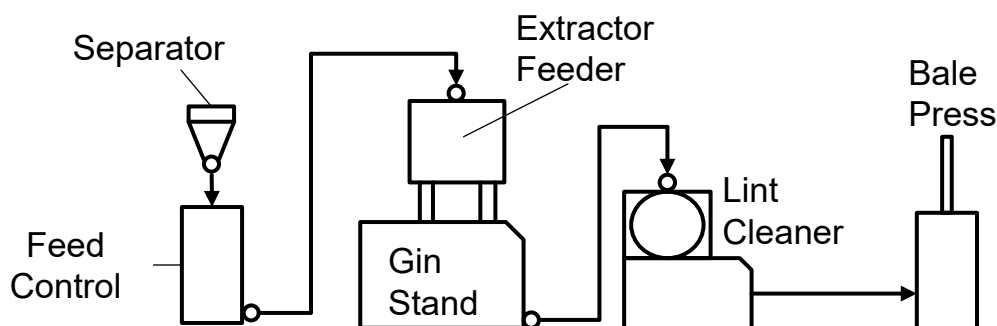


Fig. 5.5: Practical roller ginning machine set-up in low-wage countries [KFS22]

High wage countries usually install all recommended machines for proper raw seed cotton and lint cleaning. Low wage countries tend to only install the technically necessary machines. If additional machines, like further cleaning stages, are already installed, they are often not used according to energy savings. Sometimes, trash is explicitly left within the bale to gain more weight without discount in the accepted trade values (e. g. up to 3.5 % in India). Equivalent descriptions are now given below for the moisture management. [KFS22]

In contrast to other processing steps along the cotton value chain, the ginning process is partially automated. Raw seed cotton is transported to the ginnery from the stock using either a belt conveyor or air streams. The processing plant comprises three levels. On the top floor, the raw seed cotton is initially routed and if necessary, it is then directed to the roller gin stands located below. These units are equipped with conductive sensors that activate flaps to the top floor as needed. After ginning, the lint is conveyed underground.

In front of the gin stand, there is a platform designed to shield the lint slide and allow closer access to the machine. At the conclusion of this slide, the lint is conveyed to subsequent processing stages. In the visited facilities, these typically consisted of a singular type of lint cleaning measure and the bale press.

The baling procedure varied across different ginning mills. Not all ginning mills adhere to a standardized bale packaging system as prescribed by the Cotton Corporation of India (CCI). This leads to different bale size and weight, than the defined 170 kg bales. During the baling process, it is observed that certain facilities continue to utilize iron cords to secure the cotton in its compressed state.

One issue associated with this practice, particularly when dealing with moisture-laden cotton, is the occurrence of rust. Prolonged storage can lead to the development of rust on the iron cords, which may subsequently stain the cotton with a reddish hue, as depicted in Fig. 5.6. [KFS22] As the standards and values highly refer to the operating machines, these are further investigated and described below.



Fig. 5.6: Contaminated cotton by dust and rust [KFS22]

Moisture management is one major difference in India, compared to current literature. Very high (raw-) seed cotton moisture content in ginning is observed. Specifically, the moisture content at the outset of the process, reaching up to 12 %, exceeds the values documented in the literature by far. Furthermore, in the visited facilities, moisture content is not assessed using any device but rather by the touching judgment of a skilled operator. Ginning operators indicated that, based on the high surface temperature (almost 150 °C) of the washer and immediate ginning following the feeding machine, a moisture content of 12 % is considered as ideal in the interview from the Indian ginning mill representatives. [KFS22] This moisture content is likely to drop immediately, due to this high temperature and according vaporization.

The ginning temperature is closely approached to its limit. The temperature of the washer should not surpass 149°C. The ginning machines examined in India

are frequently operated at temperatures reaching up to 150°C . This practice notably results in increased maintenance requirements and greater wear of the surface layers. [KFS22] This high roller gin surface temperature does not lead to a self-ignition of the cotton fibre due to the short contact duration. The fibre temperature rises to approximately 40°C to 45°C in continuous operation.

A common issue in roller gins occur when cotton lint becomes trapped in the washer groove. As a result, the lint is carried along with the groove during additional and unnecessary rotations. To address this issue, machine manufacturers developed a lint retainer. Ginners do not utilize this device in practice. Instead, many ginners attach a rope to their machines, which comes into contact with the washer, to remove these lint fibres, as depicted in Fig. 5.7. [KFS22] In real life observation, it looks as follows in Fig. 5.8.

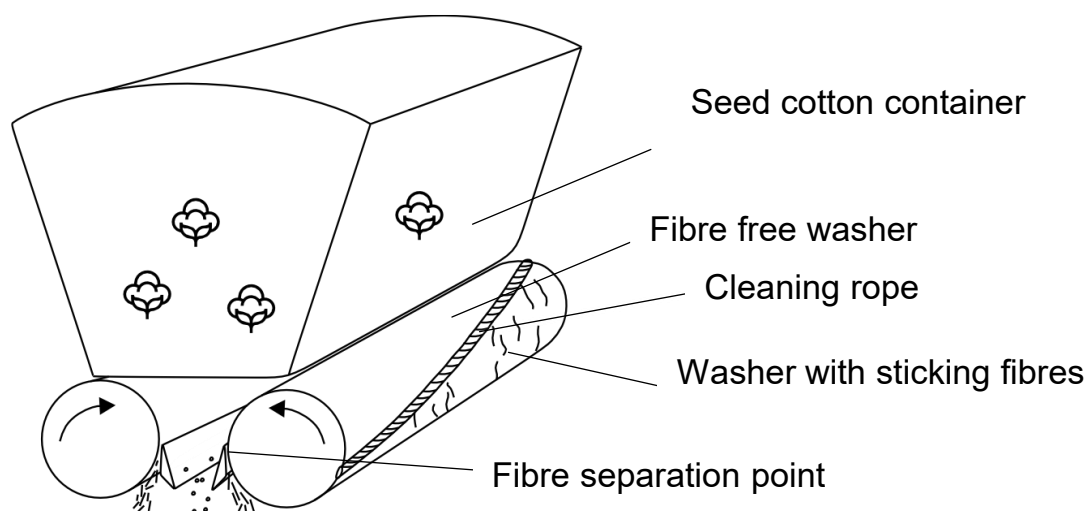


Fig. 5.7: Rope to prevent lint from sticking at the washer



Fig. 5.8: Real life appearance of the cleaning rope [KFS22]

Due to the absence of a washer-cleaner (device for removing sticking lint from the roller, in India called washer, surface), diverse components of the machine manufacturers are omitted in practical use. For instance, in the original setup, there is a grid beneath the roller designed to capture trash particles. This grid has been removed in many ginning plants to prolong the interval between two cleaning cycles of the collection tray. The trash falls on the ground or back into the machine. [KFS22] Practical maintenance is described below.

In Maintenance, there is a much different behaviour in accuracy. For example, the groove depth along the roller gin washer needs to be maintained to grip seed cotton fibres. The typical operation of ginning machines imposes significant stress on the washers and wear out of the surface. If manual grooving is done without any spacing devices, the grooving device can be pulled out of the groove and widely destroy the surface (cf. Fig. 5.9).

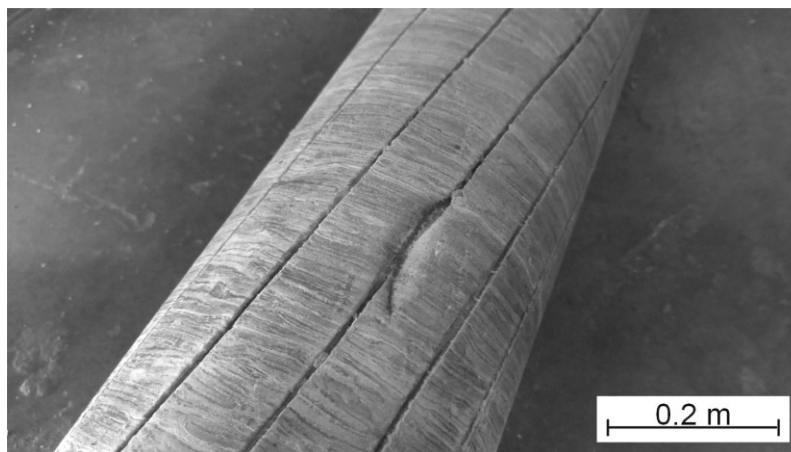


Fig. 5.9: Defect in a leather roller, due to manual grooving [KFS22]

Spacing devices are required to guarantee the distance between the washer and hand-held circular saw. Occurring defects disrupt and reduce the efficiency of the ginning process because the fibres are no longer properly caught in the grooves. Seeds may get stuck in too large grooves. Consequently, such defects must be promptly removed. However, minimizing downtime in the plants is a priority, which often results in damages to components going unnoticed for extended periods. Consequently, a machine may continue to operate with such damages for a considerable duration. Once the damage is eventually detected, reworking becomes necessary. Even if automated or guided grooving is

available, mostly simple hand cutters (cf. Fig. 5.10) are used to rework the grooves. This manual reworking process is more hazardous and less precise, compared to the products offered by machine manufacturers. [KFS22]

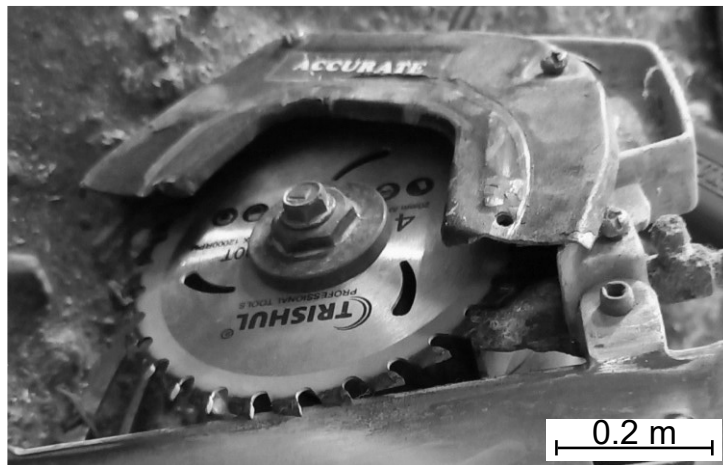


Fig. 5.10: Manual grooving device, used for roller grooving in India [KFS22]

Slipping might lead to false grooving and destroy the washer or heavily injure the operator. Moreover, circular saws produce high dust, which lead to long term diseases. Still, many washers exist out of leather. As these mostly contain hazardous substances, leather washers are prohibited in many countries by now. Therefore, new washer set ups of cotton fabric composites were developed. These washers are made out of cotton fabric, glued by composite structures. Usually, 13 layers of fabric are used for this. But not only the materials have an important impact on the processing. Labour and their employment situation are very important to get skilled operators. This is described more in detail below.

Labour employment structures are a major factor for high qualitative and constant processing. Each ginning mill visited in India operates the gin as a supplementary venture. This seasonal ginning activity is not conducive to full-time employment, prompting many owners to allocate employees from other businesses. Typically, only the director and, in larger ginning mills, one or two additional employees work full-time at the ginning plant throughout the year. [KFS22] Many Egyptian mill owner state that in the non-operating month, employees can do maintenance. On-site, the non-operating facilities visited are mostly empty.

During the ginning season, a mill operates 24 hours per day. On average, an Indian ginning mill of moderate size employs approximately 25 to 30 workers. These individuals undertake diverse tasks, including unloading raw seed cotton from trucks, manually removing impurities from delivered fibres, overseeing the ginning process, compressing ginned fibres into bales and loading these bales onto trucks for delivery to spinning mills. The organizational structure within a ginning mill is typically flat. Most owners employ a factory manager, responsible for operations. The Indian labour force primarily consists of contract workers engaged on a daily wage basis. [KFS22] In Egypt ginning mill operators are mostly full employed throughout the year.

Sources of knowledge and training are often combined in one hand with the machine sellers. Especially in India, it is the centralized nature of ginning information distribution. Bajaj Steel Industries Ltd., Nagpur, India, serves as the primary source of new information, techniques and machinery in the industry. Among their contributions is the publication of books that synthesizes contemporary ginning practices. Other than this, all other information is disseminated to ginners through private channels, fostering an exchange of the latest practices among neighbouring ginning plants. However, the infrastructure for knowledge dissemination beyond these informal networks is relatively underdeveloped. Nevertheless, the consolidation of information distribution and the commercial interest in selling machinery may potentially pose a conflict of interest and result in a high degree of dependency on the monopolist. [KFS22]

Cotton price and business adjustments are another significant observation from the visit to India. The methods used to calculate and assess the value of cotton are described later on in detail. The primary determinant of cotton value is its weight. Regarding the quality-defining parameters of trash content and moisture, there exist accepted trading limits of 3.5 % for trash and 9 % for moisture content in the cotton bale. Notably, the allowance for moisture content often leads to efforts to exploit the values to their maximum limit. Typically, this is achieved by spraying water on the ginned cotton, thereby enabling it to be sold with less lint. To facilitate this practice, additional devices known as pollinators

are sold, which emit water vapor onto the cotton. As for trash content, the minimum necessary cleaning is performed to meet the acceptable limit. [KFS22]

5.3 Machine usage requirements and measures

Especially in ginning as a seasonal business it is very important to find the right compromise of machine operation hours, skills, maintenance and storage. The machines are quite complex in operation and its settings. [KFS22] It is very important to operate ginning machines with appropriate conditions, like [KFS22]:

- amount of seed cotton
- spacing between roller and knife / saw and retaining plate
- operation speed

For knowing what appropriate means, years of experience in the machine operation are required. It always differs from the type and quality of cotton going in, as well as the surrounding conditions during operation. Full employment and constant staff significantly support knowledge preservation and proper machine handling. Additional staff management helps in transferring knowledge to younger generations. [KFS22] This could be supported and trained with *artificial intelligence (AI)*. It is important to know, how the machine operates and behaves in a cold state, during warm up and when it's on the operation temperature. Everything influences the behaviour of cotton in each machine. It is important to build trust in machines and technologies with knowledge, cf. Fig. 5.11. [KFS22]

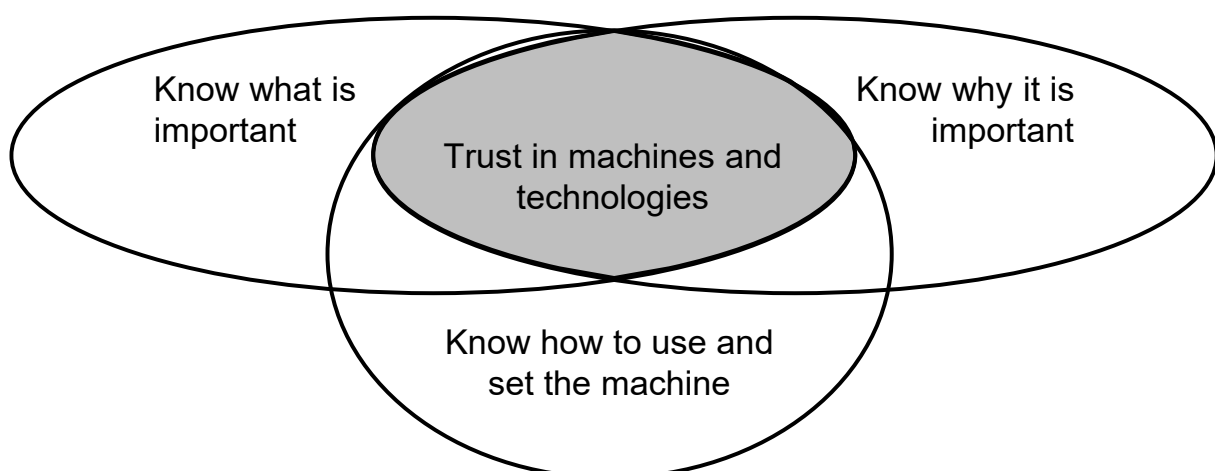


Fig. 5.11: Influences of knowing how, why and what for machine trust

Additional practical issues come up, if there is a long lunch break in hot summer days. Many operators go home during this time. Due to bad public transport infrastructures, sometimes they do not even come back the same day. As they earned just enough money to feed the whole family, it is not necessary to return. For mill manager, it is very difficult to find enough workers. Therefore, mostly the mill manager cannot release the operator. To overcome this issue, transportation infrastructure should be set to come to the place of work with limited effort. This might be provided by the government or by the mill itself, if there is no public transportation. As a combined topic, this shows the significance of joining technical as well as sociological requirements and effort in this. [KFS22] These measures need to consider the local plans, as made in Africa, India, USA, China and all others. More consideration to the sociological issues is displayed below.

5.4 Practical measures for solution implementation

Besides the already mentioned infrastructure to return to work, fulfilling the basic needs is important to keep the employees' attention on the work. Humans are not able to fulfil their best possible work or even focus on the work, if they or their families are starving. As far as existential and life critical needs are satisfied, the real operation and high qualitative work could begin. While achieving life without fears, additional motivating factors help to improve the willingness to work and bring up the very best in everyone. Concrete solutions differ from the individual and local needs, but in general the very basic options are:

- Providing water and / or food at work
- Establishing a safe surrounding (possibly providing apartments)
- Secure living income for the whole family
- Contraceptives and sex education
- Hygiene measures (e. g. after being in a pesticide contaminated field)

For high quality process chains and products, the following should be applied:

- Provide plastic free bags, which can be carried in the field
- Provide free trainings to farmers, day labourers and mill operators
- Governmental quality assurance on-site and in testing labs

While taking these fears from everybody to secure a safe life standard, more and more open mind ness is established while boosting the whole company. With this basis, employees are more willing to take fruitful trainings, which enlarges their competence and operation skills. This usually leads to further independence in the future. Therefore, training needs in content and possible concepts are now shown in Chapter 5.5.

5.5 Training content and concepts

The training content shall be divided between the usage of farmer level and ginning mill level. As spinning is much more complex and not an explicit part of this investigation, it is not further considered. This Chapter begins with the content of training, as the concepts for training are mostly similar and can be used equally. The field of economically influenced decisions and a reference to economic models is described below in Chapter 8. The recommendations made in this Chapter are based on the interviews as well as on-site findings. This Chapter is supported by the master thesis of GABLER.

For the best achievable quality in ginning stage, it is important to have clean (trash free), non-contaminated (plastic free) and high-quality (long and white) cotton. These factors can be significantly influenced by the farmers and pickers. This can be achieved while beginning with the following trainings or measures:

- Quality awareness training
- Picking technique training
- Plastic free picking (providing jute or even cotton bags)
- Wearing cotton gloves while picking
- Harvesting early in the maturing process
- Harvesting two, better three times, when a certain boll quantity is mature (less dust in the cotton fibres)
- Cause and effect sensibilisation (e. g. Trash harvesting, contamination or high moisture in storage)
- Mature boll harvesting (only) versus immature boll harvesting

On ginning mill level, it is important to consider these measures and trainings:

- Moisture measurement and management
- Cotton operation training, how to handle cotton fibre gentle
- Machine setting training (each of them is important)
- Maintenance and maintenance awareness training
- Cause and effect sensibilisation (e. g. overdrying and improper settings)

For the training concept, the knowledge level of the individual group members must be considered. This includes the technical knowledge they already have, as well as the intellectual knowledge. In the beginning of the textile process chain, less people are literate. This often leads to lower learning ability. The content and duration of trainings should be adapted to this. Repetition of the training might be useful for a long-term memory and application. Teaching work usually takes place in adult education. Here it is very important to teach the class members on equal footing. Especially, when foreigners are trainer. Furthermore, the following concepts should be considered, according to [KH63]:

- Focussing on practical training (in the processing season, on-site)
- Creating an atmosphere, where questions and mistakes are accepted (even if it's difficult in many cultures)
- Trust in the trainer and his knowledge (supported by integrating local and scientific knowledge)
- Bringing up the benefit of the participant, not only the company
- Small to medium sized groups, up to ten persons

Within the ginning sector of many low-wage countries, a Training of Trainers (ToT) model can foster worker empowerment and raising operational standards. Under this approach, a small group of individuals, typically possessing higher or technical education, receives intensive instruction from external experts, mostly in English. Those concepts are already applied by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) in other sectors. The programme combines classroom based modules with hands on sessions, ensuring that trainees command both the theoretical underpinnings of ginnery processes and the practical skills required on the shopfloor. Once qualified, these trainers cascade their knowledge to the wider workforce in the local language, tailoring the content to the specific production steps each group must perform. By embedding expertise

directly within the end users and operators, the ToT system not only mitigates reliance on foreign specialists but also cultivates a culture of continuous learning, thereby enhancing occupational safety, product quality and the bargaining position of workers along the global cotton value chain. Those trainers can later on proof the proper operation. Key findings and results are summarised below.

5.6 Interim conclusion

Key findings of the expert interviews and on-site investigation are, that descriptions differ from the situation at place and several trainings as well as measures should be fulfilled. One quality defining gate is the cotton harvest. Farmers should observe and apply, as well as harvesting (day) labourer should apply the measures shown in Fig. 5.12.

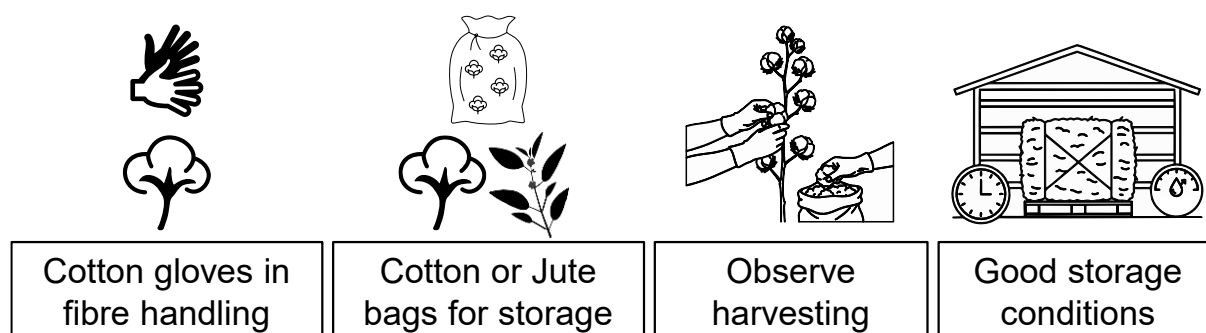


Fig. 5.12: Most important cotton handling recommendations

The results shall be proper harvesting of high-quality cotton bolls with:

- Contamination free cotton
- Minimal sweat on cotton in case of quality decrease
- Low trash content (mature fibre picking only, not the whole boll)
- Low dust contamination of sand and dust in the field or mills

Moreover, for ginning mill owners and operators, it is mandatory to have the certain experience and knowledge of these quality influencing factors as well. With this knowledge, they can better argue about price premiums or discounts. Farmers, traders and mill operators need to consider the impact of:

- Moisture measurement and management
- Maintenance
- Right setting of the machines
- Trade factors in lint value
- Continuous manual testing and quality inspections
- Processing steps according to the fibre quality
- Highly skilled workers, knowing the machines in particular

Most of these factors are already known in the mill management, but not spread to the mill operators. Therefore, knowledge distribution is still a very important task to address. These quality factors should be state wise taught or even followed up and controlled in daily business, whether it is practiced. Teaching techniques are to be considered for adult trainings, which means mainly:

- Understanding the purpose of doing
- Problem solving oriented teaching instead of simply saying what to do
- Practical training on-site, as less theoretical frontal teaching as possible

As all of this shall pay for the operator, due to a high-quality cotton product in the end of the day, it is mandatory to understand the different steps of textile processing and value addition. This can be done within a Training of Trainers (ToT) principle, which is used in many countries, for example from GIZ already. Selected fewer skilled persons, who usually have higher education, get an intensive training from experts in a particular field. Often this is done in English. It is usually a combination of theoretical and practical training days. Those trainers enable the local workforce to properly fulfil single steps in the production facility. Local trainings should be practically oriented in the workers mother tongue.

6 Analysis and prioritisation of Development measures

Based on the interviews of Raina Consulting and Associates Ltd. from Mumbai, India, potential failures and issues affecting fibre quality within the ginning process chain are identified with the following Failure Mode and Effects Analysis (FMEA). It conducts current practical processes and machinery used in Indian ginning plants, which were determined in detail in Chapter 5. Therefore, this analysis is based on eight interviews in Indian ginning mills, as well as six personal ginning mill investigations in India and Egypt. The interviews focus on machine parameters, work practices as well as quality and safety standards. This is the decision basis (3rd step) for the smart factory guide. For a better basis of the prioritisation, a Risk Priority Number (RPN) is calculated for each Failure Mode below. Afterwards in this thesis, based on this analysis, digital solution concepts are developed to reduce critical failures, prioritized for feasibility and subsequently implemented and validated.

6.1 Failure Mode and Effects Analysis

The first step in FMEA is the system analysis (cf. Chapter 2.2), which consists of the structural process and functional analysis. The next step is risk analysis, which is based on the system analysis. Risk analysis consists of identifying potential failures, their causes and their consequences. The second part of the risk analysis consists of risk assessment using RPNs.

6.1.1 System analysis

In order to analyse the ginning process in India using a Function and Performance Failure Mode Effect Analysis (PFMEA). The system boundaries and system elements of the ginning process must first be defined. The ginning process is therefore divided into four sub-processes. These steps include the provision of the raw material, the production or processing of the unprocessed cotton, packaging of cotton bales and safety of ginning plant. The system boundary encompasses all process steps from cotton harvesting to bale storage. The main process steps are categorized, shown in Fig. 6.1.

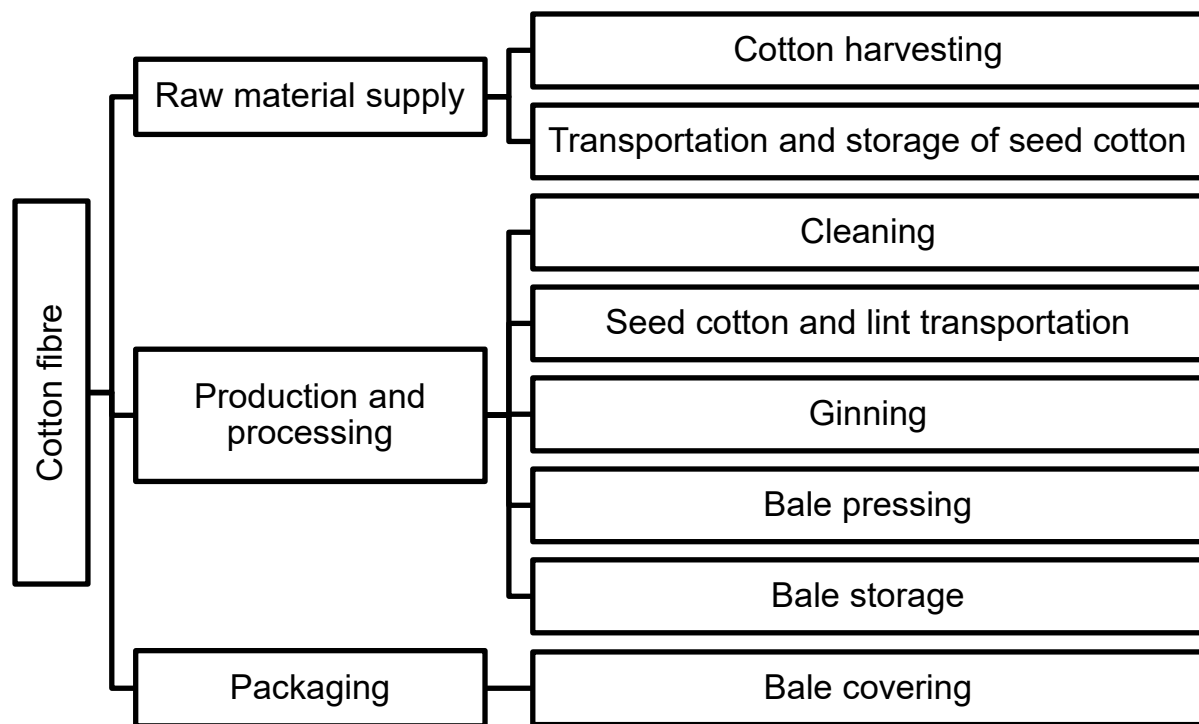


Fig. 6.1: FMEA relevant process steps and categories

The sources of failures are discussed along the process chain. Details to failure potentials of each step can be found in the following Chapter.

6.1.2 Failure mode and risk analysis

The PFMEA for Indian ginning plants explains the potential faults in the system components, the causes of the faults and, finally, the effects of the faults. This forms the basis and explanation for the subsequent risk assessment and the final RPN assigned. The following risk assessment tables show the potential failure modes of the cotton harvest, the respective RPN values and the individual components of the RPN values.

The **harvested cotton quality** is of central importance, as it is a key prerequisite for the manufacture of a high-quality end product. In addition, high-quality cotton in the form of long lint and a low contamination, as well as low foreign matter content promotes an efficient ginning process. The potential sources of failure that can occur during cotton harvesting and delivery can be summarised as follows:

- Impact on cotton quality during harvesting (immaturity, dust and trash)
- Extended storage duration (dust and trash)
- Mixing of harvests due to poor quality (manual harvesting)
- Contamination during transport
- Plastic contamination due to packaging

A reduction in quality due to immaturity and sweat plus fat contamination in raw material extraction is often caused by inadequately trained harvest workers. Moreover, poor harvesting time (long waiting time after boll opening) and wrong execution, e. g. under time pressure, lead to lower seed cotton qualities. Extended storage duration (without surrounding walls) means that dust, trash and foreign matter contaminates the seed cotton. Unprotected transport of the cotton also promotes additional contamination. Hand loading has the same effect as hand harvesting. One form of protected transport is the packaging of cotton in jute sacks. Those bags are even better than packaging in plastic bags. Mixing cotton harvests of different qualities (1st to 3rd round of manual harvesting) lead to difficulties of precisely adjusting machine settings for sufficient cleaning. The risks of potential failures during the cotton harvest is shown in Tab. 6.1. The RPN is a product of Occurrence (O), Severity (S) and Detection (D) probability.

Tab. 6.1: Harvesting failure risk priority number

Failure Mode	O	S	D	RPN
Harvesting influence on cotton quality	8	4	8	256
Lacking quality and mixing of different harvests (off season)	6	6	2	72
Packaging in jute bags (for transportation)	7	8	1	56
Long storage, high trash and dust	6	4	2	48
Contamination during transportation	6	4	2	48

The influence of fibre quality during the harvesting process has by far the highest RPN, as it can not be detected. For other potential harvesting failures, the RPN is similar but significantly lower, ranging from 48 to 72.

Seed cotton storing is usually done in open halls, which increases the risk of contamination, as dust particles and foreign objects can easily get in. Improper storage requires more intensive cleaning of the cotton, which in turn has an additional negative impact on fibre quality. Excessive cleaning damages the cotton fibres as well. Unprotected storage exposes the cotton to rainfall. Prolonged storage and a moisture content above 12% create the risk of mould forming in the cotton. Excessive moisture in the cotton fibres also promotes clumping of the cotton. The risk assessment of potential failures that may occur during the cotton harvest is shown in Tab. 6.2.

Tab. 6.2: Seed cotton storage failure risk priority number

Failure Mode	O	S	D	RPN
Rainfall due to open storage (roof only)	6	6	3	108
High contamination risk (dust and trash, contaminated soil)	6	4	2	48

The highest risk during storage are bad weather conditions, with a RPN of 108. The RPN of 108 is twice as high as the risk of failures due to contamination from dirty warehouses. The storage of pressed cotton bales also involves specific risks and is therefore described below.

Due to a lack of protective measures in **bale storage** in the form of covers, cotton bales are exposed to contamination. This leads to a reduction in value and a loss of quality of the cotton bales. In addition, the contamination causes a reduction in spinnability and fibre strength and thus a general reduction in the quality of the end product. The moisture content is also very important for maintaining the quality of the cotton fibres during storage. Cotton bales in the storage rooms are mostly moistened by direct manual water supply, for humidification. If steel wraps are used, high humidity leads to (additional) rust. The risk assessment of the potential failures that may occur during the bale storage is shown in Tab. 6.3.

Tab. 6.3: Bale storage failure risk priority number

Failure Mode	O	S	D	RPN
Contamination	8	10	8	640
Insufficient moisture management	8	10	8	640
Rust due to steel wraps and high humidity	8	6	2	96

The potential failures in the storage of cotton bales correspond to contamination and inadequate humidity management. The failures have the same RPN of 640 and are therefore in the critical range in the risk assessment. Rust is easy to see and leads to a selective loss of cotton, which rates is at a RPN of 96. A central starting point and important preparatory step for the ginning process is the drying of the cotton.

Moisture management is often not or subjectively done in Indian ginning mills. If drying is required, cotton is spread out in the soil to dry in the sun or just gets processed immediately. This type of drying means that the moisture content is uncontrolled. Immediate processing can be found in the ginning description below. Low moisture content in the cotton promotes fibre damage, while too high moisture content has a negative impact on the quality and cleaning of cotton. The risk assessment of the possible failures in cotton drying is listed in Tab. 6.4.

Tab. 6.4: Moisture management failure risk priority number

Failure Mode	O	S	D	RPN
Fibre damages due to low moisture	10	10	9	900
Low cleaning efficiency and nep formation due to high moisture	10	10	8	800

As fibre breakage can not be fixed after breakage, it reaches a critical risk potential of 900. This can take place in many steps along the ginning process chain. Especially cleaning and ginning are critical machines. The lack of control

lowers the risk of low cleaning rate, which leads to a RPN of 800. The rates of severity and detection probability are lower, as it is easier to see contamination instead of shorter fibres. Here, an increase in significance and probability of detection can be seen. This fibre quality degradation will definitely appear, if moisture content is not properly set. After drying, the next process step after ginning is lint cleaning. Additional cleaning will be done in spinning.

During **cleaning**, the potential sources of failure is fibre damaging and shortening, nep formation in the cleaning system and removal of lint fibres. This analysis includes seed cotton and lint cleaning, as mechanisms are similar. Fibre shortening primarily happens due to excessive mechanical stress on the machines. Mechanical stress is caused by excessive speed and inappropriate machine settings. Additional shortening arises in weak fibres, due to low a moisture content. Damage and breakage are a reduction in quality and value. Both mechanisms lead to reduced spinnability and strength of the yarn, while causing increased waste. Additionally, excessive stress on the cotton due to excessive speed and inappropriate machine settings lead to nep forming in the cotton fibre. Neps are formed due to insufficiently cleaned cotton as well and cause a similar reduction in value and quality of the cotton, as damaging. Neps impair spinnability and promote yarn irregularities. Excessive cleaning due to unsuitable cleaning machines remove high-quality fibres, which impairs the properties and quality of cotton. This reduction in value and quality is characterised by more difficult spinnability as well as reduced strength and fibre length in the yarn. Tab. 6.5 shows the risk assessment for cotton cleaning.

Tab. 6.5: Cleaning failure risk priority number

Failure Mode	O	S	D	RPN
Fibre damaging or shortening	7	10	8	560
Nep occurrence during cleaning	7	9	7	441
Removal of lint fibres	5	5	9	225

The potential failures in cleaning have a RPN value range of 225 to 560. The removal of fibres has a RPN of 225. It is rarely checked, therefore it might need long time to be detected. For the bale and yarn it's no loss in quality, but in quantity for ginners. Nep formation and fibre damage due to shortening are assessed with significantly higher RPN values. Nep formation achieves a RPN of 441, while fibre shortening is rated with a RPN of 560. Both have significant influence to the fibres price and are usually checked with testing instruments. Those are generally not available in most ginning mills. After cleaning, ginning is considered as the central process step, that is essential for the quality and further processing of cotton.

In **ginning** there are various potential problems that can lead to disruptions in the ginning process or a reduction in lint quality. Potential issues associated with (roller) ginning machines include increased fire hazard, clogging of the gin stand and excessive ginning speed, resulting in excessive surface temperature. Excessive ginning speed and the resulting high temperatures on the roller surface significantly increase the risk of fire during the ginning process. In the event of fire, there is a risk of spreading to the entire company's premises, causing enormous economic damage. As cotton is highly flammable and specific dust/air concentrations can cause explosions, there is a high risk of total losses. Excessive ginning speed, caused by incorrect machine settings, lack of process monitoring or contact pressure (knife and cleaning devices), also reduces fibre quality. This damage manifests itself in the form of fibre shortening, neps and seed cracking. In addition, there is a risk to the ginning machine becoming clogged, leading to breakdowns, maintenance work, machine damage and the need for exceeded manual cleaning. Clogging of the ginning machine is even worse at an excessive moisture content in the seed cotton due to inadequate drying systems, insufficient separation and incorrect dosing of the cotton.

With regard to cotton quality, problems arise in particular due to damage to the cotton fibre caused by shortening (as in cleaning), poor ginning performance (ginning out turn) and breaking of cotton seeds. Shortening mechanisms are the same as in cleaning. Low moisture lead to brittle fibres, which breaks. This reduces the value and quality of the cotton due to reduced spinnability, strength

and higher waste production as well. If the moisture content is too high, on the other hand, the cotton fibres stick to each other and to the cotton seeds. This impairs the separation of cotton fibres and cotton seeds, reducing the ginning out turn (GOT). Excessive moisture content and incorrect roller settings in terms of speed or blade settings cause the seeds to break, contaminating the lint. Seed fragments remain in the lint and get fragmented in lint cleaning. This causes an increase in the foreign matters and neps. In addition, the cotton seeds become unusable for further processing in oil production. The risk assessment for ginning is shown in Tab. 6.6.

Tab. 6.6: Ginning failure risk priority number

Failure Mode	O	S	D	RPN
Fibre shortening due to damaging (at wrong moisture)	10	10	9	900
Fibre shortening due to damaging (at optimal moisture)	7	10	8	560
Critically low ginning out turn (GOT)	7	10	4	280
Seed cracking	6	6	6	216
Critically high speed (critical surface temperatures)	7	6	4	168
Risk of fire at high roller temperature (fibres and dust)	6	10	2	120
Clogging of the machine	7	5	2	70

The RPN value range for the ginning process step is 70 to 900. The highest risk of failure is fibre damage due to shortening, at wrong moisture content with a RPN of 900, otherwise it is 560. Ginning has the highest effect on fibre shortening and is usually not detected, as fibres and seeds are immediately automatically transported and pressed. Poor ginning out turn is rated at a RPN of 280, because of its critical severity to linearly reduce income of the ginner. Poor GOT can directly be seen due to longer waiting time until the press reaches its final weight. The breaking of cotton seeds is rated with a RPN of 216 and excessive processing speed, which leads to increased temperatures, achieves a RPN of

168. Both are easy to be checked with frequent maintenance. All others are easily detected and therefore not further discussed. After ginning, the cotton is pressed into bales for further transport.

During **bale pressing** of lint, failures can occur due to missing covers of the bales after pressing, excessive moisture content, increased energy input and rust contamination of the bales. If the cotton bales are not properly covered after baling, contaminants are carried at the cotton bales, causing a reduction in value and a loss of quality of the cotton. Dust gets mixed in at opening and can not be cleaned before, only removed together with lint. If the cotton has a too high moisture content, mostly due to a lack of drying equipment, bales mould and within the process, pressing requires increased energy input. Higher energy demand leads to higher production costs. Excessive moisture in the cotton bales is also caused by spraying water before the lint slide or in the storage room. Prolonged storage with a moisture content above 12% or wet spots due to droplets promote mould growth. In addition, high moisture content has a negative effect on the colouring of the cotton, leads to decay and dissolution of the fibres and thus reducing the sales price. Insufficient moisture content during bale pressing, due to inadequate moisture control or excessive ginning speed, leads to brittle breaks and impairs fibre quality. This also reduces spinnability and yarn quality. The finished bales are held together with wire mesh and plastic wraps. This can lead to wire mesh contamination, which discolours the cotton and significantly affects its quality. Steel straps are only used to a limited extent, as the majority of companies use plastic straps. Tab. 6.7 shows the risk assessment of possible failures during cotton baling.

Tab. 6.7: Bale pressing failure risk priority number

Failure Mode	O	S	D	RPN
Fibre damaging due to low moisture content (brittleness)	6	8	10	480
Critically high moisture content	8	10	4	320
High energy demand due to moisture content	8	4	10	320

Cotton pressing has a RPN value range of 320 to 480. The highest risk in this process step is fibre damage due to insufficient moisture, which is rated with a RPN of 480. The quality reasons are the same as above. Excessive moisture content in the cotton and increased energy input are each rated with a RPN of 320. It clearly shows, that all influences in pressing are dependent on the moisture content of lint. Moreover, bale presses are heavy machines, which require a lot of energy and are used every 30 minutes, according to the GOT and feeding rate. To achieve better amortisation of this machine, down times should be reduced. Those down times can be reduced by building up ginning capacities according to the bale press production capacity. As financial aspects are no part of this risk assessment, these factors can not be found in the table above. After pressing, the cotton bales are packaged to protect them from environmental influences and preserve fibre quality.

