PRELIMINARY THERMAL IMAGING OF COTTON IMPURITIES

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Abstract

Discrepancies exist between the Advanced Fiber Information Systems (AFIS) seed coat nep measurements and the seed coat fragment count upon visual inspection. Various studies have indicated that the two techniques may not be sensing the same contaminants as seed coat entities. Thermal imaging is an emerging technique for identifying and quantifying impurities in the food industry. Heat is applied to increase body surface temperatures above background. Thermal decay of surface temperature is detected by a thermal imaging camera that senses emitted radiation in the infrared range. Images produced show the impurities with different surface temperatures visually displayed in different colors. Temperature-time series curves of each impurity spot in the thermograph give the information to build discriminating algorithms and to compare selectivity for one impurity over another. Preliminary thermal imaging of raw cotton impurities, both natural (leaf, stem, seed coat fragments, etc.) and plastic (module covers, twine, agricultural mulch, etc) has shown that this new approach to measure seed coat fragments is selective over the other contaminants. Also, the plastic impurities may be differentiated from the natural impurities. The initial time series results are presented based on adding known impurities to a control cotton.

Introduction

The Advanced Fiber Information System (Zellweger Uster, 1996) provides an automated instrumental test method to measure seed-coat fragments referred to as seed-coat neps (SCN). Seed-coat neps are entanglements of seed-coat fragments (SCF) which remain with attached fiber during opening in the AFIS. Seed-coat neps differ from the traditional neps, which are entanglements of fiber only.

Microscopically obtained numbers of SCF were significantly different compared to AFIS SCN (Jacobsen et al. 2001). The authors suggested that the AFIS does not detect the same impurities counted by the manual method or the entities are categorized differently (e.g., NEP instead of SCN). Another study obtained SCF by ASTM D2496 (1985) using low power magnification (x3) and detected visually by the operator (Boykin, 2008). Results compared to AFIS SCN were lower or higher, with little correlation, when averaged within a variety. Another study demonstrated the addition of isolated SCF to hand-cleaned cotton affected the levels of SCN and neps (Bel, 2011). The author suggested that the opener in the AFIS breaks up the SCF into smaller particles. These smaller particles may become tangled with fibers and are classified as neps. A formula for SCN selectivity was derived and modeled (Montalvo et al., 2014). Selectivity values were calculated from published AFIS results and new data. Low SCN selectivity was demonstrated in the presence of traditional fiber neps (Montalvo et al., 2014).

There is a need to understand exactly what the AFIS is sensing when it senses SCN. For example, in the processing of cotton samples in the AFIS some SCF remain with the fiber stream and enters the neps (fiber and seed coat) sensor. Due to size exclusion, other SCF are removed from the fiber stream and not counted as seed coat neps. In addition to this type of seed coat elimination in the AFIS, are there other seed coat properties that have not been identified and contribute to seed coat segregation from the fibers? If we could show the existence of these hidden seed coat properties, perhaps the findings could be exploited by developing a new processing approach to remove the contaminant before it is found in yarn and fabric.

An appropriate reference method for comparative analysis of the count and size of SCF in raw cotton and SCN in cotton opened by the AFIS fiber individualizer is not available. In fact, no common method exists in the literature that has been applied to both raw cotton and cotton opened by the AFIS. Existing microscopic test methods are performed by human operators, and the results could be affected by age, their concentration and motivation, fatigue, and room conditions (lighting, heating, ventilation, noise, etc.). The methods are time consuming, especially when the SCF or SCN particle is hidden in opaque (thick) cotton samples.

Other natural impurities in raw cotton are the trash components – leaf, stem and hulls – which must be differentiated by the reference method from seed coat particles. Another class of impurities in raw cotton is the plastic materials such as module covers, irrigation tubing, etc.

Thermal imaging (TI) is an emerging, non-invasive analytical technique in the food industry for measurement of post harvest quality and foreign body detection (Gowen et al., 2009). The sample is heated briefly to activate a gradient in the surface temperature of food, food defects and foreign bodies. A TI camera maps both spatial and temporal temperature distribution patterns. The resultant cooling (temperature)-time series images showed that the thermal properties of food and foreign bodies is different and may be used to detect and remove defects and impurities. The present study summarizes initial time series observations, using off-the-shelf thermal imaging equipment, to differentiate SCF from the other trash and plastic impurities on the surface of raw cotton. Results are promising.

