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Explorative research to identify the most efficient storage condition for Ethiopian washed green Arabica coffee beans in order to retain and control their sensorial quality.

Shelf-life study

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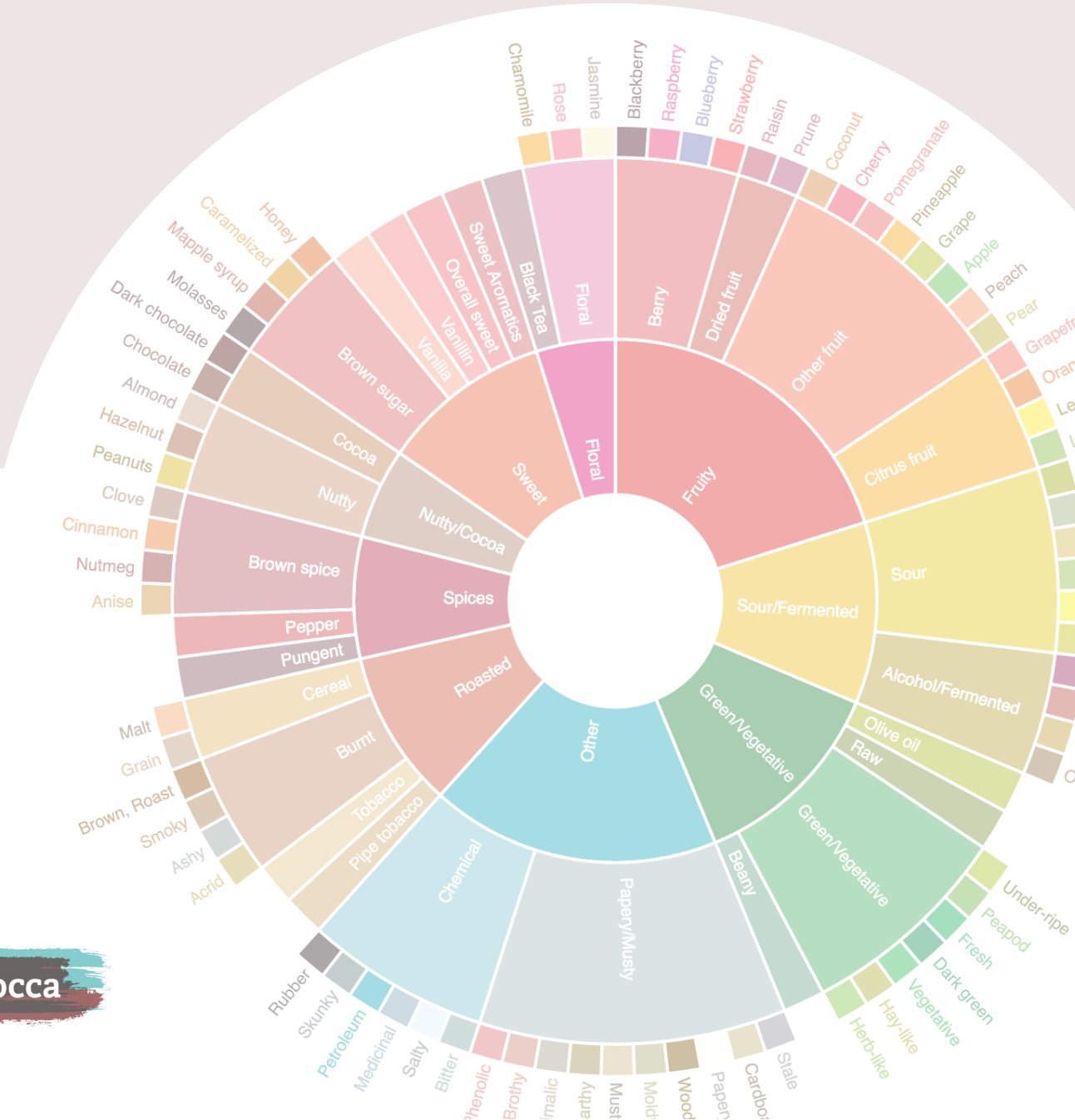

Trabocca

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Abstract

The longevity of the sensorial quality of green coffee beans is essential for the commercial quality and value of coffees. This study explores the influences of packaging materials and storage conditions on the sensorial quality of green coffee beans during storage to optimize the quality longevity of unroasted coffees. Ethiopian washed grade 2 green coffee beans were packed in 4 different types of packaging (Grainpro, Klabin, Jute, Vacuum) and stored for 18 months under both controlled conditions (15 degrees Celsius, 60% humidity) and uncontrolled conditions (influenced by Dutch climate). Sensorial analysis (according to SCA cupping) and measurements of moisture content, water activity, and peroxide value were completed on all samples after 3, 6, 12, and 18 months of storage. The study has found persistent quality scores in Grainpro and Vacuum packaging up to 12 months of storage. Major quality losses were observed in coffees stored in jute bags, in which aroma and aftertaste suffered the largest losses due to the increase in moisture content of green coffee beans. This was found to have a negative influence on the sensory profile of the coffees. Comparable profiles and quality were observed in the coffees stored in conditioned and unconditioned storage, concluding that conditioned storage might be unfavourable and may not always have an advantage over unconditioned storage. Due to this finding, conducting more and extended research on the influence of storage climates and packaging materials on the longevity of the quality of green coffee beans is advisable.

1. Introduction

Coffee is one of the highest economically valuable crops in the global markets. *Coffea arabica* (arabica) and *Coffea Canephora* (Robusta) are the most well-known species within the range of coffee species, in which *Coffea arabica* has major economic significance since its production around the world has a higher commercial value due to a higher level of aroma and acidity but less body than Robusta coffees (Rendón, Bragagnolo, & de Jesus Garcia Salva, 2013). Coffee is one of the most widely consumed products. The global production of coffee reached 175 million (60 kg) bags in the season 2020/2021. The production of Arabica coffee is relatively 103 bags, while Robusta accounted for 72 million bags (Statista, coffee market worldwide, 2022). Coffee knows three general and commonly used types of processing, the washed (wet) process, the natural (dry) process, and the honey (semi-washed) process (Korhonen, 2020). As the wording suggests, the wet process requires the use of water. Whereas, the dry process does not. The semi-washed process is a hybrid version where water in lesser amounts is required. When the processing is finalized, the

green coffee beans will be dried until the desired moisture content of approximately 12% has been reached to preserve the green coffee beans safely in storage. Afterwards, the green coffee beans are destoned, hulled, and polished before the shipment starts. The beans will be graded on bean size, colour, and quality. (Wintgens, 2004).

