UNIVERSIDADE FEDERAL DE LAVRAS

JÉSSICA OLIVEIRA GUSMÃO

OPTIMIZING THE UTILIZATION OF WHOLE PLANT CORN SILAGE AND SNAPLAGE BY SELECTION HYBRIDS AND MATURITIES

LAVRAS – MG
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Tese de doutorado apresentada à Universidade Federal de Lavras, como parte das exigências do Programa de Pós-Graduação em Zootecnia, área de concentração em Produção e Nutrição de Ruminantes, para a obtenção do título de Doutor.

Orientador
Dr. Thiago Fernandes Bernardes

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Aprovada em 15 de Abril de 2021

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LAVRAS – MG
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Aos meus pais, Juarez e Jane e aos meus irmãos Joeudes e Jordânia
por todo amor e apoio incondicional durante essa jornada.
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MUITO OBRIGADA!

RESUMO GERAL

Artigo 1**:** Dezessete híbridos de milho foram avaliados para verificar como as características agronômicas da planta de milho influenciam a produtividade de matéria seca (PMS) em híbridos usados para silagem de planta inteira e para silagem de espiga. Avaliações agronômicas dos híbridos foram feitas quando as plantas atingiram 35% de MS e quando as espigas atingiram 65% de MS. Análises descritivas foram usadas para caracterizar os híbridos e Análise de Componentes Principais (PCA) foram usadas para identificar as características agronômicas associadas a PMS. A PMS variou de 22,4 a 32,2 ton/ha e em média, a PMS foi de 26,6 ton/ha. A produtividade da porção fibrosa variou de 11,8 a 20,7 ton/ha, enquanto a produtividade de grãos variou de 9,50 a 12,9 ton/ha. O peso individual de planta mínimo, médio e máximo foram; 0,32, 0,38 0,46; kg/MS, respectivamente. A PMS de espigas variou de 12,1 a 20,9 ton/ha, e em média, os híbridos produziram 16,8 ton/ha. A proporção mínima e máxima de grãos na espiga foi de 72,6 e 81,3%, respectivamente. A proporção de sabugo e palha média foi de 11,7 e 11,9%, respectivamente. De acordo a PCA, a PMS de híbridos usados para produção de silagem de planta inteira foi principalmente explicada pelo peso individual de planta e pela produtividade da porção fibrosa. Por outro lado, a produtividade de grãos e o comprimento de espigas foram os principais fatores a explicarem a PMS de espigas. Diferentes características agronômicas determinam PMS em híbridos usados para silagem de planta inteira e silagens de espiga. Os híbridos com alta PMS de planta inteira não necessariamente são as melhores opções para produção de silagem de espiga.

Artigo 2: Cinco híbridos de milho foram colhidos em três estágios de maturidade para produzir silagens de espigas. Os híbridos foram colhidos com 600g/kg (M1); 650 g/kg (M2) e 700 g/kg (M3) de MS. Espigas de milho foram fracionadas em grãos, palha e sabugo. Em um segundo momento, as espigas foram processadas e ensiladas por 90d. Foram realizadas avaliações das produtividades de matéria seca (PMS), digestibilidade de fibra em detergente neutro (DFDN$_{30h}$,), e degradabilidade do amido *in situ* (DAis) para os componentes da espiga e para as silagens. O experimento foi conduzido em blocos causalizados usando medida repetida no tempo. Os dados foram analisados utilizando o MIXED do SAS, seguido pelo teste de *t* de Student $P \leq 0,05$. As concentrações de MS no momento da colheita foram 591, 642 e 683 g/kg para M1, M2 e M3, respectivamente. As concentrações de FDN no sabugo aumentaram (771, 793 e 819 g/kg da MS) e a DFND$_{30h}$ reduziram (261, 244 e 209 g/kg do FDN) para M1, M2 e M3, respectivamente. As concentrações de FDN na palha foram 819, 837 e 841 g/kg da MS e a DFDN$_{30h}$ foram 320, 257 e 246 g/kg da FDN, para M1, M2 e M3, respectivamente. As maiores concentrações de ácido lático (5,90 g/kg da MS) e N-NH_3 (38,2 g/kg do N) foram encontradas em M1. As concentrações de amido e a DAis em silagens de espigas foram afetadas pelo híbrido e pela maturidade ($P < 0.05$). Com o aumento da maturidade a DAis reduziu (783, 731, e 703 g/kg de amido) para MI, M2 e M3, respetivamente. Silagens de espiga devem ser produzidas no intervalo entre 600 e 700 g/kg de MS. Colheitas em estágios de maturidade inferior a 600 g/kg de MS pode comprometer a concentração de amido na silagem, e em concentrações superiores a 700 g/kg de MS pode implicar em restrições na fermentação e sobre a degradabilidade do amido.

Palavras-chave: Híbridos. Maturidade. Silagens de espiga. Amido.

GENERAL ABSTRACT

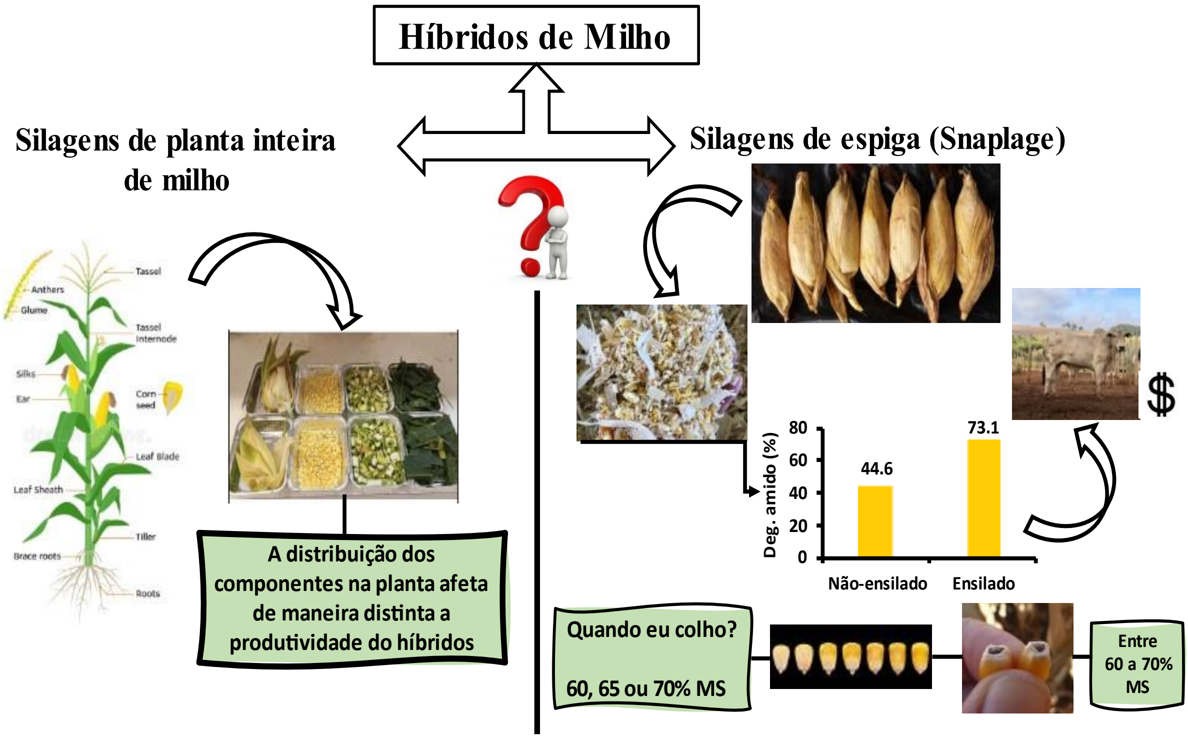
Paper 1**: S**eventeen corn hybrids were evaluated to examine agronomic characteristics that has influence on performance to make whole plant corn silage (WPCS) and snaplage. Hybrids were harvested at the target 35% of DM for WPCS, and ear corn were harvested with 65% of DM for snaplage. The descriptive statistics was used to characterize hybrids. Principal Component Analysis (PCA) was performed to identify traits associated with dry matter yield (DMY) for both type of silage. For WPCS, the DMY ranged from 22.4 to 32.2 ton/ha and on average the hybrids have 26.6 ton/ha. The stover yield ranged from 11.8 to 20.7 ton/ha, while kernel yield ranged from 9.50 to 12.9 ton/ha. The plant weight minimum, average and maximum were 0.32, 0.38 and 0.46, kg of DM, respectively. For snaplage, the ear corn DMY ranged to 12.1 to 20.9 ton/ha, and the average was 16.8 ton/ha. The minimum and maximum kernel proportion were 72.6 and 81.3%, respectively. The husk and cob proportions average were 11.7, and 11.9, respectively. According to PCA, plant weight and stover yield have great contribution to determine DMY in hybrids used by WPCS. The kernels yield and the ear length were the mains factors to determine the ear corn DMY for snaplage. Different agronomic characteristics determine DMY for WPCS and snaplage. Hybrids with great DMY of whole plant not necessarily are the best option to making snaplage.

Paper 2: In the second study, five hybrids were harvested at three maturities to make snaplage. Hybrids were harvested at the target maturity levels of 600 g/kg of DM (M1), 650 g/kg of DM (M2), and 700 g/kg of DM (M3). Fresh ears were separated into kernels, husk, and cob. Whole ears were processed and ensiled (snaplage) for 90d. Measurements included dry matter (DM) yield, nutrient analysis, neutral detergent fiber digestibility ($NDFD_{30h}$,), and *in situ* starch degradability (isSD) for ear components and snaplage. The experimental design was randomized complete blocks using a mixed repeated measures model. Data were analyzed using the MIXED procedure of SAS, followed by Student's *t*-test at $P \leq 0.05$. The DM concentrations at harvest were 591, 642, and 683 g/kg for M1, M2 and M3, respectively. The aNDF concentration of cob increased (771, 793, and 819 g/kg of DM) and the $NDFD_{30h}$ decreased (261, 244, and 209 g/kg of NDF) for M1, M2 and M3, respectively. The aNDF concentrations of husk were 819, 837, and 841 g/kg of DM, and the $NDFD_{30h}$ were 320, 257 and 246 g/kg of NDF for M1, M2, and M3, respectively. The greater lactic acid (5.90 g/kg of DM) and NH_3-N concentrations (38.2 g/kg of N) were found at M1. The starch concentrations and isSD of snaplage were affected by hybrid and maturity level ($P < 0.05$). As maturity increased, the isSD decreased (783, 731, and 703 g/kg of starch for M1, M2 and M3, respectively). The $NDFD_{30h}$ of cob and husk and the starch degradability of kernels/snaplage declined from M1 to M3. Snaplage should be produced with 600 to 700 g/kg of DM. Harvesting at DM concentrations lower than 600 g/kg compromised starch concentration; but DM concentrations greater than 700 g/kg impaired starch degradability due to restri fermentation.

Keywords: Hybrids. Maturity. Snaplage. Starch.