Fundamentals

The basic principle of thermal imaging (TI) is that all materials emit infrared radiation. In TI cameras the emitted radiation is converted into an electrical signal via IR array detectors in the camera and displayed as colors corresponding to surface temperatures. The temperatures may be digitized. In contrast, NIR imaging systems measure the diffuse reflected radiation (Gowen et al., 2009).

Generally, the application of a short-term energy pulse to a target sample, for example by use of a flash lamp, is sufficient to increase the surface temperature above background. The pulse duration can vary from milliseconds to seconds. The image acquisition speed of the TI system may be high, 50 – 60 images per second, which is especially suitable for exploring rapidly changing surface temperatures. On the other hand, low end systems using an oven to increase surface temperature and capable of producing only a single image at a time are useful in exploring the feasibility of TI in a new application.

In developing sophisticated algorithms for discriminate analysis the following independent variables for time-series data have been used (Vadivambal et al., 2010): average temperature, minimum and maximum temperature, maximum minus minimum temperature, and standard deviation. Other researchers converted the time series of decreasing temperatures to gray levels versus time (Ginesu et al., 2004). With appropriate threshold(s), the desired contaminant image can be displayed as white in a black background or the inverse.

Now consider the form of the cotton sample analyzed for non-lint impurities by TI. The ideal geometrical arrangement seems to be a translucent web rather than the thicker opaque mat. This would allow for detecting both SCF in ginned lint and SCN in AFIS analyzed lint by TI, with minimum shading from the cellulose fibers. The seed-coat particles could be qualitatively detected, counted and sized by the reference method. The webs could be archived for further investigations. Also, seed-coat particles could be extracted by forceps and placed in labeled containers along with AFIS trash box residues. Comparative analysis would allow for SCF and AFIS SCN determinations, and understanding why some seed coat particles end up as SCN and others as mere trash and dust.

A translucent web is also beneficial for qualitative detection of plastics by TI. The goal here is not to identify the individual plastic contaminants found in raw cotton but simply to group these materials under the common classification as “plastic”. Another qualitative aspect of the TI approach is to distinguish between SCF and plastic entities.

Materials and Methods

Control Cotton, Natural and Plastic Impurities

Commercially available mechanically cleaned, scoured and bleached cotton was used as the fiber medium to form translucent webs for the spiking experiments. Mixed cotton trash, separated from raw cotton during ginning and cleaning, was provided by the U.S. cotton Ginning Laboratory in Stoneville, MS. In addition, stems and hulls were included in the shipment. Module cover (yellow), agricultural mulch (black), irrigation tugging (black) and twine (red) were also obtained from the ginning lab.

Seed coat fragments were produced by cutting open seeds, removing the meats, and breaking the fragments into the desired size range.

Web Preparation and Spiking

Approximately 0.5 grams of control cotton were hand carded into an approximately 125 mm by 75 mm thin web and used as the medium to hold the impurities to be analyzed. A series of natural and plastic impurities were carefully placed upon the cotton fiber webs approximately 10 mm away from each other. Three replications of each impurity were placed in a row on the cotton fiber sample. Notation of each location of impurities was made. See Figure 1 as an example of added natural impurities, and Figure 2 as an example of added plastic impurities.

Heating

To produce surface temperatures above room temperature, the webs with added impurities were heated in a Yamato DKN 600 mechanical convection oven with a 150 liter capacity and a mean flow rate of approximately 1.3 liters/second. The samples were placed between two approximately 5 mm thick, 200 mm square glass plates to evenly dissipate heat and to keep impurities from being dislodged by the air currents in the convection oven. All samples were placed in a 75^{o}C oven, for natural impurities and 125^{o}C oven for plastic impurities for a duration of 15 minutes. Temperatures and times are not great enough to significantly damage the sample. Tables 1 and 2 contain more detailed sizing information. Samples were of adequate size to be easily detected by the thermal imager as well as to give a temperature range for the various impurities.