The sensorial quality of the coffees is generally determined by the use of a standardized scoring system by the Specialty Coffee Association. Panellists are assigned to evaluate seven sensory attributes (aroma, flavour, aftertaste, acidity, body, balance, and overall impression). Several chemical compounds are influencing the sensorial score of coffee beans. Coffee is indicated to have high concentrations of phenolic acids, with the most studied phenolic compounds being chlorogenic acids. Chlorogenic acids account for approximately 8% of the composition of the green coffee bean. More than 40 different varieties have been identified in green coffee beans, with 5-caffeoylquinic acid being the most persistent (Zarabska, et al., 2022). The degradation of several of these compounds influences the sensorial profile of coffee beverages. Coffee beverages with higher levels of caffeine and other chlorogenic acids are connected to lower quality scores, while coffees with higher levels of cafestol, sucrose, and citric acids are usually associated with higher quality scores (Barbosa, Scholz, Kirzberger, & Benassi, 2019). The degradation of these chemical compounds is influenced by the storage conditions of the green coffee beans. Both typical 'woody' notes and flattening of the cup quality are resulting from the presence of sensory precursors due to the ageing of green coffee beans, which presence might be accelerated by inefficient transport and storage (Selmar, Bytof, & Knopp, 2007). Additionally, well-known ‘off-notes’ are ascending from undesired oxidation of lipids. Optimal storage conditions are required to maintain the full quality of the product and thereby the full economic value of the coffee over a prolonged time.

Ineffectual storage might be due to the type of packaging which is used for the green coffee beans. Research from Tripetch & Borompichaichartkul in 2019 on the effect of packaging materials and storage time on chemical changes in green coffee beans indicates that packaging materials with a hermetic barrier (HDPE, high-density polyethene) offer an efficient barrier against water vapour migration over a long period more than 10 months. Green coffee beans stored in jute or paper packages that are permeable to gases and water vapour will experience higher decreases in quality over time. During storage, temperature and moisture content have been proclaimed as the major factors that cause sensorial changes in the coffees (Selmar, Bytof, & Knopp, 2007).

Within Trabocca, the green coffee beans might spend multiple months in storage before they will reach the customer (roaster). The literature above indicated that the storage conditions of green coffee beans have a large effect on the control of the coffee quality, but there is a lack of a standardized most efficient way of storage and information on its influence on the sensorial quality of the coffees is limited. Sensory scores are used as the main quality indicator for sourcing and sales within Trabocca. The longevity of the sensorial quality of green coffee beans is crucial to meeting the quality demands of customers over time. Ensuring optimal storage and packaging conditions creates a cost-efficient and sustainable quality management policy. Finding the most efficient storage condition may not only be valuable for quality properties. It might also support the sourcing of a fully controlled warehouse for more than one customer in a specific region. Therefore, this study investigated the influence of storage conditions and packaging materials on the sensorial quality of green coffee beans. The aim of this study consists of three parts. At first, the major focus was to find and identify the most effective storage condition of green coffee beans, considering packaging materials and warehouse conditioning, based on the sensorial quality of the stored coffees. The second aim was put on differences in physicochemical properties of the stored coffees within akin combinations of storage. Thirdly, the study aimed to find a reliable and representative physiochemical parameter for quality measurements, which connects physiochemical measurements to sensorial attributes. The results of the research might support Trabocca in the decision-making process regarding packaging materials and storage conditions in the future.

2. Methodology

2.1 Packaging and storage - The most traded type of green coffee bean by Trabocca; Ethiopian Arabica washed Guji (grade 2) was packed in four different types of packaging (Grainpro, Jute, Klabin, and Vacuum). The Grainpro bags, designed for 60 kg of coffee consist of a tough, transparent multilayer Polyethylene (PE) plus a barrier layer, 0.078 mm thick (0.003 inches), surrounded by a jute bag (barrier closed with a zip tie, jute is sewn) (chemical name: Ethylene vinyl alcohol copolymer). The jute bags were Ethiopian jute bags designed for 60 kg of coffee. Materials used to produce these are jute fibre (organic), food-grade rice brand oil (organic), organic emulsifier, and light water. The packaging is free of hydrocarbons and harmful chemicals such as DDT and heptachlor (sewn). Klabin offers a plastic barrier in a paper bag designed for 30 kg of coffee. This is identified as a kraft paper bag plus starch glue of PVA (polyvinyl acetate) plus ink. The plastic layer in the paper bag creates hermetic protection (sealed and sewn). For the vacuum packaging, the Univac 200 vacuum bag from Gamma-pack, designed for 22 kg of coffee was used. Consisting of 11 layers of coextruded film. The vacuum packs are packed in cardboard boxes. These packs were shipped from Djibouti in both a conditioned and an unconditioned container of which the data was used in another research. After arrival in The Netherlands in August 2019, the green coffee beans were stored in The Netherlands in two differently conditioned warehouses. The conditioned warehouse offers a controlled climate where the temperature was regulated at 15 degrees Celsius and the relative humidity was maintained at 60%. The unconditioned warehouse did not maintain climate control and had its temperature and humidity influenced by the season. Sensory evaluations and physiochemical measurements were taken from all different packaging and storage combinations after 3, 6, 12, and 18 months of storage. This study presents the results of all those 4 measurements.

2.2 *Chemical measurements* - Every sample underwent a series of chemical/physical measurements. Each sample was sent to Nutricontrol analytical solutions in Veghel (www.nutricontrol.nl) to analyse the moisture content (Sample dried for 4 hours at 103 degrees Celsius until constant weight) and the peroxide values. The water activity of the coffees was measured with an Aqualab Series 4TE laboratory specification water activity monitor (accurate: +/- .003 aw). The Sinar 6070 Grainpro moisture meter from Sinar technologies was used to measure the (bulk) density of the green coffee beans in the own lab of Trabocca B.V. in Amsterdam. The AtmoCheck DOUBLE by Hitec Systems was used to measure the residual oxygen and carbon dioxide levels inside the packages in the warehouses before sampling was done

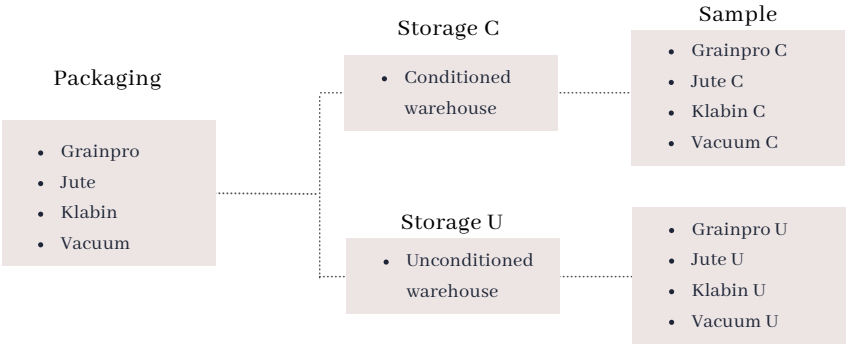

Figure 1, sample distribution. Sample were drawn and tested on sensorial quality and physiochemical properties after 3, 6, 12 and 18 months of storage.