RESUMO INTERPRETATIVO E RESUMO GRÁGICO

Em um primeiro momento, o estudo teve como objetivo determinar as características agronômicas de híbridos de milho que estão associadas com a produtividade de matéria seca em híbridos destinados a produção de silagens de planta inteira de milho e silagens de espiga. Boa parte dos híbridos avaliados apresentam um alto potencial de produtividade de matéria seca para os dois tipos de silagens. Para produção de silagens de planta inteira, as características; peso individual de planta e produtividade da porção fibrosa estiveram diretamente associadas com as respostas produtivas de matéria seca dos híbridos. Já em silagens de espiga, a produtividade de grãos e o comprimento da espiga são os principais fatores a explicarem altas produtividade de matéria seca em híbridos destinados a esse fim. Em um segundo estudo, cinco híbridos de milho colhidos em três diferentes estágios de maturidades (60, 65 e 70% de MS) foram avaliados para verificar seus efeitos sobre a conservação e valor nutricional de silagens de espigas. O valor nutritivo em silagens de espiga é influenciado pelo híbrido e pela maturidade. Híbridos com endosperma menos vítreo e com alta proporção de grãos maximizam a energia em silagens de espiga. Além disso, a maturidade afeta a digestibilidade dos componentes fibrosos; palha e sabugo, e a degradabilidade do amido. De maneira geral há um aumento sobre a concentração da fibra da palha e do sabugo, e ambos; palha, sabugo e grãos tem suas digestibilidades reduzida em maiores maturidades. Para otimizar a produtividade de silagens de espigas, a concentração de matéria seca em silagens de espiga deve estar entre 60 a no máximo 70%. Valores superiores podem levar a prejuízos sobre a fermentação do material, e valores matéria seca inferiores a esse podem prejudicar a concentração de amido e reduzir a concentração de energia nesse tipo de silagem.



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1. INTRODUÇÃO GERAL

Dentre as culturas usadas para produção de silagem, o milho é a cultura mais utilizada para esse fim (BERNARDES, DO RÊGO; 2014; FERRARETTO et al., 2018). As altas produtividades da cultura associadas ao alto valor nutritivo, facilidade de colheita mecânica, padrões de fermentação, e versatilidade quanto ao uso são os principais fatores que contribuem para escolha do milho frente a outras culturas.

A seleção de híbridos é uma das decisões de manejo mais importantes tanto para produção de silagem de planta inteira como para silagens de espigas. Para ambos os tipos de silagens, nem sempre a produtividade de grãos é um bom critério para a seleção de cultivares. Em silagens de planta inteira, não somente os aspectos produtivos, mas a composição morfológica da planta (colmo, folha, grãos, palha, sabugo) também é importante, uma vez que a distribuição desses componentes influencia produtividade e afeta diretamente o valor nutricional da silagem, devido as diferenças histológicas entre os componentes da planta de milho (DAYNARD E HUNTER, 1975; NÚSSIO et al., 2001). Por outro lado, os aspectos morfológicos de plantas de milho parecem ser menos relevantes para produção de silagens de espiga. Basicamente, entre 70 a 80% da constituição desse tipo de silagem é representada pelos grãos e os outros 20 a 30% compreendem a palha e sabugo (MAHANNA, 2008). Para esse tipo de silagem, a seleção de híbridos baseado nas produtividades de grãos parecem funcionar melhor.

No passado, silagens de espigas foram usadas como estratégia a preservação de grãos de milho para animais confinados (BEENSON et al., 1956) e recentemente, o uso desse tipo de silagem tem despertado grande interesse entre produtores no Brasil, principalmente entre confinadores de gado de corte (BERNARDES, CASTRO; 2019). Os altos custos de alimentação, juntamente a disponibilidade de maquinário para colheita e processamento desse tipo de silagem, tem impulsionado o uso desse tipo de silagem na alimentação animal (DANIEL et al., 2019). Como no Brasil, o mercado de híbridos é composto quase que exclusivamente por híbridos de endosperma vítreo, o uso de silagens de espiga também objetiva promover incrementos sobre a digestibilidade do amido, aumento da eficiência alimentar dos animais e de redução dos custos de produção dentro das propriedades.

Geralmente, silagens de espigas são produzidas com os grãos em maturidade fisiológica. Nesse momento, os grãos na espiga apresentam entre 30 a 35% de umidade (MAHANNA, 2008; AKINS, SHAVER; 2014). No Brasil, a produção desse tipo de silagem tem sido feita basicamente por meio do serviço terceirizado, e em determinadas situações, os equipamentos de colheita chegam previamente ou atrasado nas propriedades. Em consequência, diferentes maturidades de colheita são praticadas, as quais podem alterar a produtividade, a fermentação e o valor nutritivo de silagens de espiga.

Embora cultivares de milho de alto desempenho estejam disponíveis no mercado, ainda se faz importante conhecer as características de híbridos destinados a produção de silagens de planta inteira e de silagens de espiga uma vez que esses dois tipos de silagens são usados com objetivos diferentes dentro dos sistemas agropecuários. Possivelmente, existem híbridos com características mais apropriadas para produção de silagens de espiga e para produção de silagens de planta inteira. Em relação a silagem de espigas, não somente a utilização de híbridos para tal fim ainda é uma lacuna, bem como também entender a janela de corte com a qual a mesma possa ser produzida, sem que haja prejuízo sobre a qualidade desse tipo de silagem. Baseado nisso, os estudos desenvolvidos tiveram como objetivo entender como as características agronômicas de híbridos influenciam na produtividade de lavouras destinados a produção de silagens de planta inteira e de silagens de espigas e em um segundo momento, objetivou-se avaliar o efeito do uso de diferentes híbridos de milho e maturidades de colheita sobre a conservação e valor nutritivo de silagens de espigas. Para alcançar esses objetivos, a tese foi compartimentalizada em dois artigos.

a) Artigo 1: Yield performance of hybrids for whole plant corn silage and snaplage;

b) Artigo 2: Effects of hybrid and maturity on the conservation and nutritive value of snaplage.

2. REFERENCIAL TEÓRICO

2.1 Uso de híbridos de milho para produção de silagens

A utilização de híbridos de milho em campos destinados à produção de grãos ou silagens é um dos grandes pilares responsáveis pelo aumento em produtividade em áreas de milho. No Brasil, os primeiros trabalhos com avaliação de híbridos de milho se deram em 1932, e entre as décadas de 40 e 50 os primeiros campos destinados a produção de sementes de híbridos em escala comercial foram estabelecidos (KRUG, et al., 1943; GARCIA et al., 1980). O desenvolvimento de linhagens oriundas do processo de autofecundação das plantas de milho por várias gerações e da heterose foram um dos responsáveis pelo impulso que o melhoramento genético tomou no século passado. Somado a isso, em 2007, o Brasil aprovou a utilização de eventos transgênicos do milho, e biotecnologias relacionados ao controle de pragas, doenças e plantas daninhas passaram a ser utilizadas como estratégias de proteção a produtividade do milho. Atualmente, a utilização de híbridos transgênicos já ocupa mais de 90% das áreas de milho no Brasil (GALVÃO, 2019).

De acordo a Embrapa Milho e Sorgo, na safra de 2019/2020 cerca de 196 cultivares de milho estavam disponíveis para utilização nas diferentes regiões de cultivo (PEREIRA FILHO; BORGHI, 2020). De maneira geral, grande parte dos híbridos disponíveis no mercado são classificados como híbridos de duplo propósito. No entanto, silagens de planta inteira e silagens de espigas são utilizadas com diferentes objetivos nas propriedades, em função disso, a identificação de híbridos com características mais apropriadas para produção desses tipos de silagens é considerado um aspecto chave. Um dos primeiros pontos é a identificação de materiais adaptados a região. Subsequente, fatores como alta produtividade de matéria seca, resistência a pragas e doenças, e valor nutricional do material devem ser considerados (ALLEN et al., 2003; LAUER, 2006).

Em relação a silagens de planta inteira, a produtividade de matéria seca é resultado de dois fatores, da participação de grãos e da porção vegetativa (ALLEN et al., 2003). De acordo Lima (2020) híbridos com maiores comprimentos de espiga e maiores profundidades de grãos podem garantir alta produtividade de grãos. Por outro lado, elevada produtividade da fração fibrosa pode ser observada em híbridos com maior altura de planta e maior espessura de colmo. Associar essas características nos materiais escolhidos pode garantir excelentes produtividades em áreas destinadas a produção de silagem de planta inteira.

Nutricionalmente, a digestibilidade de fibra também deve ser considerada na escolha de híbridos (NUSSIO et al., 2001). Basicamente, a fração fibrosa é constituída por folha, colmo, sabugo e palha (50 a 60% do total da planta de milho) os quais possuem baixa digestibilidade em relação a fração energética (LAUER, 2013). Dentre os componentes da planta de milho, o colmo é o componente de maior participação, o mesmo representa aproximadamente 25% da planta de milho, enquanto as folhas representam aproximadamente 15% (LAUER, 2013). As maiores participações de colmo, embora promovam incrementos sobre produtividade, também podem promover aumento sobre as concentrações de fibra da silagem, uma vez que nesse componente são depositas maiores quantidade de lignina em relação as folhas, por exemplo (WILSON, 1993). Lima (2020), em estudo no qual híbridos de milho destinados a produção de silagens de milho no Brasil foram avaliados, mostraram que o colmo possui digestibilidade de fibra inferior em mais de 10 unidades percentuais em relação as folhas da planta de milho.

Em alguns países, como nos Estados Unidos, estratégias como a utilização do híbrido folhoso (*leafty)* ou *brown midrib mutante* (BMR), tem sido utilizada com intuito de aumentar a digestibilidade da fibra em silagens de planta inteira (OBA; ALLEN, 2000; COX; CHERNEY, 2001; SATTLER et al., 2010; FERRARETTO; SHAVER, 2015). Contudo, a utilização desse tipo de híbrido para produção de silagem de planta inteira no Brasil tem se mostrado inviável, uma vez que sua inclusão no mercado poderia ser pouco competitiva, em função da susceptibilidade a pragas e doenças e das menores produtividades em relação aos híbridos convencionais.

No Brasil, as estratégias de melhoria em valor nutricional em silagens de planta inteira são basicamente compostas por estratégias de manejo, tanto para silagens de planta inteira ou silagens de grãos conservados. Em silagens de planta inteira, alterações sobre a altura de corte, maturidade ou uso de enzimas fibrolíticas tem sido utilizadas com objetivo de promover incrementos sobre o valor nutricional (QUEIROZ et al., 2012; FERRARETTO et al., 2018). Embora a maturidade seja adotada como estratégia de manejo, a mesma deve ser usada com cautela. Com avanço da maturidade, incrementos sobre a participação de grãos e deposição de amido nos grãos são lineares (BUXTON, O’KIELY; 2003), mas a planta de milho tende a perder mais folha e reduções digestibilidade da fibra e do amido podem ser observadas. Na fração fibrosa, grande parte da FDN (hemicelulose) da folha e dos colmos é perdida durante o enchimento dos grãos

(OWENS et al., 2008). Nos grãos, o aumento da deposição de prolamina, principalmente em híbridos de caráter vítreo aumentam a dureza dos grãos, e isso exigirá um maior processamento dos grãos durante a colheita para que prejuízos sobre a digestibilidade do amido não ocorram.

Em relação a silagens de espigas, nos últimos anos houve um aumento no interesse em se produzir esse tipo de silagem pelas propriedades, e possivelmente, a escolha de híbridos de milho para produção desse tipo de silagem ainda é um desafio. Pouco tem sido falado a respeito do uso de híbridos de milho para produção de silagens de espiga no Brasil. Além dos fatores já mencionados anteriormente, os híbridos destinados a esse tipo de silagem devem apresentar alta produtividade de espiga, atrelada à uma maior participação de grãos e menor proporção de palha e sabugo. Por efeito diluitivo, aqueles híbridos em que a palha e o sabugo estão em maior proporção, certamente darão origem a silagens com menor concentração energética. Além disso, híbridos com grãos menos vítreos devem ser preferidos.