Table 1. Natural Added Impurities

Natural Impurities	Size range (mm)	Time (sec) of Images
Seed coat fragment, fuzz side up	1 - 3 x 1 - 3	0, 10, 20, 30, 60, 90, 120, 180, 240
Seed coat fragment, dark side up	1 - 3 x 1 - 3	0, 10, 20, 30, 60, 90, 120, 180, 240
Stem	0.5 x 3 - 5	0, 10, 20, 30, 60, 90, 120, 180, 240
Hull	2 - 3 x 2 - 3	0, 10, 20, 30, 60, 90, 120, 180, 240
Trash	1 - 3 x 1 - 3	0, 10, 20, 30, 60, 90, 120, 180, 240

Table 2. Plastic Added Impurities

Plastic Impurities	Size range (mm)	Time (sec) of Images
Module cover	2 - 3 x 2 - 3	0, 10, 20, 30
Agricultural mulch	2 - 3 x 2 - 3	0, 10, 20, 30
Bale strapping	1 - 3 x 1 - 3	0, 10, 20, 30
Irrigation tubing	2 - 3 x 2 - 3	0, 10, 20, 30
Twine	0.5 x 3 - 5	0, 10, 20, 30

Thermal Imaging

Upon removal of samples from the oven, the top glass plate was carefully removed, and the fibrous sample with heated impurities moved onto lab bench. A Fluke TI 25 Thermal Imager (range -20 to +350^{o} C, ± 2^{o}C) was placed approximately 300 mm above the sample surface with the handle stabilized with a ring stand. Images were manually taken from 0 to 240 sec at time intervals of 10 or 30 sec (Table 1) for natural impurities and from 0 to 30 sec at time intervals of 10 sec (Table 2) for plastic impurities. Fluke SmartView 1.9.021 software was used to analyze the impurities. Each impurity was marked by hand using a combination image of the thermal and visual images to ensure temperature data was gathered for the point of interest. The data were then exported to Excel for analysis. It is important to note that instrument accuracy is ± 2 ^{o}C or 2% (whichever is greater).

Figure 1a. Natural impurities in cotton. In rows from top: seed coat fragment, fuzz side up, seed coat, dark side up, stem, trash, hull

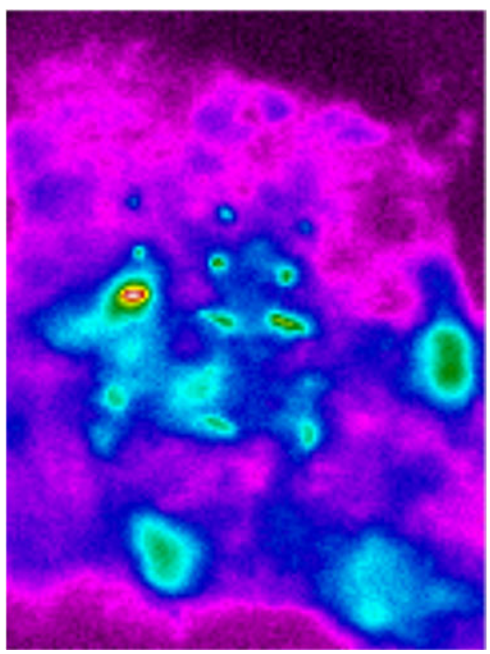

Figure 1b. Thermal Image Example of Natural impurities in cotton at time 0 sec. In rows from top: seed coat fragment, fuzz side up, seed coat, dark side up, stem, trash, hull