2.3 Roasting - After 3, 6, 12, and 18 months of storage, the unroasted coffee samples were taken from the warehouse in Barneveld. A Probat BRZ4 gas sample burner was used following Trabocca's standard roasting procedure. After pre-heating, the samples were dropped in at 150 degrees Celsius. The caramelization process took approximately 6 minutes. The starting time of the first crack occurred after 7 minutes at 200 degrees Celsius. For washed coffees, Trabocca's roasting procedure describes an ending time between 68 and 75 seconds. The total roasting time finished after 8-9 minutes.

2.4 Extraction – The roasted samples were ground immediately before the cupping sessions, with a maximum of 15 minutes prior. Different from what the SCA describes in their cupping procedure was that the sample was fully ground, before weighing out per cup, to increase cup uniformity. The optimum ratio is 8.25 grams of coffee per 150 millilitres of water. The Trabocca sensory procedure describes the use of 12 grams as the cupping bowls contain 200 millilitres of water, based on the roast, water TDS, and mesh size. The samples were ground to a mesh size of 900 microns using a Mahlkonig EK43 coffee grinder. The water used for the cupping sessions was clean and odour free. Reverse osmosis was used to ensure the purity of the water with a TDS (total dissolved solids) of 120 ppm. The water was poured on the coffee samples directly at a temperature between 94 and 97 degrees Celsius. The grounds were undisturbed for 4 minutes before the break and further sensorial evaluation continued.

2.5 *Sensorial evaluation* - Sensory analysis of the samples of coffee was performed according to the standardized procedure by the SCAA (2015). Four trained and certified panellists were asked to evaluate seven sensory attributes (aroma, flavour, aftertaste, acidity, body, balance, and overall impression) individually. Each parameter requires a score between 6 and 10 with intervals of .25. The final score consists of the sum of those scores, plus an additional 30 points (uniformity, sweetness, and clean cup) resulting in a score between 80 and 100 for specialty coffees. A lower score indicates lower quality, while higher scores represent higher qualities. Coffees scoring under 80 SCA points are not considered specialty coffees. Each panellist was given an individual set of samples to evaluate in a particular randomized order, to minimize the sensory carryover effect. Besides the seven sensory attributes, the panellists were also asked to indicate the level of perceived ageing on a 15-point line scale. The line scale indicates no perceived ageing at zero and a full loss of quality due to high perceived ageing at 15 points. A calibration session was initiated before the first sample evaluation. Moreover, a short version of this calibration was performed before the evaluation of each time interval. The sensorial analyses took place in the cupping lab of Trabocca B.V. in Amsterdam. The testing was performed under normal conditions of daylight and ambient temperature. To exclude biased panellists, all samples were coded with a randomized three-digit code. The order of the panellists was also randomized by an online tool. The samples were served in white cups, specially designed for cupping coffee. Silence was required during the evaluation since all panellists were asked to focus completely on the assignment. For every time interval, the analyses took place in the morning between 10 and 12 am. Panellists were asked to evaluate each sample one time, without going back to the previous sample. Furthermore, the panellists were asked to start the evaluation after 16 minutes of brewing.

2.6 *Statistical analysis* - All the results out of the sensorial analyses in this study are expressed as the mean from 4 independent cuppers (panellists) for both the conditioned and unconditioned transport (not considered, thereby n=8) plus standard deviation. The SCA and ageing scores were used as quality indicators. Mean values were compared by ANOVA (analysis of variance) and a Tukey correction post hoc test. The same principle was performed for both the SCA score and the ageing score on the samples. A Pearson correlation matrix and network analysis were made to indicate the correlation between sensory results and physicochemical measurements. Calculations were performed using the software 'JASP' version 0.16.1 (www.jasp-stats.org). Differences were considered significant when the probability value was <0.05.

3. Results & discussion

3.1 Influence of storage conditions and packaging materials on the sensory quality of green coffee beans - Sensory attributes were evaluated to indicate the quality of the coffee stored over a prolonged time. The cupping sessions (sensory analysis on coffees) were designed to assess 7 attributes on a 16-point scale between 6 and 10 points with an interval of .25. The final score is calculated as the sum of these individual assessments plus 30 points in addition to a clean cup, uniformity, and sweetness. All sensorial analyses were accomplished by 4 panellists who followed the coffee cupping protocol from the Specialty Coffee Association (SCA, 2015).