O mercado brasileiro é composto quase que em sua totalidade por híbridos de endosperma vítreo, os quais são caracterizados por uma maior concentração de prolamina (CORRÊA et al., 2002). Estratégias como processamento e tempo de armazenamento podem ajudar a contornar esse problema. Quando ensilado, o amido presente nos grãos pode ter sua digestibilidade alterado positivamente (HOFFMAN et al., 2011; KUNG et al., 2018). A ação de bactérias e de enzimas presentes no silo promovem degradação das prolaminas, que são as proteínas que recobrem os grânulos de amido permitindo uma maior exposição dos grânulos e acesso dos microrganismos do rúmen, aumentado a digestibilidade e obtenção de energia do amido (McALLISTER et al., 1993; JUNGES et al., 2017). Tempo de estocagem de no mínimo 60 dias tem sido apontado como adequado para permitir incrementos sobre a digestibilidade do amido em silagens (KUNG et al., 2018; Da SILVA et al., 2019).

2.2 Evolução do uso de silagens de espiga

Popularmente utilizado em diversos sistemas de nutrição ao redor do mundo, as diferentes formas de grãos de milho conservados já são adotadas em dietas de ruminantes desde décadas passadas. Por volta dos anos 60, os primeiros estudos com silagens de espigas de milho e silagens de grãos úmidos começaram a ser estabelecidos na literatura e rapidamente essa tecnologia se difundiu entre fazendas nos Estados Unidos e no Canadá

(BUCHANAM-SMITH; SMITH, 2003). No Brasil, os primeiros relatos de uso de silagens de grãos aconteceram na década de 80, na região de Castro, PR, pelos criadores de suínos e posteriormente, silagens de grãos conservados passaram a ser utilizada na dieta de bovinos de leite e corte.

O aumento dos custos de alimentação dos animais aliados a melhoria das estruturas de estocagens e os benefícios com a ensilagem, principalmente relacionados aos incrementos em digestibilidade do amido foram um dos principais fatores a impulsionarem o uso de grãos conservados na alimentação animal. Diferentes estratégias de colheita e conservação de grãos são utilizadas desde essa época, tais como silagens de grãos úmidos, silagens de grãos reconstituídos e silagens de espiga. No inglês, a terminologia snaplage tem sido bastante utilizada para se referir ao uso de silagens de espiga.

Beenson et al. (1956), em um dos estudos pioneiros desenvolvidos na Universidade de Purdue (EUA) relataram um dos primeiros casos de sucesso e o potencial de uso de silagens de espiga na alimentação de bovinos de corte confinados. Os autores compararam o uso de silagens com grãos e sabugo e milho moído na dieta novilhos Hereford. Os animais alimentados com silagens de espiga tiveram maior peso ao abate (570 *vs* 558 kg) e maior ganho médio diário (1,16 *vs* 1,05 kg) em relação aos animais alimentados com grão de milho moído seco. Além disso, nessa época os autores já ressaltavam para as possibilidades de uso de maiores taxa de lotação e as economias em uso desse alimento para animais confinados. Após isso, diversos estudos relacionados ao uso de grãos conservados passaram a ser publicados na literatura, e muitos eventos científicos também passaram a abordar tema como tópico de diversas palestras.

Em 1991, o ingrediente "*Corn high moisture snapped*" já aparecia no banco de alimentos usados na formulação de bovinos confinados no Nebraska (EUA), e nessa época, já era ressaltado que esse não era um alimento de composição constate, sendo indicado análise prévia sempre que usado em dietas de ruminantes (STOCK et al., 1991). Ainda na década de 90, estudos relacionados aos aspectos fermentativos de silagens de grãos e caracterização da população microbiana durante o uso de silagens de grãos contendo diferentes proporções de sabugo de milho foram publicados por Jobim et al. (1997). Ressalvas quanto a susceptibilidade a deterioração e propensão ao crescimento de microrganismo deterioradores foram feitas pelo autor em uma série de estudos (JOBIM et al.1997; JOBIM et al., 1999).

Em 2006, a Universidade do estado de Oklahoma (EUA) promovia a 30° edição do simpósio “*Cattle Grain Processing Symposium*”, evento idealizado por Fred Owens, e que já acontecia desde 1976, o qual tinha como objetivo difundir conhecimento sobre o as diferentes formas de processamento de grãos na dieta de ruminantes. Nesse mesmo evento, Soderlund (2006) em sua palestra compilou informações sobre resultados de análises químicas de silagens de espiga oriundas de laboratórios comerciais nos Estados Unidos. De acordo os dados desse autor, em média, silagens de espiga apresentavam 64,5% de MS, 20,7% de FDN e 59,3% de amido. Mader e Rust (2006) também abordaram o assunto em sua palestra e os mesmos ressaltaram a necessidade do processamento do sabugo nesse tipo de silagem e a necessidades de estruturas de estocagem com maiores capacidades de armazenamento em função da maior produtividade que seria acrescida pela participação dos demais componentes da espiga de milho.

A evolução dos sistemas de colheita, e a disponibilidade de maquinários e implementos agrícolas, renovaram o interesse nessa técnica, e nos últimos anos o uso de silagens de espigas passou a ser uma prática alternativa aos outros tipos de silagens de grãos em dietas de ruminantes. Em 2008, Bill Mahanna destacou em sua reportagem publicada na revista *Feedstuffs* a volta do uso de silagens de espiga nos EUA na dieta dos animais. Em sua reportagem, os aspectos como maiores produtividade (10 e 15% a mais), e as possíveis economias que poderia haver em relação colheita, processamento e armazenamento comparado aos demais tipos de silagens de grãos conservados foram apontados como aspectos positivos da tecnologia. No entanto, o autor ressaltou também para os riscos como ponto de colheita, principalmente quando o grão possui menos de 25% de umidade, problemas com fermentações, perdas durante a conservação e as possíveis contaminações com as demais partes da planta o momento da colheita. Em 2010, Greg Lardy também ressaltou em sua nota técnica o crescente uso de silagem de espiga por produtores da Dakota do norte (EUA).

Nigon et al. (2016) descreveram como as novas plataformas despigadoras atuam no momento da colheita de silagens de espiga. De acordo esses autores, para colheita de forma fracionada da planta de milho, as colhedoras automotrizes podem ser acopladas as plataformas despigadoras, as quais contém vários pares de rolos em rotação contrária. No momento do corte, os mesmos permitem que o caule da planta de milho seja empurrado para baixo, encaixando apenas a espiga no sistema de rosca dessa plataforma, o qual são encaminhas para o sistema de processamento da colhedora. Em 2018, a Universidade do Nebraska (EUA) junto a Universidade de Iowa (EUA), e a Lallemand Nutrição Animal promoveram o evento “*Silage for Beef Catle*”. Na ocasião, o Palestrante Alen Stateler (2018), abordou diversas considerações sobre o uso de silagens de espiga e de grãos úmidos na terminação de bovinos de corte. Dados compilados de análises químicas de quase 20.000 amostras de silagens de espigas avaliados durante cinco anos pelo “*Dairyland laboratory”* foram apresentados e ressalvas quanto ao uso desse tipo de silagem na alimentação animal foram feitas por esse autor. De acordo Stateler (2018), assim como em dietas com silagens de grãos úmidos, cuidados no balanceamento, quanto níveis de inclusão, interações com subprodutos e níveis de inclusão de forragens devem ser observados pelo formulador afim de otimizar a fermentação do amido ruminal oriundo desse tipo de silagem.

Em 2018, o *Journal Dairy Science* promoveu uma edição especial com diversas publicações sobre silagens, e na ocasião Ferraretto et al. (2018) abordaram o tema “*snaplage*” como parte da sua revisão no tópico sobre estratégias de colheita de plantas de milho. No Brasil o interesse pela técnica também tem sido crescente, principalmente na pecuária de corte. Em levantamento realizado por Bernardes e Castro (2019), entre 2018 e 2019, 11% dos confinadores de gado de corte já usavam silagem de espiga na dieta animais em terminação. Daniel et al. (2019) em sua revisão de literatura sobre produção e utilização de silagens em áreas Brasil também ressaltaram o crescente interesse sobre essa prática no país, e esse tipo de silagem foi apontado como alternativa promissora a silagem de grãos úmidos e grãos reconstituídos. Além da produção de silagem, estratégias de uso do resíduo após a colheita das espigas de milho também tem sido estudado por alguns pesquisados, e o resíduo da colheita desse tipo de silagem tem sido utilizado como opção ao uso da palhada na terminação de animais (BRAZ, 2020).

2.3 Características de silagens de espiga

Diferentemente de outros tipos de silagens de grãos de milho, silagens de espiga são constituídas por todos os componentes da espiga do milho (MAHANNA, 2008), o qual apresentam diferentes proporções na silagem. Em média, os grãos representam entre 70 a 80% da composição total desse tipo de silagem, e a palha juntamente com o sabugo, somam em torno de 20 a 30% (DANIEL et al., 2019). A depender das configurações da máquina, e das características da planta, entre 5 e 10% de contaminações com a parte superior da planta de milho (folha e colmo) são passíveis de acontecer (T.F. BERNARDES, comunicação pessoal). Teoricamente, as contaminações com demais partes das plantas de milhos não são desejáveis, por promoverem alterações sobre o valor nutritivo e redução das concentrações de energia desse tipo de silagem.

Em média, silagens de espiga apresentam um teor de umidade entre 30 a 40% (FERRARETTO et al., 2018). Em termos energéticos, esse tipo de silagem apresenta em média 10% a menos de amido que outras silagens de grãos conservados, como silagens de grãos úmidos por exemplo. Variações entre 50 a 55% de amido e entre 18 a 25% de FDN são característicos desse tipo de silagem (MAHANNA, 2008; EUKEN et al., 2018).

Em relação aos aspectos fermentativos, assim como em silagens de grãos úmidos e silagens de grãos reconstituídos, o processo de fermentação em silagens de espiga pode ser caracterizado como de difícil fermentação, devido as baixas concentrações de substrato para o crescimento microbiano. Tipicamente, esse tipo de silagem é produzido quando os grãos na espiga se encontram em estágio de maturidade fisiológica, e nessa fase, grande parte dos carboidratos solúveis presentes nos grãos, os quais são usados para produção de ácidos orgânicos, já foram convertidos em amido (WATSON et al., 2003), restando pouca quantidade de substrato para uso durante a fermentação. Além disso, a baixa umidade (32-40%) presente nesse tipo de material pode ser um desafio a atuação de bactérias, devido a limitada atividade de água (ROOKE; HATFIELD, 2003; KUNG et al., 2007).

A produção de ácidos orgânicos nesse tipo de silagem também pode ser baixa em comparação com outros tipos de alimentos conservados, como silagens de planta inteira de milho. Valores de pH entre 4 a 4,5 e concentrações de ácido lático entre 1 a 3% em silagens são característicos desse tipo de silagem de grão fermentados (KUNG et al., 2018). Sebastian et al. (1996) observaram valores de pH e concentrações de ácido láctico de 4,32 e de 1,32% da MS, respectivamente, em silagens de espiga com concentrações de MS de 72% após 138 dias de ensilagem. Nigon et al. (2016) reportaram valores de pH de 4,01 e concentrações de ácido lático na ordem de 2,18% da MS em silagens de espiga com concentrações de MS de 55,9% após 147 dias de estocagem sem o uso de inoculante. Em relação as concentrações de ácido acético e etanol, concentrações inferiores a 1% da MS são passíveis de serem encontrados nesse tipo de silagem (NIGON et al., 2016; AKINS; SHAVER, 2014).