In **packaging** plastic is mainly used for packaging the cotton bales. However, the use of plastic bags may lead to plastic contamination in the cotton, which a loss in value, especially visible after dyeing. The risk assessment of plastic packaging for cotton bales is shown in Tab. 6.8.

Tab. 6.8: Packaging failure risk priority number

Failure Mode	O	S	D	RPN
Fibre contamination	7	8	5	280

The contamination of cotton fibres due to plastic bags has a medium risk potential in case of coloured plastic wrapping. Therefore, considering standard coloured plastic foil, it is rated with a RPN of 280. In case of transparent or white covering, it is more difficult to detect and is rated at ten for detection, as it is mostly fully visible after yarn dyeing. The transport of cotton is an essential process step within ginning, as it ensures the flow of material between the process steps.

When **transporting** cotton, there is a high risk of dust and trash contamination, wet cotton fibres clumping together and mould forming as well as nep formation.

This evaluation covers seed cotton, lint and bale transportation. Transporting seed cotton or lint using heavy, uncovered means of transport, such as tractors, causes dust or foreign matter to get into the cotton. This increases the amount of cleaning required and impairs the quality of the cotton for the spinning mill. During long bale transportation duration, as in oversea shipment, the same mechanisms as in storing are valid for excessive moisture content in the cotton. Mechanisms of mould are just faster, as the sun might heat up the container, which fasten up mould processes. In addition, the deflection of the fibres during transport increases neps, which causes a reduction in value and loss of quality due to more difficult spinnability. The risk assessment for the transport of cotton is shown in Tab. 6.9.

Tab. 6.9: Transportation failure risk priority number

Failure Mode	O	S	D	RPN
Clogging and mould of wet fibres	8	10	7	560
Nep formation in seed cotton and lint handling	7	9	7	441
Critical contamination risk	7	8	5	280

The highest risk potential is the clumping of wet cotton fibres, which is classified with a RPN of 560. The impact is even higher as in storing, as bales are closer to each other in a fully covered room. Mould spores can spread across the whole container and contaminate surrounding bales or the whole shipment. Those can not be used for spinning anymore, according to the degree of contamination. High temperatures and moisture content at the ocean increase those mechanisms. Nep formation has a comparable risk potential with a RPN of 441. Mechanisms of nep formation are quite clear and can be taught to the operators. The risk of contamination during transport is assessed with a RPN of 280, as most contamination is just at the outer shell. In addition to process-related risks, ensuring operational safety is also of central importance. The overall comparison and evaluation for development potentials is worked out below.

6.2 Prioritisation of development measures

For systematic evaluation and prioritisation of potential failures based on RPN values, these are divided into different categories according to failure risk, need for action and measures. This enables simplified assessment and presentation of the urgency of the failure risk. This table is used to evaluate the relevance of the various potential failures. The following Tab. 6.10 is based on the calculated RPN values above.

Tab. 6.10: Failure and risk classification

RPN	Failure level	Urge of action	Measures
RPN >700	critical	immediately	immediate and essential action
500 < RPN ≤ 700	high	urgent	must be implemented
250 < RPN ≤ 500	medium	required	should be defined and done
1 < RPN ≤ 250	low	recommended, not necessary	could be defined and done
1	none	not required	none

This RPN risk classification is done individually, according to the values found in the Chapter before. There is no general assessment, which provides a fixed failure level grading. The RPN values of the system elements are specified in value ranges in order to illustrate the scope and the risks within the process steps. To determine the most critical steps within the ginning framework, RPN values are summarized along the process chain. Those values can be found in Tab. 6.11.

Tab. 6.11: Risk priority number comparison on process steps

RPN-Value spread	Process step
48 - 256	Cotton harvest
48 - 108	Seed cotton storage
800 - 900	Moisture management
225 - 560	Cleaning
70 - 560	Ginning
320 - 480	Bale pressing
256 - 560	Transportation
280	Packaging
96 - 640	Bale storage

The representation of the RPN value range illustrates that critical and high risk occur due to moisture management. This mainly relies on the moisture content or droplets on the fibres. The risk appears along the process chain, but mainly where mechanical stress or long periods without moisture circulation take occur. Therefore, moisture influences lead to potential quality degradation and price drops. Additional risks beside storing arise in cleaning, ginning and bale pressing. Those are highly dependent on moisture and the corresponding fibre properties. With this we can see, that moisture content has by far the most significant influence and should be addressed for further research. Details are further elaborated below.

Critical RPN of 900 are rated for fibre shortening due to low moisture contents, which arise in cleaning, ginning and bale pressing. Slightly lower because its ease of direct visible detection is contamination due to high moisture contents, at a RPN of 800. High moisture content lead to more sticky fibres, which tend to

hold back trash. High in this regard means above 7 %, as stated before. Additional quality degradations due to improper moisture management occur in storing. Seed cotton and bale storage should be both below 12 % moisture content, if stored for more than seven days. Otherwise, quality losses arise, which lead to significant price drops while being below the international trading base quality, further described in the economic Chapter 8.

With a RPN of 560, clogging and mould formation in the cotton during transport represents another high problem in the ginning process. This is primarily due to spraying water on cotton fibres with big droplets or dripping pipes. Excessive moisture content, could lead to the same, in case of condensing water droplets. One measure to ensure optimum moisture content is the use of moisture sensors, which enable both continuous monitoring of moisture content and process monitoring. Another option for controlling the moisture content is a climate and ventilation system. In addition, adjustments to the conveyor belt parameters, in particular the inclination and speed, improve the evenness of cotton transport and reduce clumping. As the main failure is done beforehand, the former steps at high risks get investigated below.

Medium to low RPN arise due to improper handling. This can be nep formation due to wrong cleaning or long transportation (RPN 441) and fibre contamination due to plastic usage in fibre handling (RPN 280).

An analysis of the RPN values shows that there is a particular risk of fibre damage due to insufficient moisture content and contamination caused by improper storage of the bales. Moisture management requires sufficient and trusted tools, whereas storage solely requires the installation of sufficient buildings. The lowest RPN values mainly relate to contamination of the cotton by packaging, external influences, improper storage or transport of the cotton. These statements are summarized in the following interim conclusion.

6.3 Interim conclusion

Beginning with the system analysis according to the overarching smart factory guideline, ginning is divided into the three following main stages:

- Raw material supply
- Production and processing (including storage)
- Packaging

Within every sub area of those steps, different types of potential failure and impact arise. According to the risk assessment it can be seen, that critical and high risks arise due to moisture management. Those critical steps can be found in mechanical processing, like cleaning, ginning, bale pressing and transportation. If the factor time is involved as well, storage leads to significant fibre quality degradation as well, which lowers the sales price of cotton bales. An overview of those values is provided in Fig. 6.2.

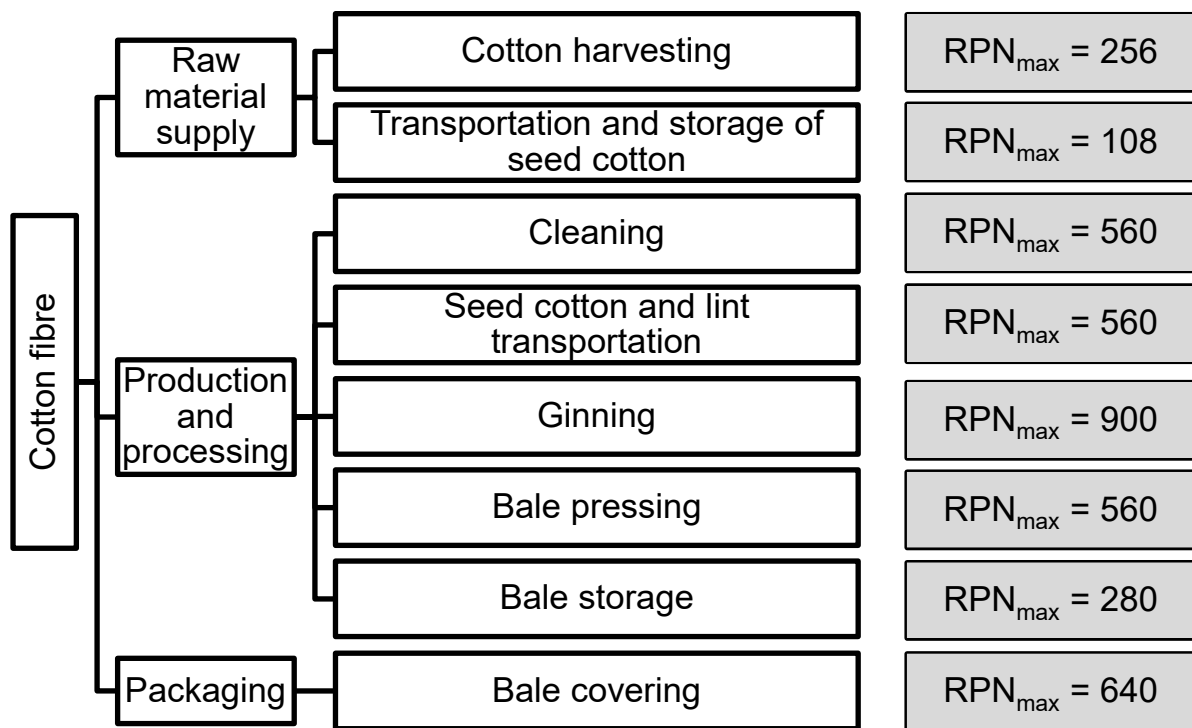


Fig. 6.2: Risk Priority Number overview in early cotton handling stages

Critical RPN above 700 are mainly dependent from insufficient moisture management. Those rely on knowing the moisture content with trusted measurement devices and properly installed and maintained moisture management stages. According to their relevance, those measures are further described and developed in the following Chapter. Due to the introductory issue of skilled worker shortage, it is combined with digitalisation approaches to reduce the need of (skilled) workers. A full implementation guideline is below provided as well.

7 Moisturization management in ginning mills

The analysis of the state of the art, as well as decades of publications show, that ginning investigation is very slow and took place decades ago. Ginning machine and process development lacks in methodology and reliable data. Since the 1970's, importance of moisture management is stated. "This means that inherent fibre length and length distribution would be better preserved by ginning at the higher moisture levels-but cotton gins cannot function satisfactorily on cotton with fibre moisture content that is much greater than 8 or 9 %." [AG01] These issues can nowadays be seen from the investigation in cotton processing countries India and Egypt within this book. Mill manager do not trust the existing measurement systems. The risk assessment of Chapter 6 shows the critical influence of moisture content to all stages of processing fibres, including storage.

To optimize ginning, the earlier mentioned requirements of moisture measurement, moisture management and automation need to be considered and applied. As machine automation is a complex topic by itself, this thesis focuses on moisture measurement and management. An outlook for automation and digitalisation in ginning is provided in Chapter 10. The corresponding developments and findings are described in this Chapter. Chapter 7.1 display requirements in moisture measurement, while Chapter 7.2 describes the moisture sensor development. Chapter 7.3 handles moisture management. Afterwards, mill implementation measures are shown in Chapter 7.4. Finally, Chapter 7.5 concludes those developments. The results are based on the project thesis of PIERLOGK, RASBACH and ZIMMERMANN, bachelor thesis of MEINCKE and master thesis of BENECKE.

7.1 Moisture measurement requirements

The practically dominating decision model for moisture valuation is gripping a sample by hand. Skilled workers have practical experience, how the cotton behaves and when to process cotton. Another indicator is biting the seed. If the seed cracks brittle, it is too dry. If the seed slide apart while biting and the seed cotton does not feel wet, it has a proper moisture level. But these indications are

subjective and individual due to the ambient temperature and total dissolved water amount. Technical evaluations, explained in Chapter 3.6 and 3.7 are:

- Oven method
- Infrared drying
- Micro wave drying
- Resistance measurement
- Near infra-red (NIR) spectroscopy

These methods can be divided into direct and indirect measurement methods. As direct measurement methods are not viable for online or at-line testing, indirect measurement methods are preferred for fast results. Online and at-line means, that measurement values can be taken in real time, directly during the production process. Direct methods can be used for live process improvements. Offline measurements, tested in a laboratory, are standard verification methods.

The results of the investigation (background described below) show, that resistance measurement is still the best way to measure cotton moisture. Especially electromagnetic fields of big capacitors, which might be installed in the conveyor system, are much more influenced by heavy moving metal parts around, instead of the moist cotton between the two plates. In this investigation, trains riding a few hundred meters from the measurement place released heavier measurement deflections than the cotton itself. The same might happen, if goods carrier are moving by to deliver new cotton or bales are loaded.

Resistance measurement led to repeatable results, slightly influenced by vibrations of the measuring body. During measurements it turns out, that constant as well as higher voltage of up to 50 Volt lead to a more precise measurement result. Having a standardized amount of cotton, which is 3 g in those trials, leads to reliable results. Especially in terms of the ongoing development of shortage of skilled workers, trusted, harmonized and standardized measurement systems are required. Comparing functionalities with a list of requirements provides an easier selection process.

Tab. 7.1 show requirements of the moisture measurement systems. Moreover, this Chapter leads through the whole development of direct and indirect

measurement methods. This enables to find out about potential failure, influences which are not known by now and finding the most suitable way of seed cotton and lint moisture measurement.

Tab. 7.1: Requirements for moisture measurement device development [Mei22]

Type of Requirement	Key Requirement	Value to be Reached
Obligatory	On-line measuring capability	Fast and automated measurement without sample taking
Obligatory	Measurement range	3 % to 15 % moisture content
Obligatory	Resolution	At least 0.25 %
Obligatory	Measurement accuracy	At least ± 1 %
Obligatory	Prototype capability	Perform measurement on proper sample material
Obligatory	Series of measurements	Automatic and automated output
Obligatory	Prototype modifiability	Must be dismantlable for improvements
Optional	Data storage	Automatic saving to a file on portable card
Optional	Power supply	Standard laboratory voltage of 5 V or 12 V
Optional	Prototype construction	Conventional tools and materials
Optional	Cost	As low as possible

The summary of evaluating advantages and disadvantages for different measurement procedures is provided in Tab. 7.2.

Tab. 7.2: Measurement methods overview and description, based on [FHN11]

Measurement Method	Advantages	Disadvantages
Oven Drying Method	Simple handling Low equipment req. Process multiple samples	Long measurement times Moisture reabsorption risk Volatile substance losses
Drying Balance	Faster than oven drying Simple operation Automatic MC calculation	Limited sample quantity Risk of result distortion by other volatiles
Thermogravimetry (TGA)	High sensitivity High precision	Very small amounts Not suitable for routines
Karl-Fischer Titration	Suitable for low moisture content samples (‰) Automation possible	Samples in solution req. Use of potentially toxic reagents
Near-Infrared Spectroscopy (NIR)	Fast and non-destructive Pot. online measurement Can determine other parameters	Requires calibration against a direct method Results can be influenced by various factors
Microwave Resonance Spectroscopy	Fast and non-destructive High selectivity to water Can compensate for bulk density and others	Technically demanding Requires understanding of dielectric properties Reference method calibration
Resistance measurement	Fast and non-destructive Cheap set up	Resistor Temp. dependent Direct contact required
Capacitive measurement	Fast and non-destructive Cheap set up Distanced measurement	Capacitor Temp. dependant, nominal voltage up to 40 °C Close contact required Fault-prone system

After knowing the advantages and disadvantages of those moisture measurement methods, a selection for further investigation within this thesis is shown below in Tab. 7.3.

Tab. 7.3: Measurement method selection for development

Measurement Method	Selection (yes/no)	Reason
Oven Drying Method	(X)	Stationary test setup, no real time use; but use as reference method
Drying Balance	X	Stationary test setup, no real time use
Thermogravimetry (TGA)	X	Stationary test setup, no real time use
Karl-Fischer Titration	X	Made for permille water values and very expensive
Near-Infrared Spectroscopy (NIR)	✓	Determine more parameters than water, only requires a big database of one-time references
Microwave Resonance Spectroscopy	✓	Highly selective to water, only requires a big database of one-time references
Resistance measurement	✓	Cheap set up, relatively fast, with only a short delay for at-/on-line testing
Capacitive measurement	✓	Cheap set up, fast real time values for on-line testing; optional clamping for constant spacing

Concluding the comparison, near-infrared and microwave resonance spectroscopy, capacitive as well as resistance measurement are favoured. In the beginning, as a potential online tool, near-infrared is investigated and designed to be used in production areas of ginning mills. The development is described below.

7.2 Moisture sensor development

For the **near-infrared method**, a specific distance to the sample is required. A 3D printed spacer shall ensure a comparable income angle of ambient light and measurement tools, across different measurements. The distance to the sample does not vary during the measurement. This and all other printed components created as part of this work are made of polylactide (PLA). Lint is used as a sample. Water is added to two of the four samples, while the other two samples are kept at the room climate. The four samples are placed one after the other below the sensor. Each measurement lasts 10 seconds. In total, 20 values are recorded for each wavelength measurement. The average of these values is shown in Tab. 7.4. The light intensity is given as a percentage.

Tab. 7.4: Infrared measurement series [Mei22]

Wavelength [nm]	610	680	730	760	810	860
Moisture content sample 1, dry [%]	32	44	40	48	38	47
Moisture content sample 2, dry [%]	41	48	49	36	41	40
Moisture content sample 3, wet [%]	37	45	53	35	43	42
Moisture content sample 4, wet [%]	35	44	41	39	39	46

It can be seen that the moisture of the cotton in this series of measurements has no recognizable influence on the measured light intensity of the respective wavelengths. The fluctuations in the measured values are high within the dry and wet samples. In addition, the measurement results of the wet samples do not differ significantly from the measurement results of the dry samples. [Mei22] Changes were expected in increasing wavelength, to the minimum resonance frequency of water at 970 nm. The selected wavelength relies on the testing ability of the sensor AS7263 from SparkFun Electronics, Niwot, Colorado, USA.

The feasibility test has shown that the measurement with near-infrared light and the selected sensor does not work for cotton. Possible sources of deviating measurements include the uncontrollable distance of the loose samples to the

sensor and the difference between the absorption wavelength of water and the measured wavelengths. As it is highly sensitive to surrounding parameters, this method is not further considered to be used in an online testing procedure. [Mei22] The same deviation of spacing between the sample and the sensor happens is for the **Microwave Resonance Spectroscopy**, which is therefore not further investigated within this thesis. Instead, the capacitive testing is evaluated for online testing.

Capacitive moisture measurement requires a better understanding of the electric field in the capacitor. By knowing the electrical field, the capacitor structure can be improved. For this reason, a simulation of the capacitor is carried out in a two-dimensional plane. The detailed results are shown in Chapter 19. The program *Finite Element Method Magnetic* by MEEKER is used. [Mee24]

The simulation was done, comparing three different piping and capacitor types. The cross-sectional area of the transport channel was constant. A direct current (DC) voltage of 5 V is applied across the capacitor for the simulation. Simulation shows that the electric field is distributed inhomogeneous over two spatial axes. The position of a sample in the capacitor therefore influences how strong the electric field is that penetrates it. Therefore, the homogeneity of the field is to be increased by changing the set-up. To ensure a uniform electric field, the shape of the internal electrode is adapted to the shape of the transport channel. This can be achieved by using a tube rather than a plate for the electrode. The diameter of the tube is four times smaller than the diameter of the transport channel.

The simulation shows most homogeneous field strength in a rectangular pipe. A capacitor is built whose capacitance is measured using the resonance method. A corresponding resonant circuit is designed for this. A microcontroller is programmed for the frequency measurement. By placing wet and dry cotton in the capacitor, a frequency change in the resonant circuit could be measured. Based on the successful feasibility test, further improvements are made by designing and building two prototypes. Testing various circuits showed, that a constant voltage supply leads to more accurate measurements. A more homogeneous field also led to better measurement results. Finally, the circuit is further

improved by using alternative Schmitt-Triggers (threshold switch) and surface-mounted device (SMD) in practical surroundings (cf. Tab. 7.5). [Mei22] Schmitt-Trigger transform a slow changing, unclear input to a clear digital output.

Tab. 7.5: Schmitt-Trigger comparison [Mei22]

Schmitt-Trigger name by Texas Instruments Inc.	Maximum switching time	Number of Schmitt-Triggers installed
SN74HC14	25 ns	6
SN74LVC1G14DBVR	4.4 ns	1
SN74AHCT1G14DBVR	7 ns	1

For extended series of measurements, 26 samples are prepared in plastic bags. The samples are moistened cellulosic fabric. Each sample is measured twice. Between the measurements, there are 24 hours. In the first series of measurements, the ambient temperature is 22 °C. In the second series of measurements one day later, the temperature is 25 °C. The amount of water added is between 0 ml and 2.4 ml. [Mei22] The measurement results are shown in Fig. 7.1.

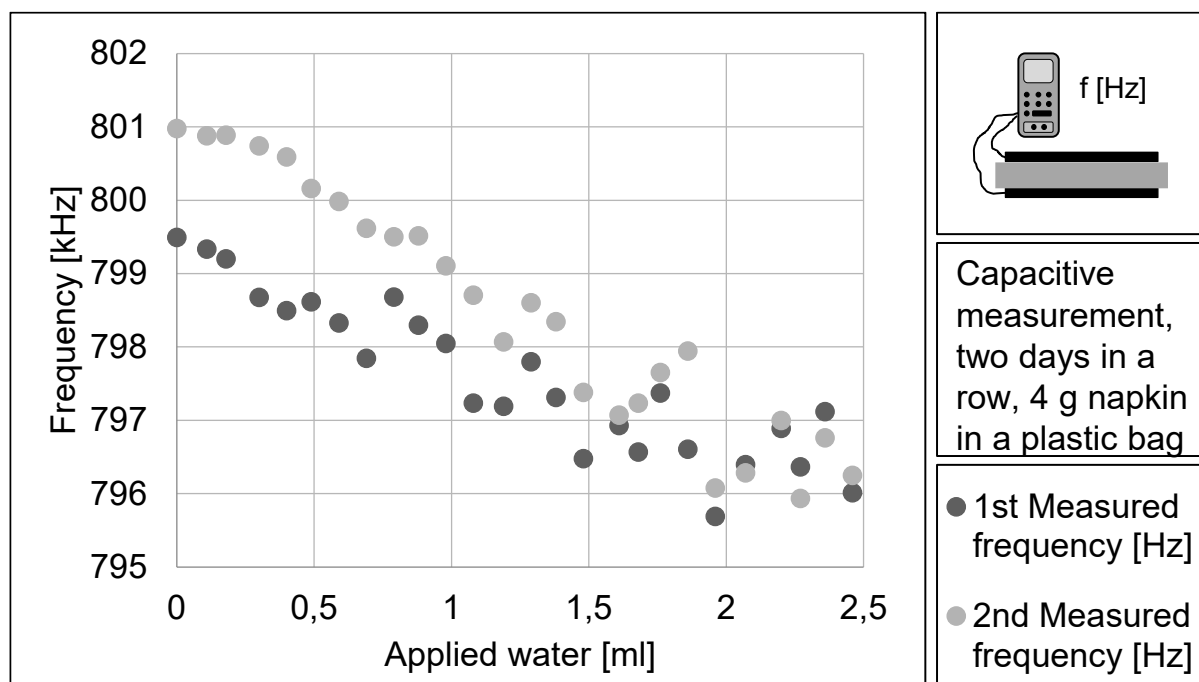


Fig. 7.1: Capacitive moisture measurement, 1st Schmitt-Trigger [Mei22]

The series of measurements confirm the correlation between the humidity and the measurable frequency. The measured values scatter less, compared to the first prototype, cf. Fig. 7.2. It can therefore be assumed, that optimizations due to the new design and printed circular board (PCB) supports the function. There is a shift in the measured values of around 700 Hz between those series. This could rely on possible material distortion of the capacitor during handling. In addition, the temperature difference of 3 °C between the series of measurements is likely to change the behaviour of the resonant circuit. [Mei22] Further optimization steps are attempt to reduce the interference of the Schmitt-Trigger.

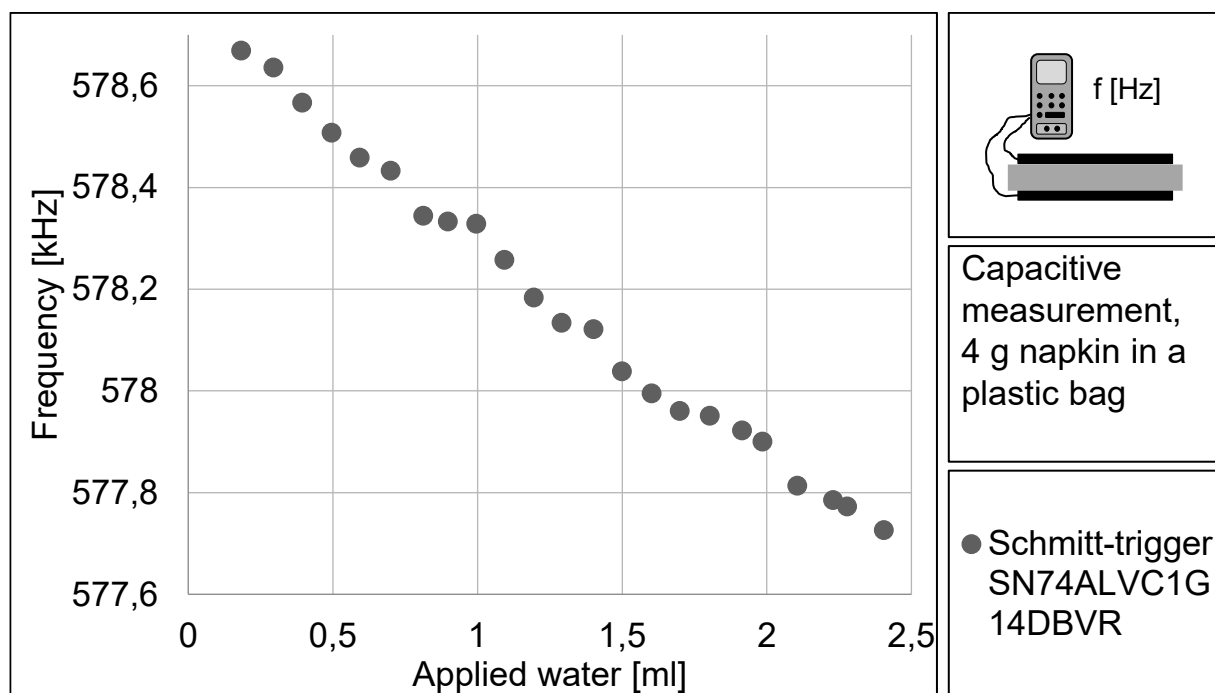


Fig. 7.2: Capacitive moisture measurement, 2nd Schmitt-Trigger [Mei22]

The measurement shows a well operating circuit board, as reliable data appear. The water content can be clearly determined by this method and set up. However, there is no significant improvement in the measured values compared to the previous circuit board. New samples are created to validate the circuit board with the Schmitt-Trigger SN74AHCT1G14DBVR. This means, any interim influence on the samples can be ruled out for comparison. 26 new samples are created using the before described method. The ambient temperature during the measurement is 20 °C. The measurement results are shown in Fig. 7.3. [Mei22]

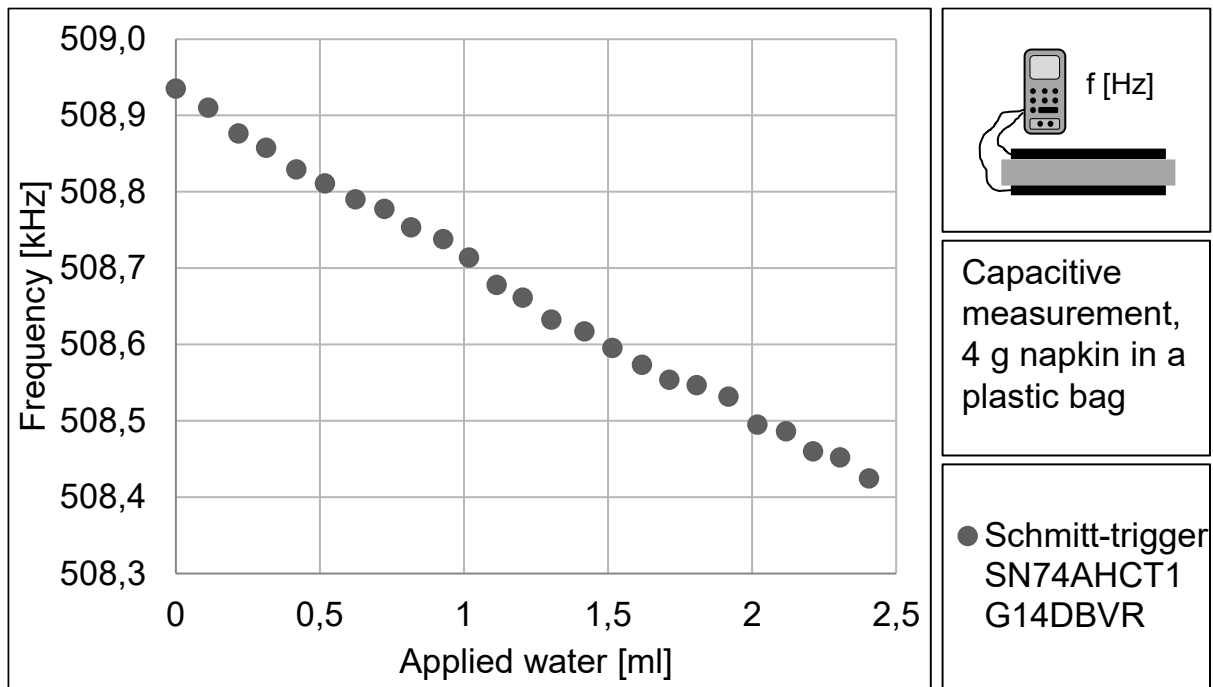


Fig. 7.3: Capacitive moisture measurement, 3rd Schmitt-Trigger [Mei22]

The measurement results of the second surface-mounted device (SMD) board show a more pronounced correlation between the amount of water and the measured frequency. A linear relationship is clearly recognizable. There are almost no significant deviations.

The improvements developed in this work are all successfully applied and tested in a final prototype. As a result of the various optimizations, a strong correlation between the moisture in the samples and the measured frequency is observed in the measurement results. The accuracy achieved is in the range of 0.1 ml for 4 g of sample material [Mei22]. The developed measuring system mostly fulfils the requirements for an on-line measurement. Nevertheless, big external influencing factor affect the measurement significantly. For example, when there are strong ferro magnetic sources around, as a by passing train, the values are unusable. There might be one opportunity to use the house of the processing facility as a *Faraday cage*. A *Faraday cage* is a grounded steel structure, blocking electric fields [FHN12]. As not every processing mill is built out of steel structures and the inner motors have high reactive power, this method will not be further considered. Instead, the electric resistance method is extended.

According to the technology impact research, as it is still not completely figured out how electromagnetic waves behave on the human body, the opinion of rejection is supported. The final prototype is built as a resistance measurement device.

A **resistance-based testing** device is developed for a sample size of 3 g. Different sample weights are possible, while inserting spacings between the top and bottom plate. This also applies for seed cotton testing, as the seeds tend to be bigger and directly linking the two copper plates. Additional spacing lead to more viable testing results. Additional calibration is required in future, according to different varieties. Findings to be integrated so far, are:

- Constant high current (50 V) is beneficial
- Irregular fibre flow needs to be managed
- System knowledge required (setting accordingly)
- Constant maintenance required
- Temperature dependency must be considered
- Material constants must be considered

The development of the moisture testing device should be a low-cost product, to be accepted in low wage countries, while fulfilling high technical performance. The moisture measurement device is based on 3D-Printed components. Two copper plates of 50,27 cm² each are placed in the 3D-Components. The defined distance between the copper plates for lint testing is between 2 mm and 10 mm. Seed cotton testing requires higher distances, according to the seed quantity and size in the measuring chamber. If there is direct contact between both plates via one or more seeds, resistance values decrease significantly and current values rise (cf. Ohms law). This leads to improper and non-usable testing results. Different types and quantities of batteries can be used for mobile device usage. Initial measurements showed, that 50 V are an appropriate voltage for stable results. Therefore, it is recommended to be close to 50 V during operation. The Arduino works with 5 V, which needs to be considered in the setup as well. Direct computer voltage of a USB-A port of 5 V turned out as being too unstable. This voltage is influencing the measurement results as well and should not be used in measurement operation. Therefore, in the executed measurements

either laboratory power supply units or five series connected 9 V Block batteries (45 V) are used. This set-up is exemplarily shown in Fig. 4.5.

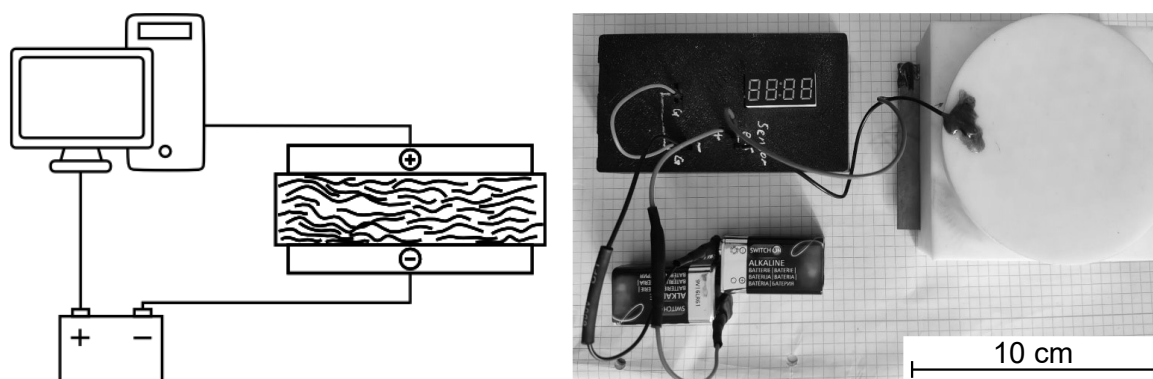


Fig. 7.4: Exemplarily set-up of the resistance moisture measurement device

An Arduino program and simple set-up of the electronic circuit enables fast, easy and cheap operation. It can be used for hand held devices, as well as automated usage. As it is complex and space consuming to be inserted here, the Arduino program code and electric circuit can be found in the appendix in Chapter 20.

As there are temperature and charge induced drifts within this test method, initial trials in the air conditioned ITA facility are fulfilled. Those trials set the basis for the evaluation of corresponding moisture values to the measured voltage.

In the electronic circuit, three different resistances can be used, according to the level of moisture or natural physiological fibre properties. As the measurement values are more precise while having higher voltage output. Comparingly, samples were weighed to determine the moisture content. Therefore, the cotton is weighed in a dry state under normative conditions at 60 % relative humidity (rH) and 20 °C. The moisture content is measured at 7 % with the oven drying method. The moisturization measurements take place for 90 Minutes at 30 °C with 95 % relative Humidity (rH). To minimize the temperature influence on the total amount of water to be absorbed in the air, this relatively low temperature is selected. All measurement series took good care to minimise the time between opening the climate chamber and measuring the samples with the resistance measurement device. These results of the moisturization phase are shown in Fig. 7.5 below.

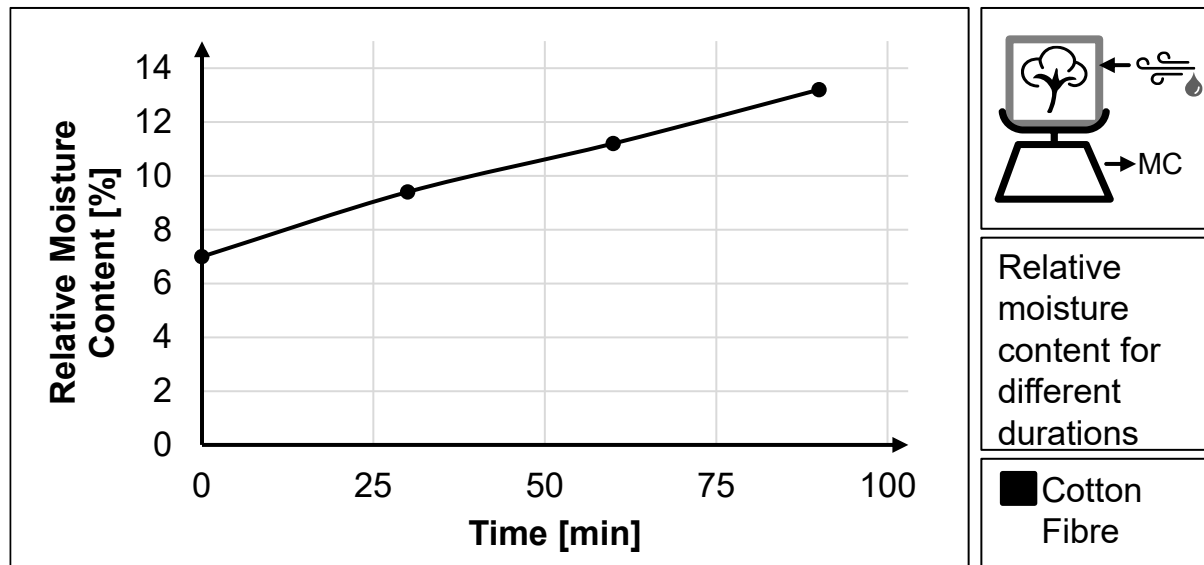


Fig. 7.5: Lint moisturization: 90 min, 30 °C, 95 % rH; base: 20 °C, 60 % rH

As there is no integrated weighing system in the moisturization oven, only two values were taken in the meantime. For this, the lint is taken out of the oven, weighed and measured in the build testing device (cf. Fig. 7.7). As the time required for this is only a few seconds, the influence of drying is negligible. Afterwards, the drying behaviour is measured with a weighing system outside the oven (cf. Fig. 7.6).

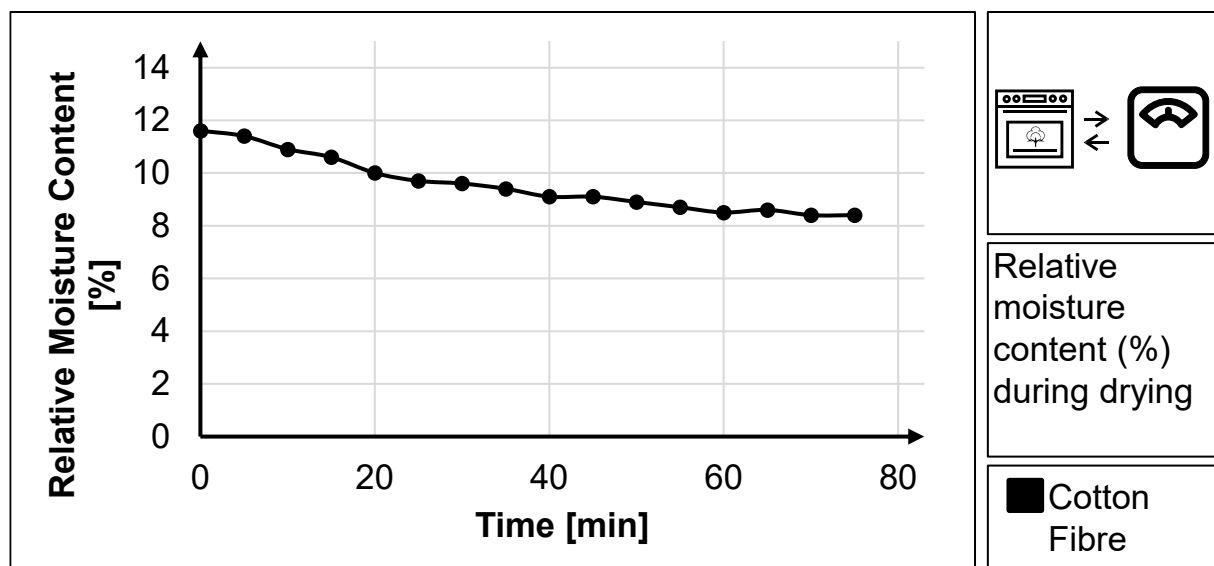


Fig. 7.6: Drying behaviour of moisturized lint at: 20 °C, 60 % rH

The graph is formed by measurements, every five minutes. These results show an almost linear regression of moisture, until it stabilizes around 8.4 % moisture

in the lint. These values show, that there is a long period, the values stabilize. For higher quantities of samples, shorter durations are selected and required in practice. The results of the drying curves are shown in the following Fig. 7.7.