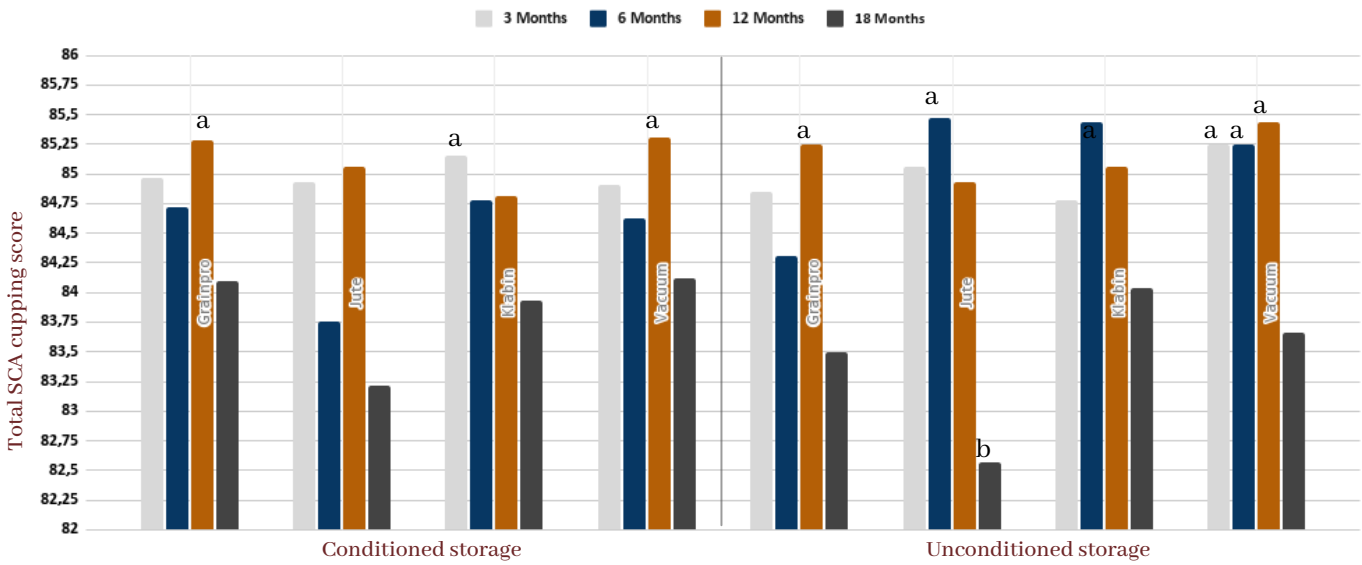

Figure 2, Comparison of total scores according SCA cupping standards (y) for the coffee samples in Grainpro, Jute, Klabin and Vacuum packaging for 3, 6, 12 and 18 months of storage in both conditioned and unconditioned storage (x). The superscripts a and b indicate significant (p<.05) differences between the coffees stored in different bags and under different conditions for 18 months in total. Mean values presented (n = 8).

Figure 2 shows all the SCA scores for all samples used in this research, divided by storage condition and packaging material. Figure 3 displays the sensorial scores for each sensory attribute depending on similar influences as a radar plot. After three months of storage (figure 2, light grey bars), the highest score was observed in the vacuum bag stored in the unconditioned warehouse (85.25 points). The unconditioned Klabin sample received the lowest score (84.78). No significant differences occurred between the scores after three months of storage in the combinations of storage condition and packaging material. 'Balance' and 'aftertaste' are scored slightly (0.25) lower, while 'flavour' and 'acidity' were kept stable in the perception of single sensory attributes after three months of storage (figure 3, green continuous and yellow dotted lines). The next evaluation appeared after 6 months of total storage time, where the largest decrease in cupping score occurs in the conditioned jute sample (1.4%). The cupping scores of both the unconditioned jute and Klabin samples increased compared to the scores of three months (0.5-0.9%). Zooming in on the single sensory attributes, it appears that the jute packaging scores perceptibly lower on 'aroma' and 'overall' in conditioned storage, while all unconditioned samples were scoring higher on each attribute. Noticeable is the higher total score of the unconditioned jute sample. This can be explained by the presence of two outliers that are increasing the mean score by more than 1 point. If taken out, the 6 months unconditioned jute sample would have a mean score of 84.22, which would have been the lowest-scoring sample of this time interval. The third evaluation occurred 6 months after the last evaluation and after 12 months of total storage time. This evaluation resulted in stable quality scores (+/- 85) for all samples. The most unconformities in single sensory attributes (figure 3, pink continuous and red dotted line) were observed in the jute packaging, suggesting that the absence of a hermetic barrier influences the quality stability of the green coffee beans. This aspect is primarily visible in the last evaluation after 18 months of total storage where the unconditioned jute packaging shows a significantly lower quality (+/- 4%) score compared to other samples (figure 2, dark grey bars). This confirms prior research on the effects of hermetic barriers on green coffee quality, indicating that the addition of a hermetic barrier does extend the quality shelf life of green coffee beans (Tripetch & Borompichaichartkul, 2019). The attributes 'flavour', 'balance', and 'aftertaste' are showing the largest decrease in the Klabin and Jute packaging after 18 months of storage (figure 3, red continuous and dark green dotted lines). The Grainpro packaging shows the highest level of stability in single sensory attributes, considering all sample scores. The Klabin and Jute packs are showing the most fluctuation in this similar comparison, suggesting that Grainpro offers better protection against quality loss over time. The highest scores were given to the conditioned Grainpro and vacuum samples (± 84.10). No significant differences in mean scores were established between the two storage conditions,