A fração nitrogenada também é afetada pela fermentação nesse tipo de silagem (AKINS; SHAVER, 2014). A solubilização e proteólise das proteínas que circundam os grânulos de amido, promovem incrementos sobre o N-NH_3 e sobre a proteína solúvel, o que geralmente está correlacionado aos ganhos sobre a digestibilidade do amido

(FERRARETTO et al., 2014). A depender de fatores como concentrações de MS no momento da ensilagem e tempo de estocagem, variações entre 1-10% de NH_3 em relação ao N total, são reportados nesse tipo de silagem (AKINS; SHAVER, 2014). Valores superiores a 50% de N-solúvel e digestibilidade do amido *in situ* (7h) próximos a 70% podem ser encontrados quando a mesma é submetida a longos períodos de estocagem (AKINS; SHAVER, 2014; SALVO et al., 2020).

Em função do alto valor nutricional, e da baixa concentração de ácidos orgânicos, silagens de espiga também são propensas a deterioração aeróbia, assim como as demais variações de grãos de milho ensilados. Microrganismos deteriorantes, como as leveduras utilizam o ácido lático produzido durante a fermentação, ou mesmo o amido presente nesse tipo de silagem como substrato para crescimento e multiplicação, elevando o pH, produzindo etanol e aumentando as perdas de MS (PAHLOW et al., 2003). Em média, silagens de grãos conservados apresentam estabilidade próxima a 45h (DA SILVA et al., 2018; SAYLOR et al., 2019).

O uso de inoculantes microbianos compostos por bactérias como o *Lactobacillus buchneri* tem sido adotado com estratégia a promover incrementos sobre a estabilidade aeróbia nesse tipo de silagem (LYNCH et al., 2012; DIAZ et al., 2013; AKINS; SHAVER, 2014). Sob condições anaeróbias, o *L. buchneri* é capaz de produzir ácido acético, o qual tem propriedades antifúngicas, prolongando a estabilidade aeróbia. Estabilidade aeróbia superior a 100h foram observados por Mellinger et al. (2020) quando silagens de espiga foram inoculadas com *L. buchneri, Pediococcus pentosaceus*, e *Proprionibacterium acidilactici* e estocadas por 90 dias. Nesse mesmo trabalho, silagens de espiga sem a adição de inoculante apresentaram estabilidade aeróbia de 69h.

2.4 Fatores que afetam a produtividade e o valor nutritivo de silagens de espiga

No campo, as interações entre fatores climáticos e genéticos, população de plantas estabelecidas na lavoura, tipo de híbrido plantado, tratos culturais e a maturidade com a qual silagens de espigas são produzidas afetam diretamente a produtividade e valor nutricional (OWENS et al., 2018).

As variações de produtividade encontradas usando diferentes híbridos quando extrapoladas para área total podem ser altamente significativos. Mahanna (2008), registraram variações de produtividade entre 14 a 16 ton/MS/ha avaliando 8 diferentes híbridos de milho no Estado de Minesota (EUA). Teoricamente as 2 toneladas de diferença quando extrapolados para área total, podem ser traduzidas em um maior número de animais alimentados com a mesma área.

Além dos fatores produtivos, o tipo de híbrido também pode afetar o valor nutricional da silagem, principalmente devido a proporção de grãos e participação dos componentes; palha, sabugo (HUNT et al., 1989; THOMAS et al., 2001). Mahanna (2008) relataram variações de 13 a 21,3% nos teores de FDN, e variações de 54,6 a 63% a nas concentrações de amido, comparando oito diferentes híbridos de milho. Basicamente, aquelas silagens produzidas com híbridos com maior proporção de grãos em relação a palha e sabugo resultarão em silagens com um maior valor energético (GUSMÃO, et al., 2021).

Juntamente ao tipo de híbrido, a maturidade no momento de colheita também afeta diretamente a produtividade, distribuição dos componentes na planta e o valor nutritivo em silagens (BUXTON; O'KIELY, 2003). Quando colheitas em maturidades tardias são praticadas, um dos principais efeitos que podem ser observados se baseiam no aumento da produtividade (/Ton/MS/ha) e aumento na quantidade de amido colhido por hectare (OWENS et al., 2018). Na espiga, durante o desenvolvimento dos grãos, os açúcares são convertidos em amido, alterando o peso dos grãos e por consequência a produtividade da lavoura (JAMES; MOORE, 2009; OWENS, 2008). Conforme a planta de milho se desenvolve, a espiga passa a ocupar maior proporção da planta como um todo. Xu et al. (1995), observaram que em estágio de maturidade fisiológica, a espiga pode representar até 60% do peso seco da planta, podendo os grãos representar até 50% desse total. Em um intervalo de 20 dias, Mahanna (2008) registraram aumento na proporção de grãos na espiga de 77% para 82,2%. Até que se atinja a maturidade fisiológica, os incrementos em amido são lineares nos grãos. Hunt et al. (1989) observaram valores de 50,8; 58,1 e 62,4% de amido em espigas de milho quando as mesmas foram colhidas com 49,6; 58,2 e 64,7% de MS, respectivamente.

De forma isolada, os componentes alteram o valor nutritivo de forma diferenciada. Nos grãos, as principais modificações com avanço da maturidade se referem a e deposição contínua de amido até o estágio de maturidade fisiológica o qual podem variar de 65 a 75% de amido no grão. No entanto, a depender do híbrido, os incrementos da deposição de amido podem vir acompanhados de reduções da digestibilidade ruminal principalmente quando híbridos de endosperma do tipo vítreo são usados. Peyrat et al. (2016) observaram redução na digestibilidade do amido no trato total de 91,3 para 86,5% quando híbridos de milho com endosperma vítreo foram colhidos com 31,3 e 46,5% de

MS, respectivamente. A principal justificativa para as perdas em digestibilidade do amido com mudanças no estágio de maturidade estão relacionadas ao aumento da proporção de endosperma vítreo nos grãos (PHILIPPEAU; MICHALET-DOREAU, 1998).

No sabugo, conforme o aumento da maturidade, as concentrações de FDN aumentam de forma progressiva. Dados de Mahanna (2008) mostraram que no sabugo, em um intervalo de 20 dias, as concentrações de FDN aumentam de 78,9 para 87,8%. Na palha, o mesmo comportamento é observado. Concentrações de FDN variando de 76,7 a 80.6% foram registrados nesse mesmo intervalo. Em decorrência, resultados de digestibilidade *in vitro* dos componentes da espiga colhidas em diferentes maturidades, mostraram que o sabugo é o componente que mais perde em digestibilidade com o avanço da maturidade (MAHANNA, 2008). Entre a primeira e a última colheita relatados por esse autor, com o mesmo intervalo citado anteriormente, o sabugo reduziu em quase 20% a sua digestibilidade. Nesse mesmo intervalo as perdas em digestibilidade da palha foram próximas a 6%. Weaver et al. (1978) ao conduzir um experimento similar a esse, em que plantas de milho foram colhidas em diferentes datas, com intervalos de 2 semanas, também verificaram queda linear sobre a digestibilidade do sabugo, de 72,8 para 52,3% entre a primeira avaliação e a última avaliação, ocorridas em 09 de setembro e 09 de Dezembro, respectivamente.

É provável que outros fatores como processamento também afetem o valor nutritivo em silagens de espiga. O tamanho teórico de partícula também pode ser um fator com potencial para alterar a digestibilidade da fração fibrosa em silagens de espiga. Na literatura não são encontradas recomendações para tamanho teórico de corte quando silagens de espigas são produzidas. No entanto, a inclusão de componentes de baixa digestibilidade, como palha e sabugo, nos faz pensar que o processamento desses componentes é fundamental para que não haja prejuízos sobre a digestibilidade dessas frações, limitação do consumo ou seleção no cocho. Silagens de espiga com maior tamanho de partícula podem ter menor digestibilidade da fibra, uma vez que uma menor área de superfície para colonização de bactérias fibrolíticas estaria disponível. Além disso, produzir silagens com tamanho de partícula maior poderia levar a maior retenção do material no rúmen, reduzindo as taxas de passagens, ou provocando enchimento ruminal (MERTENS, 1987). A regulagem da máquina para um tamanho de partícula maior e o uso de rolos processadores (crackers) distantes entre si, também podem levar também a prejuízos sobre o processamento dos grãos e sobre a digestibilidade do amido (COOKE; BERNARD, 2005). Distância entre os rolos processadores de 2 a 3 mm foram indicados por Mahanna (2008) para permitir maior processamento dos grãos. Além disso, no momento de colheita, a alta inclusão de outras partes da planta, como as folhas e o caule, podem reduzir a concentração de energia desse tipo de silagem, em função do aumento das concentrações de FDN e redução da digestibilidade da mesma.

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ARTIGO 1: **Yield performance of Brazilian hybrids for whole plant corn silage and snaplage**

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Yield performance of Brazilian hybrids for whole plant corn silage and snaplage

Abstract

The aim of this study was to examine some agronomic characteristics that may influence on performance of Brazilian hybrids to make whole plant corn silage (WPCS) and snaplage. Seventeen corn hybrids were evaluated for both types of silage. The hybrids were grown at 70,000 plants/ha on plots (6 x 5 m) in three blocks. The hybrids were harvested in two moments. The whole plant corn was harvested at the target 35% of DM and ear corn were harvested with 65% of DM. The descriptive statistics was used to characterize hybrids. The hierarchical clustering analysis was carried out to group corn hybrids and Principal Component Analysis (PCA) was performed to identify traits associated with dry matter yield (DMY) for both type of silage, using package of the statistical program R version. The DMY of hybrids ranged from 22.4 to 32.2 ton/ha. The stover yield ranged from 11.8 to 20.7 ton/ha, while kernel yield ranged from 9.50 to 12.9 ton/ha. The minimum, average, and maximum individual plant weight were 0.32, 0.38 and 0.46, kg of DM, respectively. Leaves, stem, dead material, cob, kernels and husk proportions were 16.6, 21.7, 4.22, 8,12, 41.3 and 7.95% on average, respectively. For snaplage, ear yield ranged to 12.1 to 20.9 ton/ha, and the average among hybrids was 16.8 ton/ha. The kernels proportions on the ear was for 76.2%, on average. The minimum and maximum kernel proportion were 72.6 and 81.3%, respectively. The husk and cob proportions were similar among hybrids, 11.7, and 11.9% on average, respectively. According the PCA, individual plant weight and stover yield had great contribution to determine DMY in WPCS. For snaplage, the kernel yield, and the ear length were the mains factors to determine the ear yield. Contemporary Brazilian hybrids corn offers potentially high-yielding for WPCS and for snaplage. Different agronomic characteristics determine DMY for WPCS and snaplage. Hybrids with great DMY of whole plant not necessarily are the best option to make snaplage.

Keywords: Corn silage, dry matter yield, hybrids, snaplage

1. Introduction

The corn plant is one of most versatile and popular feedstuff used for ruminants. Currently, different strategies to harvest corn is practiced. The corn plant can be totally harvested, to make whole plant corn silage (WPCS), or fractionated, to make toplage, snaplage, earlage or high moisture corn (Nigon et al., 2016; Ferraretto et al., 2018). Silage from corn have been made for decades, however in the last years, the interest in snaplage production has been increased in Brazil (Bernardes and Castro, 2019; Daniel et al., 2019).

The increase on feedstuffs price has encouraged the production of great amount of quality forage and grains on farms. The hybrids choice is one the first and important decision to make WPCS and snaplage and it directly affect yield costs (Owens et al., 2018). In Brazilian seed market, between 2019 and 2020, more than one hundred corn hybrids are available (Pereira Filho and Borghi, 2020). Furthermore, the hybrids differ in various aspects, and probably there are some hybrids with characteristics more appropriate to make WPCS and snaplage. There are no specific hybrids to make WPCS and snaplage in Brazil, and thus a dual-purpose strategy has been used by seed companies, and because of that, the farmers might poor decisions.