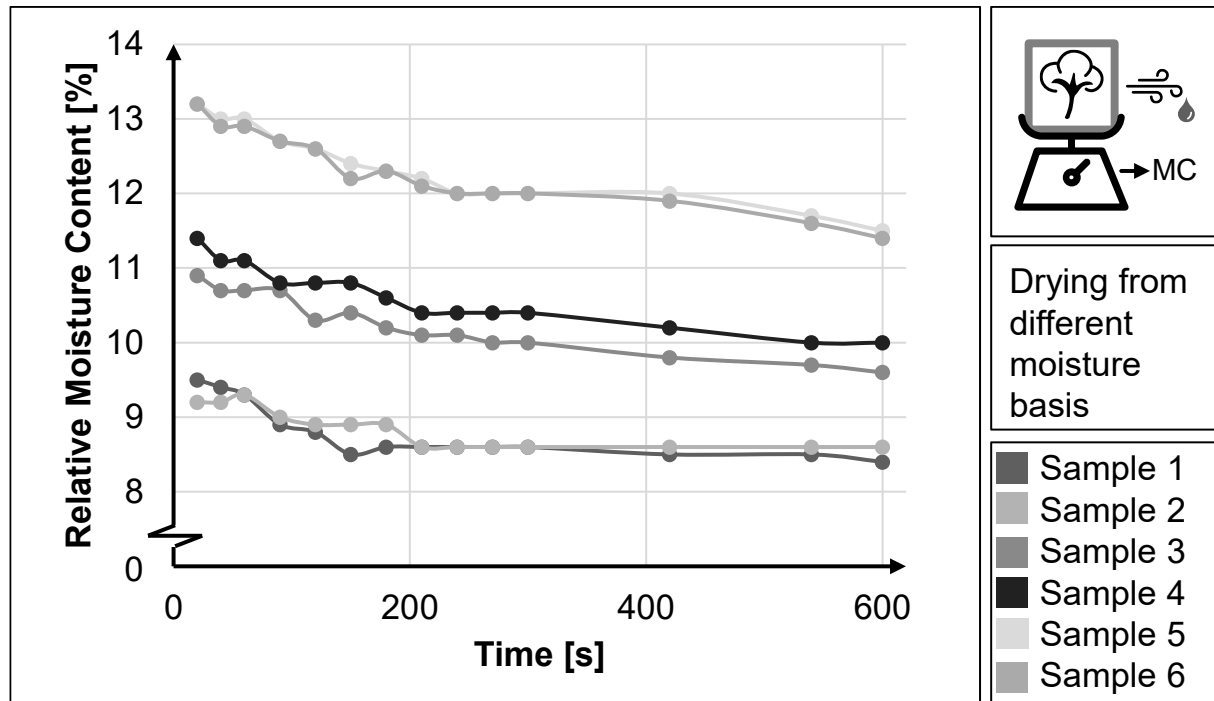


Fig. 7.7: Drying behaviour of different moisturized lint at: 20 °C, 60 % rH

These samples were moisturized in pairs of two samples. The samples are moisturized for 30, 60 and 90 minutes. The different moisturisation durations lead to the gap between the lines of initial moisture content. It can be clearly seen, that the drying behaviour is reproduceable and almost parallel to each other. Even after 10 min (600 s) there is a stagnation of the curve, which introduces a slower drying behaviour. This underlines the literature indicated hysteresis behaviour of the cotton in water absorption and desorption. These measurements are done redundantly with the resistance measurement device.

To prove the resistance measurement method, field trials show, the resistance to moving metal parts, e. g. in testing next to the ginning unit. Unlike the capacitive testing performed. Measurements are started and stored on the computer as well. This can be seen in Fig. 7.8.

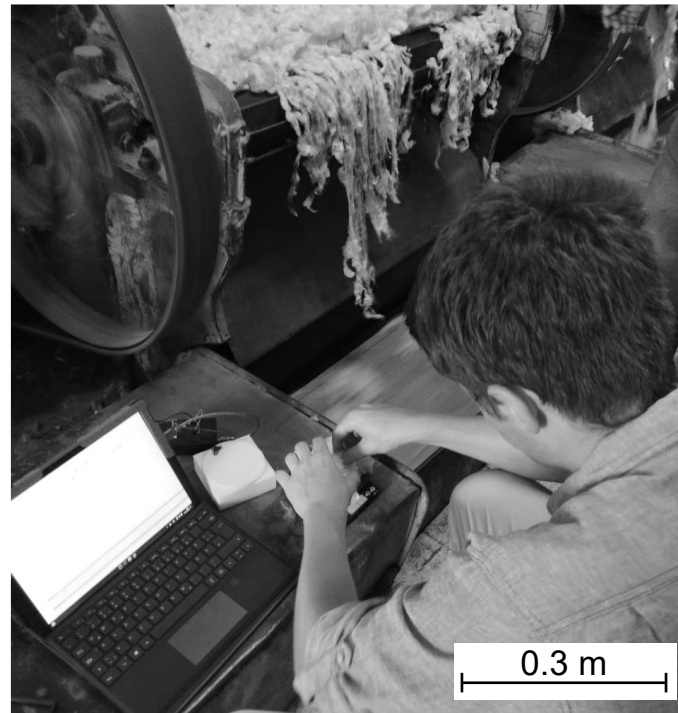


Fig. 7.8: Resistance test device usage in Egypt during ginning

The field measurements performed in Egypt show, that there are reliable measurement results of the developed moisture testing device. These results are shown in Tab. 7.6, together with the weather data at the specific times.

Tab. 7.6: Seed cotton and lint moisture measurement results from Egypt

Place	Fayoum (Giza 97)		al-Mansura (Giza 92)	
Ambient	32 °C, 50 % rH		31,5 °C, 55 % rH	
Category	Seed cotton	Lint	Seed cotton	Lint
Moisture cont. [%]	9.77 & 9.05	8.18 & 8.11	10.26 & 9.95	9.91 & 9.38

These results show, that measurements can be taken as expected and the measurement system produces reliable results, even in hot conditions. Two values are mentioned, as two measurements of each material are performed. The measured moisture values correspond to the expected literature values at this moisture content in the early morning after a more humid night. Care should be taken not measuring in the direct sunlight. This dries the cotton much faster and

influences test results. The commercial resistance measurement device C2000 from Delmhorst Instruments Co, Towaco, New Jersey, USA, used as a reference is 3 to 4 % lower, in all measures which were performed. Therefore, this testing device needs further calibration or the usage of more sensitive conductive materials. According to the seed cracking behaviour, the measurement analysis of the developed device is proven as well. While taking measurement results, values behave in a linear regression. Resistance values begin with higher values and decrease over time, until it adjusts at an almost stable value. This relative value behaviour curve is shown in Fig. 7.9.

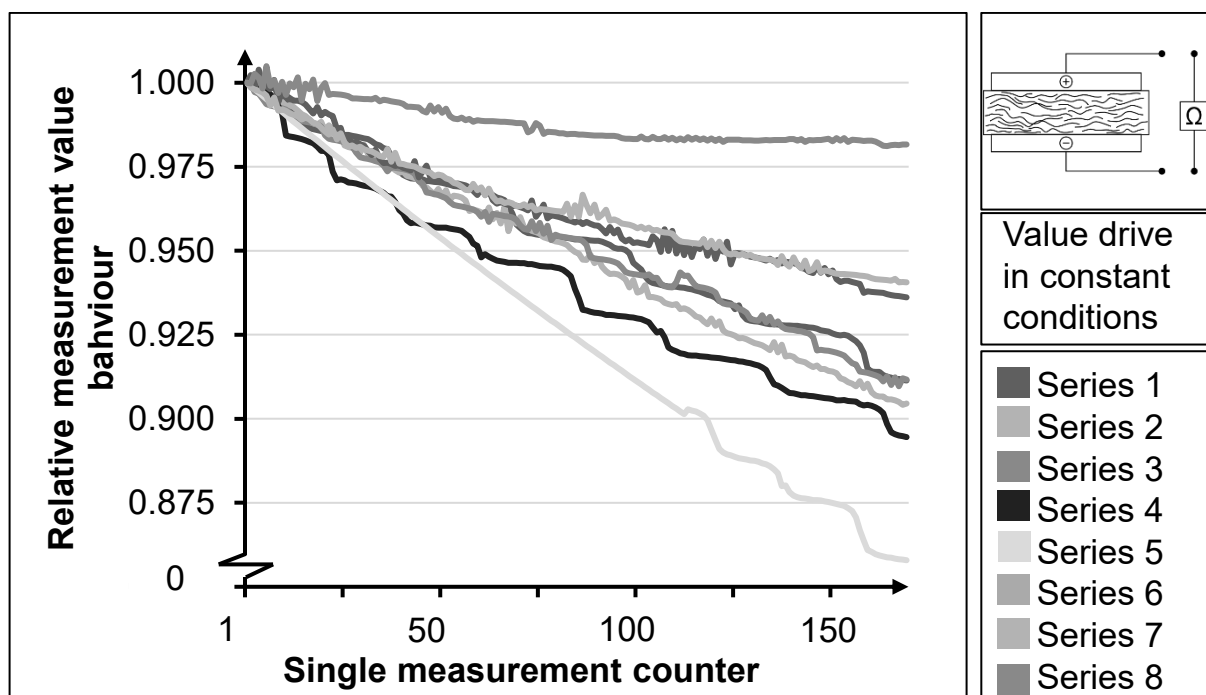


Fig. 7.9: Eight resistance measurement value curves from Egypt

These curves include eight measurements in two different locations in Egypt. The diagram shows the relative behaviour of the values according to the first value, shortened to the last 3 min of measurement. This is the most stable duration in values. Nevertheless, these value drifts show, that measurement corrections need to be considered within the program which calculates the moisture content. This might happen to the electrical charge within the sample. The light grey value, ending up at 86 % is a curve, which had a shorter measurement duration and is therefore generally more unstable. As can be seen, there is an

almost linear regression. Therefore, an interpolation of the first values needs to be used for faster measurement achievements. The above diagram shows 180 values in this period and a constant linear behaviour. Therefore, correction calculations should be easy, but based on a wide data base of those measurement results under controlled and varying ambient conditions. Further research is required in this field. Almost more important is the moisture management, described below.

The results of this technological comparison, as well as the findings of the developments in the following Chapter is then worked out for future ginning mill set-up in Chapter 7.4. Beforehand, Chapter 7.3 focuses on the moisturization of cotton, as this is the necessary step after moisture measurement to achieve quality impacts within cotton processing. In particular, preserving the fibre length and colour during ginning can be achieved by proper moisture management.

7.3 Moisturization management

“The experiments showed that moisture restoration before ginning would improve the fibre length of cottons dried in gin drying systems”. [AG01] Therefore, cotton moisture management and gentle ginning is considered within this thesis. There are many commercial drier systems, but many ginning mills lack of proper moisturisation. This thesis focusses on simple and cheap moisturization solutions. Adding moisture is critical, as wet spots might lead to neps or other devaluation of the fibre. The state of the art machines are described in Chapter 3.2. This Chapter is based on the results of the master thesis of BENECKE.

The most common way to add water to cotton is by spraying it with water near the end of its processing at the lint slide, right before it's packed. This method aims to add weight the cotton for selling the same weight with less lint cotton. It is not affecting the quality, as it is done all processing steps. [SS14]

To validate the effectiveness of humidification, measurements are carried out with these two different methods. These methods are divided into moisturizing the surrounding air and humidifying the lint therewith as well as spraying fine water drops on cotton samples. This is described more in detail below. Firstly,

the method of humidified air, moisturizing cotton, is analysed. In the experiments, 100 g cotton samples are stored in a box with an ambient humidifier. The atmosphere is 20 °C and 90 % relative Humidity (rH).

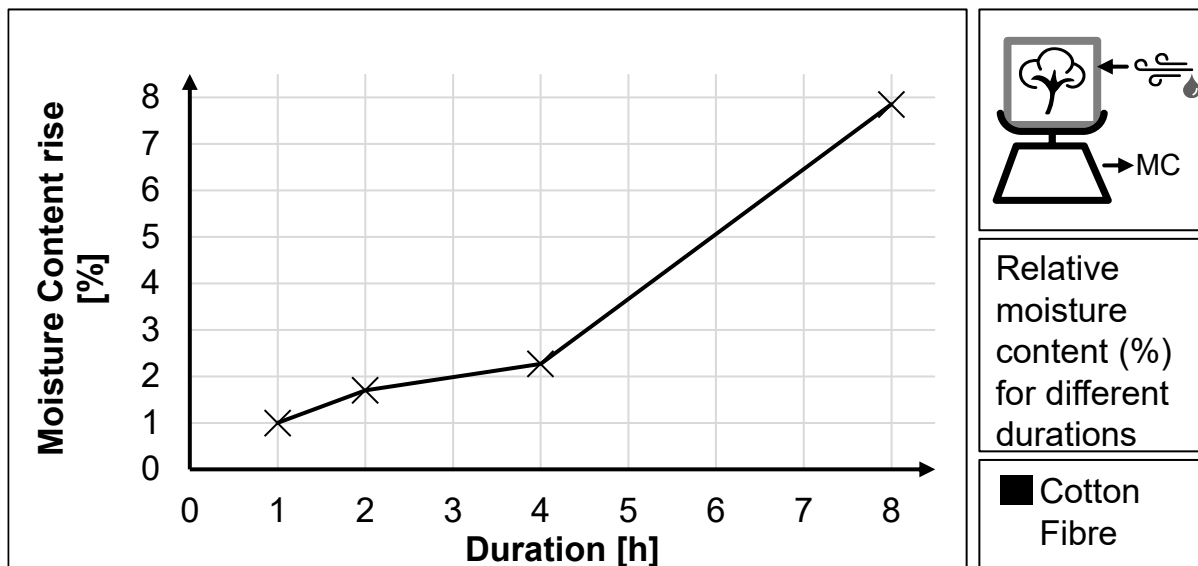


Fig. 7.10: Cotton moisturization, using an ambient humidifier in a box [Ben23]

This humidification method needs longer time than in the climate oven, mentioned in Chapter 7.1, as well as in literature. Initial moisture measurements of the cotton averaged 4.4 % across various tests. These 100 g samples are then stored in the humidification system, which initially matched the ambient humidity levels before steam is applied. [Ben23] These measurements are carried out parallelly to the moisture device development. Due to this fact and the commercial availability, these measurements are measured with an industrial standard. It is measured with the C-2000 resistance meter, by Delmhorst Instrument Co., Towaco, New Jersey, USA. This is a commercially available, but not widely trusted resistance moisture meter. It can be determined that the moisture content is increased due to the injection.

During these eight hours of moisturization, an almost linear increase of the moisture content is noted. The cotton moisture content is approximately increased by 1 % per hour on a dry basis. [Ben23] Therefore, this system is time consuming and limited in terms of frequent cotton processing. Even a change of the position of the cotton, directly in the blowing direction of the fan did not change

the results. The second measurement set-up works while spraying water directly on the cotton and is described below.

The fine opener of Trützschler SE, Mönchengladbach, Germany, is used to test spray water application. The original purpose of the machine is the opening of fibre bunches and provide a fleece lay down. The operating principle as well as the original machine are shown in Fig. 7.11.

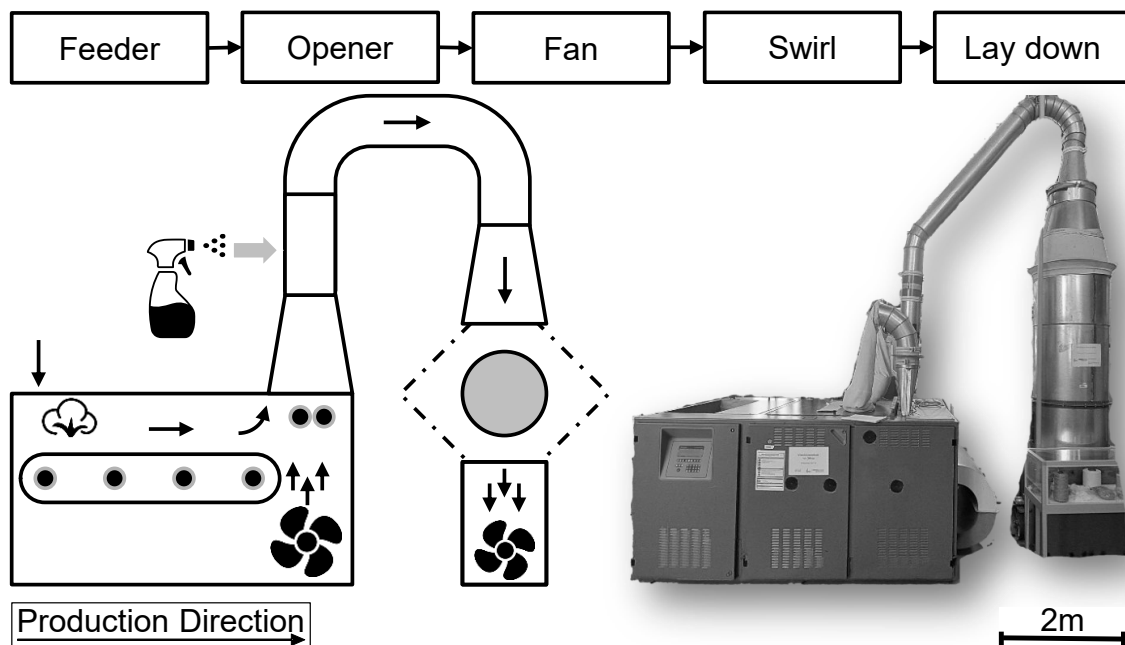


Fig. 7.11: Functional principle and illustration of the fine opener [Ben23]

The fibres are dropped on a conveyor belt. After a short transportation duration, there is a roller beater, opening the fibres. Similar to the roller ginning process, these bunches are loosened by rollers and are separating the fibres. This increases the surface area of the cotton and might have an impact to the moisturization, which needs to be considered. Two fans move the cotton in a pneumatic conveyor system to the fleece lay down. Due to the high density of lint in a bale, fibre bunches occur in every bale opener in a spinning mill (cf. Chapter 3.3).

For the measurement set-up, water is applied to the lint as early as possible. The earlier the water is inserted, the more time the cotton has to absorb the droplets in the air. For this reason, the pipe system is provided with an opening for injection right at the beginning. To prevent rust damages due to liquid water

in the fan, barrier system has been installed. This barrier is built out of a circular frame, covered by a cotton fabric. This system is inserted after the lint lay down, before the fan.

A pressurised spray bottle from Gloria Haus- und Gartengeräte GmbH, Witten, Germany, is used to distribute the water over an area, as large as possible. The system uses a pump to pressurise the water tank by hand. In this way, up to 3 bar can be applied. When the control element is actuated, the water is sprayed evenly from the nozzle. Due to the pressure and the design of the nozzle, small, mist-like droplets are produced. These spread out in the shape of a cone. This device is used, as it is more flexible than commercial vaporization systems.

In case of a frequent water flow, the pressure drops significantly. While only using short intervals, the pressure remains almost constant. This can be shown via the jet width in Fig. 7.12.

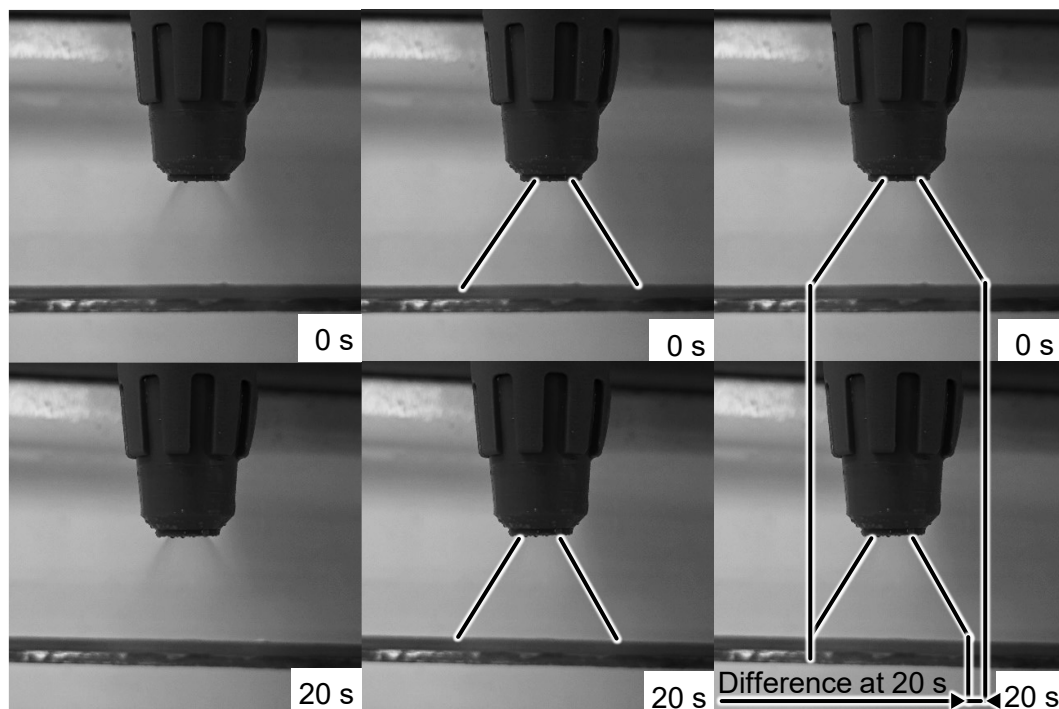


Fig. 7.12: Pressure drop of the pressurised spray bottle [Ben23]

The figure above shows the spray cone directly after actuation and after 20 s at the bottom row. For better visibility, both cones are traced in the centre image and graphically compared on the right. Due to the small difference, it is assumed

in the tests that the pressure drop is negligible. [Ben23] The setup of the moisturization investigation is shown in Fig. 7.13.

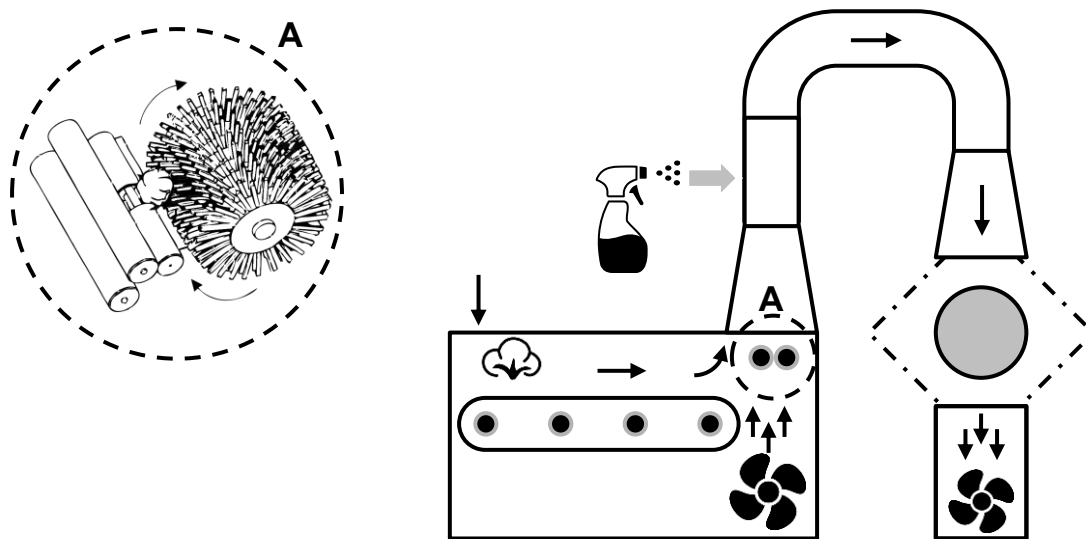


Fig. 7.13: Moisturization investigation set up

The initial moisture value of 4.6 % is increased to more than 6 %. [Ben23] Further test results within the fine opener are displayed in Tab. 7.7.

Tab. 7.7: Test results of the spraying test [Ben23]

Spray duration [s]	Water added [ml]	Average moisture content [% dry basis]	Weight loss after drying [g]	Visible dops
0	0	4,4	-0,1	No
5	30	4,7	0,2	No
10	38	5,17	0,6	No
15	54	6,77	2,3	No
20	78	8,4	2,6	No

The results of the experiment show that the spraying method is well suited to moisturising cotton. As the amount of water increases, the moisture content in the cotton also increases significantly. The first measurement with 5 s spray duration indicates, that less water reached the cotton or is improper for sufficient moisturization. Similarly, the weight of the cotton also increases. This means that the water is not only stored in the samples taken for the resistance measurement, but is also distributed throughout the entire fibre pile. In addition, the

last column shows that no drops can be seen in the fibre pile formed in any of the tests. [Ben23]

In order to illustrate the results more clearly, Fig. 7.14 shows the increase in cotton moisture. Both the moisture measured with the measuring device and the difference in weight after re-drying are shown. For the measurement with the resistance meter, the average of three measurements in the fibre pile is shown. As the cotton samples weigh 100 g each, one percentage point increase in moisture corresponds to one gram increase in mass. [Ben23]

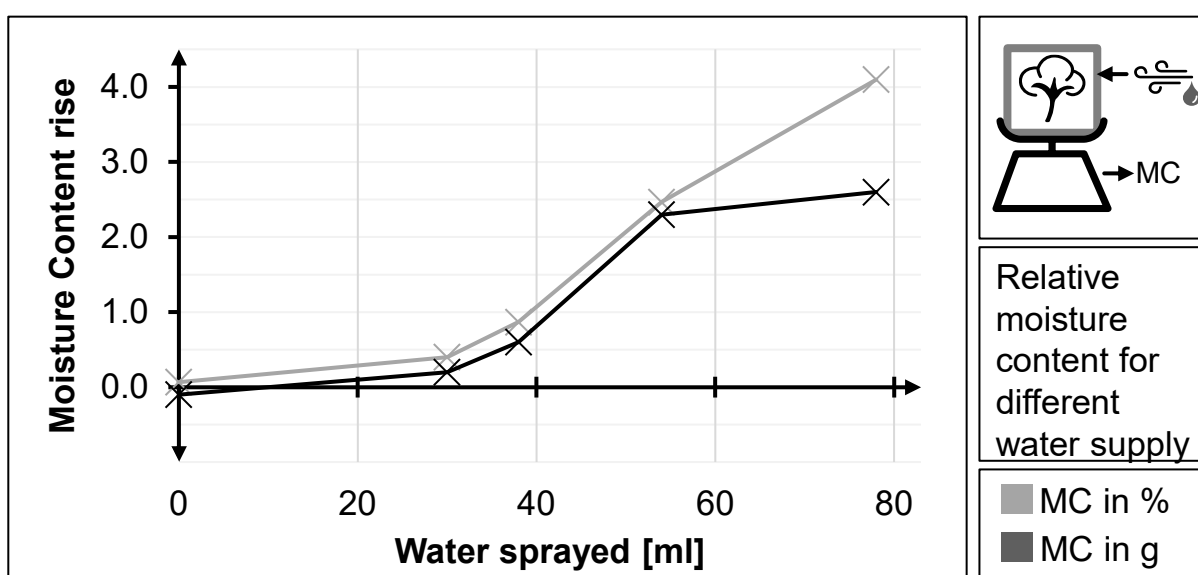


Fig. 7.14: Results of atomization moisturization [Ben23]

The recognisable deviation between the increase in weight and the increase in moisture is due to delays in the treatment for measurement of the cotton. If the cotton is not weighed within a short dwell time, the moisture content gets released back into the ambient air. In addition, a series of tests is carried out on the distribution of moisture in the cotton. The aim is to check whether reproducible areas are formed in which a particularly high cotton moisture content occurs. Accordingly, the hypothesis is that cotton moisture increases evenly at different measuring points. The counter-hypothesis is that cotton moisture has prominent maxima and minima. [Ben23]

To test the hypotheses, the moisture is measured at various measuring points within the round fibre pile. The results are shown in Fig. 7.15 graphically. The position of the measuring point is shown at the bottom right of the figure. [Ben23]

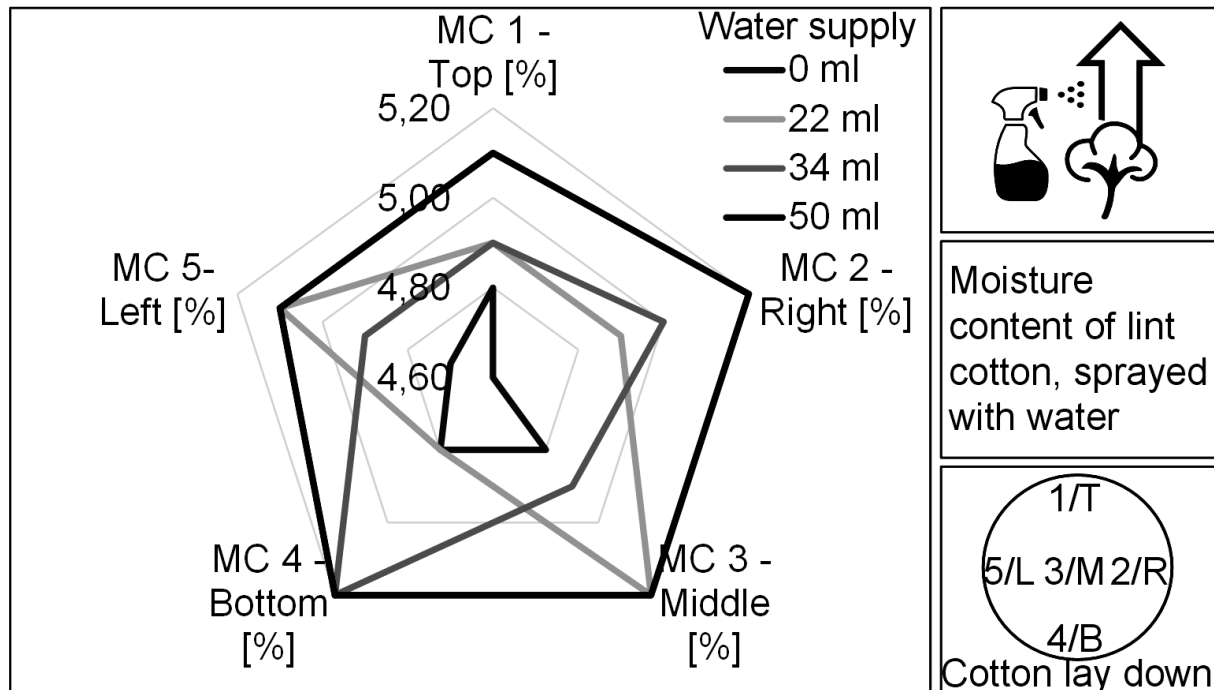


Fig. 7.15: Moisture distribution in the cotton lay down [Ben23]

It can be shown that the fibre moisture content of the individual tests results in matching measured values at all measuring points. The measuring points shown in the bottom right box indicate the position on the fine opener sieve. The moisture values in turn increase with the moisture content entered. None of the values recorded is deviating more than 0.14 % from the average moisture content determined in the respective test. The fact that there are no clear maxima and minima, but that the moisture values fluctuate in each of the tests, shows that the moisture is well distributed in the pipe. [Ben23]

One shortcoming of the tested variant is the difference between the water absorbed and the water added. If, for example, all of the 20 ml of water added had been absorbed by the cotton, the moisture content would have to increase by 20 %. In addition, it can be seen that droplet formation occurred on some connecting surfaces at the feed pipe during continuous spraying. Improvements are

therefore made to the prototype in the following. It is tested whether the improvements could eliminate these failures. [Ben23]

An investigation took place about the design of the spray nozzle. The tested circular spray nozzle is replaced by a flat spraying nozzle. This design change led to bigger droplets and therewith an increased amount of water to be sprayed. As a result, water distribution is negatively affected and wet spots within the cotton occurred. [Ben23] This can clearly be seen in Fig. 7.16.

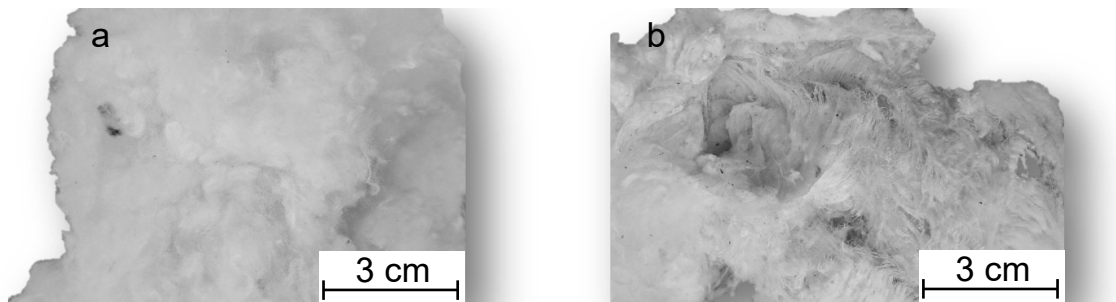


Fig. 7.16: Visualization of: a) dry/ordinary cotton, b) wet cotton [Ben23]

This wet cotton has a significant increase in neps and stickiness. Therefore, it is not reliable to be further processed. Due to the set-up of the measurements, a moisture content increase of 2.6 % on a dry basis in 20 seconds while distributing 78 ml water is the maximum. An additional set-up with a constant water supply source at 3 bar, while distributing 4 g/s from different locations within the air suction pipe, might be used for further investigations. [Ben23] This concept is further displayed within the following Chapter 7.4. As introducing those new technologies developed in the last two Chapters in practice bears risks, the following Chapter provides an assessment of the technologies' impacts.

7.4 Moisturisation management mill implementation

As mill implementation and technology impact assessment are strongly related to each other, they are displayed and discussed together within this Chapter. They are interdependent to each other and if the implementation technology or technique changes, it has an impact on the mill set-up and people working there. Therefore, these steps are carried out together and treated alternately. Starting point is a full system implementation approach, which is shown in Fig. 7.17.

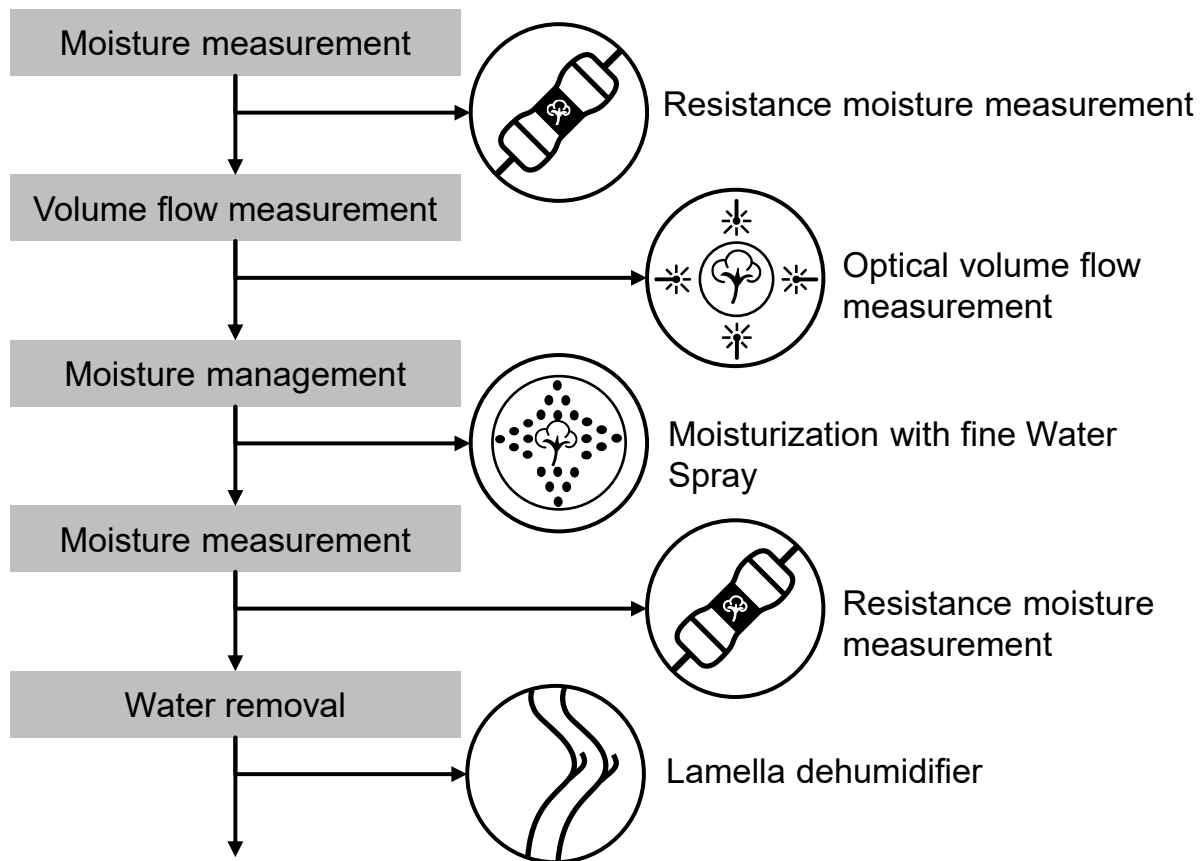


Fig. 7.17: Overall concept of cotton moisture control [Ben23]

The control concept starts with measuring the moisture content, using a resistance meter. The current moisture content of the cotton is essential for targeted humidification. An optical distance sensor is then used to determine the current outline of the cotton in the conveyor pipe. By continuously measuring the outline, it is possible to determine the flow rate. Once the mass and moisture content have been determined, the cotton is moistened using a hollow cone nozzle. This type of nozzle is particularly suitable for moistening cotton, as very fine droplets are emitted. After humidification, the moisture content is determined again using the resistance sensor. This allows the effectiveness of the humidification to be determined. The cotton is then removed from the process to the gin stand. The liquid water from the conveyor must then be filtered. A lamella separator is provided for this purpose. [Ben23]

Moisture Measurement is fulfilled via electric resistance measurement tools. The developments described in Chapter 7.1 shall be used for the implementation of moisture measurement. This could either be a bought or self-build device.

Most important is, that operators and mill manager trust in these devices. As trust is psychologically mostly build from the management, the mill management should trust in this device as well. Especially for change management, conviction of the mill management is the basis. [Ben23]

This system requires a sample picking within the suction pipe. Therefore, a hatch should be adapted at one certain point, which could be opened for measuring. It is recommended to adapt this hatch in front of a valve, which might be used to re direct to cotton, if further drying or moisturization is required. This sample represents one batch of cotton, e. g. delivered in one module or one sack. Usually, modules or sacks harvested next to each other have same conditions. Therefore, testing one sample after each other within this chamber with a delay of a few seconds leads to highly viable results to adjust the cotton moisture to its sweet spot in processing. If any adjustment in drying or moisturization is required, knowing how much cotton goes through is very important. Therefore, this measurement system should be equipped directly after moisture measurement. It is therefore described in the following. [Ben23]

Cotton volumetric flow measurement usually means feeding ginning mills in a machine supported but manual process. This might be supported by an automatic feed control, but not necessarily. A constant flow, which is suitable for all different processing steps, as cleaning, ginning and pressing, is difficult to achieve. Therefore, the transported cotton differs constantly, while having seconds of no cotton flying through the suction pipe. In turn, concepts are developed to solve this challenge. Concepts are developed in several iterative brainstorming session and described below. [Ben23]

The first idea that is found is a discontinuous measurement and feeding of the cotton. In this concept, a certain mass of cotton is weighed out again and again using a scale. This is then fed into the humidifier when the previous mass has run out of the humidifier. This ensures that the exact amount of water required is added to the cotton. A major disadvantage of this process is the discontinuity mentioned above. The delay that occurs until the desired amount of cotton has

been collected can cause downtime at the gin stands. This can continue through the entire plant and stop the ginning process. [Ben23]

Thus, the idea of an optical distance sensor is born. Assuming that the conveyor pipes have a circular cross-section, a point-symmetrical arrangement of the sensors can be installed in the pipe. Different numbers of sensors can be used. [Ben23] In Fig. 7.18 for example, four sensors are shown.