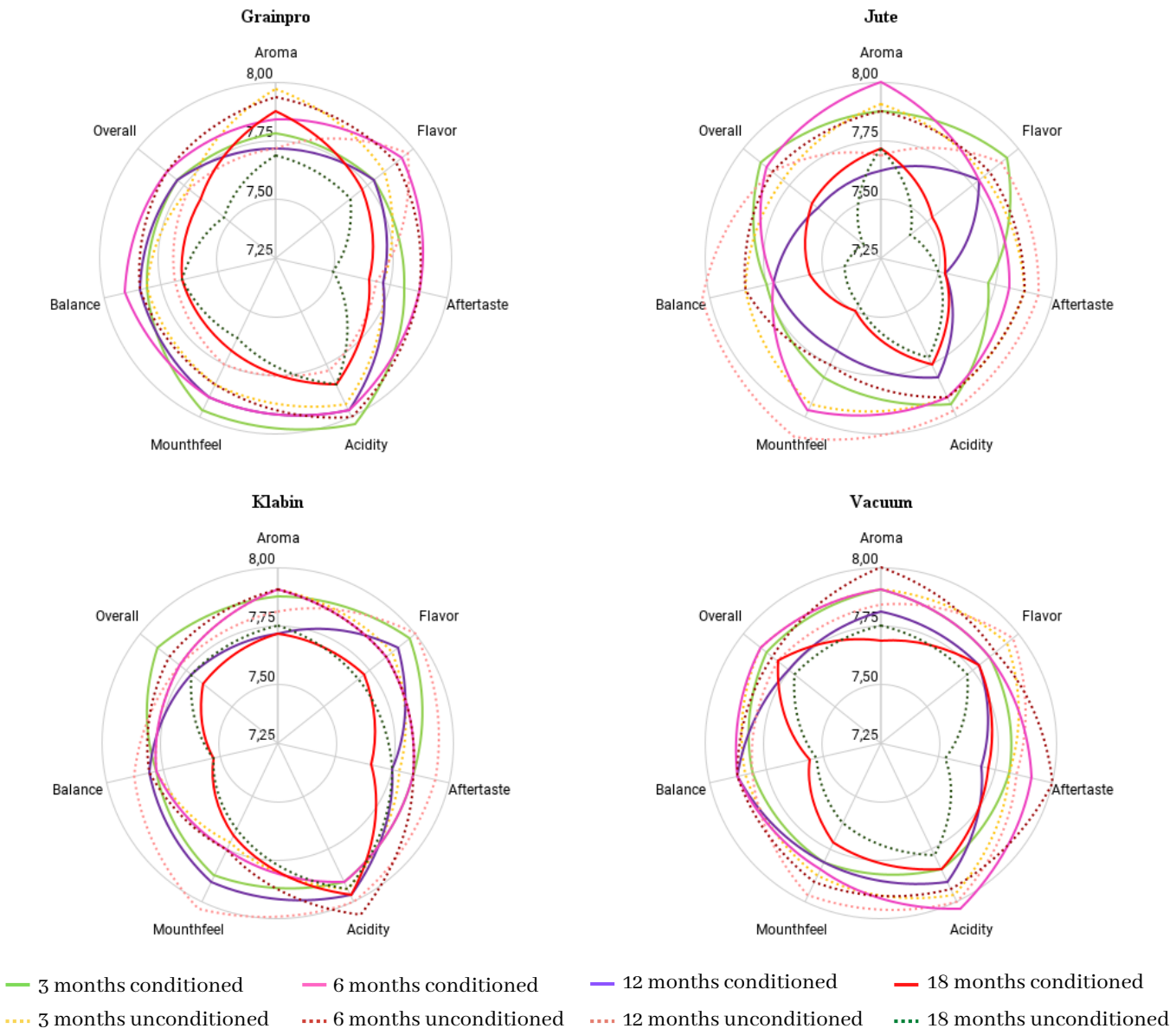

Figure 3, Scores of individual sensory attributes based on the SCA cupping standards of the roasted coffee samples after 3, 6, 12 and 18 months of storage in both conditioned and unconditioned storage, for Grainpro, jute, Klabin and vacuum packaging materials. Mean scores presented (n=8).

suggesting that conditioned storage might be less effective, taking storage time and packaging material into consideration. Statistical analysis did not display significant differences between the individual packaging materials either. Nonetheless, after 18 months of storage, larger differences between mean scores among the different types of packaging are visible, suggesting that all packaging tested, does maintain the constant quality of the green coffee beans up until 12 months of storage. When considering all packaging materials combined, conditioned storage showed a higher total mean quality score compared to unconditioned storage (figure 2, dark grey bars). The quality of the conditioned jute sample decreased by 2.15%, while the unconditioned jute sample lost 3.82% of its quality. A difference of 1.75% in score occurred between the differently conditioned samples of the Grainpro packaging after 18 months compared to 12 months of storage. The second part of the quality index, the ageing scale, which was used to indicate a more specific change in sensorial quality aspects, indicated the typical off flavours connected to ageing (woody, paper) to the stored samples of coffee. Figure 4 visualizes the mean ageing scores per sample after all time intervals. The individual sensory attributes flavour and overall score obtained the strongest significant correlation (r=-.525) to the ageing scale, indicating that these attributes decrease simultaneously when the ageing score increases.

The SCA scoring system correlated significantly (r=-.553) with the ageing scale, suggesting a sufficient calibration of this quality index. The ageing scores remained stable for all samples after three months of storage (figure 4, light grey bars), with the unconditioned Grainpro sample as the highest scoring (3.49) sample. After six months of storage (figure 4, blue bars), the mean ageing scores kept similar stability, except for the conditioned jute sample, which exceeded 4 points, implying that some ageing occurred in this sample. The SCA attribute 'overall' scores the lowest in this sample (figure 3, pink dotted line). The ageing scores decreased for all samples after 12 months of storage, which connects with the increase in SCA scores for this similar evaluation, indicating that the coffee quality was optimal after 12 months of storage. The Grainpro samples scored the lowest (<2) suggesting that the least amount of ageing was perceived in these samples. After 18 months in the warehouses, the coffees began to differentiate more in quality scores. The SCA scoring decreased, while the ageing scale increased, indicating that the total sensorial quality decreased. A slight difference in sensorial attributes is present between conditioned and unconditioned storage (Figure 3, red continuous and green dotted line). The largest increases occurred after 18 months of storage (figure 4, dark grey bars), where the samples of both the conditioned and unconditioned jute packaging scored the highest perceived ageing (5.5 – 7: ageing in some attributes). Both these coffees scored the lowest on aftertaste, mouthfeel, and overall impression, which are significantly correlated to the ageing scale. The conditioned vacuum sample scored the lowest on ageing (2.88) with a difference of 81%. The unconditioned jute sample scored significantly higher than all other samples (6.88), indicating that this jute packaging is the least efficient in the longevity of sensorial quality after 18 months of storage.

Amongst the analysed sensorial attributes, flavour and balance were the attributes that suffered the greatest losses in quality scores. A 6.6% decrease in overall score occurred in the Jute packaging between 3 and 18 months of storage. Within these attributes, Grainpro offered the most stable scores (+/- 7.75), despite the 18 months of unconditioned storage (+/- 7.5). All single sensory attributes scored significantly (p<.05) lower after 18 months of storage. Statistically, no significant difference in individual scores occurred between the packaging materials and the storage conditions.