Snaplage and WPCS differ in some characteristics, and they are used in ruminants diets with different objectives. The WPCS is the main source to provide physically effective NDF from stover fraction and energy from kernel fraction. For WPCS, the hybrids choice should focus on quantity and quality of both, stover and kernel (Lauer, 2001; Owens et al., 2018). Conversely, snaplage is composed by cob, kernels, husk and shank (Mahanna et al., 2008, Gusmão et al., 2021), and some traits is important to make WPCS is less important to produce snaplage, as the stover yield, for example. The agronomic characteristics of hybrids to make snaplage should focus mainly on ear corn aspects. Based on that, we hypothesized that the agronomic traits have different contribution to make WPCS and snaplage, and the hybrids is more appropriate for WPCS could be not appropriate for snaplage. The aim of this study was to examine some agronomic characteristics that may influence the performance of hybrids for WPCS and snaplage.

2. Material and Methods

The experiment was carried out at the Experimental Farm of the University of Lavras, Brazil (21°14′S, 45°00′W; 918 m). The regional climate is classified as humid subtropical with dry winter (Köppen-Geiger climate classification: Cwa; Sá Jr et al., 2012). Seventeen commercial corn hybrids (described as H1, H2, H3…H17) from eight seed companies (Agroceres, Biomatrix, Dekalb, Dow AgroSciences, Forseed, Limagrain, Pioneer and Syngenta) were evaluated for WPCS and snaplage during two agricultural years (2017/2018 and 2018/2019). For both years, all hybrids were sown in October and harvested in February. All genetic materials planted had transgenic technology for protection against pests and herbicides (Table 1).

Corn hybrids were planted in experimental plots (6 m long and 5 m wide) in triplicate. Each plot consisted of ten rows, representing a density of 70,000 plants per hectare. Soil characteristics were determined using the methods recommended by Embrapa (1997). Single superphosphate, urea, potassium chloride, and micronutrients were applied as fertilizer. Pesticides and insecticide application also were done during vegetative growth of the hybrids.

The two rows of each plot were used to evaluate the characteristics of plants for WPCS, and two rows of each plot were used to evaluate the ear corn characteristics for snaplage. In the first moment, the plants were evaluating for WPCS. The hybrids were harvested in different date, according to growth cycle. The plants were cut by hand at 25 cm above ground when they achieved 35% of DM. The plants were weight to calculate dry matter yield (DMY) and subsampled in two samples. The first sample were chopped to access the DM concentration. For the second sample, three plants were selected to measure the plant characteristics; plant height (m), ear corn insertion height (m), stem thickness (cm) using a mechanical caliper (W235; Western; Liu et al., 2004; Jung et al., 2006) and the number of live leaves (Adapted by Lemaire and Chapman., 1996). Subsequently, the plants were split into leaves (leaf sheath and blade), stem, dead material, husk, cob, and kernels. All the components were weighted and subsample. The subsample was dried at 55ºC for 72h in a forced air oven to assess DM content. The kernel and stover yield were also evaluate.

For ear corn evaluations, the ears were harvested about 65% of DM, when the kernel achieved the physiological maturity. The ears were removed manually, bundled, and weighed using a digital scale to calculate ear corn yield. Six ears for each plot were randomized selected and evaluated in terms of physical characteristics as follows: ear length (cm), ear thickness (cm), number of rows, total number of kernels, cob thickness(cm), and kernels depth (cm) (Meghji et al., 1984). The total number of kernels in the ear was calculated timing the number of rows by the number of kernels in the row. The kernels depth was calculated by the difference between ear thickness (cm) and cob thickness (cm). Moreover, ears were split into cob, husk, and kernels, to determine the proportion of each component. All ear components were dried at 55ºC for 72h in a forced air oven to assess DM content.

Data from the whole plant corn and ear corn were summarized. Minimum, means, maximum, standard deviation, and 95% confidence interval were carried out for agronomic variables. Data were analyzed using ExpDes package of R system. The Hierarchical Cluster Analysis (HCA) and euclidian distance were used to form groups among hybrids. Principal Component Analysis (PCA) were performed to understand the variation and the contribution of each main component (PCs) in WPCS and snaplage, using the PCA function of the Mvar.pt package of the statistical program R version 3.6.3 (Team, 2020).

3. Results

3.1 Whole plant corn characteristics

The agronomic characteristics of hybrids for WPCS are displayed in the Table 2. At harvesting, the DM concentration ranged from 31.6 to 38.6%, and on average the hybrids had 35.6% of DM. The plants reached the DM concentration for WPCS (35% DM) between 111 and 124 days after sowing (Table 1). The DMY was 26.6 ton/ha, on average. The minimum and maximum DMY were 22.4 and 32.2 ton/ha, respectively. The confidence interval for this characteristic was 25.4 to 27.8 ton/ha. The stover yield (stem, leaf, husk, and cob) ranged from 11.8 to 20.7 ton/ha, and the average was 15.6 ton/ha. The kernel yield ranged to 9.50 to 12.9 ton/ha, and the average among hybrids was 10.9 ton/ha. The minimum, average and maximum individual plant weight were 0.32, 0.38 and 0.46 kg of DM, respectively. The minimum and maximum plant height were 2.53 and 3.26 m, respectively. The ear corn insertion height was 1.68 m, on average. The stem thickness ranged from 1.89 cm to 2.38 cm. The corn plants had 10 green leaves on average. Regarding the whole plant corn proportions, the leaf, steam, dead material, cob, kernel and husk were 16.6, 21.7, 4.22, 8.12, 41.3 and 7.95% on average, respectively (Table 2).

The hierarchical analysis of clusters for whole plant characteristics is showed in Figure 1a. Three groups with similar characteristics were built. The hybrids H6, H10, H8, and H7 were in group 1. The hybrids H15, H16, H11, H4, H1, H7, H5, and H3 were in the group 2, and the hybrids H9, H2, H14, H3 and H12 were in the group 3. According to the PCA, the two components explain 58% of the variance of data (Figure 2a). The DMY of hybris was directly related with individual plant weight (kg/DM) and stover yield (ton/ha). Plant height (m) and ear corn insertion height (m) were related with stem proportion. Kernel yield was directly related with DM concentration (maturity).

3.2 Ear corn characteristics

The ear corn characteristics are shown in the Table 3. The ear DM concentration at harvesting ranged from 61.2 to 68.9%. On average, the ear corn has 65.6% of DM. The ear corn reached the DM concentration for snaplage (65% DM) between 126 and 135 days after sowing (Table 1). The ear yield was 16.8 ton/ha of DM on average. The minimum and maximum ear yield was 12.1 and 20.9 ton/ha of DM, respectively. The confidence interval for ear yield were 15.6 to 18.1 ton/ha of DM. On average, the kernel yield was 12.7 ton/ha of DM, and the minimum and the maximum kernel yield were 9.10 and 12.7 ton/ha of DM, respectively. The ear diameter, and the ear length was 6.05 and 19.7 cm on average, respectively. The cob diameter was 2.94 cm, on average. The kernel number in the ear ranged from 612 to 714 and was 635 on average. The kernel depth was 1.28 cm, on average. Regarding the ear corn proportion, the kernel proportion ranged from 72.6 to 81.3% and on average, the hybrids had 11.7, 76.2 and 11.9% of husk, kernels, and cob proportions, respectively.

The hierarchical analysis of clusters for ear corn characteristics is presented in the Figure 1b. Three groups with similar characteristics were built. The hybrids H11, H12, H6, H17, H5, H8, and H15 were in the group 1. The hybrids H1, H10, H3, H13, and H16 were in the group 2, and the hybrids H14, H2, H7, H4, and H9 in the group 3. According the PCA, for ear corn characteristics, the two components explain about 50% of the variance of data (Figure 2b). The ear yield was directly associated with kernel yield and with the ear length. Kernel proportions was inversely associated with cob and husk proportion.

4. Discussion

The DMY is one of the most important characteristics to choose hybrids to make WPCS and snaplage. Investments in corn field are high and great DMY reduce cost of silage. Great yield reduces the land area required for forage production, allowing alternative crops to be grown or a greater number of animals to be feed (Allen et al., 2003). Many factors affect DMY, as fertilize application, plant population and maturity at harvest (Cox et al., 1998; Tokatlidis and Koutroubas, 2004; Lauer, 2013). However, in this study, these factors were under control, and the genetic of hybrids is the main factor that affected the DMY. Genetic accounted for 40% of total yield in corn hybrids (Mahanna, 2015; Owens, et al., 2018). In adequate agricultural traits, the plant expresses the maximum genetic potential and this result in greater DMY (Cox, 1997; Lauer et al., 2001).

The DMY of hybrids used for WPCS is a result of both, stover and kernels yield (Owens, 2008). For WPCS, the results of this study indicated a great contribution of both; despite, stover yield had greater influence in this response (Figure 1a). Some hybrids showed stover yield about 20 ton/ha (Table 2), and this could explain the relationship between these characteristics. Nonetheless, hybrids with great stover yield in relation to kernel, increase the NDF concentration in silage. The proportion of corn components may affect NDF concentration and the digestibility of it (Dwyer et al., 1998; Cox and Cherney, 2001). The NDF is composed by hemicellulose, cellulose, and lignin, and the proportion of these individual constituents differ in stover components. The stem, for example has more lignin proportion and less digestible nutrients in relation to leaves (Moore and Jung, 2001; Lima, 2020). Hybrids with more stem proportions, has greater NDF concentration and less NDF digestibility (Lima, 2020). Especially for dairy cows, the NDF concentration and the digestibility of it has influenced fiber intake, chewing behavior, ruminal turnover, and efficiency of production (Oba and Allen, 2000; Grant and Ferraretto, 2018). On the other hands, the hybrids with greater stover yield could be considered an alternative for feedlot nutrition. The greater stover yield could provide the fiber and NDF physically effective in order to improve ruminal health and performance in beef cattle, specially, because high concentrate in the diets is practiced.

The kernel is the most representative component in the corn plant, followed by the stem and leaf (Table 2). The maximum kernel proportion was 52.6% and the minimum was 35.7%. The greater kernel proportion is important to maximize starch concentration in silage and to improve the nutritive value. The kernels yield was positively related with DM concentration on corn plant (Figure 2a). Usually, as corn crop maturity progresses, carbohydrates from photosynthesis, and from translocation of reserves temporarily stored in stems, leaves, cobs and husks move toward to kernel filling (Tollenaar et al., 2012). Thus, there is an increase on the kernel weight and kernel yield, and the starch accumulation is one the reason for why some farmers makes WPCS with great dry matter (> 35%). This practice increases the amount of starch in silage and reduce the inclusion of others starch source in the diet. However, in this situation harvest practices should be intensified. The endosperm increases kernel hardness due the increase on prolamin concentration, and this became the kernel more difficult to damage during the harvesting (Ferraretto and Shaver, 2012). For greater starch available, may harvest WPCS using kernel processing is a better alternative (Salvati et al., 2021).

As in whole plant corn, the hybrids showed different potential for ear yield. In agreement with the hypothesis of this work, some hybrids used for WPCS had high potential for DMY, but when evaluated for snaplage, the potential for ear yield were lower. This fact could be associate with the greater stover production in these hybrids, in relation of ear corn.

The kernels account about 70 % of the ear, and because of that, the kernel yield directly affect the ear corn yield on hybrids used for snaplage (Figure 2a). Ear corn with greater length also was associated with ear yield. The ear with greater length has greater potential to produce kernels. The kernels numbers on ear are a genetic function and weather conditions (Lauer, 2012; Gonzalo and Brown, 2016). If during the politization, the hybrids has good weather conditions, the maximum of kernel could be produced potentializing the ear yield.