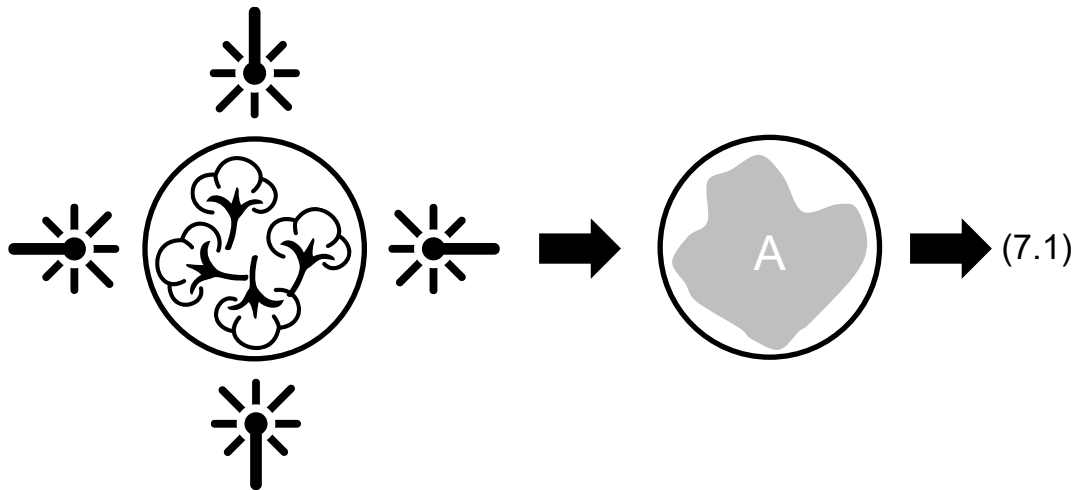


Fig. 7.18: Optical determination of the cotton mass in the tube [Ben23]

With such an arrangement, the expected area can be calculated, while assuming that the centre of the surface area is filled as well. As the later described water spray system sprays from the sides while swirling to an equilibrium, this system is seen as a cost-purpose effective solution for the purpose of moisturization. With an increasing number of sensors, the outline can be determined much more precise. [Ben23] The composition of the surface must in turn be extrapolated to the entire inner cotton mass (cf. eq (7.1)).

$$\dot{m} = A * v * \rho \quad (7.1)$$

With: $\dot{m}$ = flow rate, A = surface Area, v = flow velocity, ρ = density

As the density correlates strongly with the impurity and seed content as well as the cotton moisture, all three values must be approximately known. However, the trash and seed content on the surface could be determined using an additional optical sensor. This can be done on the basis of the colour differences to

the fibres. One advantage of this system is that the cotton mass can be determined continuously in real time data. Due to the cotton speed of 8 to 11 m/s and current data processing speed, it is possible to determine the approximate value of the weight on-line. On-line in this case means a duration of a few milliseconds and within the processing lines, while measuring in the conveyor pipes. The exact degree of cotton compression due to the air velocity speed and therefore density, is not considered yet. Average values are assumed until precise investigations and measurements are available. [Ben23]

Key requirements and functionalities for **moisture management** systems are summarized below [Ben23]:

- Water storage
- Pressurised water injection
- Atomization nozzle

There are various commercially available solutions for storing water and applying pressure. A water reservoir is recommended to ensure that liquid is always available to humidify the cotton, even in the event of transport problems from a water pipe to the humidification system. In addition, fluctuations in the pressure difference of the water supply have no influence on the functionality of the pump when using a water storage tank. In addition, the conditions of the water can be precisely controlled in a water reservoir. In particular, particles that would contaminate the cotton can be removed at an early stage. For this application, a water reservoir can also be installed at some distance from the water inlet. In this case, the pressurisation must be designed accordingly. A lot of energy is consumed by a pump, especially to overcome a height difference. [BB17]

A modern American ginning plant is used as a calculation example. This produces 60 universal standard bales per hour. Cotton bales in the USA are rated at approximately 225 kg (226.8 kg = 500 pounds) per bale. This corresponds to 13.5 t/h cotton production. By calculating the ratio of 40 % lint and 60 % seed weight, 33.75 t/h of raw seed cotton is required. If the moisture content is then increased from 5 % to 7 % for the ginning process (cf. Fig. 7.19), this corresponds to a water volume of 675 l/h, which is 11.25 l/min.

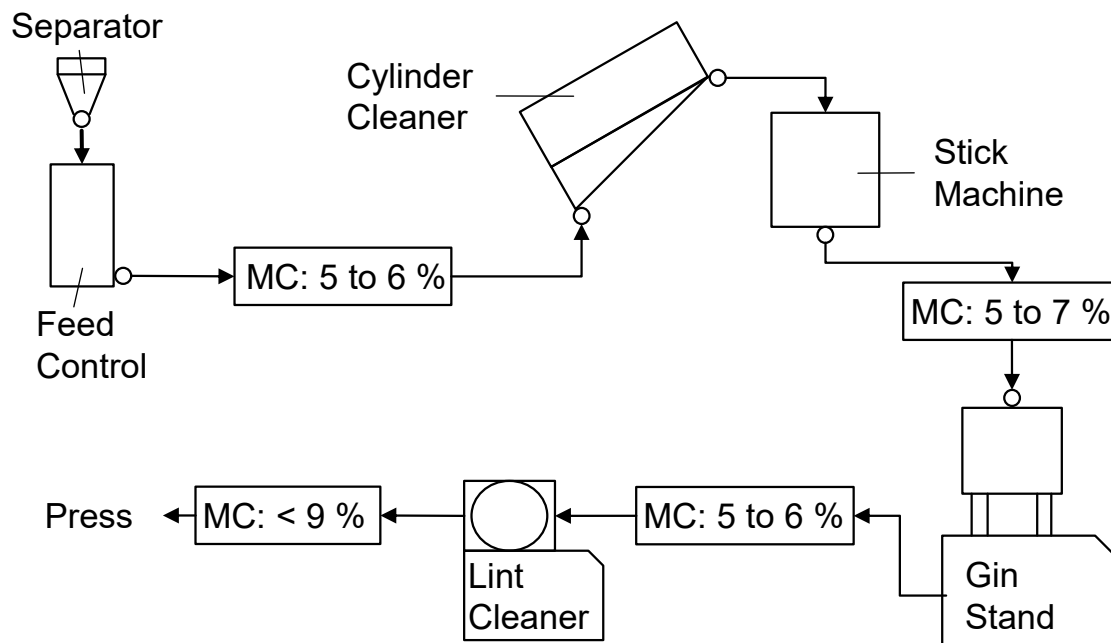


Fig. 7.19: Recommended moisture contents in ginning process stages [KSB+22]

Rotating positive displacement pumps are suitable for increasing the pressure above 10 bar. For a required pressure of less than 10 bar, a conventional pump can be used. The pressure of 10 bar is high enough to be used for the atomising nozzle. [BB17, Nat23] As the former results show, 3 bar water pressure are sufficient. Using water directly from the pipes is more efficient. In field evaluations it should be considered, whether the usage of a water tank with a pump can save much water during moisturization. With a tank, unused water can be fed back into the system and be re-used. The spray nozzles are described below.

Once the water has reached its destination, it should appear as finest droplets to be quickly absorbed by the cotton (see Chapter 7.3). The phenomenon of atomization is also known as turbulent disintegration. Atomisation is characterised by the immediate fanning out of the water jet directly after the nozzle outlet. Atomisation is primarily determined by the nozzle geometry. This means that there are several options for nozzle selection. Both single-fluid and multi-fuel nozzles are available for fine atomisation. Single-fluid nozzles atomise the water only by increasing the pressure due to the cross-section. Multi-material nozzles, on the other hand, work by injecting compressed air. However, the use of multi-component nozzles depends on the viscosity of the liquid to be atomised.

Single-fluid nozzles are sufficient for water at room temperature with a dynamic viscosity of 1 mPas. They work up to 50 mPas without any particular restriction of the spray pattern. [Wal17, Lec23, Bür22]

In Chapter 7.3 it can be seen that a single-fluid nozzle with a flat swirl chamber is used for the experiments. This produces a hollow cone. Hollow cone nozzles have the advantage over full cone nozzles that they produce finer droplets. This is due to the turbulent flows. These arise due to different tangential and axial velocities when exiting the nozzle. It is shown as well, that the smallest possible droplets are advantageous for use in cotton humidification, hollow cone nozzles are preferable. [Lec23, Woz03]

There are several designs for generating the required hollow cone geometry. In general, these designs can be divided into swirl chambers and swirl bodies. The swirl chamber is a space located in front of the outlet hole to the surroundings. The water is channelled into this chamber from the side. Inside the swirl chamber, the cross-section causes the liquid to move in a spiral pattern. These then form a hollow cone behind the outlet hole of the nozzle. Nozzles with swirlers are also known as eccentric hollow cone nozzles. The swirler is equipped with slots in the circumferential direction, which in turn generate the spiral movement in front of the outlet hole. [Lec22, Wal17]

The cone geometry must also be considered when selecting the hollow cone nozzle. Pollination in the cotton feed tube should cover as much of the area as possible. Therefore, a large spreading angle of the hollow cone is required. However, nozzles that generate the hollow cone using a swirl chamber have a maximum cone angle of 90° . For this reason, an eccentric nozzle is chosen. These can achieve a cone angle of up to 130° . [Lec22]

For permanent spraying, it should be considered to introduce the product into the pipe from several sides. As a conclusion from the test with the flat spray nozzle (see Chapter 7.3), it can be concluded that excessive, one-sided application of water can result in poor distribution. [Ben23] Therefore, an injection similar to that shown in Fig. 7.20 should be considered.

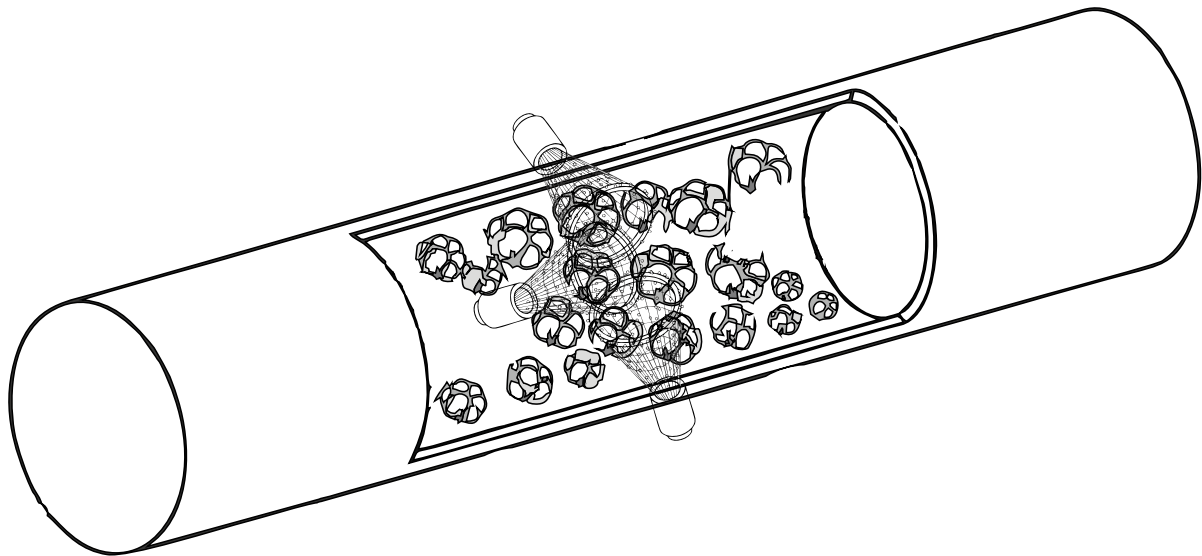


Fig. 7.20: Schematic drawing of water injection in the cotton delivery pipe

The step of **moisture measurement** should be fulfilled, as in Chapter 7.1 described. Trust and knowledge about the purpose of usage are important. While moisturizing cotton, it's important to remove any extra water that might not get absorbed by the cotton. This could lead to wet spots in the cotton, mismeasurements and electric short circuits. Short circuits might harm the operator or destroy any electrical devices. While adding too much water, water can collect inside parts of the machine, like the conveyor pipe. Therefore, water separation techniques are explored and described below. [Ben23]

In **Water separation**, there are several commercially available solutions to discharged water from conveyor systems. One example is the so called lamella separator from LECHLER (cf. Fig. 7.21). As the name suggests, the air is channelled through a lamella channel. Due to their inertia, water droplets then settle on the protruding lamella and are drawn vertically downwards out of the system by gravity. Flow-calmed drainage points are installed in the lamella for this purpose. There are various options for the arrangement and deformation of the principle and design. [Lec25]

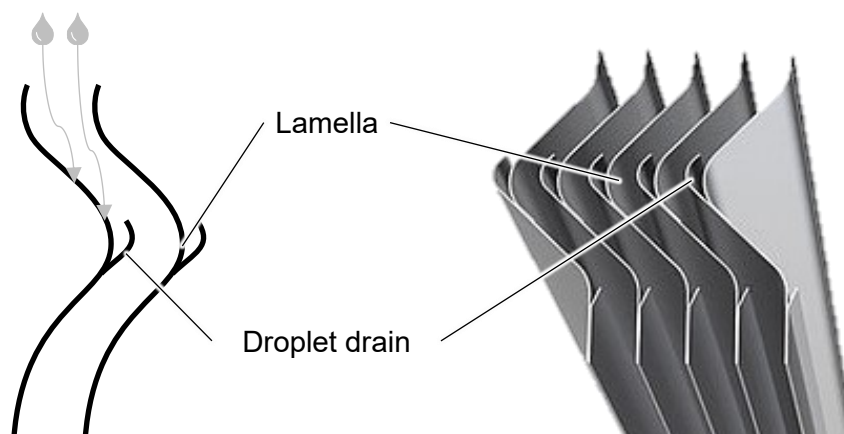


Fig. 7.21: Functional principle of lamella droplet separation [Lec25]

Knitted wire meshes are another possible principle for separating droplets. These knitted wire meshes are also called demisters. If droplets move towards the knitted fabric, they get caught in the narrow meshes. The droplets run to the knot points of the meshes and combine there to form larger droplets. Due to their weight, these droplets fall off the demister. [Env23]

For the challenge of droplet separation, the two systems presented, the demister and the lamella separator, are the most commercially available. These lamellar have not been built or implemented into cotton conveyor systems so far, therefore further exploration in this is required. While changing this shape and material, the influence of changing to stainless structures has to be considered. Possibly active or passive surface activations and adaptations might be used, to fulfil the technical requirements and guide water droplets out of the movement area of cotton lint. Chapter 7.5 provides a wider overview of the outstanding research necessities and summarizes the findings of this Chapter.

7.5 Interim conclusion

The mechanical and physical properties of cotton are mainly influenced by lint moisture and processing speed. It is constantly the case, from harvesting, across storing to processing in all stages. All stages of processing mean ginning, spinning, fabric production as well as textile manufacturing. For moisture management, the most appropriate solution for cotton moisture testing is via resistance measurement of the sample. This method is directly correlating to the

inserted moisture, can be used in every production facility and operates without disturbance. On a long-term investigation, the temperature influence according to ionisation losses in direct current (DC) driven capacitors or same acting components need to be investigated. In alternating current (AC) polarization losses occur and shall be considered. To add moisture, if the cotton is too dry, spray nozzles shall be used. Round spraying nozzles with a hollow core lead to less droplets than flat nozzles. These nozzles need to be properly installed and maintained, that no droplets occur. For drying cotton, well established tower dryer should be further used as they have a high cleaning ratio as well. Flame retardant systems should be used, not using propane gas for heating the air.

The investigations clearly states fibre length, strength and short fibre content as the most important parameter for processing staple fibres. According to the quality of the textile product containing cotton, the lifetime is most important. Textile lifetimes are mainly dependant on pilling and abrasion resistance. Both can be increased with increased fibre length. Moreover, in recycling, fibre length preservation is the only option of processing cotton again without using a cellulose dissolving process. Increased virgin fibre length therefore causes an increase of recycling cycle possibilities. In terms of dyeing, the obtained $+b$ and yellowness quality should be observed as well.

In yarn, fabric and textile production, manufacturer rarely use humidification systems for higher process stability. It is mainly justified by financial reasons. Therefore, proper online measurement systems should be developed. Moisture measurement helps in individual moisture management, according to the process step requirements. By adjusting the fibres moisture, the strength, length and flexibility of the fibre are adjusted inherently.

Currently, for online lint moisture measurement there are solely hand-held systems available, which require high efforts in operation to provide proper results. The only standardized method is the oven method, which compares weight before and after drying. Both take some time and effort. Drying systems are installed in the US cotton gins, rarely there are humidification systems as well. In

almost all developing countries, these systems are not applied. All of those measures are summarised in Fig. 7.22.

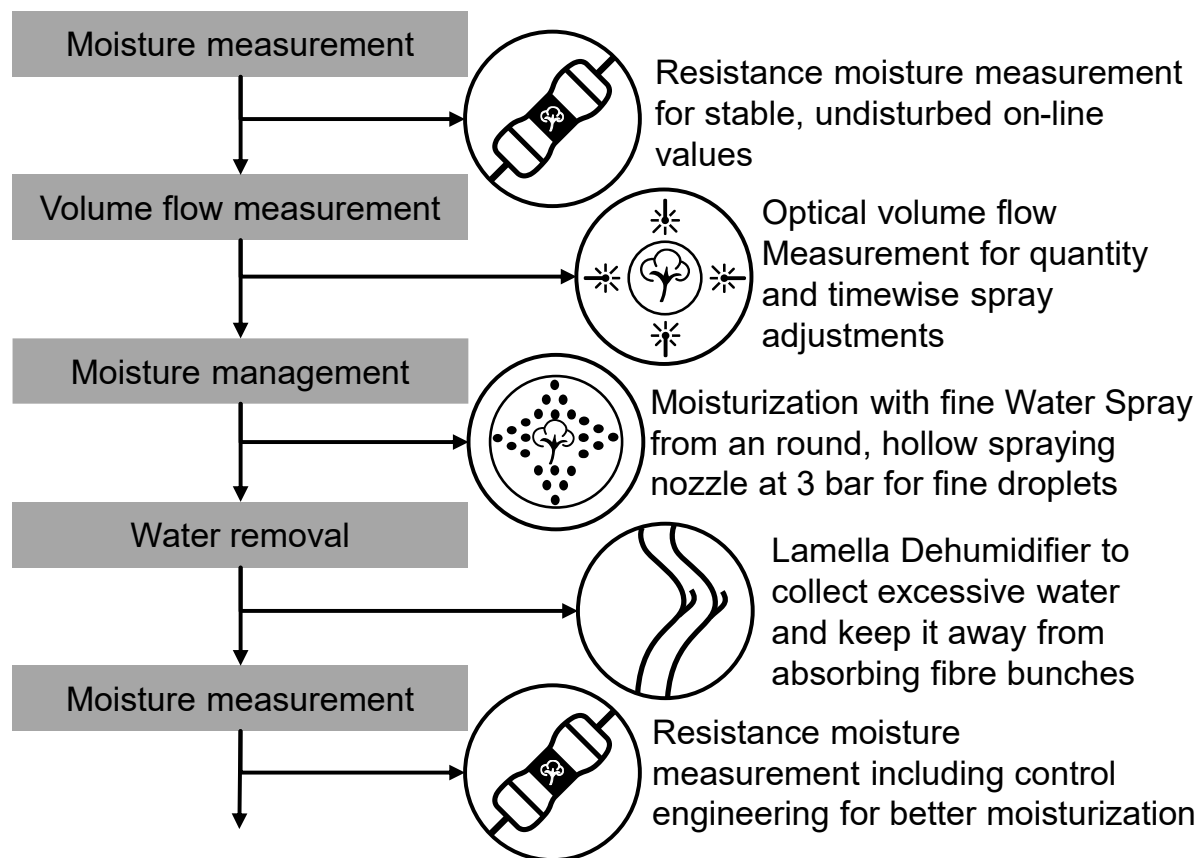


Fig. 7.22: Summary to improve quality in ginning mills via moisture management

Optimizing ginning machines has the potential of at least 15 % longer fibres, which was figured out in hand ginning trials. Due to the fact, that roller and roto-bar gins generate higher fibre qualities, these should be improved in production capacity. The engineering developments in moisture management advised before and worked out in the course of this thesis are described in the following Chapter. New business models provide an opportunity for focussing on fibre quality and cotton premiums, while preserving money for training and research, for even bigger achievements in the future. When farmers own a ginning mill, stakeholders are more interested in higher cotton grades, which means long, mature, white cotton. If preserving fibre quality is the focus of processing, not throughput, ginning mills operate more fibre gentle. This instantly leads to higher cotton prices. The physiological influence on lint prices and sociological measure implementation are described in Chapter 8.

8 Economic measure development

This Chapter analyses the economic viability of upgrading the cotton quality through the before mentioned measures. To go through this economic analysis, one has to understand the factors of generating discounts or premiums for cotton products. In general, it can be said, that discounts are much stronger, according to the base qualities as premiums are. Therefore, this introduction provides an overview of the cotton crop products. Chapter 8.1 describes predominant business models, while Chapter 8.2 provides an ongoing business model recommendation. 8.3 introduces the current bale price calculation. Afterwards, Chapter 8.4 analyses those findings and interprets it according to the viability of measure application. Concluding, Chapter 8.5 summarizes the learnings out of this Chapter.

Agricultural products are usually only financially reasonable if all parts of the plant are used. This leads to the highest possible turnover of a plant, as there are more products to sell. For cotton plant cultivation this is the case as well. Therefore, Tab. 8.1 shows the weight share of the cotton plant as well as the value share of commercial trade products of cotton. The seed price is between 275 to 460 \$/t (257 to 430 €/t) for conventional and 500 to 740 \$/t (467 to 692 €/t), according to the quality and how close it comes to planting [Uni23].

Tab. 8.1: Side-product overview of the processing of cotton seeds [Che83]

Cotton seed products	Weight share [%]	Value share [%]
Oil	16	60
Flour	45	30
Shells	26	10
<i>Linters</i> (immature short fibres)	9	
Waste products and water	4	0

As this might be a nice overview but does not refer to the sheer market size of cotton trading, the introduced content of price indications and influences follows.

8.1 Predominant business models

Cotton is grown for its fibre value, which is around 80 % of the value of seed cotton. Partially, the seed is given to the ginner as payment for its fibre separation service. [Her16] In 1989 there is a world-wide Extra Long Staple (ELS) production of 6 % according to the overall cotton production. This cotton has its own appreciation and is valued by its customers by premium payments. To preserve this quality, in the US Pima cotton is generally roller ginned. [GVN+94] Establishing a cotton processing habit that achieves frequent premiums might be supported by Industry 4.0 solutions.

To act in automated and digitalised manner, mainly research, technologies, qualification are required. Sample application in modelling automation and system optimization must be given, too. Another key factor is to use the given technology for enabling new business networks. New business models must be developed for these business networks, especially for products with corresponding services. [KWH13]

One potential way of achieving this extra value and driving the agriculturally driven market of ginning might go along with the cultural trend of sharing instead of owning. In terms of ginning it means, agricultural sectors are usually low budget sectors, especially in low-wage countries. In high-wage countries, this is often compensated with subsidies. Farmer and ginning mill owner are not able and currently willing to spend huge investments into machines. High investments usually only pay out in very big quantities. As in car leasing models, options might be to lease ginning machines instead of ownership. GNÄGI and KÜHN [GK22] calculated this model for spinning machine equipment, which usually goes along with much higher investments than ginning facilities. These higher investments come from sensor-based operation machines in very big quantities, like more than 2000 spindles per ring spinning machine. Even in case of buying 10 or 15 machines. Therefore, it can surely be used for ginning machines,

especially as it is mainly driven by two to three companies world-wide. As there are often more traders involved as intermediates for example. Fig. 8.1 provides an overview of the different participants within cotton fibre distribution.

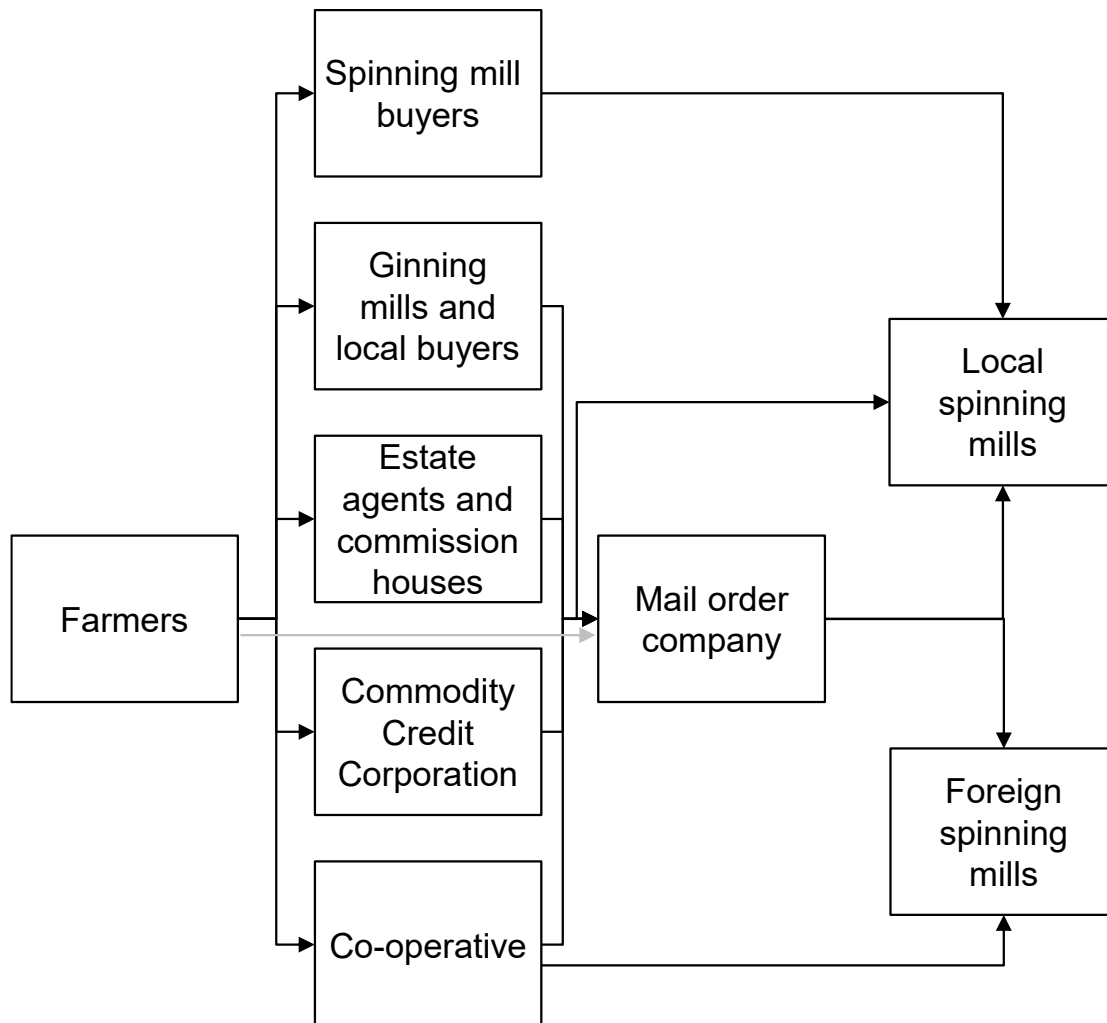


Fig. 8.1: Cotton market structural overview [GEM+96]

Depending on the given infrastructure, as logistic concepts, distance to ginning mills and financial background, some farmers can decide where to sell their seed cotton. Other farmer in poor conditions or remote regions have to use existing structures or cotton buyers. To become a better understanding for those participants, below you can find a more detailed description of:

Farmers and Spinning Mills are fundamental components within the cotton market. These entities, serving neither strictly as suppliers nor consumers, occupy unique positions. It is typical for farmers to seek the highest possible sales

price for their cotton, whereas spinning mills aim to procure cotton at the lowest feasible price. Positioned between these two are various participants who facilitate the connection between farmers and spinning mills. [Sit23] As previously mentioned, these participants are further divided into two primary groups. Its intermediates as pure traders and brokers.

Intermediates usually buy from several farmers, take care about transportation to the ginning mill and sell it for a higher price. This category includes mail-order companies, local purchasers, distribution cooperatives and occasionally, the *Commodity Credit Corporation* (CCC). Unlike mail-order companies, distribution cooperatives are farmer-managed. [KL84] The *Commodity Credit Corporation*, an extension of the USDA, plays a governmental role [Uni23]. It supports farmers through loans secured against their cotton, while taking ownership of the cotton. If loans default, the *Commodity Credit Corporation* is acting as a middleman. [GEM+96] Ginning plants typically offer ginning as a service without changing cotton's ownership. Although in rare instances, spinning mills might also serve as intermediaries. [KL84]

Broker trades within the cotton market, while never owning the cotton during trading. These brokers often represent farmers, spinning mills, or intermediaries, earning profits via volume-based commissions or by consolidating smaller cotton quantities from various sources. Similar concepts to brokers are: commission houses and spinning mill buyers. They do not own the cotton as well but distribute it to the next processing step while earning money with it. [Dow22] Spinning mill buyers negotiate directly with farmers on behalf of the spinning mills, while acting as brokers. Ginning mills may act as brokers themselves, if they engage in marketing without owning the cotton. [KL84]

These individual groups have their own interest of dealing with the fibres and how to earn money with it. Those interests are investing, transport or processing. Profit and margins are in everybody's focus. Farmer and spinner centre profit via quality. They want to buy the cheapest raw material to produce the expected product quality with high margins in between. All others focus on quantity, to buy cheap seed cotton, process as much as possible and sell lint to a

highest possible price. To suppress this change of ownership and lay the influence of cotton quality to the poorest along the textile value chain, the farmers, an approach is provided below.

8.2 Recommended business model

The assumed business model should transfer pure profit orientation due to throughput into high quality fibre and seed processing while preserving margins. This should bring the power of choice to the weakest partner of the value chain, the farmers. Transformation is only possible, if farmer have the possibility of taking free active decisions in processing their seed cotton. Farmer have to be independent from intermediates or ginning mill owner, who profits from higher throughput by earning more seeds for oil pressing. Investigation takes place about similar models which are driven in the past or nowadays. Based on the sociological findings of Chapter 5, the recommended business model should fulfil the following requirements. As those measures can only be taken together, it is called consortium below.

Technology Transfer and Training: A consortium, can invest in technology transfer programs aimed at farmers and ginning facilities, especially in low-wage countries. This could involve providing access to new and advanced ginning machinery as well as techniques that prioritize fibre quality over throughput. Additionally, training programs can be organized to educate workers in the fields and ginning facilities on the importance of fibre quality and how to achieve it.

Quality Incentives: Consortial ginning mills can establish quality incentives or bonuses for ginning facilities based on the quality of the fibre they produce. This means for example bonuses for cleaner cotton (e. g. trash much below the expected trade values and low contamination) or lower moisture contents, as no water is sprayed before the lint slide. Especially the processing without water spray is a big benefit in storage and preserving fibre mould or other losses. As a result, rewarding gins for packing more lint weight and producing higher-quality fibres, they incentivize them to prioritize quality over sheer throughput.

Technical Support: The consortium can offer technical support to farmers as well as ginning facilities to help them optimize their processes in terms of high fibre quality. This support could include regular monitoring and evaluation of the ginning process, troubleshooting assistance and recommendations for improvement. This could run as a state-wide role model in many countries, especially those who mainly benefit from the textile business. Those countries might be inspected and supported by running a textile ministry or temporary qualification institution. Quality control institutions should be permanent established.

Market Access: Consortia can leverage its market presence and networks to help other ginning facilities to access markets that value higher-quality fibre. By connecting these facilities with buyers who are willing to pay a premium for superior fibre quality and higher fibre content instead of water in the bale. This can create a market-driven incentive for gins to improve their quality standards.

Research and Development: The consortium can also invest in research and development initiatives. Especially while being supported from the government with the share of expert insights. As pointed out earlier, one aim might be improving ginning techniques, specifically focused on fibre quality. This could involve collaborative research projects with academic institutions or partnerships with technology providers to develop innovative solutions for enhancing fibre quality during the ginning process. There are already plenty of possibilities for improvement, which are just generally unknown by farmers or ginners.

For this purpose, world-wide several models established. Many of those established parallel at the same time or without knowing of the others. These models work similar in many occasions, others are built on existing models. As there are still notable differences, five pre-selected models are described below.

Model 1: Producer-owned cooperatives, including cooperative gins and marketing coops. Farmer cooperatives pool supply, invest in shared quality infrastructure and negotiate better terms. In cotton, many U.S. gins and marketing entities are producer-owned, which helps pass quality premiums back to members. Cooperatives can embed quality protocols, collective training and transparent premium distribution. Well established examples are the *Plains Cotton*

Cooperative Association (PCCA) for marketing and services to member gins and growers. The USDA AMS as an additional governmental stakeholder contributes in cotton classing that enables quality-based price premiums and discounts. [Uni25, Bij16]

Model 2: New Generation Cooperatives and producer-owned processing allocate delivery rights and tradable equity shares to members, tying ownership to supply commitments and quality standards. This model has been successful in value-added agri-processing (grains, sugar) and is applicable to ginning and spinning (especially for premium long-staple cotton). Benefits are a stronger capital base for quality upgrades (automation, contamination control), clear member incentives to meet grades and better alignment of risk/reward. [CC04]

Model 3: Multi-stakeholder cooperatives include producers, workers, processors, brands/retailers and sometimes local communities in one governance structure. This helps balance interests, set joint quality roadmaps and formalize living-income price floors with buyer participation. Evidence suggests that multi-stakeholder governance can improve resilience and performance of agriculture chains under quality pressure by balancing voice and incentives. [LN16]

Model 4: Employee ownership combined with producer representation give workers ownership stakes; combined with farmer board seats or producer advisory councils, this can distribute gains and build a quality culture inside processing plants (e.g., gins/spinners). Research on shared capitalism shows higher productivity and better outcomes when employees share in ownership and performance. When farmers also have formal voice, plants can co-design premium schedules and technical upgrades that improve fiber quality and reduce defects. [FBK10]

Model 5: Raiffeisen cooperatives in agriculture are farmer-owned organizations that pool resources to supply inputs, process products and market agricultural goods collectively. These cooperatives provide members with access to essential inputs such as seeds, fertilizers, feed and machinery, while also offering services like equipment maintenance and environmental compliance

support. By working together, members strengthen their market position and improve operational efficiency. The democratic governance structure ensures that all members have equal voting rights, promoting shared decision-making and aligning the cooperative's activities with members' needs. The cooperatives also contribute to rural development by maintaining local supply chains and providing services to the wider community. [Öst25]

In the USA, cotton ginning is often organized as farmer-owned cooperatives or associations and many gins provide integrated services (classing coordination, marketing through coops or merchants). Cooperative governance here strengthens farmer bargaining power and helps pass through quality premiums determined by USDA classing (premiums/discounts for staple, strength, micronaire, uniformity). [Uni25] The USDA division of Rural Development provide a wide basis of teaching and information material on establishing cooperatives as well as how to run them. A wide basis of legal document templates is provided, too.

The Raiffeisen system, applied with this name in Austria and Germany since more than 100 years can offer significant opportunities for ginning facilities in low-wage countries to achieve higher fibre quality. This means, driving a ginning mill unit, owned by a consortium or a cooperative society of farmers instead of an independent ginning mill owner. This does not mean, farmers have to run it. Instead, they take the action to directly influence the production capacity required, cleaning effort, overall cotton quality and *ginning out turn*. Additionally, it builds up an exchange platform for the farmers itself for cultivation practices and economic calculations. Here you can see, what such a collaboration could include to facilitate benefits for farmers':

In Egypt, multi-stakeholder approaches can be considered as used, as government has a high impact on the cotton cultivation and ginning sector. In India, none of those systems is widely used and considered as helpful. Most ginning mills operate independently, run as a side business of successful business families. To know about advantages and disadvantages of every model and form a decision on what cooperative models should be based world-wide, Tab. 8.2 provides and overview.

Tab. 8.2: Cooperative models advantages and disadvantages [Öst25; Uni25; CC04; LN16; FBK10]

Model	Advantages	Disadvantages
Producer-owned cooperatives (incl. cooperative gins)	Strong farmer voice; economies of scale in quality; widely used in U.S. ginning; good teaching material	Governance complexity; member capital needed; slower decisions; may need external branding to maximize premiums
New Generation Cooperatives	High invest capacity; tight incentive alignment; good capture of premium value-added for grades	Setup/legal complexity; living-income floors not inherent; lock-in can reduce flexibility
Multi-stakeholder cooperatives	Balanced voice; transparent premium design; collective bargaining and learning; feasible living-income	Coordination/transaction costs; slower decisions; potential dominance by large buyers; complex compliance; conflict risks
Employee ownership and producer representation	Productivity and quality gains; worker retention; some farmer voice; easier to implement than full coop conversion	Farmer power limited if only advisory; living-income floors not guaranteed; financing constraints; valuation bias decisions
Raiffeisen cooperative	Good farmers' market position; access to affordable inputs, services and infrastructure; democratic decision-making & transparency; equal votes	Decision-making can be slow; limited access to external capital; potential for conflicts between members with different priorities; success depends on active member participation

To provide local structures who support the farmers in business operation and integrity, the Raiffeisen and producer owned cooperatives seem to be most promising. The approaches introduces aside that either do not guarantee a living income for the farmer or weakens the farmers position due to further voting participants. Therefore, especially similarities and differences of Raiffeisen and producer owned cooperatives are described below.

Similarities are, that both systems (Raiffeisen and producer owned cooperatives) are based on cooperative values like working together, sharing resources and democratic control. In both, members usually have one vote each. The main goal in both systems is to help members and improve their economic situation, not just to make a profit. Both systems have ways to share risks and support each other, for example through joint funds or insurance.

Differences are, that the Raiffeisen system is focused on exclusively supporting its members and democratic participation. Only people who use the cooperative's services can become members and every member has one vote, no matter how much money they invest. Pure investors are not allowed as members. In the USDA system, cooperatives can sometimes allow outside investors. Some cooperatives within the USA are more flexible and can accept investor members who are mainly interested in financial returns. Therefore, the USDA RD provides many materials publicly, which makes the system independent from any overarching organization. Raiffeisen cooperatives are usually local and follow the principles of self-help, self-responsibility and solidarity. Producer owned cooperatives can be more centralized and are often designed for economic efficiency and growth. The legal rules are different. Raiffeisen cooperatives follow German cooperative law, which protects member control and self-management. USDA cooperatives follow U.S. federal and state laws, which allow more options for membership and capital. Those have to be adjusted and potentially taken into account, if one of those systems is considered to be applied internationally within the same organizational framework.

Concludingly, a slight tendency for the Raiffeisen approach exists, due to its local strength and independence from investors. By following the Raiffeisen

approach, ginning facilities in low-wage countries have the opportunity to transition from a focus solely on throughput to one that also prioritizes fibre quality and gain living worth income. This brings up a combination of technology transfer (e. g. in common trainings), incentives, technical support, market access plus research and development. These facilities can enhance the value of their fibre and position themselves more competitively in the global market.

Additional financial calculations, based on the information of this Chapter are made in Chapter 8. These include the extra achievements of necessary premiums while properly managing the moisture content and earning higher fibre quality. Before coming to this, summing up the findings of this Chapter, below there is a conclusion of the formerly read, including development potentials.

8.3 Cotton bale price calculation

The cotton bale price results out of different buying mechanisms, the produced amount of cotton as well as the stock market. Constantly, there is almost one year harvest on stock. Currently it is about 75 % stock to yearly use ratio [MLM+24]. As in the season of 2020/21 there is an approximately 10 % higher consumption than production, this increased the cotton prices sharply. This can be seen in the price overview figure between August 2019 and early 2024.

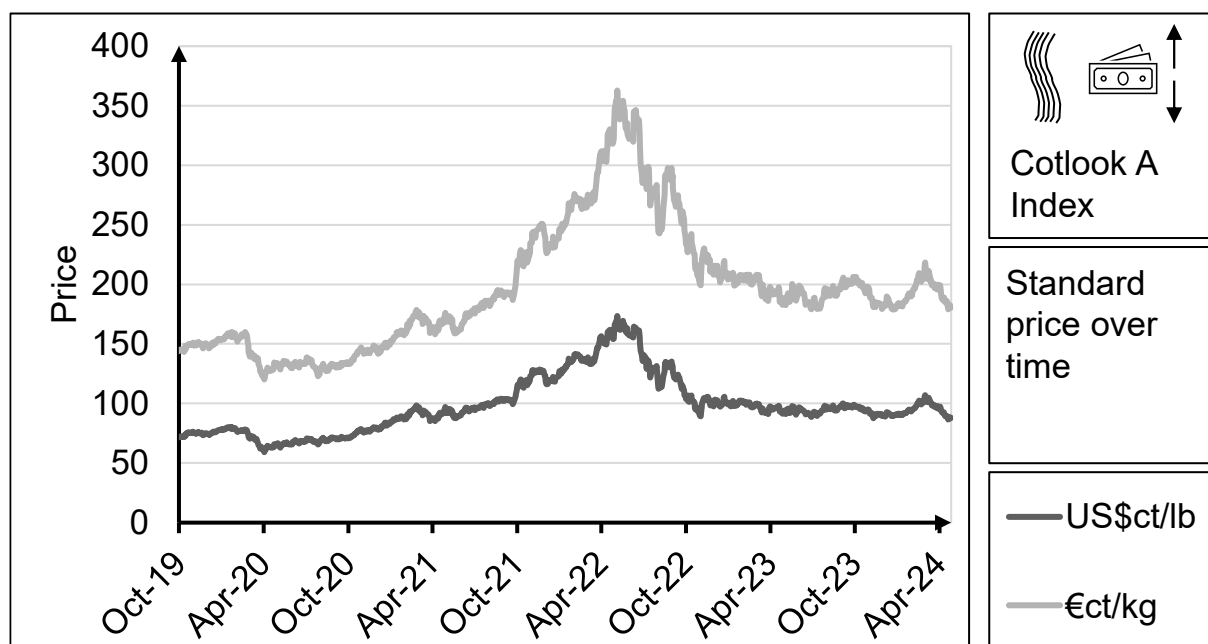


Fig. 8.2: Cotton price overview September 2019 until April 2024 [Int24]

This figure shows, that cotton prices are very sensitive to miss matches in production and consumption. The overconsumption in 2021 lead to price increases, which drop only one year later after production and consumption are on an equal level. Even slight changes can significantly influence the price, while having enough cotton in the world's ending stocks. To gain a better understanding of these price mechanisms, the three main types of trading need to be understood first. These types are: contracts, spots and futures/options; which are described more in detail below.