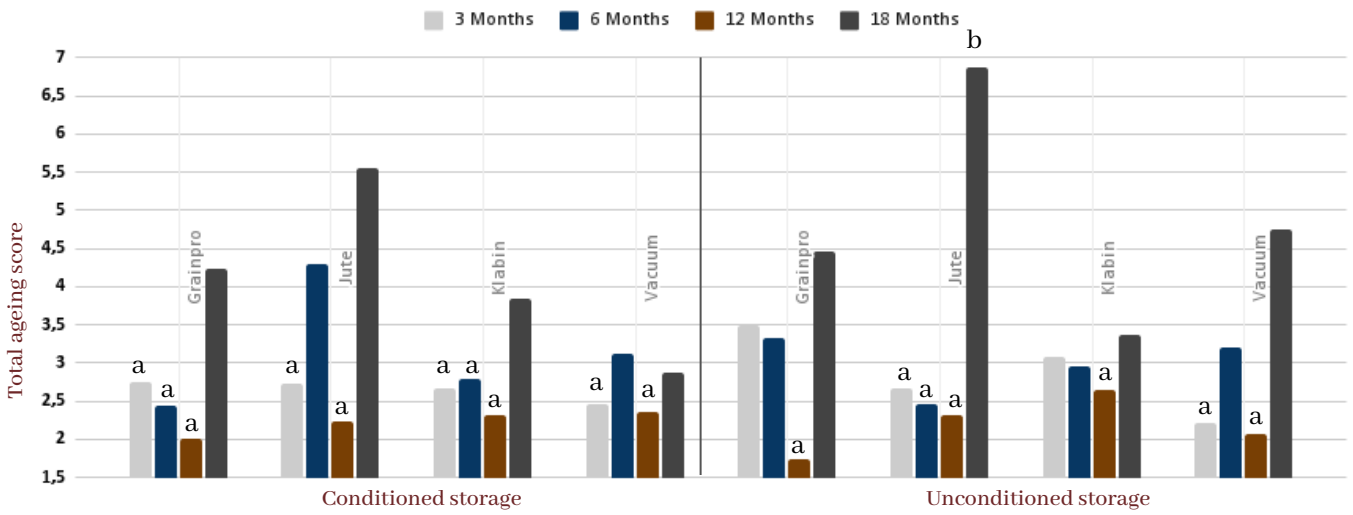

Figure 4, Comparison of total scores based on the aging scale (y) for the coffee samples in Grainpro, Jute, Klabin and Vacuum packaging for 3, 6, 12 and 18 months of storage in both conditioned and unconditioned storage (x). The superscripts a and b indicate significant (p<.05) differences between the coffees stored in different bags and under different conditions for 18 months in total. Mean values presented (n = 8).

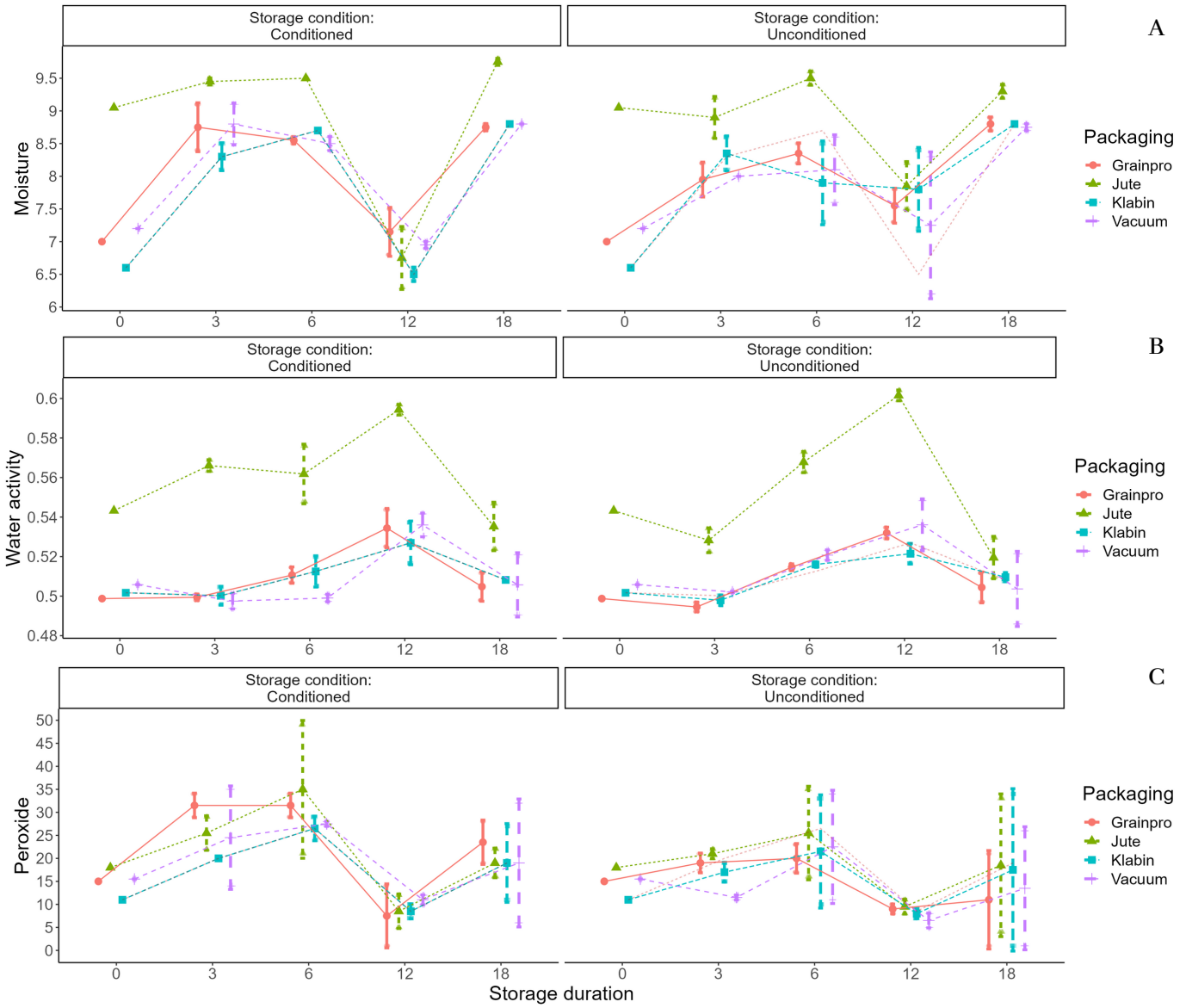

Figure 5, Measurements of moisture content (A), water activity (B) and peroxide values (C) after 3, 6, 12 and 18 months of conditioned and unconditioned storage in Grainpro, Jute, Klabin and Vacuum packaging. Data presented as mean values (n=2) plus standard deviation. Moisture content expresses in grams/100grams, peroxide value expressed in meq O/kg fat (milliequivalent O/kg fat. Water activity is unitless.

3.2 Influence of storage conditions and packaging materials on the physicochemical properties of green coffee beans - The second aim of this study was to find the differences in chemical measurements during the storage of green coffee beans. To find these influences, physiochemical measurements were performed on each sample. Water activity measurements were facilitated by Trabocca in the internal cupping lab. Measurements of moisture content and peroxide values were outsourced to an external laboratory.

3.2.1 *Moisture content* - Moisture content is an important parameter for the quality of green coffee beans. The objective of the drying process is to lower the moisture content of parchment or cherry to about 12% for preservation purposes during storage (Wintgens, 2004). The first moisture content measurement was performed after the arrival of the green coffee beans in Rotterdam after being transported from Ethiopia. Figure 5A displays the moisture content measurements. The initial measurements after the arrival of the green coffee beans showed a higher moisture content (9% ± 2%) in the jute bags compared to the other three types of packaging (± 7%). After three months of storage, a slight but insignificant difference in moisture content between conditioned and unconditioned storage was visible (figure 5A) generally in the jute bags.