The husk plus cob represented about 20 to 30% of the ear, and these components always contribute to DMY in snaplage (Hill et al., 1999). In feedlot systems, this characteristic has been considered one advantage in relation to another kernels conservation, as high moisture corn. The greater DMY allows the farmers to feed more animals using the same are. Besides that, this type of silage is source of great degradable starch and fiber to the animals (Hill et al., 1999; Daniel et al., 2019; Salvo et al., 2020). As in whole plant corn, the NDF concentration of snaplage could be affect by the proportion of ear components. Usually, cob and husk have around 80% of NDF and these components has lower digestibility (Lynch et al., 2012). Snaplage make with hybrids with greater husk and cob proportion has greater NDF and low digestibility of it (Gusmão et al., 2021). Therefore, the increase on husk and cob proportion reduces the energy this type of silage. The nutritive value of kernel is greater than cob and husk, and kernel yield should be a priority to make snaplage.

5. Conclusion

Contemporary corn hybrids offers potentially high-yielding for WPCS and for snaplage in Brazil. For WPCS, the yield was determined mainly by individual plant weight and stover yield. For snaplage, the ear yield was mainly determined by kernel yield and ear length. Careful hybrids selection to make WPCS and snaplage. Hybrids with great DMY for WPCS is not consistently the best option to make snaplage.

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Figures

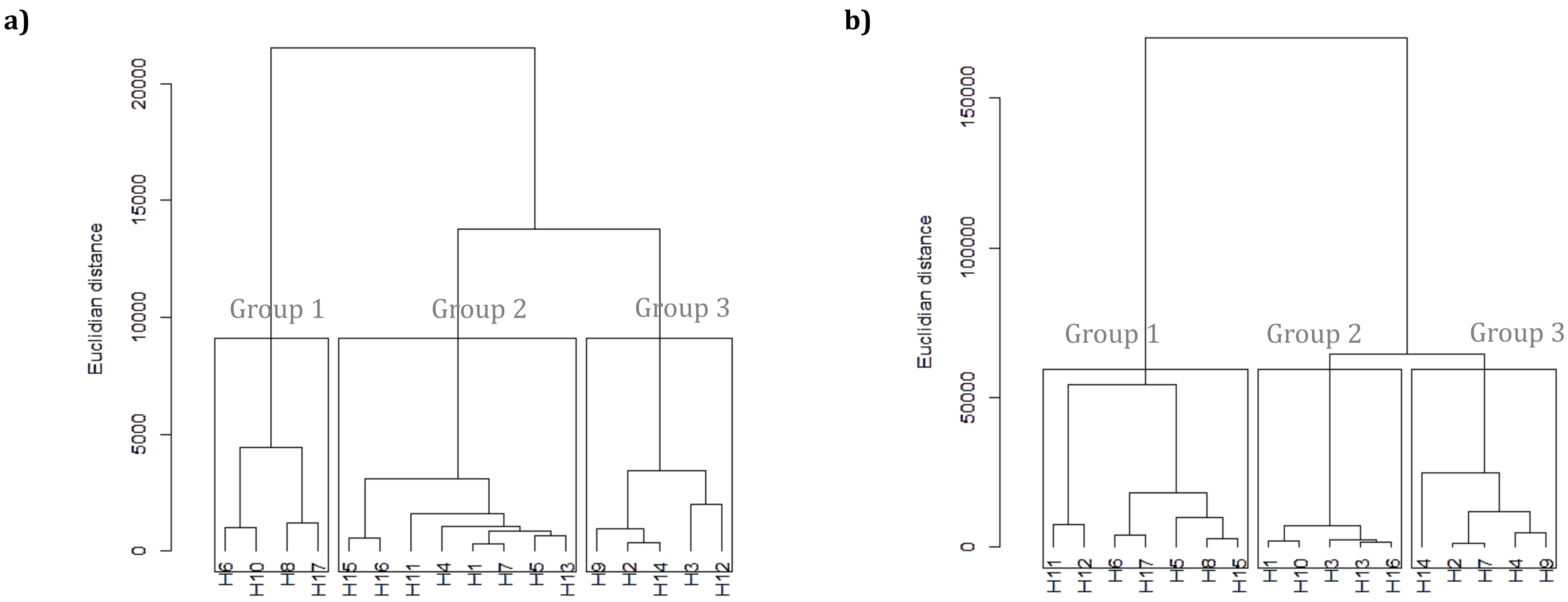

Figure 1- a) Hierarchical cluster analysis for corn hybrids to making whole plant corn silage; **b)** Hierarchical cluster analysis for corn hybrids to making Snaplage.

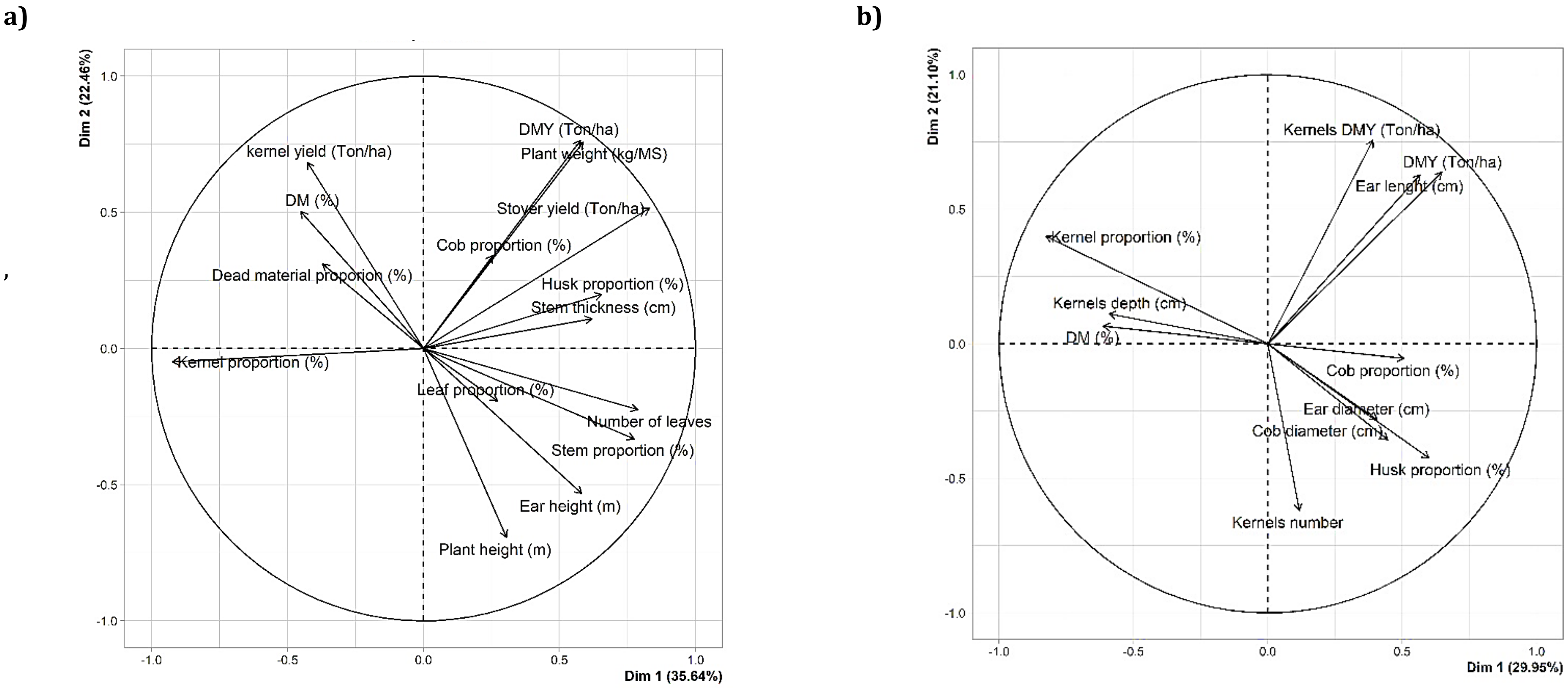

Figure 2- a) Principal component analysis (PCA) according to agronomic characteristics to making whole plant corn silage **b)** Principal component analysis (PCA) according to agronomic characteristics to making snaplage.

Tables

Table 1- Corn hybrids characteristics according of the manufacturing companies and days after to swon (DAS) for WPCS and Snaplage evaluations.

Hybrid	Cycle	Technology	DAS (WPCS)	DAS (Snaplage)
H1	Early	PowerCore[1]	115	130
H2	Early	PowerCore[1]	112	130
H3	Normal	VtPro3[2]	120	135
H4	Early	VtPro3[2]	112	126
H5	Early	VtPro2[3]	116	132
H6	Early	VtPro3[2]	116	128
H7	Early	VtPro3[2]	118	135
H8	Normal	VtPro3[2]	120	135
H9	Normal	VtPro3[2]	118	135
H10	Normal	VtPro3[2]	120	135
H11	Normal	VtPro3[2]	120	135
H12	Normal	VtPro3[2]	115	132
H13	Normal	VtPro2[3]	124	135
H14	Normal	VtPro3[2]	120	135
H15	Early	VtPro3[2]	115	130
H16	Early	VtPro3[2]	115	130
H17	Early	YHR[4]	110	130

[1]Transgenic corn hybrid with three protein insecticide (cry1F, cry1A.105, and cry2Ab2) against lepidopteran pests; [2]Transgenic corn hybrid with protection against lepidopteran pests and pests in the roots. [3]Transgenic corn hybrid with two protein *Bacillus thuringiensis*, against lepidopteran pests. [4]Transgenic corn hybrids with protection two protein *Bacillus thuringiensis*, against lepidopteran pests and herbicide tolerance.

Table 2- Agronomic characteristics of corn hybrids to making whole plant corn silage

Item	Mean	SD	Min	Max	C.I. 95%	
					Lower	Greater
DM (%)	35.6	1.85	31.6	38.5	34.7	36.6
DMY (ton/ha)	26.6	2.33	22.4	32.2	25.4	27.8
Stover Yield (Ton/ha)	15.6	2.13	11.8	20.7	14.5	16.7
Kernel Yield (Ton/ha)	10.9	0.97	9.50	12.9	10.4	11.4
Plant weight (kg/DM)	0.38	0.03	0.32	0.46	0.36	0.39
Plant height (m)	2.85	0.23	2.53	3.26	2.73	2.97
Ear insertion height (m)	1.68	0.16	1.50	2.19	1.59	1.76
Stem thickness (cm)	2.16	0.17	1.89	2.38	2.07	2.24
Number of leaves	10.1	1.27	7.90	12.3	9.46	10.7
Leaf proportion (%)	16.6	1.63	13.0	18.7	15.8	17.5
Stem proportion (%)	21.7	3.34	14.4	27.2	20.1	23.4
Dead material proportion (%)	4.22	1.82	2.02	8.42	3.28	5.16
Cob proportion (%)	8.12	1.34	6.27	11.2	7.43	8.81
Kernel proportion (%)	41.3	4.06	35.7	52.6	39.2	43.4
Husk proportion (%)	7.95	1.38	5.50	10.7	7.24	8.66

Table 3- Agronomic characteristics of corn hybrids to making snaplage.