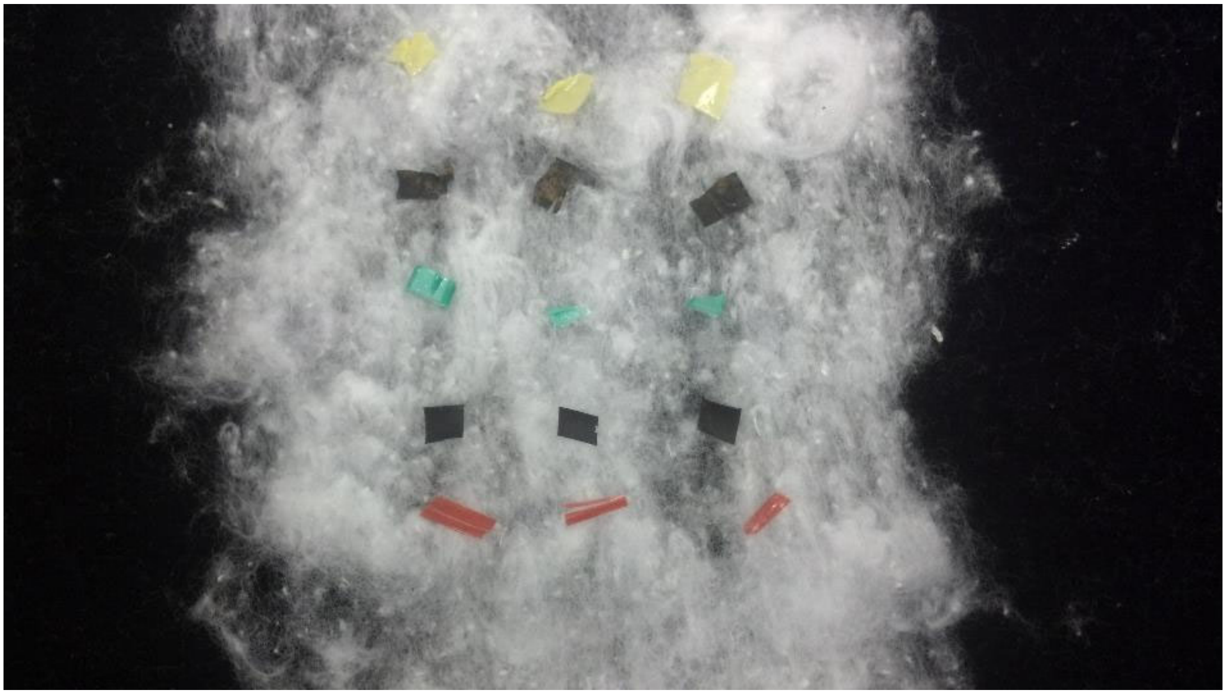

Figure 2a. Plastic impurities in cotton. In rows from top: yellow module cover, agricultural mulch, green bale strapping, irrigation tubing, red twine

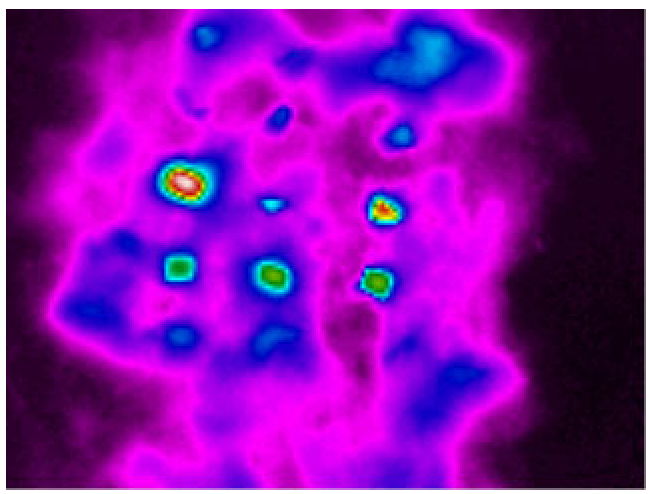

Figure 2b. Thermal Image Example of Plastic impurities in cotton at time 0 sec. In rows from top: yellow module cover, agricultural mulch, green bale strapping, irrigation tubing, red twine

Results and Discussion

Natural Impurities

Figure 3 shows the thermal decay curves after warming the sample for 15 min at 75°C. Averaged surface temperature of the spiked impurities was plotted against the time in seconds after removal from the oven. The black surface of the SCF entity faced the TI camera. When the time delay was one or more minutes, the surface temperature of the materials of interest reduced to the background temperature. As the delay approached zero seconds, the surface temperature rose and the seed coat particles were the warmest. At zero seconds, averaged temperature difference between the seed coat (maximum temperature) and stem (minimum temperature) was 1.56°C.