The moisture content increased in all samples after three months of storage. The moisture content remained stable for all packaging types after six months of storage. A slight difference is noticeable in the jute samples amongst the storage conditions. The largest difference in moisture content occurs after 12 months of storage, where the moisture content drops significantly in all samples. The higher ambient temperature due to season change might have influenced the characteristics of the samples. However, the conditioned sample shows a higher decrease in moisture content than the unconditioned sample, excluding the influence of weather during this time. Six months later, after 18 months of total storage time, the moisture content increased back to the initial percentages for all samples. The last increase occurred within the unconditioned warehouse. No significant differences in moisture content were found between conditioned and unconditioned storage, indicating that conditioned storage offers no benefit in the retainment of required moisture content during storage when compared to unconditioned storage.

3.2.2 *Water activity* - Similar to each coffee sample, water activity measurements were performed on the coffees as part of the internal food safety program. Figure 5B displays all water activity measurements during storage. Noticeable is the significant difference between the jute and the other types of packaging material, which again confirms research from (Tripetch & Borompichaichartkul, 2019) focused on the effect of a hermetic barrier. Comparable to the moisture content, a slight peak in water activity occurred after 12 months of storage. After 12 months of storage, the water activity decreased in all samples, indicating that the water activity was stable after 18 months. No significant differences were found between the packaging materials, storage conditions, or the combination of both, suggesting that those variables are not influencing the water activity in the green coffee beans during storage.

3.2.3 *Peroxide value* - One important parameter that influences the oxidation of oils is the degree of unsaturated fatty acids. When double bonds of unsaturated fatty acids oxidize, peroxide is formed as the primary oxidation product (Speer & Kölling-Speer, 2006). To determine the primary degree of fatty acid oxidation (rancidity), the peroxide value was measured for each sample. The peroxide value is defined as the reactive oxygen contents expressed in milliequivalent/kg fat). Higher oxidative stability is usually connected to a slower increase in the peroxide value. The determination of the peroxide value is essential because it is one of the most typically used parameters to monitor lipid oxidation and control quality. The effect of storage condition and packaging material on the peroxide value is visualized in figure 5C. The peroxide values were found not to differ significantly concerning packaging material. The mean (n=4) initial peroxide value of the green coffee beans was 14.875 ± 5.55 meq/kg fat. After 3 months of storage, the mean (n=8) peroxide value did differ significantly between conditioned (25.375 ± 7.11 meq/kg fat) and unconditioned storage (17.125 ± 3.91 meq/kg fat) respectively. The mean difference in peroxide value of 7.75 ± 1.9 meq/kg fat between conditioned and unconditioned storage after 6 months of storage has also been found significant. The 6 months conditioned jute sample contained the highest peroxide value of 49 meq/kg fat. After 12 and 18 months of storage, no significant differences in peroxide value between both storage conditions occurred. The slower increase in peroxide value concerning storage durations within the unconditioned warehouse suggests a more stable oxidative stability in the green coffee beans.

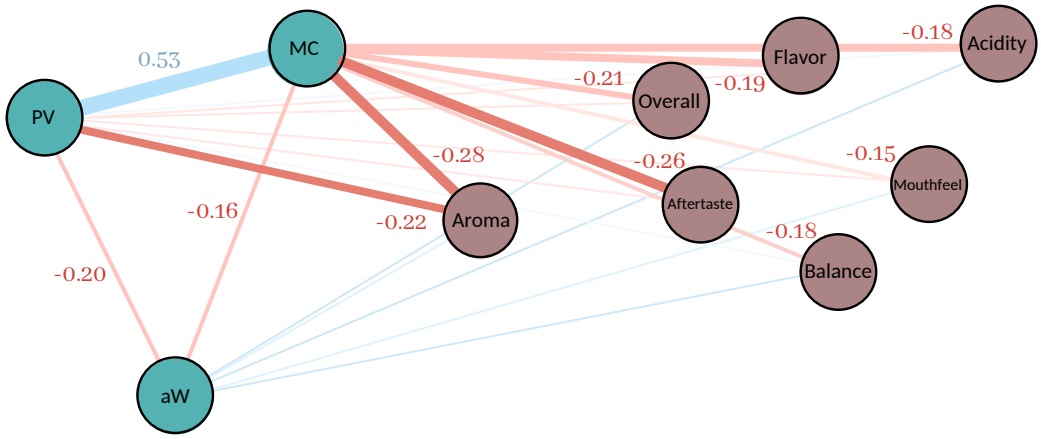

Figure 6, Network analysis based on correlations between physiochemical and sensorial attributes. Stronger associations between data, represent a thicker and more saturated connection in the network. The colouring of the connection refers to the direction of the correlation where blue edges represent positive correlations and red edges negative correlations. Pearson's r has been implemented for only significant (p=<.05) correlations between physiochemical and sensorial parameters. PV - Peroxide value, aW- Water activity, MC - Moisture content. Note: All sensorial attributes are correlated significantly together, but are not considered in this chart.

3.3 Correlations between physiochemical measurements and sensorial quality of green coffee beans (statistical analysis) – The third aim of this research was the optional finding of a reliable and representative parameter for quality measurements. A network analysis was performed to find significant connections between the physiochemical and sensorial measurements (figure 6). This overview displays the correlations between the sensorial and chemical evaluations. Furthermore, it shows that the increase in moisture content caused a loss in all individual sensory attributes and is thereby affecting the overall sensorial quality of the green coffee beans. The sensory attributes 'aroma' and 'aftertaste' suffer from the highest loss in sensorial quality due to the increase of moisture content within the green coffee beans (r = -.28, -.26; p=<.001). This phenomenon occurs the most in jute bags, but also shows the most positive associations between water activity and the sensorial attributes. The attribute mouthfeel found the least effects from the increase in moisture content. Klabin packaging shows the least negative correlations between physicochemical and sensorial attributes in total, indicating that the physiochemical properties have the least influence on the sensorial quality of the green coffee beans in Klabin packs. The most negative correlations between the two groups are observed within the vacuum packaging, predominantly between MC, PV, and the sensorial attributes. The moisture content displays a strong relationship (r=.53; p=<.001) with the peroxide value in every storage condition, implying that both increase simultaneously and are influencing each other. No significantly different correlations occurred between conditioned and unconditioned storage.