Item	Mean	SD	Min	Max	C.I. 95%	
					Lower	Greater
DM (%)	65.6	2.17	61.2	68.6	64.5	66.7
Ear Yield (Ton/ha)	16.8	2.37	12.1	20.9	15.6	18.1
Kernels Yield (Ton/ha)	12.7	1.78	9.1	16.1	11.8	13.7
Ear diameter (cm)	6.05	0.71	5.25	7.43	5.8	6.53
Ear length (cm)	19.7	1.41	17.1	22.3	18.9	20.4
Cob diameter (cm)	2.94	0.28	2.38	3.53	2.79	3.08
Kernels number	635	36.3	531	714	612	659
Kernel depth (cm)	1.28	0.26	1.01	1.92	1.14	1.41
Husk proportion (%)	11.7	2.58	8.31	17.1	10.4	13.1
Kernel proportion (%)	76.2	2.94	72.6	81.3	74.7	77.8
Cob proportion (%)	11.9	1.74	9.3	15.7	11.1	12.8

ARTIGO 2: **Effects of hybrid and maturity on the conservation and nutritive value of snaplage**

Artigo publicado no periódico científico Animal Feed Science and Technology

Highlights

The conservation and nutritive value of snaplage is influenced by corn hybrids and maturity.

Snaplage produced from hybrids with low vitreous endosperm and high kernel proportion maximizes starch availability.

Ear maturity affects cob and husk fiber digestibility and kernel starch digestibility.

To optimize snaplage production, the dry matter concentration should be between 600 and 700 g/kg.

Effects of hybrid and maturity on the conservation and nutritive value of snaplage

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Declarations of interest: none

Abstract

The aim of this study was to assess different hybrids of corn harvested at three maturities to make snaplage. Over two crop years, five hybrids were grown at 70,000 plants/ha on plots (6 x 5 m) in three blocks. Hybrids were harvested at the target maturity levels of 600 g/kg of dry matter (DM; M1), 650 g/kg of DM (M2), and 700 g/kg of DM (M3). Fresh ears were separated into kernels, husk, and cob. Whole ears were processed and ensiled (snaplage) in 5-L jars for 90 d. Measurements included DM yield, nutrient analysis, *in vitro* neutral detergent fiber digestibility ($NDFD_{30h}$,), and *in situ* starch degradability (isSD) for ear components and snaplage. The experimental design was randomized complete blocks using a mixed repeated measures model. Data were analyzed using the MIXED procedure of SAS, followed by Student's *t*-test at $P \leq 0.05$. The DM concentrations at harvest were 591, 642, and 683 g/kg for M1, M2 and M3, respectively. There was an interaction between hybrid and maturity ($P = 0.03$) for kernel proportion. The aNDF concentrations of cob and husk increased and the $NDFD_{30h}$ of both parameters decreased from M1 to M3. The greatest lactic acid and NH_3-N concentrations (38.2 g/kg of N) were found at M1. The M3 had the longest aerobic stability. The starch concentrations and isSD of snaplage were affected by hybrid and maturity level ($P < 0.05$). As maturity increased, the isSD decreased (783, 731, and 703 g/kg of starch for M1, M2 and M3, respectively). Overall, corn hybrids differed in ear components proportions and those with lower vitreous endosperm had greater starch degradability. The $NDFD_{30h}$ of cob and husk and the starch degradability of kernels and snaplage declined from M1 to M3. Snaplage should be produced with 600 to 700 g/kg of DM. Harvesting at DM concentrations lower than 600 g/kg compromised starch concentration; but DM concentrations greater than 700 g/kg may impair starch degradability due to restriction in fermentation.

Keywords: harvest window, maturity, snaplage, starch degradability

Abbreviations: aNDF, neutral detergent fiber using α-amylase and sodium sulfite; CP, crude protein; DM, dry matter; isSD, ruminal *in situ* starch degradability; LAB, lactic acid bacteria; M1, first maturity; M2, second maturity; M3, third maturity; $NDFD_{30h}$, *in vitro* neutral detergent fiber digestibility; NH_3-N, ammonia nitrogen.

1. Introduction

To maximize starch availability, corn must be processed. Steam flaking and high-moisture corn have been the most common methods used to increase the total tract starch digestion, otherwise obtained from dry rolled kernels (Owens et al., 1997). However, in recent years, in every corn-growing country interest in making whole-ear corn silage (snaplage) has expanded to increase energy available from the corn crop (Bernardes et al., 2018; Daniel et al., 2019). Although fermented ear corn has been fed to dairy and beef cattle for over 60 years (Beeson and Perry, 1958), harvesting techniques have changed dramatically in the past decade. Snaplage is now produced by using a self-propelled forage chopper equipped with a snapper head (Ferraretto et al., 2018). Snaplage allows harvesting and processing of the whole ear (cob, kernels, husk, and shank) in a single operation, with considerable logistic advantages, especially for beef feedlots (Daniel et al., 2019).

Ear corn is commonly harvested when kernels reach the black layer stage, which indicates physiological maturity (Akins and Shaver, 2014). At that time, snaplage has DM ranging from 650 to 700 g/kg (Akins and Shaver, 2014). In Brazil, as farmers have hired custom operators to make snaplage, ears have been harvested at differing maturities, which may affect yield, the fermentation pattern, and snaplage nutritive value. Therefore, it is crucial to understand how ear maturity changes over the harvest window period, as snaplage is comprised of different ear components.

Corn hybrids differ in their proportions of vitreous and floury endosperm. In Brazil, most commercial hybrids have vitreous endosperm (Daniel et al., 2019). In recent years, new corn hybrids have emerged, with a greater proportion of floury endosperm, which makes them more accessible to ruminal bacteria because the granules are less compact and the protein matrix is discontinuous (McAllister et al., 1993). Furthermore, the proportions of ear components (cob, kernels, and husk) vary among hybrids, and this variation may affect the nutritive value of snaplage. Therefore, we hypothesized that some hybrids are more appropriate than others for snaplage production, and that the maturity level at harvest alters the yield, fermentation pattern, nutrient composition, and digestibility of snaplage. The aim of this study was to assess snaplage as affected by five corn hybrids harvested at three maturities.

2. Materials and methods

2.1 Treatments and silage preparation

The experiment was carried out at the Experimental Farm of the University of Lavras, Brazil (21°14′S, 45°00′W; 918 m). The regional climate is classified as humid subtropical with dry winter (Köppen-Geiger climate classification: Cwa; Sá Jr et al., 2012). Five commercial corn hybrids (described as H1, H2, H3, H4, and H5) from four seed companies were used for snaplage production over two crop years (Table 1). For both years (2017/2018 and 2018/2019), hybrids were sown in October and harvested in February. Whole ears were harvested at three maturities. For the first (M1), second (M2), and third (M3) maturity, the snaplage DM targets were 600, 650, and 700 g/kg, respectively.

Corn hybrids were planted in experimental plots (6 m long and 5 m wide) in triplicate. Each plot consisted of ten rows, representing a density of 70,000 plants per hectare. Soil characteristics were determined using the methods recommended by Embrapa (1997). Single superphosphate, urea, potassium chloride, and micronutrients were applied as fertilizer.

The six central rows of each plot were used for making silage (two rows for each maturity level), whereas the other four were considered border rows. Ears were removed manually, bundled, and weighed using a digital scale to calculate DM yield. Then, ears were separated into two subsamples. For the first subsample, ears were separated into kernels, cob, and husk (bracts + shank). All the components were weighed to determine their proportion within the whole ear. At the third maturity level, kernels were sampled to determine kernel vitreouness by manual dissection (Dombrink-Kurtzman and Bietz, 1993), followed by the procedures described by Corrêa et al. (2002). For the second subsample, ears were processed in a stationary chopper (JF 40 Maxximum, Itapira, Brazil) to a 9 mm theoretical length of cut. Chopped ears were then homogenized and ensiled in 5-L plastic jars, for a total of 15 laboratory silos for each maturity level for both years. Silage density was 600 ± 16.3 kg/m^3. The silos were conserved at 22 °C and opened after 90 d. At opening, silos were weighed, opened, and the snaplage material was homogenized and subsampled. Fermentation end products, microbial counts, and nutritive value were determined in duplicate for each subsample.

An aerobic stability assay was performed on the snaplage. Approximately 2 kg of silage from each silo was placed in polystyrene boxes (250 x 175 mm) for 168 h at 25.5 ± 1.2°C. A sheet of aluminum foil was placed on top of each box to prevent silage dehydration and dust contamination while allowing the ingress of air. Ambient and silage temperatures were measured hourly by data loggers (Pro 2.07.09, Escort Console, SP, Brazil). To record the ambient temperature, three data loggers were distributed across the room. Data loggers for recording silage temperatures were placed at the geometric centers of the silage masses. Aerobic stability was defined as the number of hours that the silage remained stable before reaching a temperature of 2°C above the ambient temperature (Ranjit and Kung, 2000). Losses of DM during the aerobic phase were also evaluated by the difference in weight of the silage contained in the boxes before and after the aerobic stability test.

2.2 Sample preparation, analyses, and calculations

Fresh chopped ear, ear components, and snaplage were oven dried at 55°C for 72 h to determine DM concentration, and then air equilibrated, weighed, and ground in a Cyclotec mill (Tecator, Herndon, VA, USA) to pass through a 1-mm screen. Samples were analyzed for total nitrogen (CP = N × 6.25) determined by the Kjeldahl method (AOAC, 2006). To determine neutral detergent fiber (aNDF) concentration, samples were treated with thermostable α-amylase and sodium sulfite, and the results were corrected for residual ash (Mertens, 2002). Starch concentrations of kernels and snaplage were measured according to an enzymatic method (Hall, 2015) with thermostable α-amylase (Ankom Tchnology, Macedon, NY) and amyloglucosidase (Megazyme E-AMGDF, Bray, Co. Wicklow, Ireland). Cob, husk, and snaplage were analyzed for *in vitro* NDF digestibility at 30 h ($NDFD_{30h}$) following the method proposed by Goeser and Combs (2009) using a DAISY II incubator (ANKOM Technology Corp., Fairport, NY, USA). Ruminal fluid was collected via cannula before feeding from two cannulated cows fed a diet that consisted of 80% corn silage and 20% concentrates.

Ruminal *in situ* incubation were conducted at the University of Florida Dairy Research Unit (Gainesville, FL) under a protocol approved by the University of Florida, Institute of Food and Agricultural Sciences, Animal Care Research Committee. To determine *in situ* starch degradability (isSD), samples of chopped fresh ear and snaplage were dried for 72h in a forced-air oven at 55°C and ground to pass through a 6-mm screen in a Wiley mill (A. H. Thomas Scientific, Swedesboro, NJ, USA). Dacron polyester cloth bags (R1020, 10 × 20 cm and 50 ± 10 microporosity; Ankom Technology, Macedon, NY, USA) containing 5.00 ± 0.20 g of DM, yielding a ratio of sample mass per bag area of 16.6 mg/cm^2 were used. Three ruminally cannulated, mid lactation, multiparous Holstein cows were used. Cows were fed a total mixed ration containing (DM basis) corn silage (38.2%), alfalfa hay (4.00%), dry ground shelled corn (27.3%), soybean meal (14.5%), citrus pulp (9.10%), and minerals and supplements (6.80%). The *in situ* bags were place in a nylon laundry bag (30 × 40 cm) and incubated in the ventral rumen for 7h. Bags were moistened in warm water prior to incubation. Blank bags were also incubated to allow correction for any infiltration of DM into samples bags. After removal, samples were soaked in ice water for 15 min, rinsed in a washing machine set on the rinse and spin cycle with room temperature water for 30 minutes. Two bags for each sample (0 h bags) were washed with the rest of the bags to correct for particulate losses. Individual bags were dried in a forced air oven set at 60 °C for 48 h, ground, with a pestle and mortar to pass through a 1 mm sieve, and analyzed for starch as previously described.