The experiment was repeated with the following changes. Another row of SCF was added to the translucent web such that the white, fibrous fuzzy side of the SCN would face the TI camera. The dark, hard surface of the SCF remained as a row to face the TI camera. Also, TI temperatures were taken at 0, 10, 20 and 30 seconds after heating. The resultant averaged temperature decay curves are shown in Fig.4. This study confirmed Fig. 3 results. At zero seconds, with the SCF dark side up, its surface temperature was the warmest compared to SCF fuzzy side up and the other natural contaminants. The surface composition, texture, smoothness, heat conductance and heat capacity all play a role in the initial surface temperature and the rate of thermal decay. At zero seconds, averaged temperature difference between the SCF dark side up (maximum temperature) and trash (minimum temperature) was 5.2°C. Thus, the temperature distribution of the SCF is complex. Temperature control of the room would have maintained the background temperature and temperature of the spiked entities at a fixed value (Vadivambal, 2010) and is recommended for the cotton impurity applications.

Heating at 125°C for 15 min followed by thermal imaging at 0, 10, 20 and 30 seconds produced different results (Fig. 5) compared to Fig. 4. Evaporation of water from the interior of the natural impurities followed by evaporative cooling at the surface may have changed the order of the surface temperatures. Thermal decay was more rapid compared to Fig. 4. The TI method is not as selective for SCF in the presence of the other natural impurities when the web was warmed at 125°C.

Plastic Impurities

Since the best TI results with the natural impurities in cotton were produced by heating the spiked web at 75°C and thermal imaging at 0 to 30 sec, the plastic impurity experiments were conducted at similar conditions. Figure 6 represents the temperature-time series curves. The surfaces of the agricultural mulch, irrigation, red twine and yellow module cover did not warm up much above background when the differential temperatures were produced by warming at 75°C for 15 min. However, the averaged green bale surface was 36.2°C at 0 sec and after a 10 sec delay before thermal imaging; the average surface temperature was 33.1°C.

These results are explained as follows. In contrast to the natural impurities, the plastic entities are drier, smoother surface, and a lower heat conductance and heat capacity. Thus, these materials are more difficult to warm, and lose their heat more slowly. When the temperature differential was forced by heating at 125°C for 15 min (Fig. 7), all synthetic materials responded to the thermal radiation input. The averaged green bale surface was 51.5°C at 0 sec and after a 10 sec delay before thermal imaging, the average surface temperature was > 45°C. The thickness of the bale (1.5 mm) is probably responsible for the higher surface temperature compared to the other plastic impurities.

A careful examination of Figs. 4 to 7 suggests that good selectivity for SCF (dark side up) over the other natural impurities, and plastic impurities, is possible by warming the web at 75°C and thermal imaging 0 to 10 sec followed by re-warming at 125°C and a repeat imaging 0 to 10 sec. Good selectivity for the plastic impurities over the natural impurities is possible by analysis of the same imaging data but with a different discriminating algorithm.

Conclusions

This is the first report of the use of thermal imaging to address the needs of the industry in rapid detection of seed coat and plastic impurities in ginned (raw) cotton. After thermal activation of the differential temperature of impurity surfaces, the recorded thermal decays at 0 to 10 after excitation followed the same pattern as, for example, detection of foreign bodies in food.

The cotton web results justify the evaluation of a more sensitive TI camera and pulse heating system. A two-stage system may be needed to analyze for SCF in the presence of the other natural impurities, and the presence of plastic impurities. Stage One: As in the food analysis, the pulse may be applied to the web for several milliseconds and a turntable move the warmed sample to the camera. A fast TI camera may record 50 to 100 frames/sec for several seconds. Stage Two: The turntable returns the web to the pulse heating station for application of a more intense pulse followed by the TI recordings. One entire cycle may be completed in less than a minute. With greater amounts of data gathered in a shorter period of time, sophisticated algorithms may be developed to provide discriminating analysis of seed coat and plastic impurities in the cotton.

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Disclaimer

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JCIBPC Polyethylene terephthalate bale strap http://www.cotton.org/tech/bale/specs/ties.cfm