The parameter aroma corresponded slightly negatively (r=-.22) with the peroxide measurements noticing the loss of aroma with the increase of the peroxide value, indicating that the degradation of fatty acids can be found sensorially. Besides the attribute aroma, no significant Pearson correlations were observed between the peroxide value and other sensorial attributes but correlated most negatively with the attributes within vacuum packaging. The correlation between the total SCA scores and the peroxide values is observed to be r = -0.05. Since correlations higher than (-)0.7 are considered to be representative, this is indicating that the peroxide value may not be seen as a representative parameter for measuring quality loss in green coffees during storage. The water activity measurements show a weaker correlation between the peroxide value and the moisture content, but both correlations were found to be significant. Moisture content is thereby correlated to the peroxide value, where a higher moisture content correlates with a higher peroxide value. Higher moisture content correlates to lower scores on SCA attributes and thereby the total SCA quality score.

The strongest positive correlations between water activity and sensorial attributes occur in the jute packaging where 'flavour' and 'overall' are affected most positively (r= >0.3). No correlation between these groups was observed in the Klabin packs, where the water activity only can be associated negatively with the moisture content (r= -0.61; p=<.001). All other variables could not be correlated to the water activity measurements respectively.

4. Conclusions

- Conditioned warehousing does not appear to better protect green coffee from ageing compared to unconditioned storage
- Grainpro offers the best quality retainable, sustainable and profitable option when choosing packaging materials.
- Vacuum packaging scores high, but might be less profitable and sustainable compared to Grainpro packages which are showing similar quality results.
- Klabin bags might be considered as packaging material, but shows larger quality losses after 12 months of storage
- Jute bags are considered the least stable option during long-term storage since large quality losses were observed

This research shows that both Grainpro and Vacuum packaging offer the most stable solution for quality control during 18 months of storage. Both packages show the lowest decrease in quality scores through these 18 months. In terms of sensorial parameters, this study observed that flavour and acidity retain their quality during storage, while balance and aftertaste seem to slightly decrease. The differences between Grainpro and vacuum packaging have not been found significant, resulting in a more profitable and sustainable solution in Grainpro. The lack of a hermetic barrier in jute bags might be unfavourable during long-term storage since the coffees stored in jute bags are more sensitive to climate changes. Klabin might be considered as a packaging solution but shows quality decreases after 12 months of storage. Klabin packaging is not commonly used and might not be worth the effort to use as a substitute for Grainpro and Vacuum packaging. Based on this study, CO2 packaging might not be worth the effort since green coffee beans stored in these bags show similar quality scores as Grainpro and vacuum packaging. Moreover, the acquired data on these samples was limited and not considered in the complete study.

Comparable profiles and quality were observed in the coffees stored in the warehouses with conditioned climate and unconditioned storage. Conditioned storage thereby might be unfavourable due to the lower sustainability and profitability of costs from maintaining storage conditions such as temperature and humidity. The largest fluctuations in quality scores between the two warehouses occurred within Jute bags, where the environment has a significant influence on their quality due to the lack of a hermetic barrier. This outcome was unexpected since multiple studies have shown benefits of conditioned storage and supports the performance for further research towards this topic.

Higher moisture contents were observed in coffees stored in jute packaging. Storage conditions did not influence the moisture content of the green coffee beans but showed a correlation with the peroxide values. Unconditioned storage displays a minor increase in peroxide values compared to conditioned storage, suggesting higher oxidative stability. The highest peroxide value appeared in jute packaging, but no significant differences in peroxide values appeared amongst packaging materials. Statistical analysis showed that the moisture content of the green coffee beans is associated with their sensorial quality. All individual sensory attributes were affected by the increased moisture content of the green coffee beans respectively. Peroxide values are found to be traceable in sensory analysis, related to the decrease in the aroma. However, the peroxide value may not be seen as a representative physiochemical parameter to measure the general quality of green coffee beans. In perspective, the type of packaging material should be taken into consideration during the long-term storage of green coffee beans respectively.

5. Disclaimers

Packaging – Some of the packaging materials used in this research are named and categorized according to the brand name (Grainpro, Klabin) due to the internal procedure for classifying these packaging materials. The specifications of these packaging materials are explained in the methodology part of this research. Trabocca B.V. does not have any affiliation with these brands. Packaging materials with similar properties from other brands may display a comparable result.

Coffee - Ethiopian grade 2 washed coffee was used for this research since this is the most traded product by Trabocca. As multiple studies are suggesting, washed coffees do present a prominent quality profile compared to natural coffees (Coradi, Borém, & Saath, 2015). Additionally, differences in processing and drying within the country of origin may have significant effects on the stability of the product over time. Storage and packaging may have a different effect on different (processing) types of coffee.

6. Additions

6.1 Modified Atmosphere Packaging – MAP (modified atmosphere packaging) with CO2 was used as an additional packaging type in this project but is not included in the main section of the research due to the limited data. The CO2 sample consisted of a Klabin bag, infused with carbon dioxide. This sample was only stored in an unconditioned warehouse, and thereby provides an incomplete result when compared to the rest of the data. While considering unconditioned storage only, the CO2 packs are scoring 84.25 compared to 82.50 from the jute packaging, which scored the lowest, after 18 months of storage respectively. No significantly different scores did occur between the five different packaging materials during the complete duration of the experiment. Both the SCA and the Aging scoring index were stable during the first 12 months of storage in the CO2 packaging. The moisture content of the CO2 samples was comparable with the Grainpro, Vacuum, and Klabin bags. Peroxide values were observed slightly higher in CO2 bags after 6 months of storage, but not found to differ significantly. In terms of physiochemical correlations, the CO2 packaging showed less negative correlations between moisture content and sensorial attributes compared to the other packaging materials, indicating that the MAP might prevent the negative influence of moisture content on the sensorial quality.

6.2 *CO2 & O2 measurements* – Both these measurements were performed on every sample starting at the arrival in The Netherlands. During the second measurement at 6 months of total storage time, The AtmoCheck DOUBLE broke down, resulting in a lack of data in the datasheets. The device was usable again in the last evaluation after 18 months of total storage time. The data of both these measurements are thereby not complete and not considered in this research. The O2 and CO2 levels of all samples of 3 and 18 months of storage were compared statistically. No significant differences were observed in O2 and CO2 levels between the different packaging materials, storage conditions, or the combination of both. Vacuum packaging showed lower levels of O2, but these were not correlated to quality losses or increases. Higher CO2 levels were connected to these O2 measurements in vacuum packaging. No significant correlations were observed between O2, CO2 levels, and individual sensory attributes, indicating a similar stable quality control depending on these atmospheric measurements within all packages.

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