Contracts offer market the possibility to safe the todays price for a future delivery date. They serve as a risk mitigation tool for farmers and enable intermediates and spinning mills to better estimate costs and plan negotiations. Typically, intermediates sign annual contracts with farmers, who engage in short-term contracts with spinning mills, sometimes directly in gin-direct contracts. [Ada15, PEB84] Prices in contracts can be fixed, with quality premiums or discounts, or variable, influenced by market conditions [PEB84]. These prices often reflect the spot market trends, which also impact contractual dealings. This Chapter does not dive deeper into research about contracts as a negotiation method.

The spot market provides an immediate trading platform, where participants post their buying or selling prices, leading to the establishment of a spot price based on supply, demand and quality specifications [Ada15]. Brokers play a key role in facilitating transactions, making spot prices valuable indicators of market dynamics [Hay21]. The transparency and directness of the spot market influence both contracts and overall market movements, with the focus of this analysis being on the spot market's effects.

Futures and options act as mechanisms to hedge against price volatility, with futures prices determined by the supply and demand for cotton. Futures contracts allow for future delivery at present prices, offering flexibility to resell before delivery [Ada15]. While options have a similar market impact, their functioning differs. This thesis simplifies their explanation. Despite their use for hedging and speculation, futures and options, which rarely result in actual delivery (about 98 % of transactions), are mainly financial tools not focused on cotton quality

[PEB84]. This means, less than 2 % of the worlds cotton trade is done by futures and options. Therefore, an in-depth examination of futures and options is not pursued in this context, focussing instead on their broader market implications.

It must be said, that the calculations made in this Chapter are the best possible estimation for such a complex market and price behaviour. Trade models are different all across the world. The USDA AMS has one price calculation as well as the International Cotton Association (ICA). As the ICA has different basis fibre length and other quality parameter per country, the USDA AMS table is considered for further calculations.

These bale price indicators significantly represent, how volatile and sensitive the cotton price is. It clearly shows, that there is a standard trade quality, on which all cotton prices rely on. The best comparison basis we have for it is the *Cotlook A Index*, by Cotlook Ltd., Liverpool, UK, most entities world-wide rely on.

The Cotlook A Index is daily determined and published, based on middling cotton of 1-1/8" (28.58 mm). The compared staple length changed over the last few years. Some countries are still based on the old values of 1-3/32" (27,78 mm) or 1-1/16" (26,99 mm). It takes the five cheapest quotations of far eastern cotton. [Cot24] These prices include the following selection in the season of 2023/2024.

Tab. 8.3: Cotlook A Index specimen selection in season 2023/24 [Cot24]

Australian	Chinese 328	Memphis/Orleans/Texas
Benin BELA	Greek	Mexican
Brazilian	Indian Medium grade	Tanzanian Type 1 SG
Burkina Faso RUDY	Mali KATY	Turkish S. Eastern Std 1 RG
California/Arizona	Memphis/Eastern	Uzbekistan

*Only two African Franc Zone origins are currently allowed to figure in the A Index calculated on any day

**Applicable ICS standard, as adopted by ICA is ICS 105 fine

Furthermore, it is not displayed which kind of quality parameter is considered within this price. The opposite is the case in the United States Department of Agriculture – Agricultural Market Service (USDA AMS). They provide two detailed definitions of the base quality (cf. Tab. 8.4).

Tab. 8.4: Basic quality of lint [Uni23]

Bundle properties			Other properties			-	Price
Colour [-]	Leaf Grade [-]	Staple length [inch/32]	Length Uniformity Index [%]	Micronaire [-]	Strength [g/tex]	Contamination [-]	Average [US\$ct/lb & €ct/kg]
41	4	34 / 27	81.0 – 81.9	3.5 – 3.6 & 4.3 – 4.9	27.0 – 28.9	None	85.22 & 178.29
31	3	34 / 27	81.0 – 81.9	3.5 – 3.6 & 4.3 – 4.9	27.0 – 28.9	None	86.21 & 180.36

Exceeding these quality parameters add a premium. The cotton value, falling below the benchmark quality parameter lead to a discount of the particular specimen. For a better world-wide overview of the reader, the following Figures show price differences in US\$ct/lb and €ct/kg. The exchange rate is averaged for the duration of the USDA market report, from August 2022 to July 2023 at 0.95 € per US-Dollar [boe24]. Calculating the exchange rate with the weight of 453,59 g/lb, the exchange factor is: 1 US\$/lb is equal 2,09 €/kg.

As we can see in these different fibre lengths, that the ICA values constantly change over time, while longer cotton fibres are harvested. This change in length occurs through breeding. The USDA AMS values remain constant at 1-1/16" (26,99 mm). All following calculations in this Chapter remain on the USDA AMS values.

The main change in cotton pricing occurs through plastic contamination. If plastic contamination is detected, the price drops by 40 US\$ct/lb (81.8 €ct/kg). The

most complex price calculation takes place, according to the colour and leaf grade. This is explained in this Chapter below. Beginning with the simpler changes, Micronaire, strength and uniformity are considered. The Micronaire value behaves according to the following Fig. 8.3.

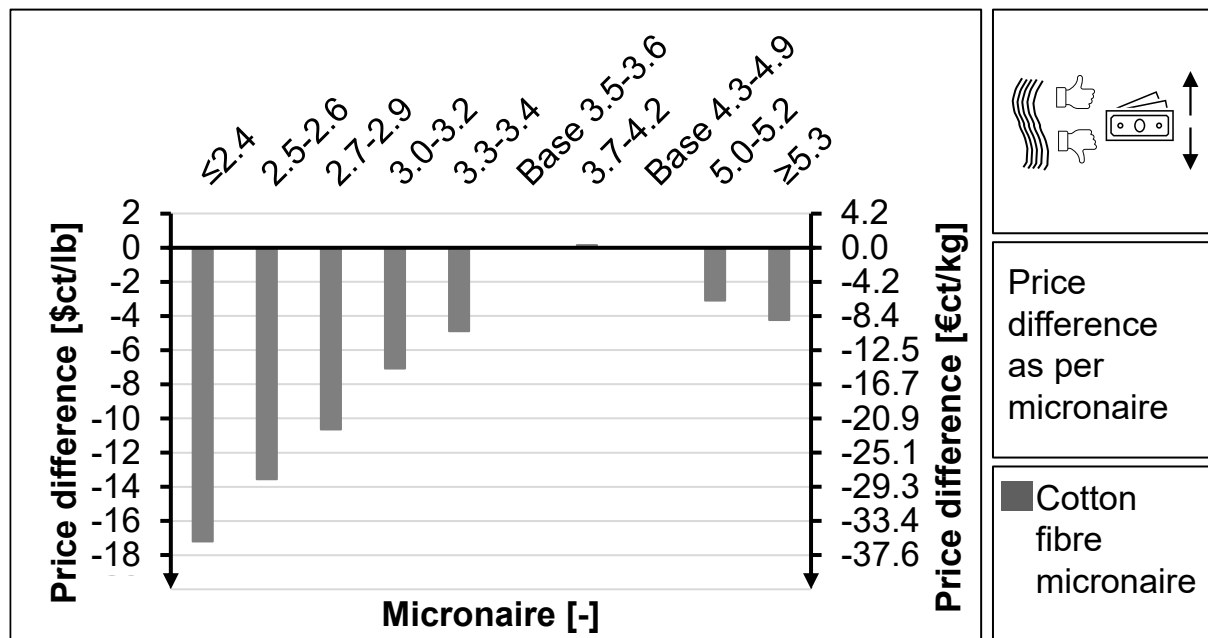


Fig. 8.3: Micronaire price difference overview, based on [Uni23]

There are two bases considered in the graph above. This again refers to the differentiation of fine (Mic. 3.5 – 3.6) and coarse (Mic. 4.3 – 4.9) cotton varieties, as earlier shown. As smaller Micronaire numbers refer to a finer cotton, it is surprising that there is a discount for lower Micronaire values. This might refer to the practical experience, that finer measurements are mostly dependent on lower degree of maturity. Moreover, while adding small amounts of short fibres to the lint, Micronaire values decrease in measurement. The measured fibre length in these quantities remains constant or almost constant. The second factor to be mentioned here is the fibre strength (cf. Fig. 8.4).

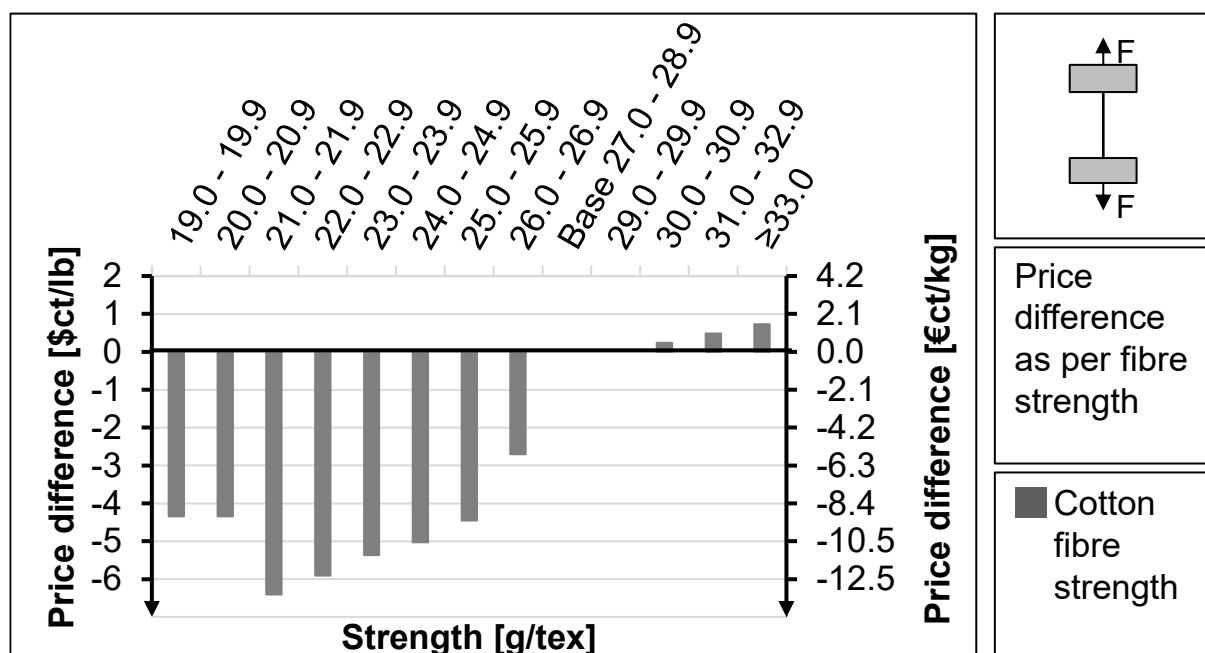


Fig. 8.4: Strength price difference overview, based on [Uni23]

The strength of a fibre can be a big disadvantage, already decreasing the base value of 27 g/tex at the lower end. One class below the base, a discount of 2.7 US\$/ct/lb (5.66 €/ct/kg) is applied. While increasing the fibre strength in cultivation and preserving it to the lint, there is a minor premium up to 0.73 US\$/ct/lb (1.52 €/ct/kg). This shows, quality decrease is four times stronger valued than a quality increase. Fibre uniformity has the lowest influence (cf. Fig. 8.5).

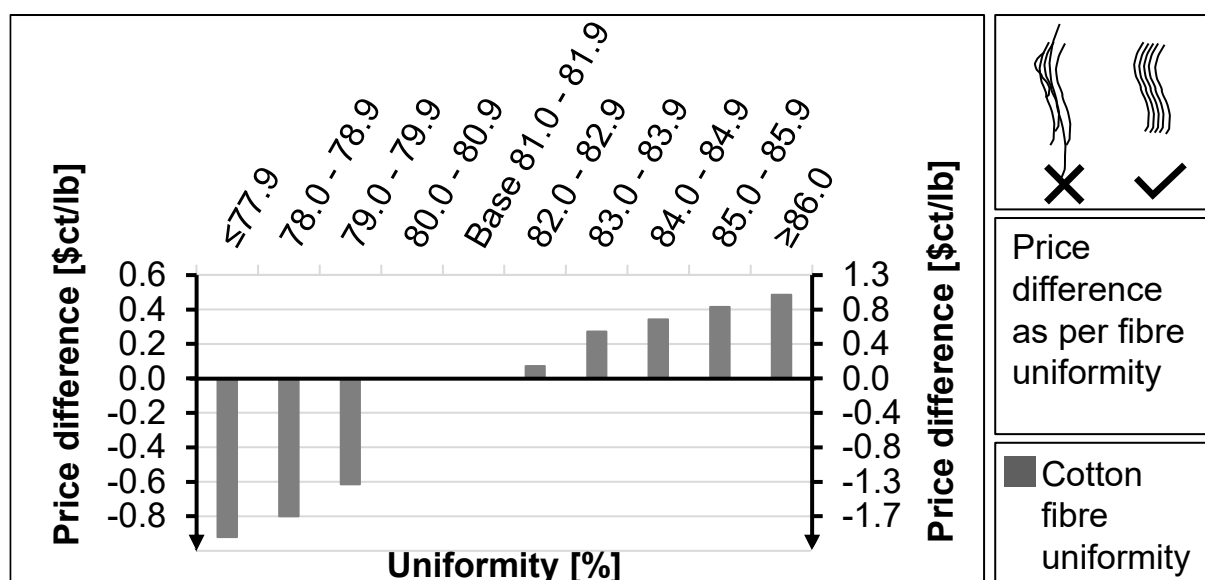


Fig. 8.5: Uniformity price difference overview, based on [Uni23]

Nevertheless, we can directly see that an increase according to the base quality is valued more than in other categories. The increase for a premium is some slower and ends up at half of the discount, which might be applied for underreaching this value. Additionally, there is no direct discount for not reaching the base uniformity by 1 %, according to the basis of 81 % at the lower end. Last but not least, the fibre length distribution is considered below, beginning with length differences in Fig. 8.6.

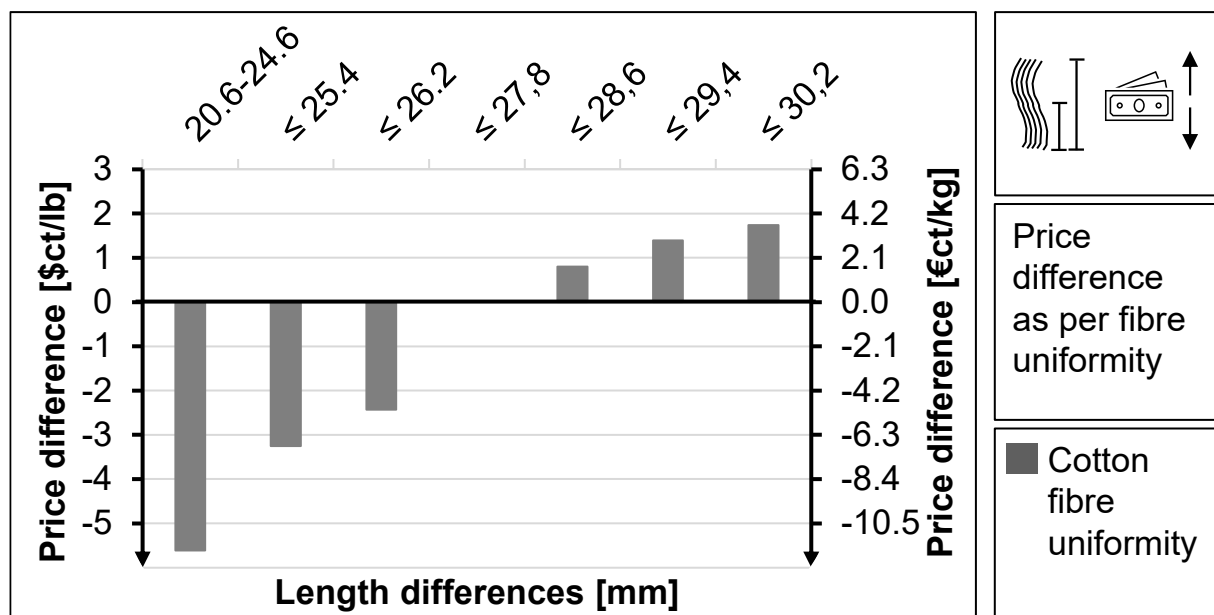


Fig. 8.6: Length difference price difference overview, based on [Uni23]

Fibre length averages have approximately 2.5 times discounts than premiums for experiencing increased fibre length. According to the US production and bale distribution, fibre shortening below 34/32 inch or about 27 mm is not big issue. In total, there are 13,639,699 produced bales in the 2022/23 season in the US. 262,532 bales are shorter than 1 1/16" (27 mm). These 13.64 million bales are distributed over the following qualities (cf. Fig. 8.7).

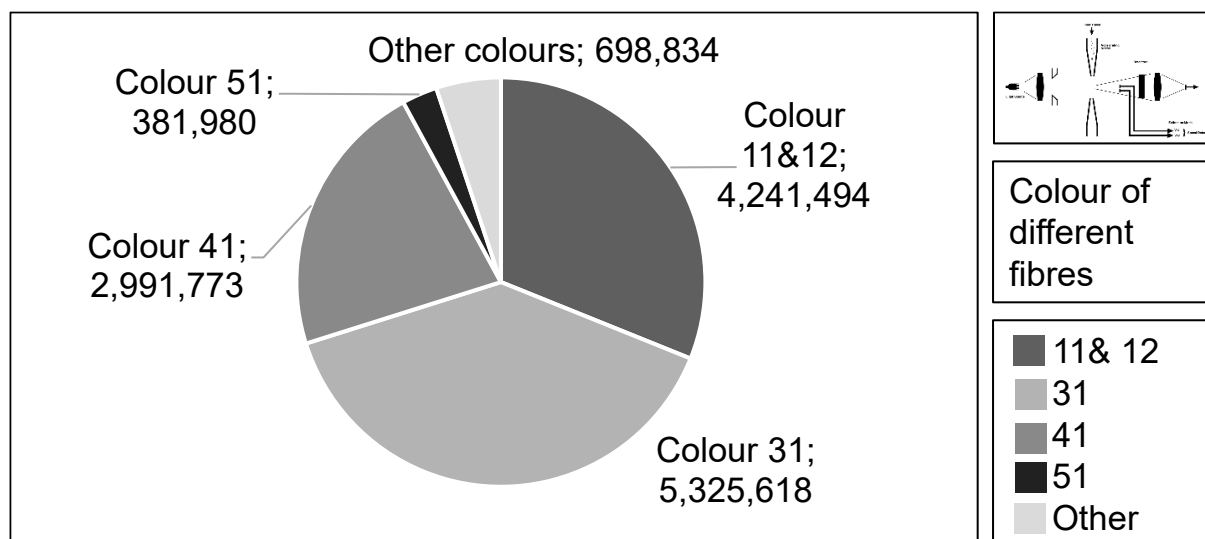


Fig. 8.7: Bale pieces by colour grade distribution, based on [Uni23]

All “other” traded bales are accumulated to nearly 700,000 pcs. These are spread to twelve different categories and are not further considered in the evaluation. For the distribution of different staple length, see Fig. 8.8. As Colour grade 51 has a significantly lower amount, it is left out for a clearer presentation.

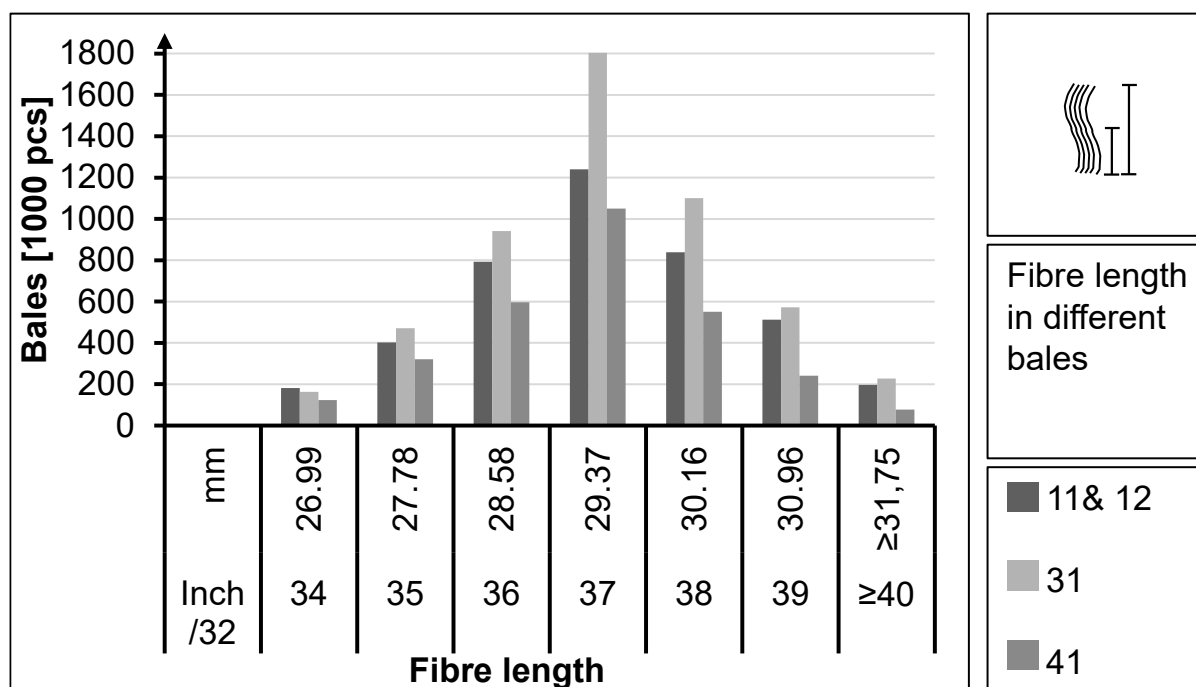


Fig. 8.8: Cotton bales over fibre length, acc. to their colour, based on [Uni23]

The colours observed in this investigation are followed by the price changes between the different leaf and colour grades. Calculating the price differences

is very complex and strongly related to each other. Average values of the USDA AMS tables are taken for this visualisation. In the following Fig. 8.9, colour changes with constant leaf grade values are displayed.

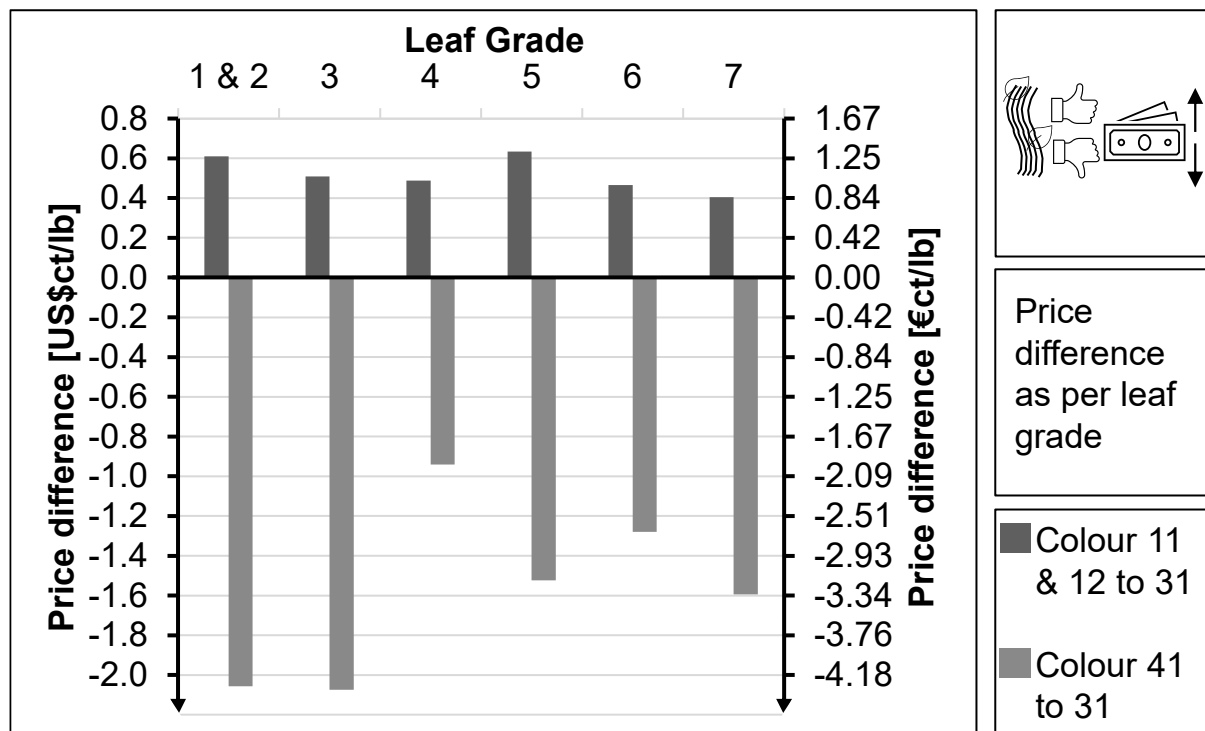


Fig. 8.9: Price changes in colour changes at base colour 31, based on [USDA23]

Comparingly, Fig. 8.10 is based on leaf grade 3 in the same spot cotton quality definition. Both are described and interpreted below.

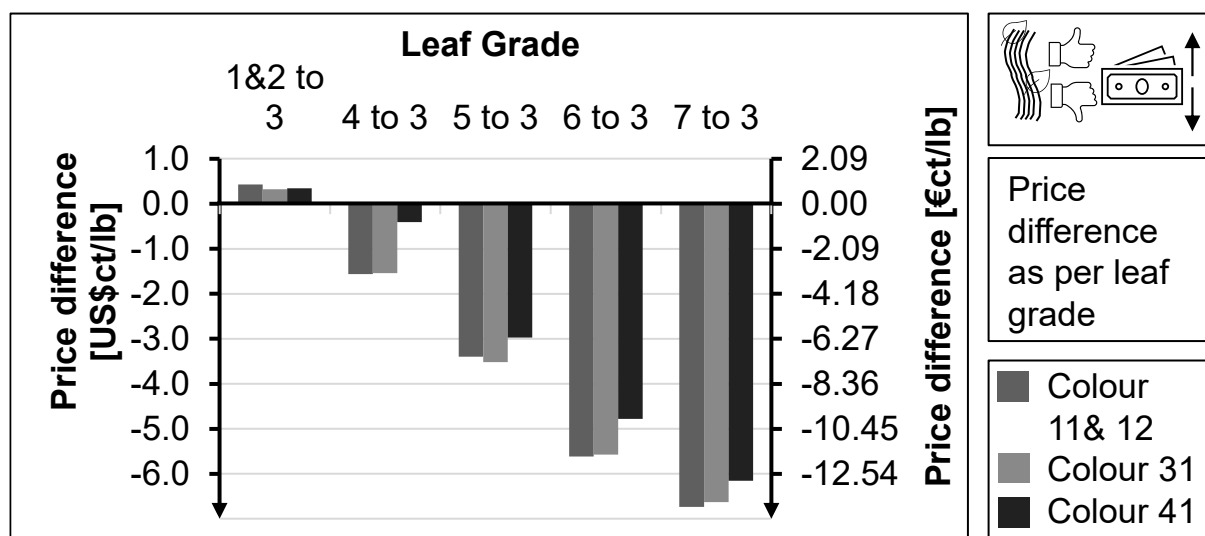


Fig. 8.10: Price changes: leaf grade change, constant colour, based on [Uni23]

As there is no single pre-defined base in colour changes, this visualisation set colour 31 as a base. This is one of two USDA AMS standards, as well as the Cotlook A Index basis (cf. Tab. 8.4). Again, as shown both Figure, price drops are significantly higher while falling below grade three, instead of valuing the higher grades one and two. While considering these price developments, Chapter 8.4 evaluates the profitability of the proposed measures of this thesis.

8.4 Pricing analysis and solution ROI calculation

As visualized in the Chapter before, price drops are significant, opposite to price increases while achieving higher qualities. Therefore, the first goal is to keep rather to decrease the fibre's quality. Increases in quality are nice, as they bring a slight bonus to the trader and farmer. Assumptions are made according to the achievable quality as follows:

- Leaf grade: one higher (-1)
- Length: two higher (+2/32)
- Colour: constant / up to one higher (-10)
- Micronaire: constant
- Strength: constant
- Length uniformity index (LUI): constant

Depending on the basis, these changes can have significant price differences. The defined quality is selected according to the most sold length and ICA base.

Tab. 8.5: International Cotton Association base quality pricing [Uni23, Int24]

Co- lour [-]	Leaf Grade [-]	Staple length		Length Uniformity Index [%]	Mic. [-]	Strength [g/tex]	Price	
		[inch/32]	[mm]				[US\$ ct /lb]	[€ct/kg]
31	3	36	28.58	81.0 – 81.9	3.5 – 3.6	27.0 – 28.9	91,08	190,55

From the International Cotton Association (ICA) basis, different scenarios are set. These scenarios focus on quality increases. Additionally, the achievement of one or two grade changes at the same time are considered. Length uniformity will most probably be increased due to the recommended measures as well. This index does only influence up to 0.55 US\$ct/lb (1.15 €ct/kg). It will not be further considered in the calculation and therefore serve as an additional financial benefit. As Micronaire and strength are constant according to the assumptions, these is excluded from the further scenarios in Tab. 8.6.

Tab. 8.6: Price scenarios of quality increases, prices based on [USDA23a]

Scenario	Colour [-]	Leaf Grade [-]	Staple length		Price	
			[inch/32]	[mm]	[US\$ct/lb]	[€ct/kg]
Base	31	3	36	28.58	90,51	190,55
1	11&21	3	36	28.58	91.05	190.48
2	31	1&2	36	28.58	90.87	190.11
3	31	3	37	29.37	91.08	190.55
4	31	3	38	30.16	91.41	191.24
5	11&21	1&2	36	28.58	91.43	191.28
6	11&21	1&2	37	29.37	92.17	192.83
7	11&21	1&2	38	30.16	92.59	193.71

This shows, that each quality parameter increase has a price increase of approximately 0.5 US\$ct/lb and 1.1 €ct/kg. While calculating this to one universal standard bale of 500 lb (225 kg), the main price difference is around 250 ct per parameter and bale. As US\$ and Euro exchange courses are close to each

other, it is considered as one. While assuming the buying and installation cost of a moisture management system, plus running cost, the following cost arise.

Tab. 8.7: Investment costs for moisture measurement and -management

Category	Position	Cost [€]
At-Line Measure	Arduino Mega	50
At-Line Measure	Copper plates	15
At-Line Measure	Cables	10
At-Line Measure	Scale	30
At-Line Measure	System build up labour (2h)	60
On-Line Measure	Cotton flow sensor & equipment	250
On-Line Measure	Measurement chamber equipment	350
On-Line Measure	Resistance measurement equipment	150
On-Line Measure	System build up labour (20h)	600
Moisturize	Pipes	500
Moisturize	Spray nozzles	100
Moisturize	Switching system for spray impulses	150
Moisturize	Additional Tank and pump	400
Moisturize	System build up labour (30h)	900
Sum	Sum up of one-time material cost	3,565
Category	Position	Cost [€]
Moisturize	12 l / bale (operation cost) at 7,5 €/m ³ water	0.09
Moisturize	2 kW/(h*bale) (operation cost) at 35 €ct/kWh	0.02
Sum	Sum up of operation cost per bale	0.11

As the table above shows, 3,565 € investment for the whole system, while labour cost makes 1,560 €. The calculation includes 52 hours at 30 €/h. As contracting untrained workers, it takes some longer, but usually at lower cost. Calculating the different scenarios, increasing one to five values of quality addition, Fig. 8.11 shows the required bales for a return of invest.

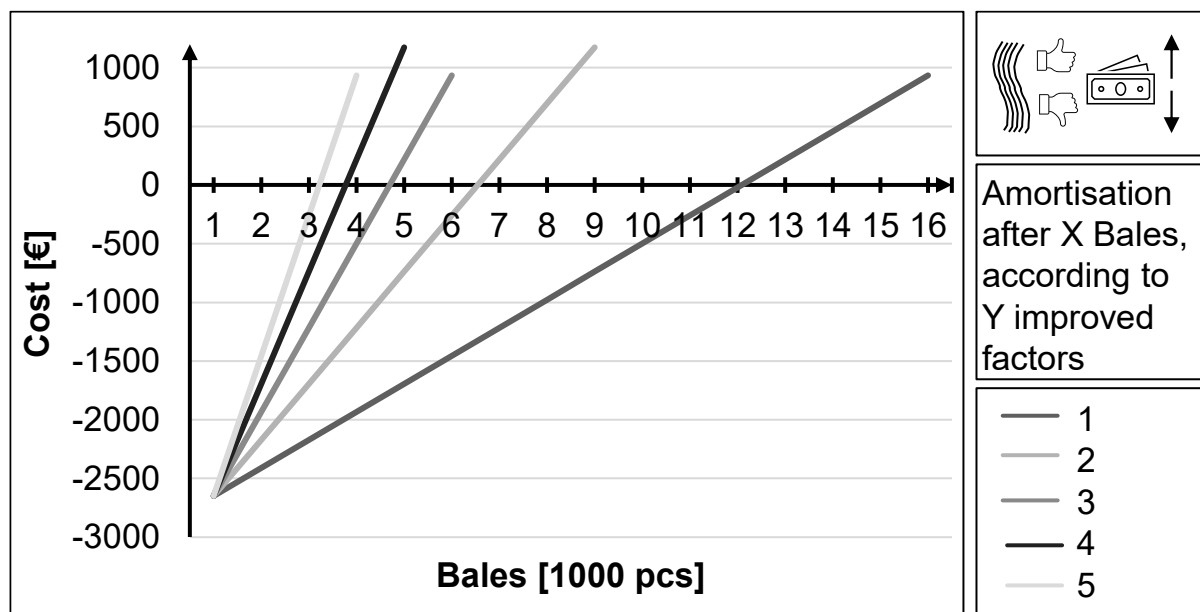


Fig. 8.11: Return of invest calculation in five scenarios

The diagram above shows, that increasing one parameter achieves a return of invest (ROI) at 11088 bales. This is the one-year production of a 15 machines roller gin ginning mill, operating at 100 kg/h seed cotton for 5-month, 24/7 production. This ends up in 5,000 t lint. For additional parameters increase of lint quality, the number of bales to reach the ROI is divided by two, three, four or five. This shows a huge potential for increasing cotton lint quality, more sustainable moisturization, as well as higher margins in ginning. These economical findings are summarized in the following Chapter.

8.5 Interim conclusion

Cotton price calculations as well as quality decreases show a very high sensitivity. If there is a higher cotton demand than production, prices increase significantly until the next harvest. This took place in 2021. At this time, cotton prices doubled to the season before. The influencing factors in cotton prices are:

- Leaf grade
- Length
- Colour
- Micronaire
- Strength
- Length uniformity index (LUI)

The strongest impacts are by quality decreases. As there are different defined base qualities from United States Department of Agriculture (USDA) and International Cotton Association (ICA), it is difficult to define one strict basis. The USDA refers to ever given values, while ICA changed the base quality over years. ICA base quality is called 31/3/36, which means colour 31, leaf grade 3 and staple length 36/32 inch (28.58 mm). This is one of the most sold cotton qualities (around 526,000 bales), outbid by 31/3/37, which is the most sold quality with almost 1,000,000 bales [USDA23b]. For specific values, see Tab. 8.8.

Tab. 8.8: Cotton quality influencing parameter overview, based on [Eva23]

Fibre prop- erties	Quality base	Relevant in ginning mill processing	Influence on Lint value [%]	
Length	27.0 mm	✓	0.74	1.17
Uniformity	80.0 %	✓	0.43	
Leaf grade	4	✓	0.50	
+b	3	✓	0.69	
Micronaire	3.5 - 3.6 & 4.3 - 4.9	✗	0.59	
Strength	27.0 cN/tex	✗	0.27	
Trash	Absence of trash	✓	0.11	
Colour grade	3	✓	0.10	
Total	-	-	3.6	

To ease the calculation of the extra value according to the return of invest, it is assumed that every parameter increases cause 0.25 €/bale higher margin.

These are 0.28 % price increase per bale. If bales are getting rated worse due to quality losses in ginning, this can be multiplied by two to six, according to the parameter. Therefore, moisture management can have a return of investment after 11,000 bales while having one parameter increase. It can even have its return after 2,000 bales already, if the decrease of one parameter can be prevented.

9 Summary

This book addresses a clear problem: cotton fibres are often shortened during ginning more than necessary, which undermines mechanical recycling and reduces real recycling rates. Long and strong fibres are essential to survive two or more recycling cycles. Otherwise, short fibre content rises and does not bring strength to the yarn anymore. At the same time, ginning is seen between agriculture and textiles, operating under low margins and a frequent trade-off between throughput and fibre quality. Current deficits include poor machine settings and maintenance, wrong storage at high humidity and missing practical knowledge on the shop floor. The working hypothesis is that losses in fibre length in ginning can be reduced with proper moisture management and structured knowledge transfer. The approach combines literature and patent review, expert interviews and on-site investigations in India and Egypt. Afterwards, lab developments at RWTH Aachen University and validation against the oven-drying standard take place. Moisture management effects are assessed via the fibre length distribution after ginning. This strategy aims to deliver simple, low-budget measures and training concepts to raise cotton quality and support the Sustainable Development Goals. Main criteria to preserve cotton fibre quality according to the surrounding conditions are shown in Fig. 9.1.

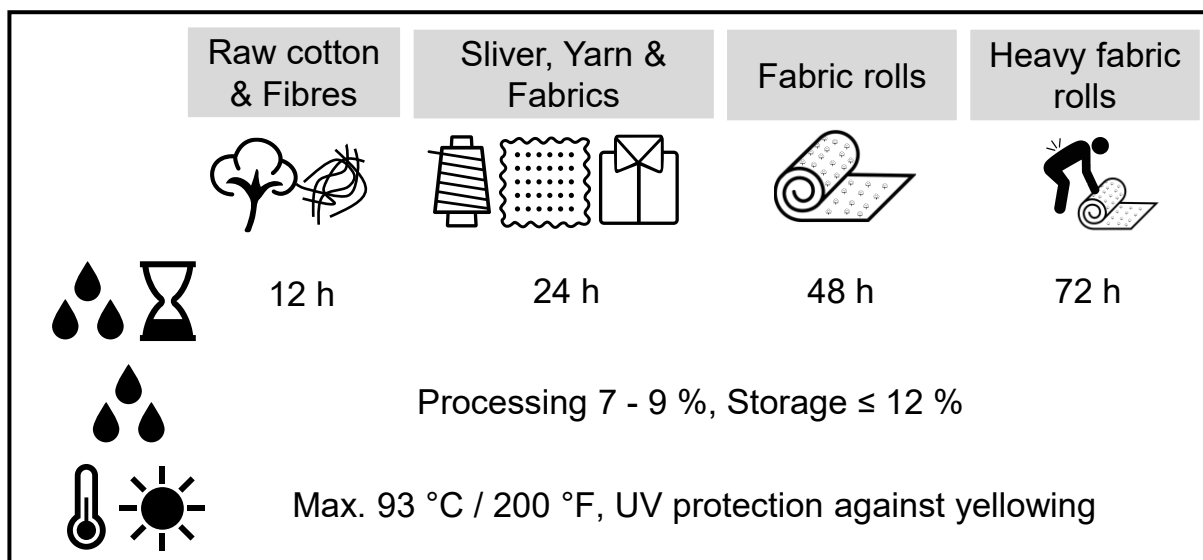


Fig. 9.1: Cotton handling conditions recommendation

A systematic risk analysis justifies these developments, based on the expert interviews, on-site investigations and literature findings. When ginning is divided into raw material supply, production and processing (including storage) and packaging, moisture management repeatedly appears as the critical factor (cf. Fig. 9.2). The most critical Risk Priority Numbers (RPN) are linked to insufficient moisture control at cleaning, ginning, bale pressing and during transport. If time in storage is added, quality degradation accelerates, lowering bale prices significantly. Resistance sensors meet this need, enabling rapid decisions and stabilising operations across variable environments. Integrating measurement with conditioning, humidification and drying tailored to process steps, addresses the dominant variability in fibre strength, length and flexibility. Pairing these tools with digital approaches can reduce dependence on scarce skilled labour, while improving consistency in settings and maintenance. Closed-loop moisture control at critical points in the line helps balance productivity with fibre preservation, which is essential for downstream spinning performance and recyclability. Overall, the risk-driven rationale supports investment in simple, robust measurement and conditioning devices that fit the realities of low-wage, high-throughput mills.