John Deere module cover http://www.tama.co.il/tama-round-module-wrap/tama-rmw/

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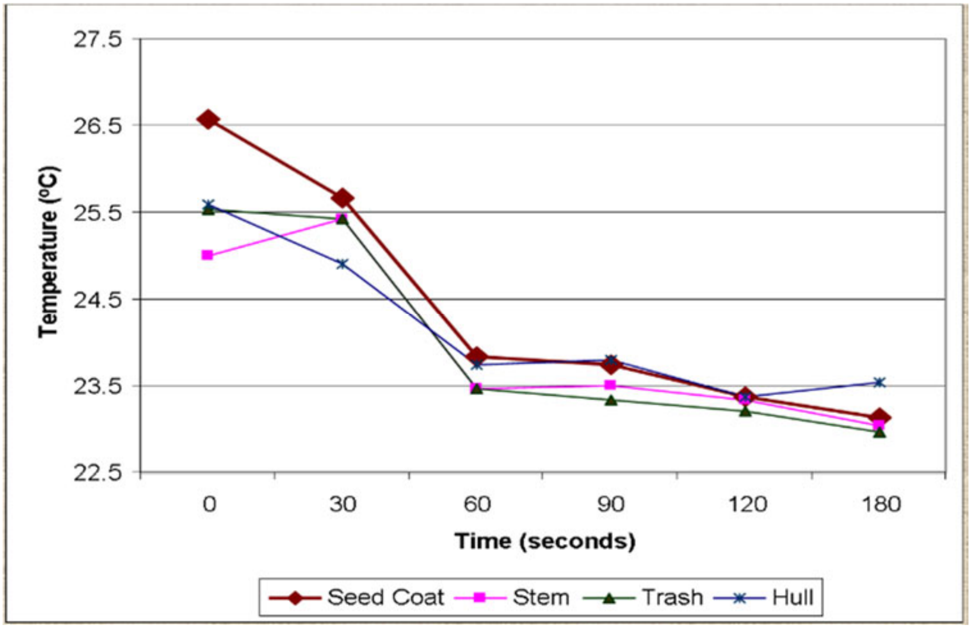

Figure 3. Natural impurities in cotton. Mean surface temperature after heating for 15 minutes in 75°C oven.

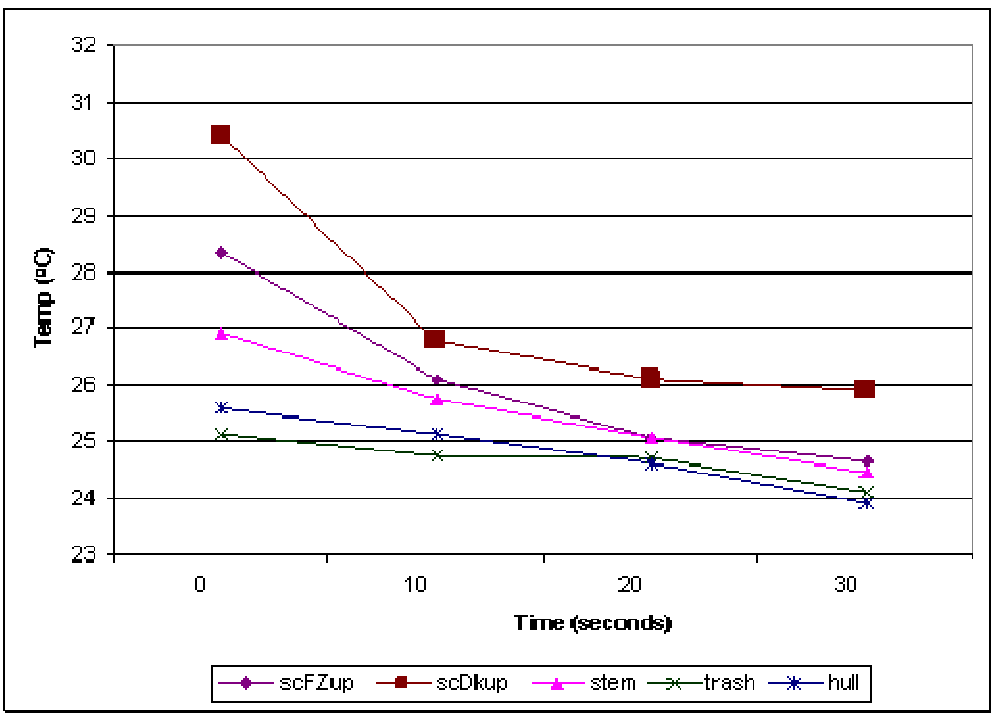

Figure 4. Natural impurities in cotton. Mean surface temperature after heating for 15 minutes in 75° C oven. Seed coat fragment: fuzzy side up (scFZup) and dark side up (scDKup).