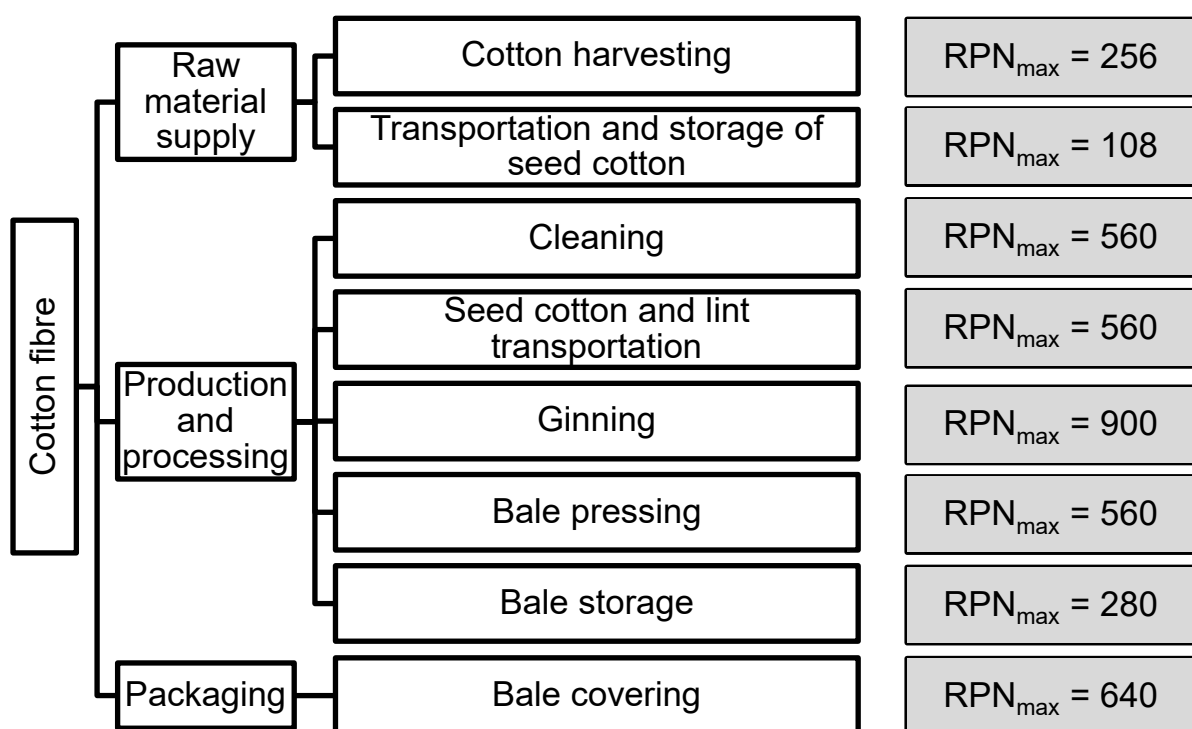


Fig. 9.2: Critical Risk Priority Numbers according to process steps

Based on this risk assessment, the technical developments focus on reliable moisture measurement and practical conditioning to preserve the named conditions and inherently fibre quality. An overview of measures is provided in

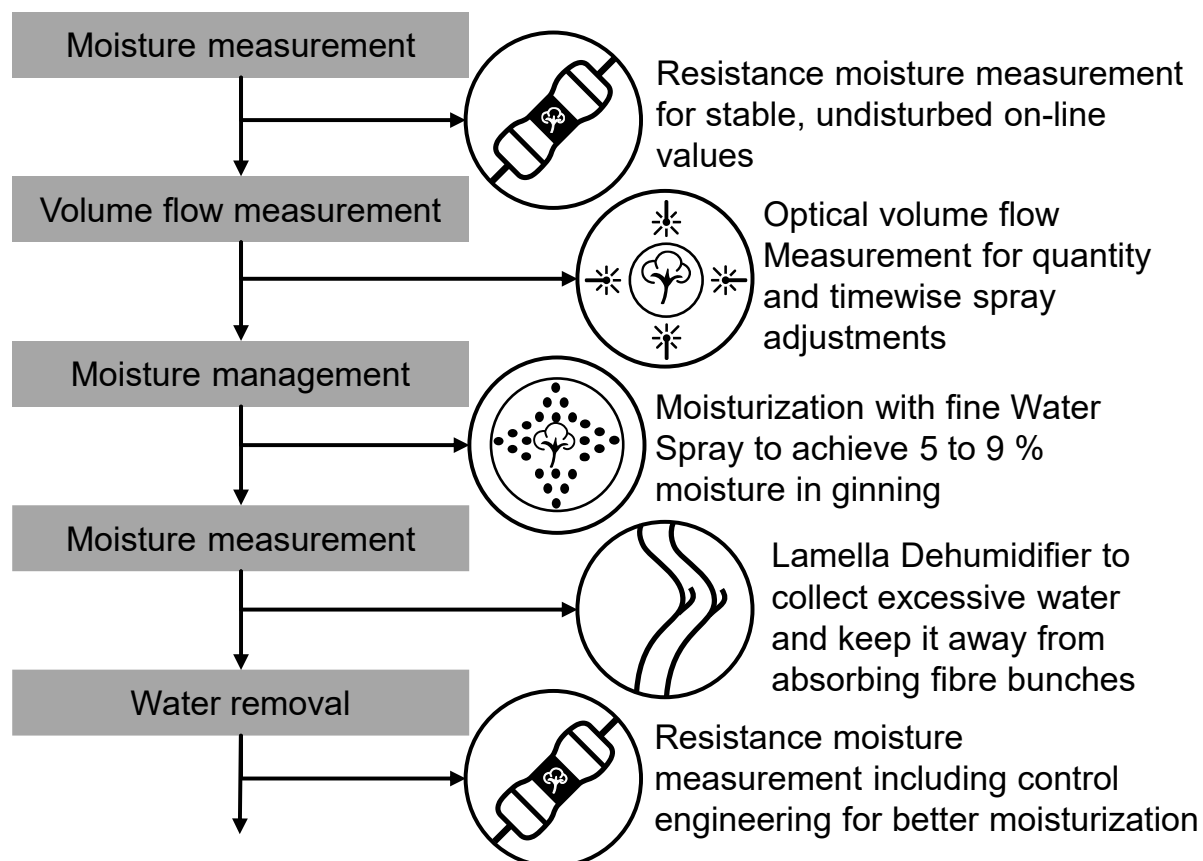


Fig. 9.3: Technical measures for moisture management and quality preservation

Beside this, machine- improvements in settings and maintenance are required to preserve fibre length. Measurement methods are grouped into direct and indirect techniques. Direct methods, like the oven standard, quantify water loss precisely but are slow and unsuitable for on-line control. Indirect approaches translate correlating signals into moisture content through calibration. Resistance measurement emerges as the most viable on-line usability in ginning, low cost and robustness. To ensure stable readings, temperature effects must be managed, including ionisation losses in DC circuits and polarisation losses in AC circuits. A simple microcontroller-based device, calibrated against the oven method, can provide rapid feedback. For moisturisation, hollow-core round spray nozzles at around 3 bar shall be used, which form finer droplets and reduce spotting risk, instead of flat spray nozzles. Operationally, fibres reach peak

strength at 15% moisture. For drying, tower dryers with flame-retardant, non-propane heat sources, should be used. High-temperature drying should be short, ideally below 3 s and paired with adequate air velocity to avoid thermal damage. Hand-ginning trials demonstrate at least 10–15% potential gains in staple length, guiding machine redesign. Roller and rotobar gins, already gentler than saw gins, deserve capacity upgrades.

The sociological core elements start in the field, where harvest is a crucial quality gate. Cotton should be picked as contamination-free as possible, avoiding plastic fragments, sweat-related staining and excessive trash; dust and sand need to be minimised. Inside ginning mills, knowledge about moisture control, machine settings, regular maintenance and lint-value trade factors is often unevenly distributed. Managers may understand these aspects, but operators frequently do not, so knowledge transfer becomes a central task. Adult-oriented, problem-solving training works best, with practical, on-site sessions in the workers' mother tongue instead of lectures. A Training of Trainers model can create cascaded teaching capacity: selected specialists receive intensive instruction (often in English). Then those trainers train local teams with hands-on methods aligned to daily tasks. Main quality and training goals are shown in Fig. 9.4.

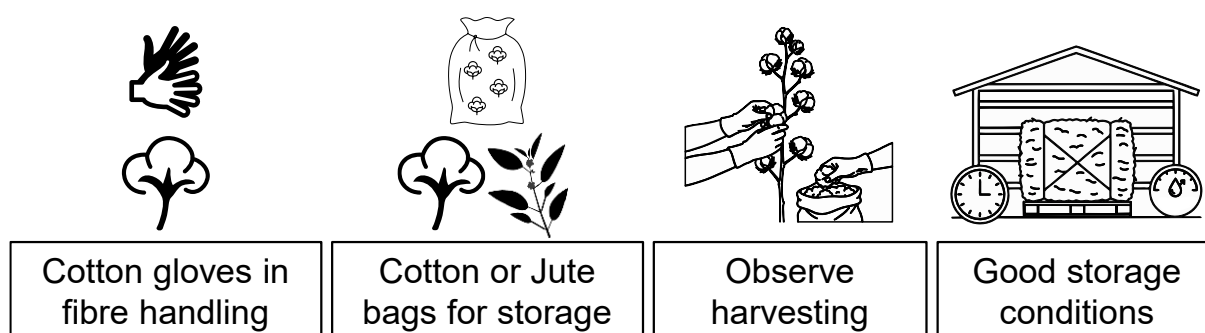


Fig. 9.4: Main Training of Trainers goals for better quality preservation

To align incentives and foster sustained quality, a Raiffeisen-style consortium model is recommended, in which farmers hold equity in cooperative ginning mills. When farmers are co-owners, the operational focus shifts from throughput to premium fibre attributes. These are long, mature, white cotton. Part of the margins can be reinvested in training, applied research and lowers personal risks. This cooperative structure supports fairer value sharing and builds a

culture of continuous improvement, helping ensure that simple measures in harvesting, measurement, settings and maintenance are actually practiced.

The economic perspective confirms that bale pricing is highly sensitive to quality differentials and that the business case for moisture management and fibre preservation is strong. While trade bases differ between USDA and ICA, price drivers are: staple length, uniformity, leaf grade, colour (+b), micronaire, strength and trash. Conservative modelling assumes a 0.25 € margin increase per bale for each parameter improvement, roughly a 0.28% price uplift. Penalties for degradation are often two- to six-times higher. Under these assumptions, a moisture-management system can reach return on investment after around 11,000 bales through one parameter improvement alone; if several parameters are protected from loss, payback can be reached after about 2,000 bales (less than one ginning season). Because fibre length and uniformity have outsized impacts on lint value, preserving staple length through correct moisture control and gentle ginning offers direct revenue benefits. Calibrated, rapid resistance-based measurement linked to context-specific humidification and drying, combined with machine settings that prevent length loss and keep neps low, systematically raise lint quality. This approach fits cooperative mills that reinvest in training and maintenance, stabilises costs by avoiding rework and rejects and supports circularity by enabling more mechanical recycling cycles. Together, these measures protect cotton's inherent quality and strengthen both economic viability and worker empowerment across low-wage production environments. For the last steps of implementation, the following Chapter provides an outlook of measures.

10 Outlook

The key problem remains excess fibre shortening in ginning due to poor machine settings, storage at unsuitable humidity and uneven knowledge distribution. The interviews and on-site observation showed, that there is a high understanding of the importance of moisture management, but less action in properly setting the moisture content. For this, first stages are shown in Fig. 10.1.

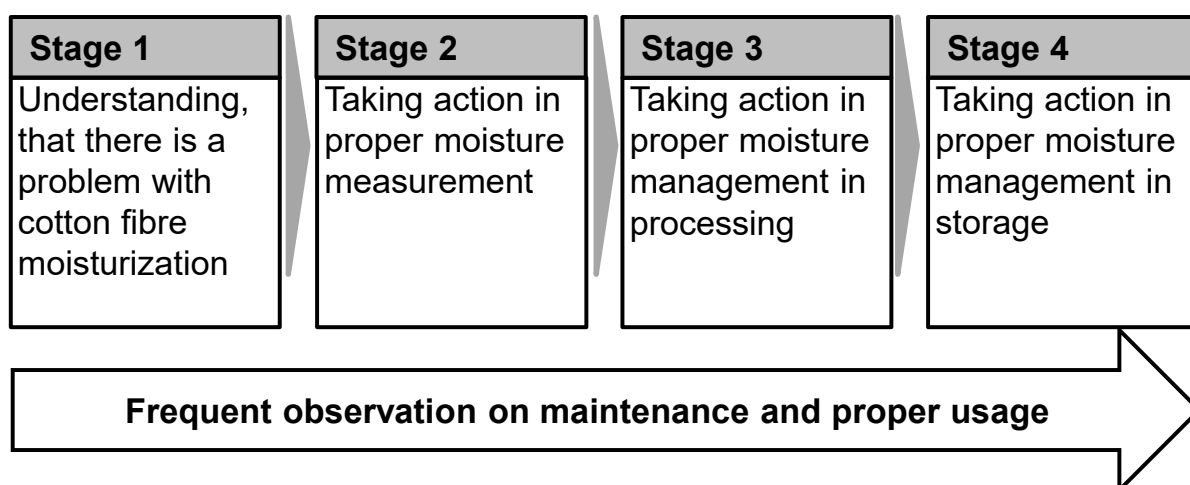


Fig. 10.1: Stages of addressing moisture issues

On technical developments, the priority is robust, on-line moisture measurement and safe, effective conditioning, followed by fibre-preserving machine optimisation. In first trials it was shown, that different cotton varieties show different moisturization and drying behaviour. A wide database for resistance measurement values, corresponding to the oven drying method, should be established across different cotton varieties. As measurement is the basis for controlling the moisture content within the process, this has highest priority. For the technical implementation of a moisturization system, a ginning mill should be selected for implementation of those systems. It requires early adopters to use new practices. Moreover, the first implementations of control systems, which can do a wide range of data collection, probably requires governmental funding as the ginning industry is far beyond from Industry 4.0 practices. As even autonomous driving starts for tractors in the agriculture sector, this can be implemented with the following steps, according to Fig. 10.2 below.

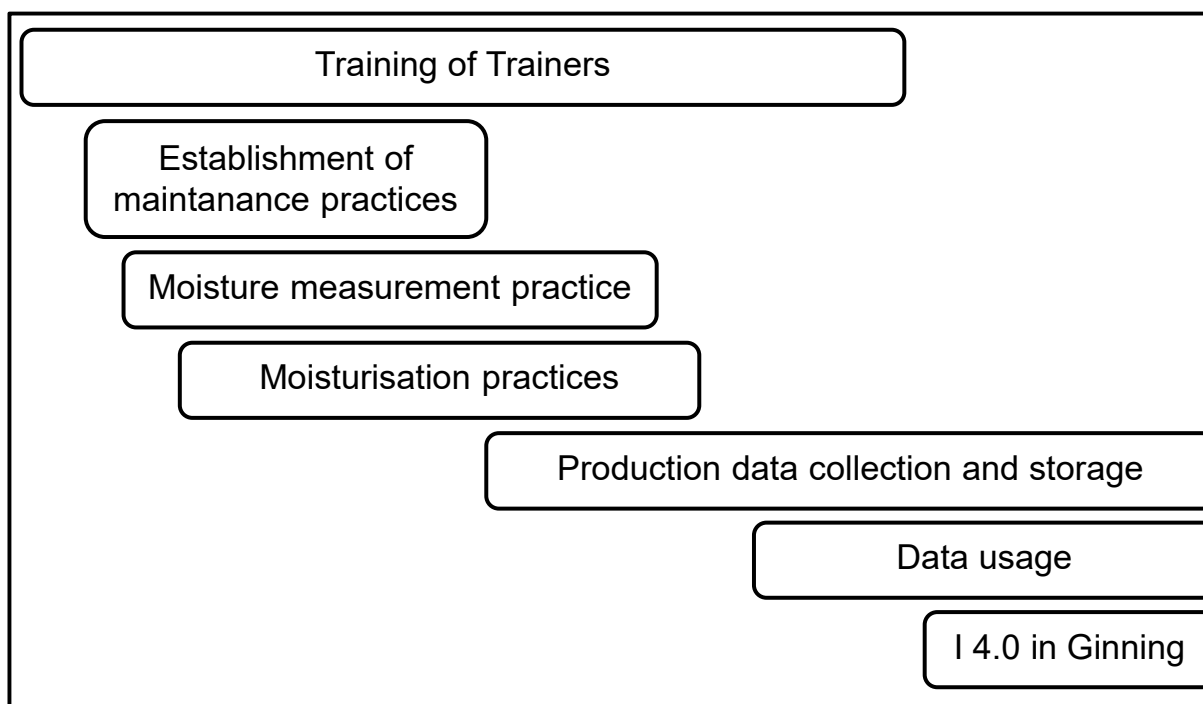


Fig. 10.2: Overview of the main technical steps, with compressed time axis

To close the loop, linking sensor feedback to humidification and drying setpoints per process step is required. In machine optimisation, benchmarks are roller and roto-bar gins. For capacity upgrades while minimising nep formation and length loss, define setting windows for saw gins that reduce aggressiveness without losing throughput. These call for extended field validation, redundancy in sensing and simple operator cues to sustain calibration quality over time.

The organisational outlook focuses on harvest discipline, adult-oriented knowledge transfer and a Raiffeisen-style cooperative model to align incentives. Develop practical Training of Trainers (ToT) modules that turn quality gates into simple daily routines: contamination-free picking, minimal sweat and dust exposure, selective mature-boll picking and routine moisture checks. Inside mills, create task-focused micro-trainings for operators on machine settings, maintenance and lint-value trade factors, delivered in the local language and emphasising problem-solving rather than lectures. Establish checklists and visible “quality boards” for moisture, machine settings and manual inspections and implement brief daily stand-ups to review deviations. For the consortium model, define governance and pay-out rules, as well as bringing together the relevant farmers from governmental or NGO side is required. In parallel, the particular

training concepts and contents as well as designated trainers should be found for a quick implementation. Align cooperative goals with mill targets, so fibre-preserving settings become the default rather than an exception. All of those practices are combined in a future outlook picture, shown in Fig. 10.3.

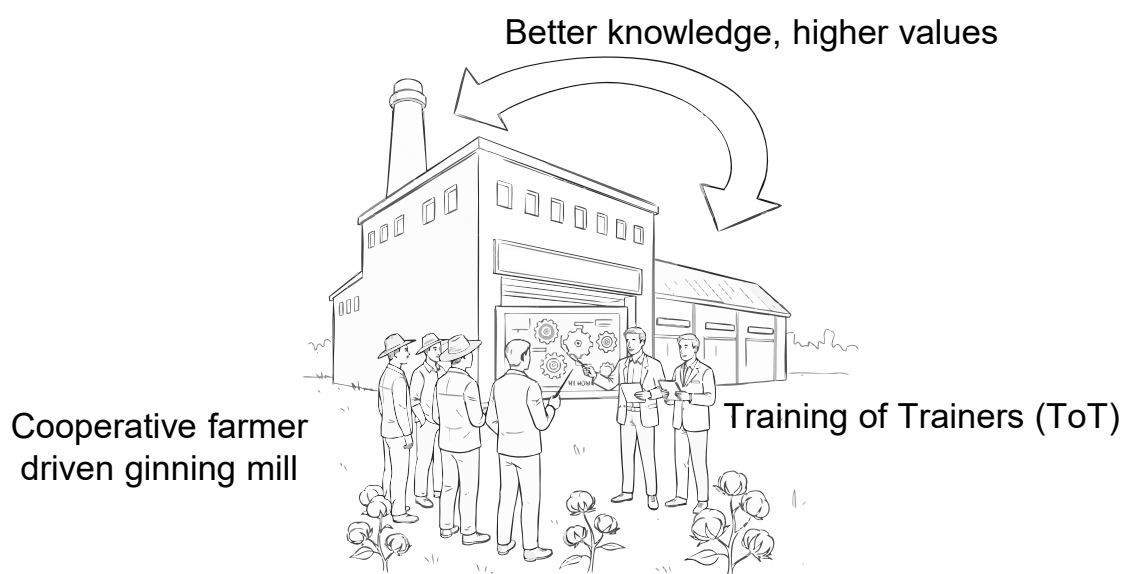


Fig. 10.3: Ideal sketch of combining training and operatives

From an economic point of view, the outlook is to convert sensitivity into actionable, site-ready tools while acknowledging market volatility and standards differences. As the price indication values currently focus on one base quality and provide premium or price drops, it should focus on the usability of cotton. Especially corresponding factors, like fibre length and strength should be focussed and considered together. On the one hand, these factors have the highest influence on re-usability of fibres. On the other hand, excessive cleaning due to the heavy machines in ginning should be much less considered in pricing. Main international actors, able to change price policies are ICA, USDA and Bremen Cotton Exchange, to address those factors.

11 Zusammenfassung

Baumwollfasern werden bei der Entkörnung oft mehr als nötig gekürzt, was eine Kreislaufführung durch mechanisches Recycling beeinträchtigt und den erreichbaren Lebenszyklus verringert. Lange und starke Fasern sind unerlässlich, um zwei oder mehr Recyclingzyklen zu überstehen. Andernfalls steigt der Anteil kurzer Fasern und das Garn verliert an Festigkeit. Gleichzeitig wird die Entkörnung als Schnittstelle zwischen Landwirtschaft und Textilindustrie betrachtet. Daher herrschen geringe Margen vor und häufig müssen Kompromisse zwischen Durchsatz und Faserqualität eingegangen werden. Zu den aktuellen Defiziten zählen schlechte Maschineneinstellungen und -wartung, falsche Lagerung bei hoher Faserfeuchtigkeit und fehlendes praktisches Wissen in der Produktion. Die Arbeitshypothese lautet, dass Verluste an Faserlänge bei der Entkörnung durch ein angemessenes Feuchtigkeitsmanagement und einen strukturierten Wissenstransfer reduziert werden können. Der Ansatz kombiniert Literatur- und Patentrecherchen, Experteninterviews und Untersuchungen vor Ort in Indien und Ägypten. Anschließend finden Laborentwicklungen an der RWTH Aachen statt. Die Auswirkungen des Feuchtigkeitsmanagements werden anhand der Faserlängenverteilung nach der Entkörnung bewertet. Die wichtigsten Kriterien zur Erhaltung der Baumwollfaserqualität unter den gegebenen Umgebungsbedingungen sind in Abb. 11.1 dargestellt.

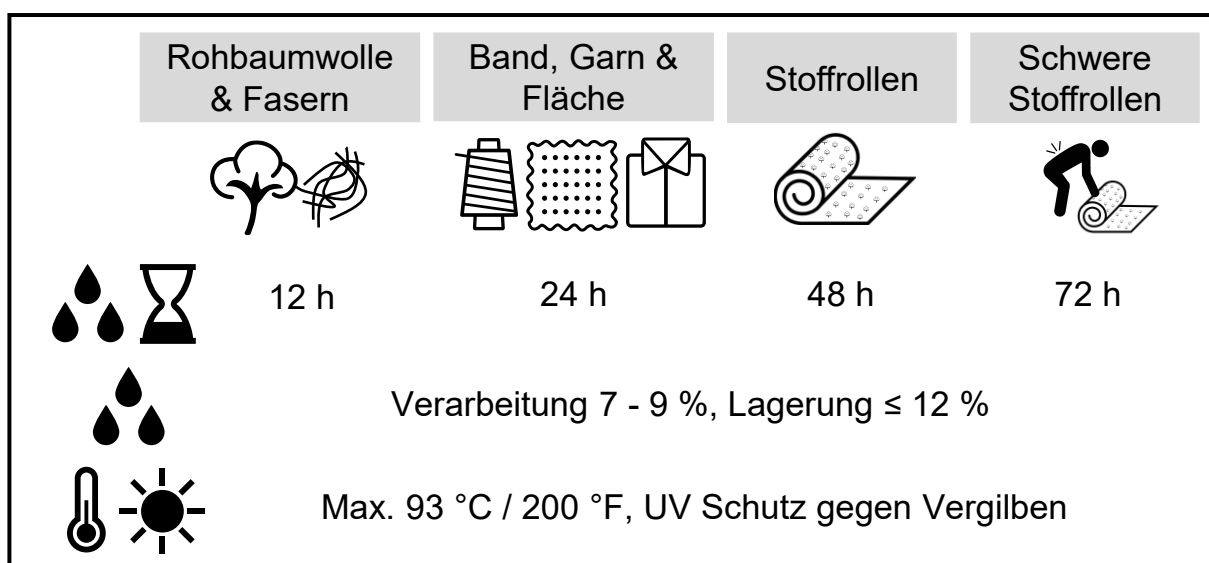


Abb. 11.1: Empfehlungen für die Handhabung von Baumwolle

Diese Strategie zielt darauf ab, einfache, kostengünstige Maßnahmen und Schulungskonzepte zu liefern, um die Baumwollqualität zu verbessern und die Ziele für nachhaltige Entwicklung zu unterstützen. Eine Validierung des Feuchtegehalts zu Feuchtemessung findet anhand der Ofentrocknungsmethode statt.

Eine systematische Risikoanalyse bildet die Grundlage für diese Entwicklungen, auf der Basis von Experteninterviews, Untersuchungen vor Ort und Literaturrecherchen. Wenn man die Entkörnung in Rohstoffversorgung, Produktion und Verarbeitung (einschließlich Lagerung) sowie Verpackung unterteilt, erscheint das Feuchtigkeitsmanagement als kritischer Faktor (vgl. Abb. 11.2).

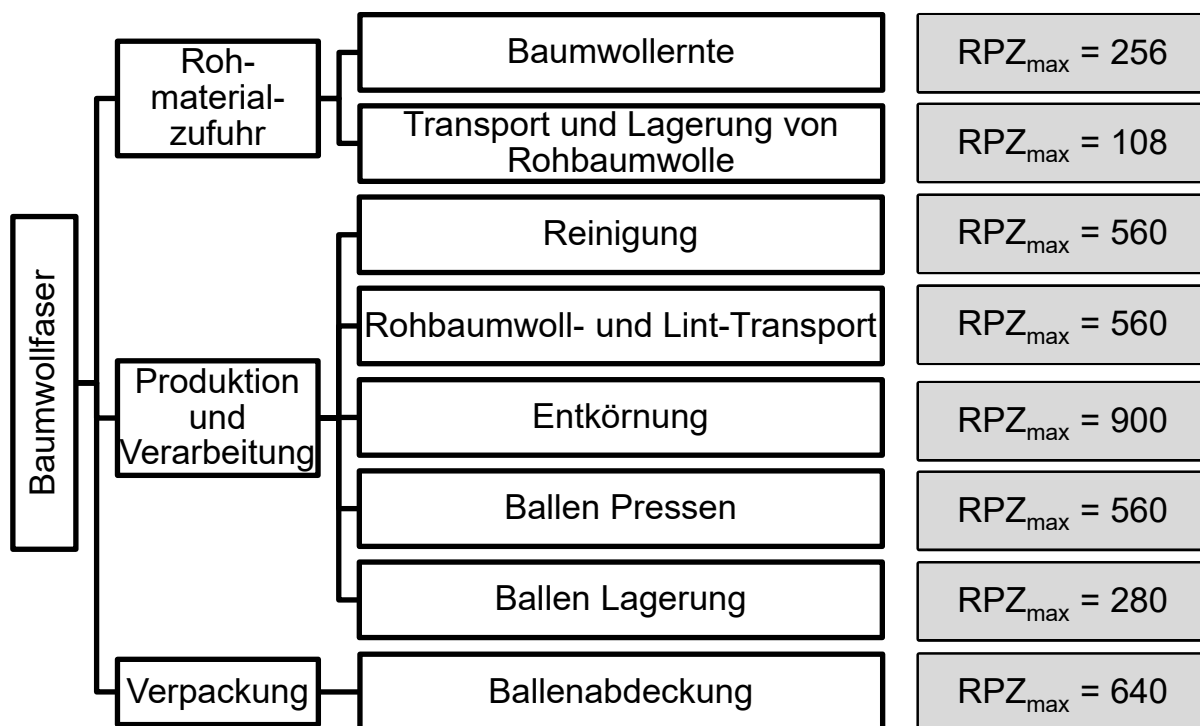


Abb. 11.2: Kritische Risiko Prioritätszahlen entlang der Prozesskette

Die kritischsten Risikoprioritätszahlen (RPN) stehen im Zusammenhang mit einer unzureichenden Feuchtigkeitskontrolle bei der Reinigung, Entkörnung, Ballenpressung und während des Transports. Wenn die Lagerzeit hinzukommt, beschleunigt sich der Qualitätsverlust, wodurch die Ballenpreise erheblich sinken.

Widerstandssensoren erfüllen diese Anforderung, ermöglichen schnelle Entscheidungen und stabilisieren den Betrieb in unterschiedlichen Umgebungen. Durch die Integration von Messungen, mit auf die Prozessschritte

zugeschnittener Konditionierung, Befeuchtung und Trocknung wird die vorherrschende Variabilität in Bezug auf Faserfestigkeit, -länge und -flexibilität berücksichtigt (vgl. Abb. 11.3). Die Kombination dieser Werkzeuge mit digitalen Ansätzen kann die Abhängigkeit von knappen Fachkräften verringern und gleichzeitig die Konsistenz der Einstellungen und Wartung verbessern. Eine geschlossene Feuchtigkeitskontrolle an kritischen Punkten der Produktionslinie trägt dazu bei, die Produktivität mit der Erhaltung der Fasern in Einklang zu bringen, was für die nachgelagerte Spinnleistung und Recyclingfähigkeit von entscheidender Bedeutung ist. Insgesamt spricht die risikobasierte Argumentation für Investitionen in einfache sowie robuste Mess- und Konditionierungsgeräte. Diese entsprechen den Realitäten von Fabriken mit niedrigen Löhnen und hohem Durchsatz.

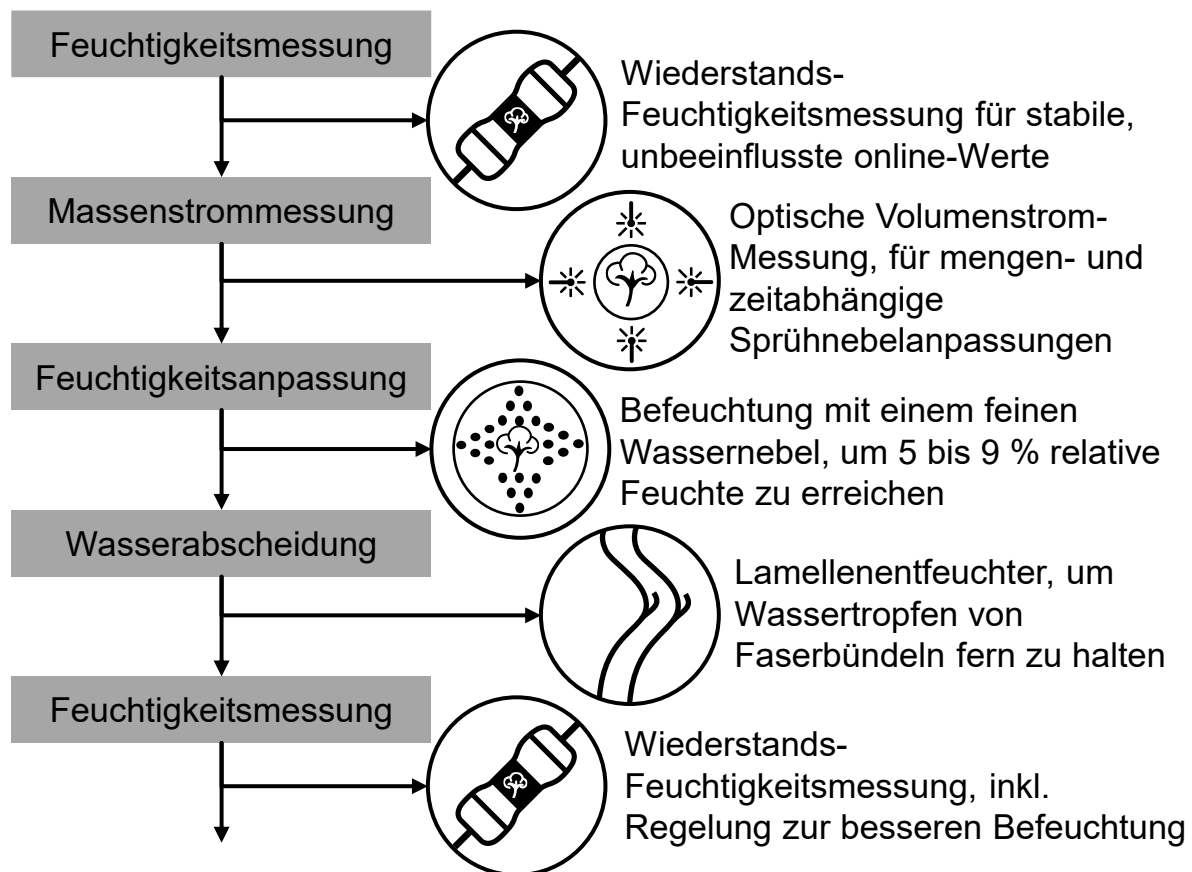


Abb. 11.3: Übersicht für Lösungen zur Feuchtigkeitsregulierung

Basierend auf dieser Risikobewertung konzentrieren sich die technischen Entwicklungen auf eine zuverlässige Feuchtemessung und praktische Konditionierung, um die genannten Bedingungen und die inhärente Faserqualität zu erhalten. Darüber hinaus sind Maschinenverbesserungen hinsichtlich Einstellungen

und Wartung erforderlich, um die Faserlänge zu erhalten. Messmethoden werden in direkte und indirekte Techniken unterteilt. Direkte Methoden, wie der Ofenstandard, quantifizieren den Wasserverlust präzise, sind jedoch langsam und für die Online-Kontrolle ungeeignet. Indirekte Ansätze wandeln korrelierende Signale durch Kalibrierung in den Feuchtigkeitsgehalt um. Die Widerstandsmessung erweist sich als die praktikabelste Online-Anwendung in der Entkörnung, da sie kostengünstig und robust ist. Um stabile Messwerte zu gewährleisten, müssen Temperatureinflüsse berücksichtigt werden, darunter Ionsationsverluste in Gleichstromkreisen und Polarisationsverluste in Wechselstromkreisen. Ein einfaches, auf einem Mikrocontroller basierendes Gerät, das nach der Ofenmethode kalibriert ist, kann schnelle Rückmeldungen liefern. Zur Befeuchtung sollten anstelle von Flachstrahldüsen Hohlkern-Rundstrahldüsen mit einem Druck von etwa 3 bar verwendet werden, die feinere Tröpfchen bilden und das Risiko von Fleckenbildung verringern. In der Praxis erreichen die Fasern ihre maximale Festigkeit bei einem Feuchtigkeitsgehalt von 15 %. Zum Trocknen sollten Turmtrockner mit flammhemmenden, propanfreien Wärmequellen verwendet werden. Die Trocknung bei hohen Temperaturen sollte kurz sein, idealerweise unter 3 Sekunden, und mit einer angemessenen Luftgeschwindigkeit einhergehen, um thermische Schäden zu vermeiden. Versuche mit Handentkörnungsmaschinen zeigen ein Potenzial von mindestens 10–15 % bei der Stapellänge, was als Leitlinie für die Neukonstruktion von Maschinen dienen kann. Walzen- und Rotationsentkörnungsmaschinen, die bereits schonender als Sägeentkörnungsmaschinen sind, sollten verbessert werden.

Die soziologischen Kernelemente beginnen auf dem Feld, wo die Ernte ein entscheidender Qualitätsfaktor ist. Baumwolle sollte so kontaminationsfrei wie möglich gepflückt werden, wobei Plastikfragmente, Schweißflecken und übermäßiger Schmutz zu vermeiden sind. Staub und Sand müssen auf ein Minimum reduziert werden. In Entkörnungsanlagen ist das Wissen über Feuchtigkeitskontrolle, Maschineneinstellungen, regelmäßige Wartung und Handelsfaktoren für die Lint-Werte oft ungleich verteilt. Betreiber verstehen diese Aspekte teils, Bediener häufig nicht, sodass der Wissenstransfer einer zentralen Aufgabe ist. Es eignet sich eine auf Erwachsene ausgerichtete, problemlösungsorientierte

Schulung von Multiplikatoren, die das praktische Wissen vor-Ort in der Muttersprache der Maschinenbediener vermittelt. Ein Modell zur Ausbildung von Multiplikatoren kann eine kaskadierende Lehrkapazität schaffen: Ausgewählte Spezialisten erhalten eine intensive Schulung (oft in englischer Sprache). Anschließend schulen diese Ausbilder lokale Teams mit Inhalten, die auf die täglichen Aufgaben abgestimmt sind. Eine Übersicht über die Maßnahmen gibt Abb. 11.4.

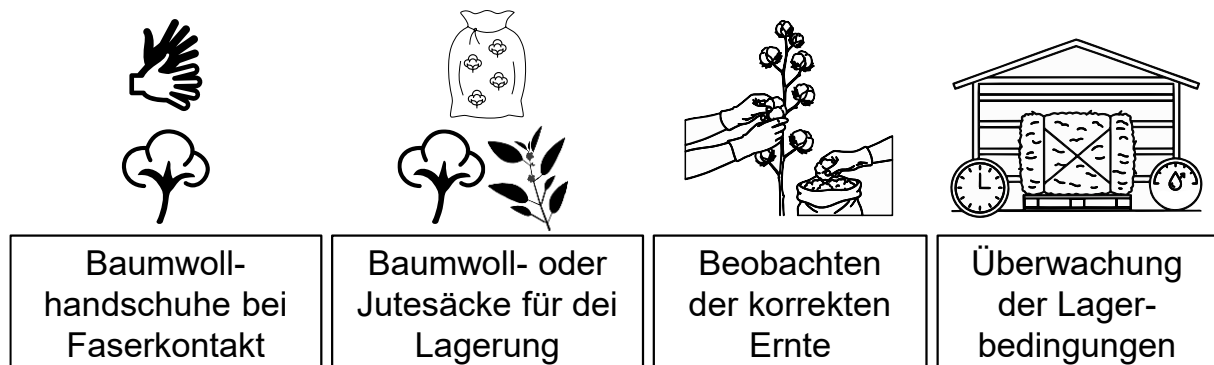


Abb. 11.4: Kritische Faktoren der Baumwollhandhabung für Qualitätserhalt

Um Anreize aufeinander abzustimmen und eine nachhaltige Qualität zu fördern, wird ein Konsortialmodell nach Raiffeisen-Art empfohlen, bei dem die Landwirte Anteile an genossenschaftlichen Entkörnungsanlagen halten. Wenn Landwirte Miteigentümer sind, verlagert sich der operative Schwerpunkt vom Durchsatz auf hochwertige Fasereigenschaften. Dabei handelt es sich um lange, reife, weiße Baumwolle. Ein Teil der Margen kann in Schulungen, angewandte Forschung und die Senkung persönlicher Risiken reinvestiert werden. Diese genossenschaftliche Struktur unterstützt eine gerechtere Wertverteilung und schafft eine Kultur der kontinuierlichen Verbesserung, die dazu beiträgt, dass einfache Maßnahmen bei der Ernte, Messung, Einstellung und Wartung tatsächlich umgesetzt werden.

Die wirtschaftliche Perspektive zeigt, dass die Preisgestaltung für Ballen sehr empfindlich auf Qualitätsunterschiede reagiert. Die finanziellen Argumente für Feuchtigkeitsmanagement und Faserkonservierung sind sehr überzeugend. Während sich die Bemessungsgrundlagen zwischen USDA und ICA unterscheiden, sind die Preistreiber: Stapellänge, Gleichmäßigkeit, Blattqualität, Farbe (+b), Micronaire, Festigkeit und Verunreinigungen gleich. Modellrechnungen

gehen von einer Steigerung der Marge von 0,25 € pro Ballen für jede Parameterverbesserung aus, was einer Preiserhöhung von etwa 0,28 % entspricht. Die Abschläge für Qualitätsminderungen sind oft zwei- bis sechsmal höher. Unter diesen Annahmen kann ein Feuchtigkeitsmanagementsystem allein durch die Verbesserung eines Parameters nach etwa 11.000 Ballen eine Kapitalrendite erzielen. Wenn mehrere Parameter vor Verlusten geschützt werden, kann die Amortisation nach etwa 2.000 Ballen (weniger als einer Entkörnungssaison) erreicht werden. Da die Faserlänge und -gleichmäßigkeit einen überproportionalen Einfluss auf den Wert der Baumwolle haben, bietet die Erhaltung der Stapellänge durch richtige Feuchtigkeitskontrolle und schonende Entkörnung direkte Umsatzvorteile. Kalibrierte, schnelle, widerstandsbasierte Messungen in Verbindung mit kontextspezifischer Befeuchtung und Trocknung sowie Maschineneinstellungen, die Längenverluste verhindern und die Anzahl der Nissen gering halten, erhöhen systematisch die Qualität der Baumwolle. Dieser Ansatz eignet sich für Genossenschaftsbetriebe, die in Schulungen und Wartung reinvestieren. Zudem unterstützt dies die Kreislaufwirtschaft, indem mehr Recyclingzyklen ermöglicht. Zusammen schützen diese Maßnahmen die inhärente Qualität der Baumwolle und stärken sowohl die Wirtschaftlichkeit als auch die Position der Arbeitnehmer.

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14 Annex A: List of abbreviations and formula symbols

$\hat{E}_y$	Parameters of the electric waves in y-direction
A_R	Cross-sectional area of the resistor
E_y	Electric wave in y-direction
E_y^i	Incident electric wave in y-direction
E_y^r	Reflected electric wave in y-direction
Z_0	Impedance in a vacuum
b_L	Line width of the empty resonator
b_V	Linewidth with sample in the resonator
c_0	Speed of light in a vacuum
f_L	Resonant frequency of the empty resonator
f_V	Resonant frequency with sample in the resonator
β_0	Phase constant as a function of the wavelength in a vacuum
ε_0	Absolute permittivity [$\frac{V s}{A m}$]
ε_r	Relative permittivity [–]
ε_r'	Real part of the relative permittivity [–]
ε_r''	Imaginary part of the relative permittivity [–]
μ_0	Magnetic field constant
ρ_R	Specific resistance
€	Euro
+b	Yellowness of cotton
°C	Temperature in degree Centigrade
°F	Temperature in degree Fahrenheit
AC	Alternating current
AFIS	Advanced Fibre Information System
ASTM	American Society for Testing and Materials
BCI	Better Cotton Initiative
BCI	Better Cotton Initiative
BF	Burkina Faso
BMFTR	German: Bundesministerium für Fortschung, Technologie und Raumfahrt; Federal Ministry for Research, Technology and Space

BMWE	German: Bundesministerium für Wirtschaft und Energie; Federal Ministry for Economy and Energy
BMWK	German: Bundesministerium für Wirtschaft und Klimaschutz; Federal Ministry for Economy and Climate Action
Bt-cotton	Bacillus thuringiensis bacteria modified cotton
CCC	Commodity Credit Corporation
CCD	Charge Coupled Devices
CCI	Cotton Corporation of India
CEN	Comité Européen de Normalisation (European Committee for Standardization)
CEO	Chief Executive Officer
Co.	Company
ct	Cent
d	Day
DC	Direct current (counterpart of AC – Alternating current)
DIN	Deutsches Institut für Normung (German Standardisation Organization)
DR	Double Roller (Gin)
E	Electrical Field strength [V/m]
e. g.	exempli gratia (Latin, meaning: for example)
e. V.	Registered Association (German: eingetragener Verein)
EET	Eastern European Time
ELS	Extra Long Staple
EN	Europäische Norm (European Norm / Standard)
ETA	Event Tree Analysis
etc.	et cetera (Latin, meaning: and other similar things)
Fig.	Figure
FMEA	Failure Mode Effect Analysis
FTA	Fault Tree Analysis
FTIR	Fourier-transform infrared spectrometer
FW	Final (dry) Weight
g	Gram
G.	Gossypium

GMO	Genetic Modified Organisms
GOT	Ginning Out Turn
GOTS	Global Organic Textile Standard
h	hour
HAZOP	Hazard and Operability Study
HVI	High Volume Instrument (Cotton Classing device)
Hz	Herz (s^{-1})
I X.0	Industry X.0 (defined for 1.0, 2.0, 3.0 and 4.0)
i. e.	id est (Latin, meaning 'that is')
ICA	International Cotton Association
ICAC	International Cotton Advisory Committee
inch	2,54 cm
ISO	International Organization for Standardization
ITMF	International Textile Manufacturers Federation
l	Liter
L.	Linnaeus (plant classification by Carl von Linné)
lb	Pound (0,453592 kg)
m	Meter
MC	Moisture Content
MDTA	Micro Dust and Trash Analyser
MDZ	German: Mittelstand Digital Zentrum; SME Digital Centre
Mic.	Micronaire
min	Minute
MLR	Multi-linear regression
MR	Moisture Regain (dry basis)
MSP	Minimum support price (low price, Indian government pays for unsold cotton to cover cultivation costs)
NIR	Near-infrared
OW	Original (wet) Weight
PCB	Printed circular board
PLA	Polylactide
PLSR	Partial least square regression
PP	Polypropylene

Pvt. Ltd.	Private Limited (Type of Company with limited financial liability)
Rd	Reflectance degree (whiteness scale of cotton)
rH	relative Humidity
ROI	Return of invest
s	Second
SBCE	Set-based concurrent engineering
SE	Societas Europaea (legal form for european stock corporation)
SMD	Surface-mounted device
SME	Small and Medium Sized Enterprise
t	Time
Tab.	Table
TRIZ	Russian: <i>teorija rezhenija izobretatelskih zadach</i> ; translated: the theory of Rezhenija Izobretatelskih Zadach
TS	Technische Spezifikation (Technical Specification (in Standardization))
UK	United Kingdom
US\$ or \$	Dollar of the United States of America
USA	United States of America
USDA	United States Department of Agriculture
USDA-ARS	United States Department of Agriculture – Agricultural Research Service
USDA AMS	United States Department of Agriculture – Agricultural Marketing Service
UV	Ultra-Violet
V	Volt
VDI	German: Verein Deutscher Ingenieure; translated: Association of German Engineers
VDMA	German: Verband Deutscher Maschinen- und Anlagenbauer: German Engineering Federation
C	Circumference of the sample
I	Amperage
L	Length of the resistor
R	Ohmic resistance

U	Voltage
Z	Impedance
f	Frequency
i	Imaginary unit
r	Complex reflection coefficient
x	Directional coefficient
α	Attenuation coefficient
β	Phase constant
γ	Complex propagation constant
δ	Dissipation factor
ε	Permittivity [$\frac{V s}{A m}$]
μ	Magnetic permeability
ω	Angular frequency

15 Annex B: Interview Questionnaire India

Here, you can find the questionnaire worked out within the project of GIZ, including the initial answers from GIZ which are known in February 2021. Afterwards, the detailed recorded notes of the ginning mill visit in December 2021 is displayed as well. Further visits as well as ongoing expert exchanges are too much in number to be all written down here.

Brief summary:

- a. Focus on medium and long staple fibres
- b. Mainly small and medium-sized farmers with 1.2-1.6 hectares of cotton fields
- c. Fixed prices through quality control in the field (MSP approx. 5000 rupees/tonne)
- d. Cotton processed in category A, B or C ginning plants

Observation guideline:

- i. Confirmation Business Model by SCHLICHTER → Ginner start and receive seeds as payment
 - a. Machine settings, knowledge and experience required?
 - b. Employment situation?
 - c. Specific machine and system manufacturers?
- ii. Carrying out a situation analysis of the existing status of ginning plants and the state of the art of Indian ginning plants with regard to the processing of non-GMO cotton
 - a. Machines/technology (i.e. drawings, pictures, manufacturers, technical data sheets) used throughout the plant with regard to technical performance and worker safety
 - b. Operating efficiency of the ginning machines (energy requirement to quality and potential)
 - c. Technical performance of the ginning machines
 - d. Average qualities coming out of a ginning plant - comparison between the quality of the raw seed cotton and the ginned cotton in relation to the possible and produced quality - i.e. HVI values
 - e. Capacity of the ginning plants and number of operators required
 - f. Qualification of machine operators

- g. Maintenance plan for the machine
 - h. Factors that influence the quality of cotton at the farmer and ginner level
 - storage quality of harvested cotton, offcuts, environmental influences, transport, etc.
 - i. Climatic conditions
- iii. Assessment of the business model of ginning companies
- a. Key cost elements and revenue streams for a ginning plant
 - b. Stability of business models due to price and market fluctuations, which are a function of the demand and supply scenario
 - c. Identification and evaluation of criteria and quality specifications that define the payment to farmers (cotton moisture controls)
 - d. Potential areas of improvement for a possible standardisation of their ginning processes and materials
 - e. Types of financial support from the Indian government for the purchase of machinery / general loans for ginners (easy access to credit, favourable interest rates, direct financing, etc.)
 - f. Detailed description of the commercial interaction between ginners and spinners - pricing criteria, pre-purchase and pre-sale quality checks (e.g. pre-purchase moisture checks)
 - g. Description of non-GMO cotton business model from farmer (or middleman) level to spinning mill level - pricing, profitability and benefits for all parties, understanding of Indian ginning operations
 - h. How does the minimum support price (MSP) and electronic national agricultural market reach the farmer and how is it used? What about the proportional distribution of internet access?
 - i. Frequency of ownership structures (independent ginning plants, co-operations with farmers and spinning mills) and quality control
 - j. Conversion from standard cotton to non-GMO cotton (for farmers and ginners) - financial and other efforts, challenges, government support
 - k. Business model Export of non-GMO cotton to Europe / USA etc. - Profitability, export quota, demand, available contacts to export countries, etc.
 - l. Use / role of intermediaries - advantages of using intermediaries for farmers and ginners, challenges for direct trade between farmers and ginners
 - opportunities and risks of this model

- m. non-GMO cotton premiums for farmers - reasons for delayed payment, reasons for separate payment in the first instance, challenges for direct payment
- n. How does the ginner take care of the quality of the cotton fibres after his process and what needs to be done so that the ginner feels responsible for good quality
- o. Influence of the Indian Standard for Organic Textiles on the ginning process and safety
- p. Checks by certification initiatives (BCI, Fairtrade, GOTS, etc.) to ensure compliance with non-GMO cotton standards - how and how often
- q. Illustration of material and financial flows and description of pricing across the value-added stages (procurement area of a mill, material throughput, intermediaries, time of payment, influence of quality on the material price, etc.).
- r. Financing of the ginning plant (state ownership, average duration of ownership, etc.)
- s. Condition of the system technology (average system service life, assumption of maintenance costs, maintenance personnel, maintenance intervals, etc.)
- t. Identification of the causes of price and market fluctuations and their magnitude (overproduction, crop failures, guaranteed fixed prices, etc.)
- u. Investigation of quality management in the ginning process (process steps for quality control, automated quality control, normalised standards, calibration of measuring systems, etc.)
- v. Logistics (means of transport, transport quantities, cost assumption for logistics, etc.)
- w. Employment and training of employees of the ginning plant and remuneration (number of employees, unskilled seasonal workers, permanently employed skilled workers, average length of service, piecework, hourly wage, fixed salary, shift work, etc.).

On-Site impressions:**01.12.2021**

Participants: Sameer Memon (Raina Consulting Pvt. Ltd.), Justin Kühn, Local, owner

Observation:

- Do not want to spend 25-30 lakh rupees for pre cleaner, because it is not worth the price add in cotton
- Smaller enterprise, 3 storages of 5.000.000 each. Which may be processed in 10 days
- Also pressing seeds in the building next to it
- Fire detection system is very important, because cotton may burn down the whole building in seconds to minutes
- Cotton lint is the main business, the others are by products
- Uses poly cotton loose knit, that it takes no fibres in the cotton while opening
- Changed from steel to plastic strips, because steel was corroding which dyed the cotton
- Later harvests lead to more contamination (normally 3 harvests) - like stones, sand, ... (picture Sameer)
- Cotton quality may be checked with the number of seeds you can count per crop. Around 10 it begins with bad cotton
- Linters on the seed should be removed, because they suck the oil & get a higher price for longer lint
- Starting with around 12 % of moisture for ginning, getting dried due to the hot roller (washer), then bring it up to 9 % with water fog again
- Holding 20-30 cows - feeding their seed left overs after pressing to those cows, taking the milk for good chai

Process chain: CPS, Beater, DR-Ginning, lint cleaning, pressing; Seed pressing

Personal Impression: high staple length (29.3 as guess by owner), samples are taken, medium to high seeds (8-10 per boll)

Additional:

- Cotton lint → textiles
- Cotton linters → bed linen (inside)
- Cotton oil → Cooking, Margarine,... (around 1750 rupees per 15 l)
- Refine left overs → soap
- Oil pressing left overs from seed → animal feeding

02.12.2021

(1) - Participants: Sameer Memon (Raina Consulting Pvt. Ltd.), Justin Kühn, Local, GM

Observation:

- Biggest quality point is the cotton contamination
- Separate the different harvests (first, second and third picking), if possible. Many farmers put together all harvests to get an appropriate price for all of them. Fear a very low price for only the 3rd harvest, if selling this
- Many trash back holder in gins are down but still work okay (I would say)
- In the time standing at the oil press, electricity stopped, manually moving the belts to remove remaining material out of the flow, because nobody knows when it starts again. - very low noise appeared before machines started again (video GoPro)
- Workers live on the companies area, to be better available, working in 3 shifts (8h) - probably more (guessing)
- Drive a separate seed cleaner for less contamination in here & using the linters for bed linen - a lot of dust but operated outside

Process chain: CPS, Beater, pre cleaner, DR-Ginning, lint cleaning, pressing - beside Seed pressing

Personal Impression: medium staple length, medium seeds in the cotton (around 7) - 1st and later harvest but later more trash

Additional:

- House construction, if money available
- Fundamentals and steel structure are visible until there is enough money
- From Local on cotton field: many people don't pick proper and just take the whole crop including the whole shell

(2) - Participants: Sameer Memon (Raina Consulting Pvt. Ltd.), Justin Kühn, Local, owner

Observation:

- Short drive by
- Today not operating, because they have not enough material
- One roller (better washer) is good for 200 bales (170 kg $\pm$ 10 %) - groove almost every week (here by hand, see video GoPro)
- Packing in knit material for stretch
- When we left, ca. 10 small good carrier brought cotton, approx. 2 t each
- Fire detection system installed, reverting material flow in case of fire. Lately happened two years ago
- Signal horn bells, when press is turning
- Working in 2 shifts (12h)
- Only cleaned on day where the mill is not operating. Operating days require all workers
- Seeds get sold in Jute sacks

Process chain: CPS, Beater, DR-Ginning, lint cleaning, pressing

Personal Impression: still much trash in the lint

Additional:

- House construction, if money there
- Fundamentals and steel structure is visible until there is enough money
- From Local on cotton field: many ppl. Don't pick proper and just take the whole crop including the whole shell

(3) Bajaj Steel Pvt. Ltd.

Participants: Sameer Memon (Raina Consulting Pvt. Ltd.), Justin Kühn, Local, Dr. M. K. Sharma (Whole time director & CEO), Lav Bajaj (Business Director), Milind Raut (Asst. General Manager Sales (Export))

Observation:

- 1500 employees - offer whole ginning plant, including all ginning machinery, electrics, steel construction, fire front door, ... (all self build)
- Only collaborating with CCI for research and ginners training
- Training is 5 (100\$) to 14 days (250\$), covering food, accommodation, etc.
- Most important in information distribution is personal training, their instruction book (e. g. "Double Roller Ginning Technology Ginning cotton in a gentle way", by PATIL, ANAP and SHARMA) and training while machine delivery
- Around 2010, market share domestic/international is 75/25, now it is 50/50
- Training is mostly done by one or two employees of one company and then transferred to the others
- 2nd hand machine market is existing but not tracked by them. Most ppl. Buy spare parts from them, that they could follow up machine sells by serial number

16 Annex C: Interviews Egypt

First of all, according to the already held interviews, a guiding questionnaire is prepared for the expert interviews. All interviews held in Egypt are carried out in October and November 2023. Therefore, this Chapter first displays the questionnaire, followed by the interview transcripts. The documentation of the interviews took place as a transcript according to BOHNSACK. The transcription rules are close to his *TiQ – Talk in Qualitative research* [Boh10]:

(.)	Pause up to one second
(2)	Count of seconds
.	Sharp falling intonation
;	Slightly falling intonation
?	Sharp increasing intonation
,	Slightly increasing intonation
Mayb-	Cancelling of a word
Oh=no	Word obfuscation
(Mumble)	Bad audible words in recording, unclear whether its right
((Note))	Comment from interviewer
//Reaction//	Hearing signals, e. g. //mhm// from interviewer
@.@	Laughing up to one second
hhh	Word expansions, quantity equals duration

Q&A Egypt:

Optional: I would like to understand the daily business in a ginning mill. Could you please tell me about it? (Typical tasks, issues, ...)

What are upcoming issues, you have to deal with frequently? → How do you overcome it?

Are there unsolved issues in your business? → What do you think, why is it unsolved? → Please tell me about upcoming issues in your daily business.

How do you define cotton and process quality? → Why is it important to you?

What comes into your mind, if I talk about employee qualification?

How do deal with Material samples and testing? (Seed cotton & Lint)

Which approaches of knowledge distribution do you realize?

Who brings up development potentials and requirements?

How does the ginning mill of the future look like? (eg. In the 22nd Century)

Interview Dr. Mohamed Negm:

The meeting took place in the evening of October 23rd 2023 in the City 6th of October, Egypt, beginning at 10 PM (EET)

Setting: The interview took place on the roof top of the house, Dr. Negm and me are living in at this time. Dr. Negm and me know each other for 2 weeks at this time and I was living in the apartment since one week. Dr. Negm mediated the apartment to me as he heard it's about to be free and the land lord and neighbour is searching for a new tenant. It took place in a familiar and cozy surrounding, with the two of us as participants. We had an ongoing discussion before, about many different topics along the whole textile process chain.

- 1 *Speaker 1:* Okay. So, Doctor Mohammed, thank you very much that you uh are willing to do this uh expert interview together with me. Um and I would like to hear especially how you see the ginning in um comparison from Egypt to the rest of the world. And what are major um importancies in terms of quality and how you see the um the quality shrinkage or improvement um due to which measures. Could you tell me about it?
- 2 *Speaker 2:* Yes. Uh it's my pleasure to to take this advantage with you. Uh the Egyptian cotton is unique uh fibres. So, as you know that the cotton is growing to be spun, not to in other things. So I have to very care about the fibres, because we know what is the spinner needs. The spinner needs clean cotton. The spinner need less short fibre. The spinner need less neps in the fibres. In this regard we have the extra long stable and long stable. And in Egypt we are a special case because we we don't produce any GMO cotton, which is genetic modified organism. And we have a long stable and we have mechanical, we have hand picking. We don't use mechanical picking because we have very short uh small area for each farmers. So each farmers, each farmer have almost one hectares. So we cannot use big machine to, to

pick one hectare. Okay. So in in Egypt we have only roller gin uh system, which is the keep the fibre length as it is. Because as you know, the the saw gin can damage the fibre, can cut the fibre from any part of the fibres. So we use only roller gin system to keep the fibre as it is. In previous uh era, we we didn't have uh cleaning point in the, in our old ginning mills, which is built since, let's say, more than 100 years. //Mhm// And nowadays the government started to to take care for about, for uh for the ginning process. In this regard, we built a new for spinning uh ginning mill. And this spinning uh ginning mill is already run and you will see it maybe next week. //Mhm// The first step of the the cotton came in in sacks, because it is hand picking. We put it in in good fibres. Okay? //Mhm// And it is started by uh 100 % cotton thread we don't use any type of polyester or uh, polyamide in, in the, in the, the sacks. And after that it is going through the ginning process which contain of the dryer. Because sometimes the cotton is weighted by let's say rainfall or by the humidity in north of Egypt. And these dryers are very important to uh eliminate or to make the cleaning point is very successful. And after that uh we have uh rotobar machines, which is huge capacity, almost 360 kilogram per hours to produce this. To separate the fibre lengths in the fibre and uh seed the fibre, go to the uh another point, another cleaning point, which is uh centrifugal uh machine to clean the cotton as well. And after that, for the proce- the bale pressing to produce the bale. And the seed have another, another way to, to, let's say decorticating and healing and extracting the oil in the same building, in the same ginning. The ginning have two this uh, system to separate the, the fibre from the seed and to make oil from the seed as well. Uh as you know, Egypt is very unique for the others uh because the Egypt and the India is still uh 100 % handpicking. So we are different from other countries. I give you some ideas of what I saw in other countries in, let's say, in United States, in Australia, in Brazil and in Greece, all these countries have uh mechanical picking in different ways. There are two. There are two types of uh of uh mechanical picking. One machine is called stripper and the one machine is called picker. //Mhm, ja// Picker is very gentle uh picking uh for the the fibres for the seed cotton. It is used spindle to take this uh bolls or seed cotton with the cotton with the seed and make it as a module. Big module. Okay? //Mhm// And the other machine is called stripper, which is cutting all the the plant after uh desired uh 30 centimeter from the soil is started to cut everything. Okay? //Mhm// And pack it as, also as a module. So both of them need very, very uh successful cleaning point. Maybe they use 2 or 3 cleaning point for the seed cotton and another 2 or 3 cleaning point for the lint. //Mhm// Uh, which is make aggressive for the fibres. This is 100 % uh affected for the fibre. Can you- can all the ginning mill can produce a lot of short fibre content, can produce a lot of neps because the solution producing a lot of neps. //Mhm// In this regard, the the spinning companies is not happy about about the saw gin cotton because it is almost the the efficiency are reduced from, let's say uh 96 or 95 % up to uh 89 or 88 %, because there is a lot of short fibres, a lot of neps and uh the, the biggest company like Trützschler, like uh Rieter started to to thinking how- to thinking about uh special system to eliminate all the neps which came from the saw gin. It is very important to to know that. Uh (.) the same situation in United States, the same situation in, in Greece. They have also this uh mechanical uh process. There is a lot of different

type of cotton uh regarding to the country regarding to the weather. Uh as I, you know, in Egypt, we produce only long staple in uh (.) in Greece they producing another type of cotton. It is medium stable. I can't say short, but it's medium. Sp around 29, 28 to 29. In Australia, they have another advantage of the fibre length from 28 up to 31. In the United States they have a different category from 98 also up to 34. In India, they have a wide range of fibre. They can produce fibre length up to 22 millimeter, which is very good for open end spinning. They can produce also 24 millimeters. They can produce 26 millimeter, 28 millimeter. So India produce almost four genotypes of cotton. This is used in *Gossypium Barbadense*, *Gossypium Hirsutum*, *Gossypium Arboreum*, *Gossypium Herbaceum*, which- they have a very big category in this regard you can find India one of the biggest spinning in the world. //Yeah.// And the very cheap and very good price, competitive price because they have very, very short staple cotton. They can produce open end with let's say very, very low quality of cotton. They have all the category of cotton so they can produce whatever they- the customer need. And in the end of the day, all the countries, all the cotton traders looking for the spinners, the spinner //Mhm// who lead the market, the spinner always need very clean cotton, very less short uh short fibre content uh very less uhh, neps. So all the, the cotton trading is make uh let's say competitiveness to, to reduce all this, uh uh uhh let's say (.) the bad properties to enable to export their cotton ((blow horn in the background)) to the spinners. //Mhm.//

- 3 *Speaker 1*: Okay. Yes, I see and when you talk about this cotton quality, as it's very important to have um low neps, short fibre content and um contamination like trash in it. Um how does it refer to the ginning machine itself and to the, um (.) um, to the knowledge of the operator of the ginning order in the mill. (.)
- 4 *Speaker 2*: Frankly, spoke the hand picking machine, the hand, the picking hand picking cotton is make a lot of contamination more than a mechanical picking. This is important to know that. In this regard uh, Egypt and India, they have also they have to install, uh seed cotton cleaners to eliminate all the uh, this issue of the contamination and uh and the foreign matters. It is important to, to to do like this. (.) Uh (4) so as I said that the hand picking is much more contaminated than the mechanical picking. But came to the the machine in the uh ginning mills uh the uh reciprocating knife or roller gin system. Uh very uh good for the fibre quality, because the roller gin can save the fibre lengths as it is. And they can save the the strength as it is and they can save all the physical properties of the fibres. For the other type of ginning, which is saw gin. The saw gin is very hard for the fibres. It's can make a lot of defects, can make a lot of short fibres, can reduce the fibre length distribution. In this regard nowadays United States started to convert the saw gin by uh, roller gin. //Mhm// They almost now 40 % of the the cotton ginning in uh, in United States. Uh gin on roller gin, which is the roto-bar, which is a high capacity roto-bar. Because they understand=uh nowadays that that spinner need uh very less short fibre content. The spinner need less contamination, the spinner need low neps to produce a very good yarn. So they started to convert all the ginning mill to be uh roller system,

the roller gin system. S=keep the fibre length as it is. This is very important. Another another, another uh the ginning method also affect for the fibre strength. For example (3) the saw gin also can scratch the fibres. And this scratching make the the the strength is lower than normal uh ginning mill or uh, roller gin by let's say 1 to 1.5 centinewton tex which is important to for for the the spinner also. Not only for the fibre length but also for the uh, the, the strength also can affect uh, the strength also can affect the length hundred percent affected the length. So uh this is a inside the uh, the the ginning mill. Also, another important uh issue is uh moisture content, which is very tricky if you buy a cotton with very high moisture content, more than 8.5. So you will lose in the efficiency of the spinning mill because you buy, let's say, 100 kilogram of cotton and after two three days you can find this only it is uh 95 kilogram. So where is this, //@.@// uh, five kilogram? It is evaporated. //Yes. @.@// Okay. So this is important to, to set it up in the ginning mill, because some ginning mill make this tricky issue with uh with the spinner uh which is uh make a lot of pressure for the uh the, the spinning mill to, to, let's say, clarify the, the quality, clarify everything, clarify also the moisture content, which is very important uh parameters uh you can depend on when you buy your cotton. //Mhm// Okay. (3)

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- 5 *Speaker 1:* And how do you see the influence of the qualification of the um employees working in the ginning mill? (2)
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- 6 *Speaker 2:* Uh, in the mill, the the the people should be understand the quality. The people should be understand how to set it up. The the the uh the machines to produce a a a good fibre quality. The ginning mill should be qualified and equipped by HVI to know what they produce. We cannot depend on the, let's say, the the sense of the cotton cluster to see the the quality of the fibres. It's cannot be happen nowadays because there is a lot of parameters in the fibres. So in the training mill, we need high qualified uhh employee for the for the ginning process to notice the quality control, to notice uh the bale pressing, to notice the fibre properties and how it is affected by the ginning by each uh ginning by each ginning machine. Maybe some machines is not set well so it is damaged. The, the seeds and the seed coat fragment came with the fibres, which is very dangerous for the carding machine. //Mhm.// (2)
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- 7 *Speaker 1:* So with the different ginning machines. You mean um like pre-clear, the rotobar itself and the dryer, for example?
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- 8 *Speaker 2:* Yes. Because in, in the ginning mill, normally uh every ginning mill contain almost 14 rotobars. So maybe some rotobars is not setted well. So you have to check all these 14. They have to check also for the uh seed cotton cleaner. Uh they have to check also the uh lint cotton cleaner. So it is easy to take samples from every stage to test to see. (3) I would like to reserve all the fibre as it is. If we find some machine is not working well or some damaging the fibre, uh we can set it up also, in the same situation in the uh saw gin uh mill, we have to see this saw. We have every, let's say, every 2 3 days. We have to check the sharpness of the saw if
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this sharpness is good or it is uh blocked because it's uh saw it's heard of the uh ginning machine can affect, let's say, more than uh 50 % of short fibre contents. This is according to the sharpness of the the saw gin. //Mhm// So it is uh it should be uh takes care about all these parts also. //Mhm//

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- 9 *Speaker 1:* And could you say, are there typical um issues or typical failures which are in the ginning mill which you investigated? (.)
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- 10 *Speaker 2:* Yes. It's almost when I visit, let's say Sudan. Uh I found uh they use a very uh prepared saw gin. It is made in, in another country. I don't like to to note to spoke about this country, but the sharpness it's very, very low. So it is make a lot of short fibres for example, the, the, the length-, the length from the seed cotton, it= is around 28 when this seed cotton going to this the this mill or this saw gin machine, the fibre came 26. So it is cut two millimeter from the fibres (.) //Mhm// and the short fibre content up to uh, let's say uh, 83. So it is it is horrible. Less than 83. I found some samples. It's 77 or 75. It is it is horrible because the saw gin is very, very (blocked). It is not sharpness. So this is effective for the fibre quality as well and also for the strength and all the fibre uh properties, not only the fibre length and the strength. All the other fibre is affected by this uh the type of the saw gin. (.) Uh, it is important to, to notice, to, to fix, to, to set it up with uh with the, the sharpness and the and also the dimension and the diameter and the, the distance between uh the grade and the saw gin. It is important to set all this issue. It is it is like a carding machine. If you cannot set very well the carding machine, you have a very bad uh web or very bad slivers. //Mhm// You can find a lot of uh neps, a lot of uh seed, a lot of uh seed coat fragments came with uh with uh with the sliver or from the uh the carding. You have to set the carding very well. (Liquor=in) and (slanders) and the (.) and uh every single it is the same setting like the saw gin. (.) //Mhm// (2)
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- 11 *Speaker 1:* So this uh in particular for the ginning uh for the roller gin, which you mentioned.
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- 12 *Speaker 2:* Yes. Yes.
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- 13 *Speaker 1:* Okay. (3) All right. So um at this point, I have no further questions. (.) Or is there something you would like to um further explain or which-
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- 14 *Speaker 2:* Uh, yes. I- I have to inform you, let's say the situation in, in Greece. Uh Greece it's located in Europe, as you know. And they uh the the picking season is starting from uh end of September (.) up to, let's say uh end of October. And uh this time the, the winter is coming. So they would like to finish uh the ginning process as soon as they can. //Mhm// So they have a big capacity of the ginning mill, every ginning mill have, let's say, producing from 60 bale per hour up to 90 bale per hours, because they would like to finish all the crop in very, very short time //Mhm// before
-

the rain is coming and before- before the snow is coming because the rain and snow uh change the colour of the fibres from white to grey, from white to brown, from white to, let's say creamy. Uh so this is make the duration for the fibres. So they would like to, to finish all the, the ginning process as soon as they can. The same situation in, in Australia also as well. And in some uh countries like also United States they would like to finish all the crops as uh as they whatever they, they, they can in, in hemisphere uh uh, hemisphere uh they would like to finish as soon as possible as the same situation in Egypt. So the capacity of the ginning mill should be very big to finish the crop as soon as possible before the rain is coming. //Mhm// In this regard, they put a lot of pressure for the ginning mill also because the ginning mill should, should be equipped by uh uh driers machines, cleaning machines to and the big yard to finish all the crop in in very short period. (.) //Mhm// (2)

15 *Speaker 1*: So do you think this affects the um the cotton quality?

16 *Speaker 2*: Yes, sure. Hundred percent. Because if the cotton have uh some water and this water is cannot be evaporated, it will make (.) a fan guy to come to=0 because you know that the cotton is cellulose and cellulose is desired by fungi. And this converted to sugar. Okay. //Mhm// And the, the, the other fungi is coming to uh, to, let's say make uh the duration for the, the sugar for the cellulose. And this is effective for, for sure for the strength, for the quality and for the colours of the cotton. And you know that uh that the (.) the trader, the trading companies looking for the white cotton and the spotted cotton and the grey cotton. And this is effective for the price and for the quality hundred percent, for sure. //Mhm// (2)

17 *Speaker 1*: All right. (.)

18 *Speaker 2*: Okay.

19 *Speaker 1*: So thank you very much for this.

20 *Speaker 2*: Thank you.

21 *Speaker 1*: And then we are finished. Okay.

Interview transcript Mr. Sayeed:

The Interview takes place in Fayoum, Egypt, on October 29th 2023 in the ginning mill's office.

Setting: Engineer El Sayeed Saad El-Gaweesh is consultant in many ginning mills, including Fayoum ginning mill. It is driven by the Egyptian government. This mill is newly equipped with Bajaj roller ginning machines. It replaces Platt brother machines, installed around 1920. There are many difficulties within the ginning mill and the operation is still not on full scale, since setting up the machines. The interview takes place directly after an emotional discussion with Bajaj about missing parts, insufficient fan operation and other minor issues. Before the Interview and discussion, we did a tour through the ginning mill and I took some moisture measurements with a self build moisture meter. The interview shall be with Mr. Sayeed. He is sitting on the heavy wooden desk, all other 7 people attending are sitting on small office chairs on the other side of the desk, double sided with small and low desks, four chairs on each side opposite of each other. Speaker 1 is me, the Interviewer, Speaker 2 is translator and familiar with Dr. Mohamed Negm, because Mr. Sayeed feels more comfortable with answering those questions in Arabic. Dr. Negm organized the meeting in the ginning mill for me. Speaker 3 is Mr. Sayeed. Speaker 4 is an Egyptian intermediate who is selling Bajaj machines and guided me from Cairo to the ginning mill. Speaker 5 is GM of the company, sitting with us on the guest side of the desk. He left his desk for Mr. Sayeed to pay respect to him.

Before the meeting was about to start, I was assured that this way of discussion with a supplier is usual procedure in Egypt and there is no reason, to not take the interview by now. It was a very nice and friendly atmosphere, with which we begun.

- 1 [0:00:00.0] *Speaker 1:* ((constant, partly quiet, partly louder background talks, 8 people. in the room)) Okay, Mr. Sayeed, thank you very much that you take the time um to get this interview together with me for my PhD thesis according to um the Ginning technology um and the uh cotton uh cotton quality, how it comes out of the ginning mill um and especially um knowledge training for the ginning operators um which is (.) uh yeah. Which I would like to hear your opinion about. So

	um I know we already talked about uh it a little bit um but could you tell again what is the most important quality factor in cotton ginning for you?
2	[0:00:51.0] <i>Speaker 2:</i> ((Arabic translation)) The first question what is the main factors of the uh cotton gin quality? //Yes//
3	[0:01:31.0] <i>Speaker 3:</i> ((Arabic Reply to the translated question))
4	[0:03:00.0] <i>Speaker 2:</i> ((Cough)) Uhhhh it's a big factor uhhh the main factor uhh for the uh cotton gin quality. Uh number one uhhhh is the seed cotton uh seed cotton itself. Uhh it must be ehh in aa good grade and a good classification. Uhhhhh uh uh, thrash is less uh full mature. Full mature. Uhhh, this is the main factor. Second one is the ginning machines. Ginning machines itself, that must be ready and adapted to the ginning variety according to their variety characteristics. Uhhhh mostly the operators must be have uh awareness, uhhh, to keep the cotton clean. Don't touch the don't touch the cotton. Don't spoil it. Uh and something like that. Uh also ehh we have to ehhh eh we have to observe the HVI ehh the HVI. And each time we try to see what is the drop, what is the breaking uh for the HVI and eh try to uh solve it. //mhm// This is the main part.
5	[0:04:16.0] <i>Speaker 3:</i> ((arabic follow up of the answer)) ((cough))
6	[0:04:34.0] <i>Speaker 2:</i> Uh uh uh also, the cotton moisture uh uh it should be uh not less than six and not above more seven. //Okay// This is the main factors.
7	[0:04:48.0] <i>Speaker 3:</i> ((arabic follow up of the answer; 2 times vertical drier is mentioned))
8	[0:05:08.0] <i>Speaker 2:</i> Uh uh, also, we we should. This uh device, we should run the vertical drier uh because it's it's had two functions, not only uh adapting the moisture, but also it uh it make the loss uh uh, get more um get more ready. And it's to be easier to remove the lint from the seed. //mhm okay// Great. Thank you.
9	[0:05:38.0] <i>Speaker 1:</i> Um, so, so could you say what are the most upcoming issues you have to deal with? Um according to these quality factors um, especially in like daily business um what is upcoming most?
10	[0:05:57.0] <i>Speaker 2:</i> ((Arabic translation of the Question)) (9)
11	[0:06:10.0] <i>Speaker 3:</i> ((Arabic Reply to the translated question))

-
- 12 [0:07:25.0] *Speaker 2*: Uhhh, the daily issues or we can say the uh the daily uh duties uh that the operator uh must do for getting uh uh high quality of uh of the of the ginning. Uh after each shift, we have to clean uh good cleaning for the ginning men. And also we have to adjust the, the machines uh after each uh shift. Uhh and also is uh the cleverness uhhh of the of the labor uh in adjusting the machine itself. And also, he must know the distance uhh between the roller and the station and the stationary ((background noise)) and also the distance between the uh roto=knife and the //stationary knife *Speaker 3*// stationary knife with the roller. This is uh the main issues.
-
- 13 [0:08:19.0] *Speaker 1*: Okay um According to the knowledge of the operator um how do you assure that they know well, how to set the machine?
-
- 14 [0:08:33.0] *Speaker 2*: ((Arabic translation of the Question))
-
- 15 [0:08:45.0] *Speaker 3*: ((Arabic Reply to the translated question))
-
- 16 [0:09:52.0] *Speaker 2*: Uhhh for the operator uhh first the the uh first they have got uh well training uh theoretical training and uh practical training. Uh ((Arabic input *Speaker 3*)) @.@ and uh, the the second main factor is there experience. Experience about uh handling with the machines. Uhh, for these issues uh the operators use, uhh, special devices for adapting this distance between the stationary life and the uh roller. Uh and also the eh eh the roller and the uh rotary knife. Uh and also they observe the, um uh there is one pressure meter uh between 5 and 6 for uh for the alignment of the uh //leveling, leveling between the rotary and the stationary knife *Speaker 3*// leveling between eh eh the stationary knife and eh and eh roto=eh=tary. And also eh the operator must observe uhh the surface of the uh //roller *Speaker 3*// of the roller uhh and also uh he must also observe the surface of the stationary knife uh the alignment of the, the stationary and make sure that uh nothing is damaged or any part uh get damaged. //Okay. Mhm//
-
- 17 [0:11:20.0] *Speaker 1*: So the training is held by uh Doctor Mohammed Negm or did I get it right? Or who does the training? Is there some some central organization for it or do they do=they do it in=house?
-
- 18 [0:11:33.0] *Speaker 2*: Uh for the training uh actually, we got we got a lot of uh of help of uh Doctor Mohammed Negm. He helped us a lot uh and also Bajaj provide us by the uh consistence of subject, uhh and we make one uh uh theoretical uh training uh for uh seven days uh for the all the operator uh in uh, in the ginning mills uh we describe uh we describe the parts of the machine and the annual maintenance and, thee, weekly maintenance. And also we make eh something like discussion if uh and also the troubleshooting, the problem uh and the uh practical training, uhh, is a hold maybe uh by the middle of November, it is hold also
-

- uh by Bajaj. But for uh I take this opportunity to thank Doctor Mohammed Negm because he helped us a lot very uhh I have to say uh he gave us a lot of uh uh, subject and a lot of of uh of material. The training material it helped us out. //Okay. Mhm.// But but the training itself but it's done by Bajaj. //Okay.// Yesterday all the technicals and also uh they got one programmer, Mr. Sundeep. Uh he can also gave a lecture about electricity and the programming.
-
- 19 [0:13:06.0] *Speaker 1*: Mhm. Okay, so it's uh every season uh of the running um there's a new training.
-
- 20 [0:13:14.0] *Speaker 2*: Uh, actually this model we did not uh we did not uh the the discuss=uh, but eh maybe it's a good idea from you=eh.
-
- 21 [0:13:23.4] *Speaker 3*: Uh, you can suggest it to Rawan Atika. //@.@//
-
- 22 [0:13:27.0] *Speaker 2*: ((Arabic translation))
-
- 23 [0:14:08.0] *Speaker 3*: ((Arabic Answer))
-
- 24 [0:14:40.0] *Speaker 1*: Uh, Mr. Sayeed also added ((opening of a soft drink can)) the uh added that uh he insisted on that the practical training, it must uh it must be held uh during the running of the uh of the uh observent //ginning *Speaker 3*// and also uh for uh for your observation that uh why don't we make any more training um uh Mr. Sayeed and also Mr. Mohammed said uh this in case of a new staff. Come, if we hire a new staff, we we will make a training for them. All, if any new technology we have to uh move to them. We will. We will hold uh annual training.
-
- 25 [0:15:23.0] *Speaker 2*: Okay, so normally you have the same stuff year by year.
-
- 26 [0:15:27.0] *Speaker 4*: Mm yes. This is industry and uh no new comer too much. //Okay mhm//
-
- 27 [0:15:32.0] *Speaker 2*: Okay. ((Arabic comment)) Yes, yes.
-
- 28 [0:15:38.0] ((Many double noises, no understandable content)) @.@ ((all))
-
- 29 [0:15:46.0] *Speaker 1*: Perfect. (.) Yeah, just from India I know that it's uh like they change every year. Uh just according
-
- 30 [0:15:52.4] *Speaker 3*: No, here from year seven? to the grave. @.@
-

-
- 31 [0:15:55.0] *Speaker 1*: Perfect. Um and as you say, the moisture is a very important factor in the ginning, how the moisture //ah moisture// is very important. So um you said, uhm uh uh, Delmhorst is not a good device for testing. How do you um measure or uh like, assure that it's the right moisture for processing?
-
- 32 [0:16:23.0] *Speaker 2*: ((Arabic translation))
-
- 33 [0:16:39.0] *Speaker 3*: ((Arabic answer))
-
- 34 [0:17:01.0] *Speaker 2*: Uh, this is knowledge, you know? ((Arabic addition *Speaker 3*)) Uhhhh, uhh, you know, uhhh, you you heard that because uh in last season uh we used to measure by the American Delmhorst uh seed cotton and lint and also we had two nails to go into the bale uh and you will report uh this, uhh, results. And when we send our samples, same sample to Catgo uh we will find a difference. Because Cat- Catgo may in the labels uh the uh in the end, they do buy maybe another technology or something like that. So we find, uhh, some difference.
-
- 35 [0:17:45.0] *Speaker 3*: Maybe. ((Arabic addition)) ((Phone Mr. Sayeed ringing))
-
- 36 [0:17:57.0] *Speaker 2*: So, uhhh, the the lab ((Arabic clarification)) uh, we uh we have the one lap uh in tomorrow, you will see it belongs to Catgo uh you will see the the uhh uh the instrument which is they use uh, but is not working. Still not working. But you can see the instrument. ((Phone Mr. Sayeed ringing 2nd time)) Uh, they use another technology like they make preparation for the uh for the samples uh and make uh the room uh uh, atmosphere suitable for for doing this analysis. But here uh when you use American Delmhorst uh for the seed and the for the bale uh it's not accurate.
-
- 37 [0:18:42.0] *Speaker 3*: ((Arabic addition))
-
- 38 [0:18:46.0] *Speaker 2*: Also, Mr. Sayid said when you catch one piece of cotton and put it, then this is, you touch it by your hand. So you give it uh extra moisture.
-
- 39 [0:18:55.0] *Speaker 1*: Of course, yes. ((Phone Mr. Sayeed ringing 3rd time)) Shall I pause? ((Silent confirmation)) (6)
-
- 40 [0:19:05.0] *Speaker 3*: Okay. (5)
-
- 41 [0:19:07.0] *Speaker 1*: Okay. Yes. So, uhh (2) Thank you for these insights. Um and now I'm curious. Uh (.) do you think there is still unsolved problems or things
-

	which uh need or should be addressed um for the generic technique or the the training part? (4)
42	[0:19:33.0] <i>Speaker 2</i> : ((Arabic translation of the question))
43	[0:19:46.0] <i>Speaker 3</i> : ((Arabic Answer))
44	[0:20:18.0] <i>Speaker 2</i> : Uhhh, for the unsolved problem, sure, we have some unsolved problem but we are able to uh to solve it and to pass this stage. Uhh but uhh we um you know, uhhh, here in Egypt, we used to run the old, uhh, the old ginning technology about uh 140 years. Uh so uh moving from this technology, tools and rotobar technology uh take much time and it take much effort from the operators uh and also a lot of awareness and also uh confessing the customers uh to uh to be ready to uh accept or to applied to the uh uh, rotobar technology.
45	[0:21:05.0] <i>Speaker 1</i> : Okay. But it's all done by the company itself? Or do you think there should be additional help from (.) the industry, like Bajaj, for example, or from um universities or research institutes? //Mh// Uh.
46	[0:21:19.0] <i>Speaker 2</i> : ((Arabic translation))
47	[0:21:36.0] <i>Speaker 3</i> : ((Arabic answer))
48	[0:21:52.0] <i>Speaker 2</i> : Uh, first uhhh people itself. They have to uh they have to be an open mind and you have to be able to uhhh through the toolkits and new technology. And also we need uh propaganda uh for this=uh rotobar technology for our customer uh inside Egypt and outside Egypt. And also the university uh and the research in the institute they must help us by making and publish the uh the recent of the rotobar machines and the uh and the rotobar gin the cotton and also Bajaj itself uh it must help us, uhh, also by solving the problem and and and improve uh, is working and it will not be also it will not be a success for us only, but on- one will see by Bajaj. Bajaj also is succeed. And uh when they, they, they publish a new uh a new site. They said that in Egypt we make for rotobar sides by uh productivity uhh number and all this for Bajaj and us. //Okay mhm//
49	[0:23:11.0] <i>Speaker 3</i> : ((Arabic addition))
50	[0:23:15.0] <i>Speaker 2</i> : Uh uh Mr. Sayeed believe that the, the rotobar technology. It is the future of the=whole world.