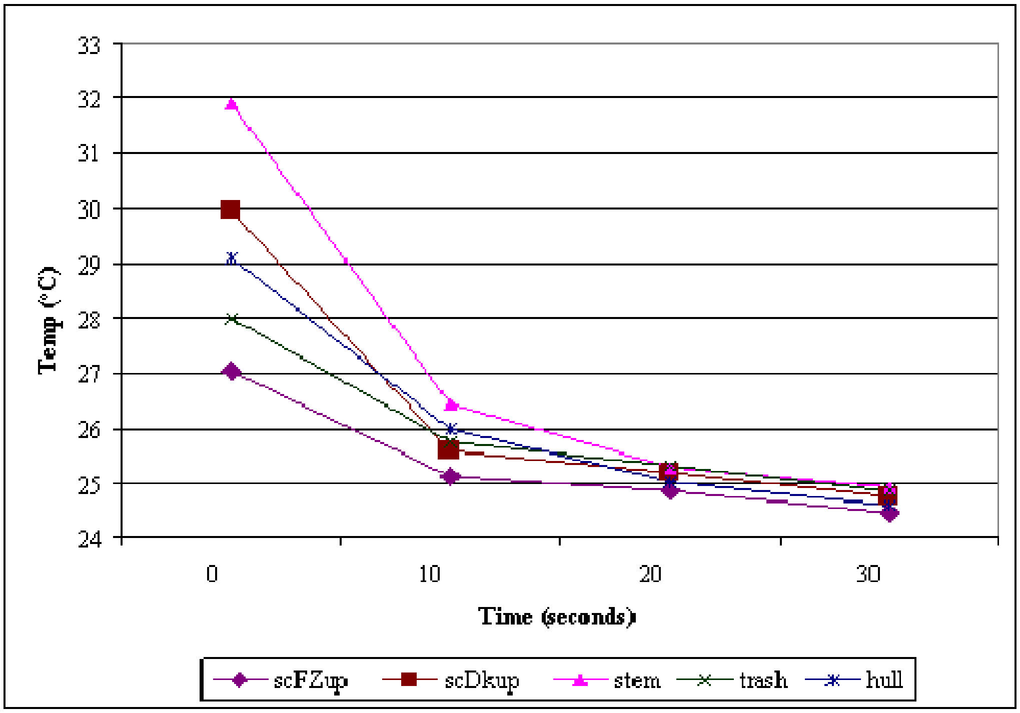

Figure 5. Natural impurities in cotton. Mean surface temperature after heating for 15 minutes in 125°C oven. Seed coat fragment: fuzzy side up (scFZup) and dark side up (scDKup).