-
- 51 [0:23:23.0] *Speaker 3*: For any kind of-
-
- 52 [0:23:25.0] *Speaker 2*: Any kind of-
-
- 53 [0:23:26.0] *Speaker 1*: Okay, so it's also suitable for the medium or short staple fibres. //Yes, yes *Speaker 3*// Okay.
-
- 54 [0:23:34.0] *Speaker 3*: Work in Sudan. Short staple. Work in Turkish, China. Work in America. //Okay, ja// And in Israel Pima more and more. (.) All country, rotobar work. This. The end of ginning rotobar is the future.
-
- 55 [0:24:00.0] *Speaker 1*: Okay. This actually brings me to to one question I wrote down. Um what do you think the ginning will look like in the 22nd century? For example. (2) Um. (2) Do you think it is uh yeah something different? Still the same amount of operators or how it might change?
-
- 56 [0:24:26.0] *Speaker 2*: ((Arabic translation)) ((Background noise, someone is calling)) (10)
-
- 57 [0:24:54.0] *Speaker 3*: ((Arabic answer)) ((Cough))
-
- 58 [0:25:32.0] *Speaker 2*: Uhh Mr. Sayeed say this a new technology here in Egypt and by the uh sustainable, uhh, operating. Uh we may eh we may have a new invention. We may have new ideas. Uh and also, Mr. Mohammed said, like the bypass, which uh Mr. Sayeed and Bajaj done uh no one thinked by this=but=but by four years working uh we see that we need, uh uh a bypass uh uh at stage. //Mhm//
-
- 59 [0:26:03.0] *Speaker 3*: ((Arabic addition))
-
- 60 [0:26:41.0] *Speaker 2*: Uhhh, from the sustainable uh operations, uhhh, we discovered that, uh uhh, a cleaning for the seed cotton is not a problem. Make one stage, two stage, three stage, whatever you want. But in the in the in the lint cleaner, it's only one stage uh for the lint. //Take care *Speaker 3*// Uh, because the lint, the limit itself, it's too weeks. Uh so uh we make the bypass uh as an as you also you see in the one recent site uh according to the customer, uh uhh according to the um the the the uhm customer uh demand uh then he asked for uh bypass.
-
- 61 [0:27:26.0] *Speaker 1*: Okay. Mhm. (4) So you already know to whom you will sell the cotton after this?
-

-
- 62 [0:27:34.0] *Speaker 2:* ((Arabic translation)) Uh, no. Uhhhh the the um the circle here, we uh our company, we sold the cotton from the farmers. We ginning. Uh after that=after that, uhh, you know, we have the sales department, so it's for export or for the local consumption.
-
- 63 [0:28:02.1] *Speaker 4:* ((Arabic addition))
-
- 64 [0:28:05.0] *Speaker 2:* Tamam. Uh also uh Mr. Muhammad, the GM here said that uh uh we not only this side, this ginning mill is not only working for our company mass, but also in uh other company uh is uh they come here. We gin the seed cotton and give them the lint and the seed.
-
- 65 [0:28:24.0] *Speaker 5:* And the company of the seed uh despite cotton and get uh the ginning uh with money. And they take the whole machine as business.
-
- 66 [0:28:37.0] *Speaker 2:* From the textile=textile companies.
-
- 67 [0:28:41.0] *Speaker 1:* Okay. So you get um a certain amount of money for each, I don't know, kg or uh ton //ton *Speaker 3*// of cotton, which you get.
-
- 68 [0:28:50.0] *Speaker 4:* Money got still (.) It has to be kilo a lot of ten //in ton, ton *Speaker 3*// with kilo, with kilo.
-
- 69 [0:28:58.0] *Speaker 3:* By kilogram //by kilogram *Speaker4*// counter Egyptian equal 50 kilogram. (1) //Okay mhm// (.) Selling the lint but=uh seed cotton, 100 uhhs=uhs=uhs fiv- fiv- fifty 57.5.
-
- 70 [0:29:20.0] *Speaker 1:* Okay mhm. (.) And then the (.) uh the fibres go back to the farmer and he can sell it?
-
- 71 [0:29:30.0] *Speaker 2:* No=No=No. Hear, hear. Uh the relationship between the farmer and his group in this on the auction. //Okay// After the auction, it's uh become for the company. Uh he only takes the money. Uh the company. Uh but uh it's uh cotton yield and BT-Agent and it's uh free to solve the or export. Uh the lint and the seed uh to be uh to be in the in the oil mill or uh also, uh.
-
- 72 [0:30:03.4] *Speaker 4:* ((Arabic addition))
-

- 73 [0:30:12.9] *Speaker 1*: Uh, Mr. Muhammad also said that ((cough)) when we export uh uh, cotton uh for example, for Deutschland or any other uh uh, country uh we we the shipping start from here.
- 74 [0:30:28.0] ((Several unclear voices))
- 75 [0:30:32.0] *Speaker 1*: @.@ Okay. Mhm. (4) Um and yeah, these are almost all my questions. Um when we just talk about this topic, there's something more which is coming up to your mind, which you um would like to share with me?
- 76 [0:30:50.0] *Speaker 2*: ((Arabic translation)) (6) ((some arabic background talks))
- 77 [0:31:05.0] *Speaker 2*: Tamam uh as I told you in the morning, uh.
- 78 [0:31:10.0] *Speaker 5*: For Fayoum is the beginning to get Egypt on the top of uh world cotton. With our trademark Egyptian cotton. //Mhm// (2) Premier. //Nice//
- 79 [0:31:25.0] *Speaker 1*: Are there more than this ginning mill in Fayoum?
- 80 [0:31:29.0] *Speaker 5*: There is more=but this is the beginning of.
- 81 [0:31:32.0] *Speaker 2*: Uh, the.
- 82 [0:31:33.0] *Speaker 3*: Development.
- 83 [0:31:34.0] *Speaker 1*: Yes, as you said-
- 84 [0:31:35.0] *Speaker 3*: No. Uh Egypt for Egypt like this. ((double hit on table)) One here one in the- ((arabic words)). And in future can be exhibit for this. Rotobar //Bajaj words *Speaker 2*//
- 85 [0:31:54.0] *Speaker 2*: Oh, no. ((Phone Mr. Sayeed ringing)) //@.@ allll
- 86 [0:31:56.0] *Speaker 3*: I don't know. ((@.@ background)) ((Arabic discussion, future ginning is audible))
- 87 [0:32:37.0] *Speaker 2*: Uhh one point. Uh according to the uh uh to the future and the new idea and the invention uh like the oil trap uh the oil trap idea started from here uh when we said- when we saw that the uh the cotton in Fayoum or in Upper Egypt uh it had a lot of contamination=and here uh farmers, they don't have any

- awareness about the cotton. They put stones and as you see in the, in the road trap. So we start to make a tool and uh reach it for uh road trap to decrease the contamination. //Arabic addition *Speaker 3*// And also, you saw=you saw the results. //Mhm//
-
- 88 [0:33:16.0] *Speaker 3*: ((Arabic addition))
-
- 89 [0:33:34.0] *Speaker 2*: Uh. And also one uh one information about the rotobar machine is that, uhh, you have to to get sure that the seed cotton uh is is clean because this will make uh will affect the lifetime of the roller chain itself. If any, in stone of any something uh came to the roller, it will do a big harmful.
-
- 90 [0:34:00.2] *Speaker 1*: Mhm, of course yes. (2) And um do you think the problem of cotton contamination could be solved by um getting more training to the farmers itself?
-
- 91 [0:34:13.0] *Speaker 2*: ((Arabic translation))
-
- 92 [0:34:19.9] *Speaker 2*: ((Arabic discussion))
-
- 93 [0:34:25.2] *Speaker 2*: This is essential uh because if you if you want to uh uh prevent the contamination you have to start from the field. //Mhm//
-
- 94 [0:34:34.6] *Speaker 3*: ((Arabic addition))
-
- 95 [0:34:59.0] *Speaker 2*: Uhh here in Egypt here in Egypt uh to uh to make uh automatic making. Uhh maybe is, is um is not uh //impossible *Speaker 3*// Uh, yes. It's really-
-
- 96 [0:35:11.0] *Speaker 3*: ((Arabic Discussion))
-
- 97 [0:35:18.0] *Speaker 2*: Aaa the cultivated area is uh is not wild. It's not wild. Uh but here it's very novel. So we can't do uh automatic uh picking. Uhh and here, our main problem uh for the farmers, as we say, in the field uh plastic bags uh they use plastic bags uh here uh you know, many, many contamination. It's it's it's very hard to uh remove all to collect and then an-.
-
- 98 [0:35:53.0] *Speaker 3*: ((Arabic addition))
-

- 99 [0:36:00.0] *Speaker 2*: Tamam. And also uh this must be uh this could be controlled uh from the authority uh or any authority like Ministry of Agriculture. Uh like uh cotton companies is a must. They must do this. Uh and also here in Egypt uh a real cotton a real cotton- (3) ((Arabic discussion with *Speaker 3*)) Also here some companies, but uh private sector is already there. They start to involve in real cotton and BCI cotton also, but uh private uh private companies, they doing this. Uh they hire fields from the farmers and they start to- they do uh the organic cotton and uh real cotton and um the BCI. //Mhm. Okay//
-
- 100 [0:36:55.0] *Speaker 1*: And when you say it would be necessary to start on the field um what do you think about uh how this could be overcome? Like, what are potential measures?
-
- 101 [0:37:07.1] *Speaker 2*: ((Arabic translation))
-
- 102 [0:37:17.0] *Speaker 3*: ((Arabic answer))
-
- 103 [0:37:36.0] *Speaker 2*: Uhhh if we start uh from the field and prevent the contamination. Uh thi- thi- this would be useful for us in the production of the uh production of the cotton. And also for zero contamination. We start to reach the zero contamination. Also, this will help us in the world marketing. Uh. (6)
-
- 104 [0:38:03.0] ((Arabic discussion))
-
- 105 [0:38:14.0] *Speaker 3*: We already have BCI here. (.) //Yes.//
-
- 106 [0:38:17.0] *Speaker 1*: And now the GOTS for your uh certification? (2)
-
- 107 [0:38:22.9] *Speaker 2*: Is GOT Ginning Out Turn?
-
- 108 [0:38:25.0] *Speaker 1*: No the um GOTS certification? //Yes. *Speaker 3*//
-
- 109 [0:38:28.0] *Speaker 2*: Yes.
-
- 110 [0:38:30.0] *Speaker 1*: Yes. (3) Okay, so um if there's nothing to add from your side.
-
- 111 [0:38:37.0] *Speaker 2*: ((Arabic translation)) (.)
-

-
- 112 [0:38:46.0] *Speaker 3*: ((Arabic answer))
-
- 113 [0:38:59.0] *Speaker 2*: The main the main um the main goal. The main aim uh for uh any uh ginning uh any ginning mill is the quality uh of the lint.
-
- 114 [0:39:14.0] *Speaker 1*: Yes. //It matter *Speaker 3*// Okay.
-
- 115 [0:39:19.0] ((Arabic Discussion and non audible english))
-
- 116 [0:40:23.0] *Speaker 1*: Maybe just aa organizational part. Um I would like as I told to, to take this interview for my PhD thesis. Um shall I rather take it anonymized or um with your name as um the expert of this interview?
-
- 117 [0:40:42.0] *Speaker 2*: ((Arabic translation))
-
- 118 [0:41:00.0] *Speaker 3*: ((Arabic answer)) ((Silent confirmation for using the Name))
-
- 119 [0:41:19.0] *Speaker 1*: Okay.
-
- 120 [0:41:20.0] *Speaker 5*: Thank you.
-
- 121 [0:41:21.0] *Speaker 1*: Thank you so much. Uh Habibi Shukran Mr. Sayeed.

17 Annex D: Key elements of Interviews

Well selected interviewee lead to a low necessary number of interviews. Further interviews will only double the content. [Akr22] Therefore, after first interviews from consultants in India, expert interviews are selected for the ongoing process of this research. Nevertheless, the following aspects should be considered.

Arguments or self constructed theories in stories might show, that the storyteller has actively dealt with the situation. [LD04] There are different interview times, to talk in. Their specifics are described in the following [LD04]:

- Time-lapsing interviews are summaries of month, years or decades, in which there are no specific moments to talk about from the speakers view. Only the flag ship moments get recognised.
- Time-covering (isochronous) interviews conveys the feeling, that the situation happened in the same speed and exactly as explained.
- Time-stretching interview (stretching) make it seem like in slow motion. It is characterised by including thoughts and feelings. It happens rarely but if so, it is particularly for thoughtful or emotional situations.
- Omissions are interview time jumps. They can happen explicit or implicit. This might include an information about the duration of the time jump. Sometimes, the storyteller wants to hide information, in other cases it just happens by not rating the happenings as relevant enough.
- Interruptions let the interview pause to add arguments, theoretical comments or descriptions. This is a need of the storyteller.

Ususally, these stories are based on the ordinary timeline, which is School, Job, Wedding, Move and other spectacular or live changing events. Key interviews have a special significance in the live of the storyteller. It changes the way of remembering, thinking and or living. It is recognisable by increasing degree of details, dramaturgy and pointed presentation. [LD04]

Sometimes arguments are used to win the interviewer over to the interviewee's point of view. This is the heart of the interview identity of the interview. The interviewee is somehow convinced, that he has to bring listening persons to the same point of view or at least closer to this to understand the motivations for his decisions. Therefore, the interviewer should not ask evaluative or critical background questions. [LD04] Especially important for psychology are [May95]:

- interviews
- half structured Interviews and
- Group discussions

To analyze the most important parts of the story, these steps could be observed and evaluated accordingly. [LD04] For evaluating the interviews, there are common questions, which should be applied for the analysis. These questions are [LD04]:

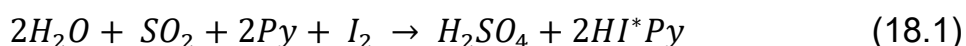
- What is described?
- How is it described?
- Why is it now and like this described?

With these questions, every single unit of expression shall be analysed. One unit after another is considered and all relevant information are derived from it. [LD04]

18 Annex E: Moisture measurement expanded description

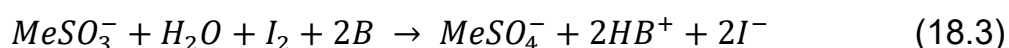
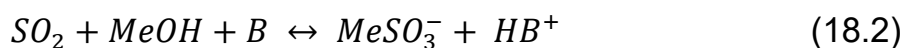
Karl Fischer Method

The water is titrated using a specific solution. The amount of solution used is in the same ratio to the water content of the test specimen. The volumetric measuring solution is initially placed in a burette. [Sch00] A burette is a narrow tube with a scale that allows precise volumes of liquid to be dispensed. The solution is added to the sample until the water present in the sample has completely reacted with the reagent [Sch00]. The original reagent used in the Karl Fischer method is Sulphur Dioxide (SO₂), Iodine (I) and Pyridine (Py) in a benzene-methanol mixture. The chemical formula for Pyridine is C₅H₅N, simplified as Py. [Sch00, Int71] This reacts with water according equation (18.1) [Sch00]:



Pyridine and benzene are no longer used. Pyridine is only used as a base and does not participate directly in the reaction. Today, imidazole (C₃N₂H₄) and diethanolamine (HN(CH₂CH₂OH)₂) are used as new bases, as they are less harmful to health. This advanced method is named after Eugen Scholz. [Sch00, Int71]

Two reactions take place during titration. Firstly, the sulphur dioxide in the reagent reacts with the alcohol to form methyl sulphate (18.2). In the second reaction, the reagent reacts with the water present in the sample according to the reaction equation (18.3) [Sch00]:



With: B = Base (for neutralisation of the occurring protones)

The decisive factor in this reaction is that exactly one mole of iodine reacts with one mole of water [Sch00]. This allows the water content in the sample to be determined from the consumption of the volumetric standard solution.

The time at which the reaction is complete is determined as follows. In conventional acid-base titrations, the pH value changes significantly when the entire base has been converted. This time can be determined by adding a suitable indicator that changes the colour of the mixture when the pH value changes. However, the colour change from yellow to light brown is not very clearly visible in the Karl Fischer titration. [Sch00]

For this reason, the electrochemical indication is more suitable. In this method, a double platinum electrode is added to the titration vessel. A potential is present in the solution due to the redox reaction. A current is applied to the electrode, which can only flow if the potential is present in the solution. At the moment when iodine and iodide are present at the same time, the potential drops to almost zero. This voltage drop is the indicator for the complete conversion of the reaction. [Sch00]

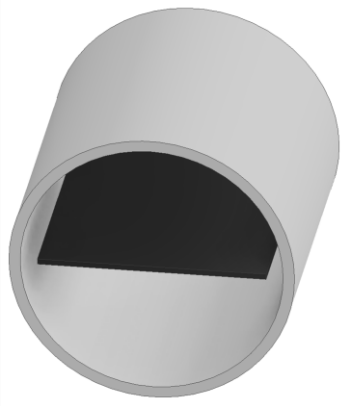
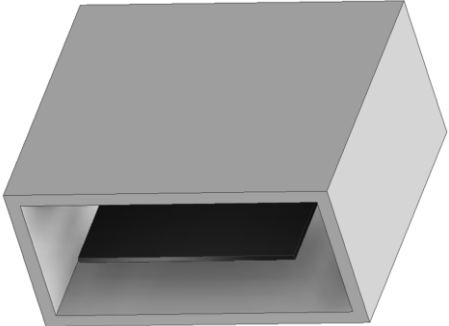
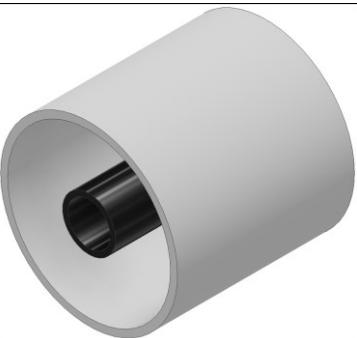
The measurement of the moisture content in cotton using the Karl Fischer titration is carried out as follows. The cotton fibre is first heated in a closed vessel until the water in the fibre has completely evaporated. It should be noted that during this evaporation, not only water but also other volatile components pass into the gas phase. The result is a vapour mixture. In a further step, this vapour mixture is separated and titrated with the reagent according to the Karl Fischer titration. The reagent reacts specifically with the water in the vapour mixture. The weakness of the gravimetric method is that the vapour mixture is interpreted as pure water vapour. This leads to a systematic overestimation of the moisture content of the cotton fibre. This is particularly the case when the drying temperature is well above 100 °C. [DR16]

As this method is used for moisture content determination in synthetic materials, it is usually used in very low moisture content levels. Former investigations at the Institut für Textiltechnik showed, that 40 ml solvent are needed for 20 ml of water extraction. This quantity already costs approximately 100 €. Therefore, the Karl Fischer Titration is not a viable concept for cotton moisture determination as it is too expensive.

19 Annex F: Moisture Sensor Development additions

For the simulation, three different types of pipes were used. These are:

Tab. 19.1: Design of simulation setup for field strength simulation

Description	Image
1. Flat plate in circular pipeline	 A 3D perspective view of a gray cylindrical pipe. Inside the pipe, a black flat rectangular plate is positioned horizontally, resting on the bottom inner surface. The plate is slightly offset from the center, leaving a gap between it and the top of the pipe.
2. Flat plate in rectangular pipeline	 A 3D perspective view of a gray rectangular pipe. Inside the pipe, a black flat rectangular plate is positioned horizontally, resting on the bottom inner surface. The plate is centered and fits snugly within the width of the pipe.
3. Round plate in circular pipeline	 A 3D perspective view of a gray cylindrical pipe. Inside the pipe, a black cylindrical core is positioned horizontally, centered within the pipe's diameter. The core is shorter than the pipe, leaving gaps at both ends.

Results of the simulation according to these three types of pipelines with different dimensions and copper core are shown below in Fig. 19.1, Fig. 19.2 and Fig. 19.3.

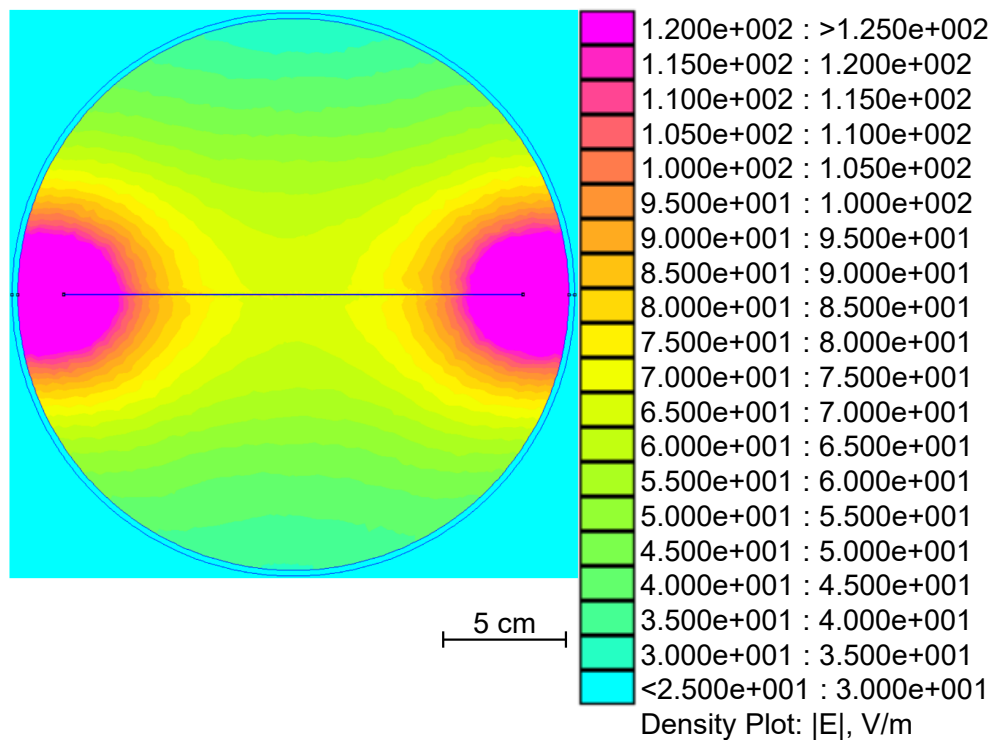


Fig. 19.1: Electrical field strength simulation flat capacitor in round pipe [Mei22]

The simulation shows the electric field strength in the first prototype. The cross-sectional area of the transport channel is shown. A direct current (DC) voltage of 5 V is applied across the capacitor for the simulation. The simulation shows that the electric field is distributed inhomogeneous over two spatial axes. The position of a sample in the capacitor therefore influences how strong the electric field is that penetrates it. In the following, the homogeneity of the field is to be increased by changing the set-up. [Mei22]

The field strength of the first prototype still depended on two spatial dimensions. the field strength now only changes with the distance to the centre point. Nevertheless, the electric field has an inhomogeneous distribution. For this reason, the shape of the transport channel is adapted to the flat electrode in second version. The cross-section of the channel is now rectangular, the inner electrode is a surface, as in first prototype and the cross-section is therefore a line. The simulation result is shown in Fig. 19.3 is shown. [Mei22]

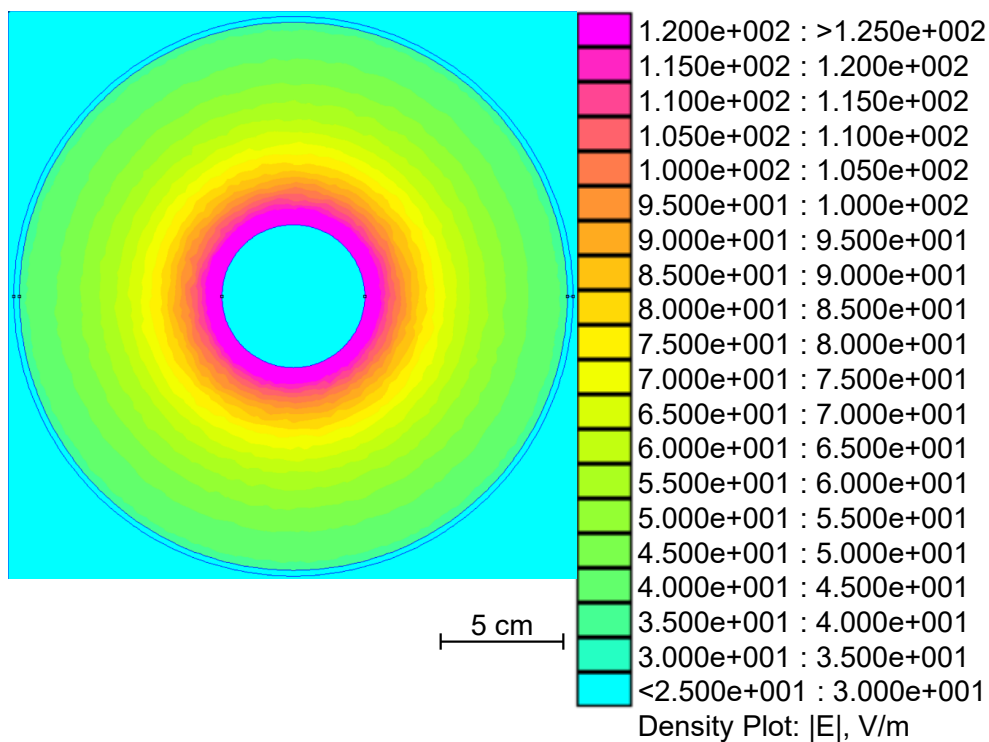


Fig. 19.2: Electrical field strength simulation, round capacitor and pipe [Mei22]

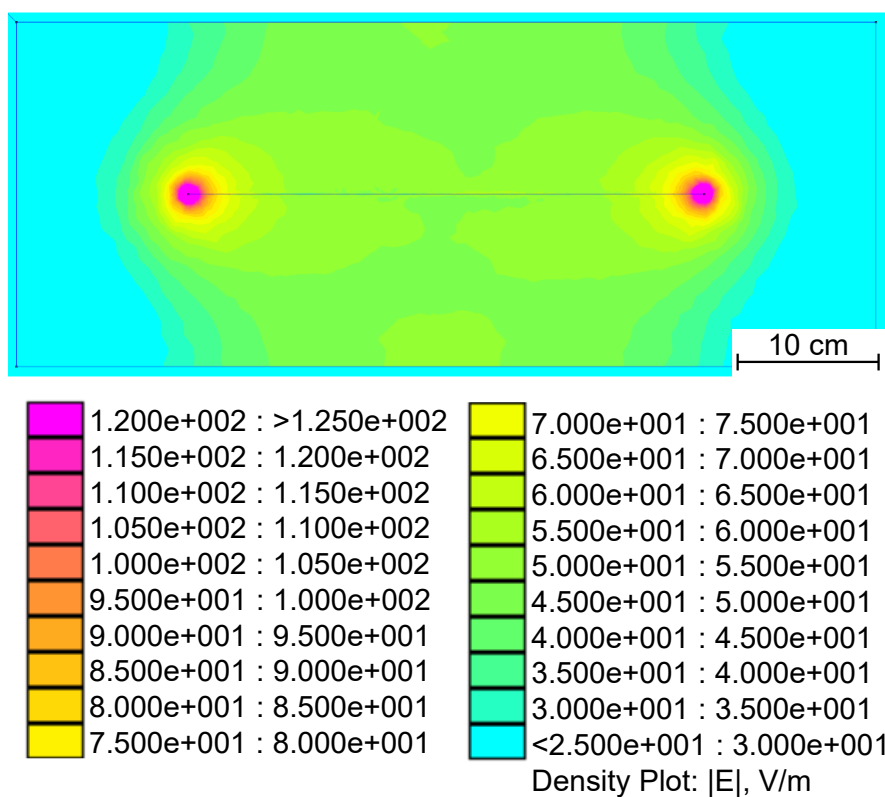
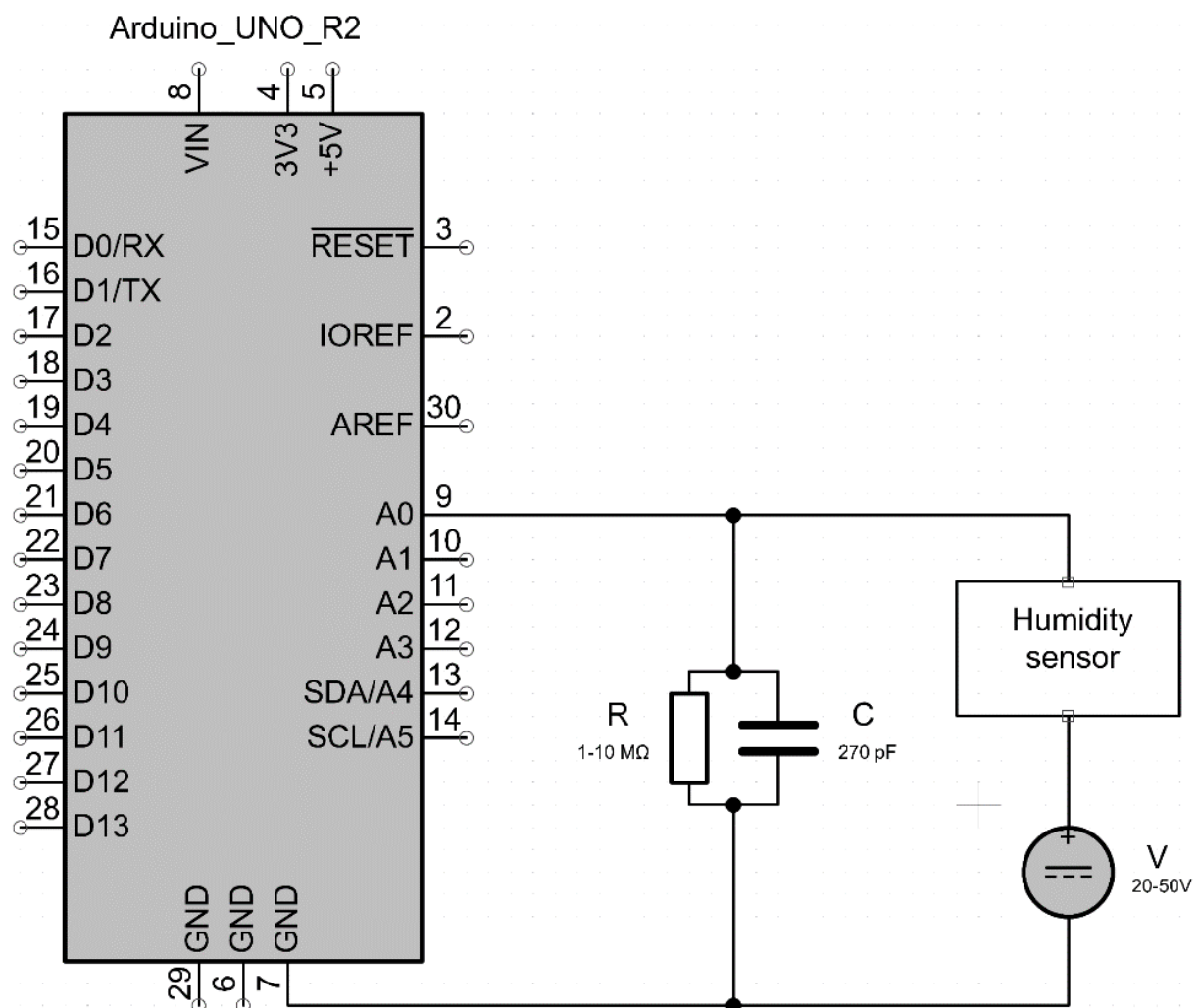


Fig. 19.3: Electrical field strength simulation, flat capacitor in rectangular pipe [Mei22]

20 Annex G: Arduino set-up and program Code for moisture measurement

For a fast understanding, there are the ports of the Arduino Uni Board described left sided. Only few ports are used. The Electric circuit is included in this schematic drawing on the right side. Below, the used standard protocols as well as the specific code is displayed for re-building this Arduino measurement system.



```
#include <TM1637Display.h>
```

```
#define CLK_PIN 4 // Define the CLK pin
```

```
#define DIO_PIN 3 // Define the DIO pin
```

```
TM1637Display display(CLK_PIN, DIO_PIN);

const int A0_PIN = A0;

void setup() {

  Serial.begin(9600);

  display.setBrightness(0x0f);

  display.showNumberDec(1234);

}

void loop() {

  unsigned long startMillis = millis();

  unsigned long summe = 0;

  unsigned int anzahlWerte = 0;

  while (millis() - startMillis < 1000) {

    int rohwert = analogRead(A0_PIN); //

    summe += rohwert;

    anzahlWerte++;

  }

  float mittelwert = static_cast<float>(summe) / anzahlWerte; // Mittelwert berechnen

  Serial.println(mittelwert);

  int Messwert = (mittelwert);

  display.showNumberDec(Messwert);
```

21 Annex H: Occupational Safety and Health (OSH) view

The most often high expense accident is arm or hand caught in a lint cleaner or gin stand. Further statistics can be found in [RMS+94] or from the USDA. [RMS+94]

But even beside those sources of injury, there are several more things, which could go wrong. These are divided to the following categories within this Chapter:

- Noise
- Dust
- Crushes

To get a better overview of the background, Chapter 21.1 gives an overview of the types of injuries and how they occur. Afterwards, Chapter 21.2 deals with Concepts of risk reduction, due to logical conclusions of the before mentioned.

To get rid of the undesired short fibre flies and dust exhaust, easy mechanical design changes could help. Most fibres and dust are exhausted by the condenser fans. Covering those fans completely, significantly reduces the ejection of those particles. They do not only keep the housekeeping busy. Instead, it may harm the operators health and causes serious fire hazards. This is the case for the mill staff as well as residents of the immediate surrounding. [PCM94]

In combination with the very high amount of linters in the air, fires expand very quickly or even lead to explosions. This phenomenon is well known as a dust explosion in the area of fire fighting, for example from carpenter's workshops with sawdust. Not only the fibres laying on the construction site could burn. An ignitable mixture of dust and air could lead to dust explosions, as it is the case in several bakeries in Germany some decades back. It is especially dangerous in a surrounding, where gas or even electrical heating devices are used at critical ignition temperatures for cotton drying or other purposes. In India fire detection systems are widely used in the air conveyor system to sort out burning cotton to a water bin outside the ginning facility. Especially in those areas, proper maintenance and awareness are highly important.

21.1 Sources of occupational safety and health issues

Many failures occur, due to the long shifts of 12 hours, from 8 to 8 in two shift models. Sometimes two shifts are done after each other, which increases the risk of accidents significantly. [Pra07] Most of the employees in this segment are untrained. All steps, cleaning, over operating the machines, up to mechanical or electrical power line works are done by the same, untrained operators. Therefore, often short circuits or free hanging power lines lead to serious accidents or fires in the ginning mills. [Pra07]

21.2 Concepts to reduce the risk of injury

Several observations already have been pointed out by Eigenstetter in earlier publications. These refer to observations within the research project of ITA, supported by Deutsche Gesellschaft für international Zusammenarbeit (GIZ) GmbH, Bonn, Germany and funded by the Federal Ministry for Economic Cooperation and Development (BMZ), Berlin, Germany. Within this project, it was possible to go to India for two weeks for investigations in the ginning facilities. Moreover, the project was supported by the Indian consultant Raina Consulting and Associates Pvt. Ltd., Mumbai, India.

Noise

It is investigated, that a noise level above 85 dB in a prolonged exposure lead to hearing impairments [Coo74]. Cotton gins generally create noise levels of 95 to 98 dB. This varies from the position of the operator and how close he is to the most noise exposing machines. Most noisy are fans and (tandem) lint cleaners. Reduction could be made by ear protection devices. It just needs to be assured, that they are worn properly. Most probably this is done if they are fitting well. [AW94]

Dust

If fugitive dust is a issue in the ginning mill, it should be measured for its management. A critical amount of fugitive dust could be reduced or suppressed by

spraying water at the cyclone level. This even promote the composting of the trash. In some US states it is mandatory to use. [PCM94] These injuries might be significantly reduced by reducing the dust in the ginning mill and content of interactions with the machines. If there is no manual interaction required with the machine, the risk to be drawn into the machine by the washer for example, is next to zero. This is also valid for injuries due to burns by a hot surface, as the washer is.

Crushes

Often, moving party which are covered with metal sheets get uncovered during maintenance. Probably to save time or by motivation, those coverings often don't get installed before running the machine again. Open turning parts as the gears and belts must remain covered to stay safe [Pra07]. Otherwise, extremities, clothes, hair or other free moving thing might get withdrawn.