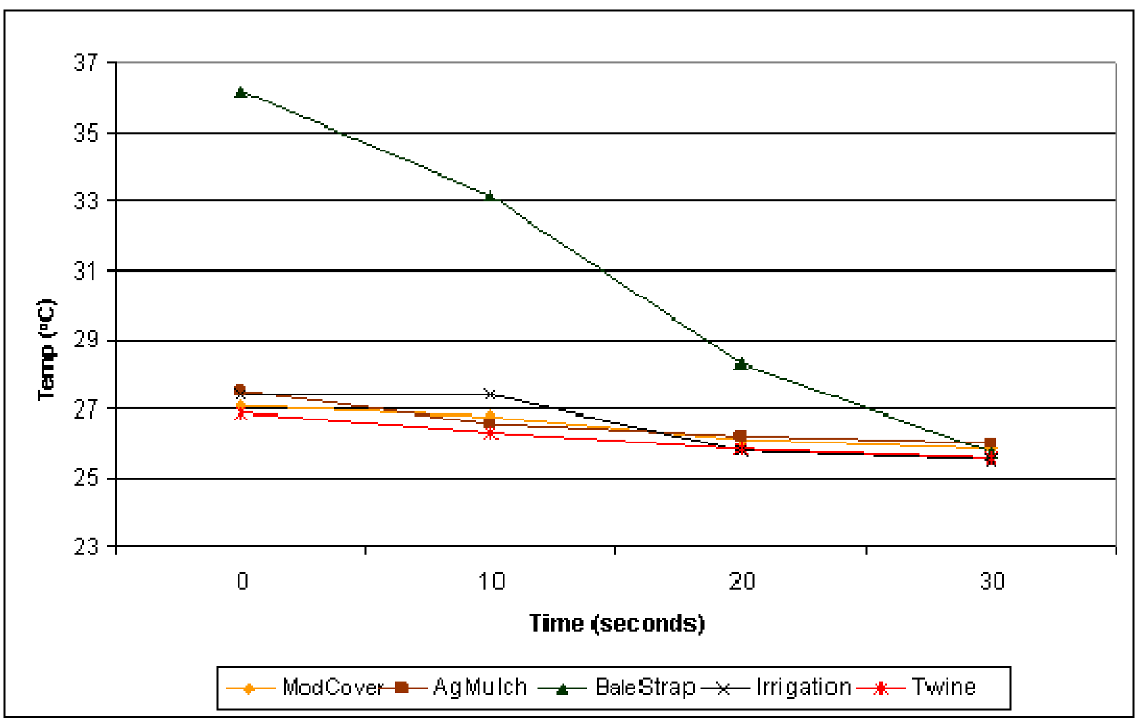

Figure 6. Plastic impurities in cotton. Mean surface temperature after heating for 15 minutes in 75°C oven. Plastic: yellow module cover (ModCover), black agricultural mulch (AgMulch), green bale strap(BaleStrap), black irrigation tube (Irrigation), red twine (Twine).

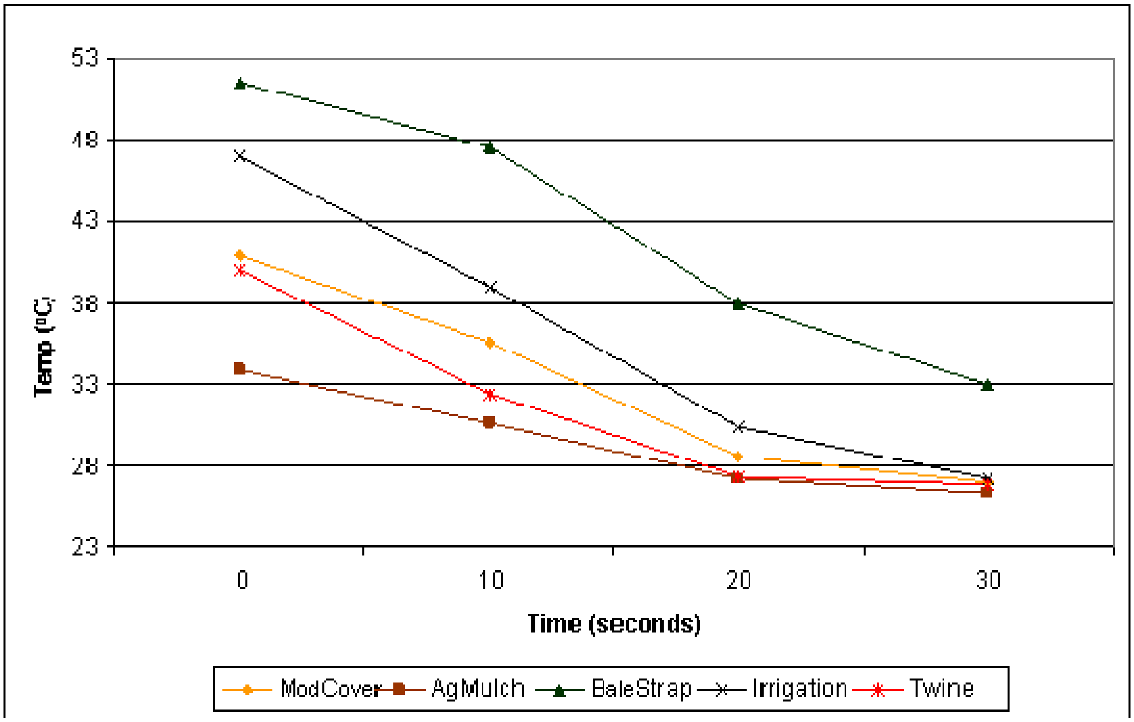

Figure 7. Plastic impurities in cotton. Mean surface temperature after heating for15 minutes in 125ºC oven. Plastic: yellow module cover (ModCover), black agricultural mulch (AgMulch), green bale strap(BaleStrap), black irrigation tube (Irrigation), red twine (Twine).