A second subsample of snaplage was used to obtain the yeast, mold, and LAB counts. Samples were transferred to sterile homogenization bags before suspension in a peptone physiological salt solution and homogenization for 4 min in a Stomacher laboratory blender (model 400 Circulator; Seward Inc., Bohemia, NY, USA). For counting of yeasts and molds, the surface plating technique with the YGC Agar culture medium (Sigma-

Aldrich) was used. Serial dilutions (10^{-1} to 10^{-5}) were prepared in duplicate. After incubation at 28°C for 3 d for yeasts and 5 d for molds the colonies were counted separately, based on their macromorphological characteristics. For LAB counts, the same technique described for yeasts and molds was used; however, the culture medium used was MRS Agar (HiMedia). The material was incubated at 35°C for 3 d, according to the method described by Spoelstra et al. (1988).

A third subsample of snaplage was used to obtain the fermentation profile. A snaplage extract was obtained from a mixture of deionized water with the sample in a 9:1 ratio (water to sample), which was kept under constant stirring in a homogenizing apparatus (Stomacher 400, Seward, London, UK) for 4 min. Measurement of pH was performed with a pH meter (model Edge HI 11310; Hanna Instruments, Woonsocket, RI, USA; Bernardes et al., 2019) and measurement of ammonia nitrogen by the colorimetric method (Okuda et al., 1965). The fermentation end products (organic acids and alcohols) were analyzed using HPLC, following the procedures described by Bernardes et al. (2015).

The weight losses during storage were calculated as the difference between the weight of DM placed in each silo at ensiling and the DM removed at the end of storage (Tabacco et al., 2009).

2.3 Statistical analysis

Microbial counts from silage were log-transformed before statistical procedures. A randomized block design with five hybrids and three maturities, with three replications was used over two years. Corn hybrids and maturities were considered as fixed effects, and blocks and years were considered as random. The best covariance structure was chosen using the Akaike information criterion of SAS based on Wolfinger and O'Connell (1993). Variables were analyzed with the PROC MIXED procedure of SAS (SAS

Institute, version 9.4) and means were determined using the LSMEANS statement. The treatment means were compared using Student's *t*-test ($P \leq 0.05$).

3. Results

3.1 Fresh ear characteristics

The chemical composition of fresh chopped ears at ensiling is described in Table 2. The DM concentrations were 591, 640, and 683 g/kg for M1, M2, and M3, respectively. The aNDF concentrations ranged from 188 to 235 g/kg of DM and starch contents from 500 to 554 g/kg of DM. The isSD was 457, 446, and 432 g/kg of starch for M1, M2 and M3, respectively.

The agronomic aspects of corn hybrids as affected by maturity levels are shown in Table 3. The DM yield was unaffected by hybrid ($P = 0.35$), but was altered by maturity ($P = 0.01$). The DM yield was greater for M3 (19.6 t DM/ha), followed by M2 (18.5 t DM/ha) and M1 (17.6 t DM/ha). There was an interaction between hybrid and maturity ($P = 0.03$) for kernel proportion. Among the hybrids, H5 had the lowest kernel proportion at M1 (692 g/kg), M2 (724 g/kg), and M3 (721 g/kg). As maturity progressed, the kernel proportion increased and averaged 711, 735, and 745 g/kg for M1, M2, and M3, respectively. The cob proportion was affected by hybrid and maturity ($P < 0.01$ for both). The H2 and H3 hybrids had lowest cob proportion, 124 and 114 g/kg of DM, respectively. The cob proportion declined as maturity advanced (140, 124, and 115 g/kg of DM for M1, M2, and M3, respectively). The husk proportion was affected by hybrid ($P < 0.01$), and H1 had lower husk proportion than other hybrids.

The chemical composition of the kernels is shown in Table 4. The DM concentrations were affected by hybrid ($P < 0.02$) and maturity ($P < 0.01$). The H4 and H5 hybrids showed greater DM content. For M1, M2, and M3, the DM contents were 665, 707, and 749 g/kg, respectively. Ash and CP concentrations were unaffected by hybrid and maturity (*P* > 0.05). There was an interaction between hybrid and maturity for aNDF (*P* = 0.05) and starch concentrations (*P* = 0.01). The H2 showed lower aNDF concentration at M1 (116 g/kg of DM) and H5 had greater concentration at M2 (148 g/kg of DM). The starch concentration increased as maturity advanced and averaged 607, 678 and 683 g/kg for M1, M2, and M3, respectively. The H5 had the greatest starch concentration at M1 (657 g/kg of DM), whereas for M2 and M3, H4 showed greater starch concentration (703 g/kg of DM).

The nutritive value of cob is displayed in Table 5. The DM concentrations were affected by hybrid (*P* = 0.01) and maturity (*P* = 0.01). The H3 had greater DM content (543 g/kg). The M3 showed greater DM content, followed by M2 and M1. The aNDF concentration of cob was affected by maturity (*P* < 0.01). The aNDF concentration was greater for M3 (819 g/kg of DM), intermediate for M2 (793 g/kg of DM), and lower for M1 (771 g/kg of DM). The $NDFD_{30h}$ was affected by maturity (*P* < 0.01). The first maturity had greater $NFDD_{30h}$ (261 g/kg of NDF), followed by M2 (244 g/kg of NDF) and M3 (209 g/kg of NDF).

The nutritive value of husk is shown in Table 6. There was an interaction between hybrid and maturity for DM content (*P* < 0.01). The H4 and H5 had greater DM content than the other hybrids at all maturities. The DM concentrations for M1, M2, and M3 were 588, 689, and 731 g/kg, respectively. Ash concentrations were affected by hybrid (*P* = 0.05). The H5 had lower ash concentration compared to the other hybrids. The aNDF concentration was affected by hybrid (*P* = 0.04) and maturity (*P* < 0.01). The greater aNDF concentrations were found at M2 and M3 (837 and 845 g/kg of DM). The H4 and H5 hybrids had greater aNDF concentrations at all maturities. There was an interaction between hybrid and maturity for $NDFD_{30h}$ (*P* = 0.02). The $NDFD_{30h}$ declined as maturity advanced and averaged 320, 257, and 246 g/kg of NDF for M1, M2, and M3, respectively.

3.2 Snaplage characteristics

The effects of hybrid and maturity and their interactions on the fermentation end products, microbial counts, losses, and aerobic stability of snaplage are shown in Table 7. The DM concentrations were affected by hybrid ($P < 0.01$) and maturity ($P < 0.01$). The H4 and H5 hybrids showed greater concentrations of DM. The DM contents were 583, 634, and 681 g/kg for M1, M2, and M3, respectively. There was an interaction between hybrid and maturity for pH values ($P = 0.01$). The H3, H4, and H5 hybrids had the greater pH values. The hybrid ($P = 0.04$) and maturity level ($P < 0.01$) affected the lactic acid concentration. Snaplage from H1, H2, and H3 had greater lactic acid concentrations. The lactic acid concentrations were greater for M1 (59.4 g/kg of DM), intermediate for M2 (50.1 g/kg of DM), and lower for M3 (37.1 g/kg of DM). There was an interaction for acetic acid ($P = 0.02$) and ethanol concentrations ($P = 0.04$). Both acetic acid and ethanol decreased as maturity increased. Regarding hybrids, greater acetic acid and ethanol concentrations were found for H1, H2, and H3 at M1. The H2, H3, and H5 hybrids had greater concentrations at M2. At M3, the ethanol concentrations were similar among all hybrids. Propionic and butyric acids and 1,2-propanediol concentrations were not detected in the silages. The NH_{3-}N concentrations were influenced by hybrid ($P < 0.01$) and maturity ($P < 0.01$). The H1 and H2 had the greater NH_3^-N concentrations. As maturity increased, the NH_3^-N concentration declined. The averages were 38.2, 27.1, and 15.2 g/kg of total N for M1, M2, and M3, respectively.

Lactic acid bacteria, yeasts, and molds counts were unaffected by hybrid ($P \geq 0.05$) and maturity ($P \geq 0.05$). The weight losses, aerobic stability, and DM losses during aerobic exposure were affected by maturity ($P < 0.01$ for all parameters). The lower weight losses were found at M3 (29.4 g/kg). The snaplage from M3 had longer aerobic stability (124 h) than the snaplage from M1 (70 h) and M2 (79 h). The DM losses were greater for M1 compared to M2 and M3.

The nutritive value of snaplage is shown in Table 8. The ash concentrations were affected by maturity ($P = 0.03$), with the concentration of M1 greater than M2 and M3. The CP concentrations were influenced by hybrid ($P = 0.05$) and maturity ($P = 0.01$). The concentration was lower in H2 than in the other hybrids. Regarding maturity, greater concentration of CP was found at M1. The aNDF concentrations were affected by hybrid ($P = 0.01$) and maturity ($P = 0.01$). The aNDF concentrations were lower in H2 and H3 than in other hybrids. The aNDF concentrations were 219, 206, and 221 g/kg for M1, M2, and M3, respectively. The $NDFD_{30h}$ was affect by hybrid ($P = 0.01$) and maturity ($P = 0.03$). Snaplage harvested at M1 and M2 had greater $NDFD_{30h}$ (523 and 493 g/kg of NDF, respectively) than at M3 (471 g/kg of NDF). The starch concentrations were affected by hybrid ($P < 0.01$) and maturity ($P = 0.02$). The H1 had greater starch concentration, intermediate for H4 and H5, and lower for H2 and H3. The starch concentrations among maturities were 503 g/kg at M1, 546 g/kg at M2, and 556 g/kg at M3. The hybrid and maturity affected starch degradability ($P < 0.01$ for both). The H2 and H3 hybrids showed greater starch degradability than other hybrids. The starch degradability of snaplage harvested at M1 was greatest (783 g/kg of starch) compared to M2 and M3.

4. Discussion

Snaplage growers seek maximum return on investment, determined by DM yield and nutritive value (Owens et al., 2018). It is important to choose the most suitable corn hybrid to make snaplage, and hybrids with greater yield potential should be prioritized. In this study, the DM yield was not altered by the hybrids evaluated (Table 3), and all hybrids had good productivity (about 18 t of DM/ha).

In addition to DM yield, the proportions of the ear components are of fundamental importance, since kernels have greater nutritive value than cob and husk. Ear component proportions were affected by hybrid and maturity at harvest (Table 3). The H2 and H3 hybrids had greater kernel proportion, and lower cob and husk proportions than other hybrids. As ear maturity progresses, the kernel develops and there is an increase in the kernel proportion. Sugar in amyloplasts cells in kernels is converted to starch during ear development until physiological maturity, at which time the kernel reaches maximum DM weight. From that time on, all ear components lose water, and the proportions among them changes (Daynard and Duncan, 1969; Hunt et al., 1989).

Regarding the nutritive value of ear components (Tables 4, 5 and 6), as maturity advanced, the DM content of the components increased, while water loss from the cob was less intense. At physiological maturity, when photoassimilate translocation to the kernel is completed, its moisture content is approximately 30–34%, and that of the cob is around 53% (Kiesselbach and Walker, 1952). The moisture and the passage of nutrients from cob to the kernel become discontinued by suberization of the closing tissue (Kiesselbach and Walker, 1952). The formation of a semipermeable membrane on the cob that has become infiltrated with suberin causes resistence to moisture loss (Kiesselbach and Walker, 1952). Thus, at harvest, the cob contributes to the moisture content in snaplage. Under practical harvesting conditions, this may be considered an advantage of snaplage compared to high-moisture corn, since snaplage may provide a longer harvest window. Among ear components, the cob and husk had a lower proportion of non-fiber carbohydrates and, as maturity advanced, a lower concentration of soluble carbohydrates, as fructose and glucose decreased and, consequently, the NDF concentration increased in these components (Hunt et al., 1989; Arriola et al., 2012). Furthermore, with greater maturity, the $NDFD_{30h}$ decreased for both (Tables 5 and 6).

The $NDFD_{30h}$ declined almost 20% from M1 to M3. Soderlund (2006), evaluated the nutritive value of snaplage harvested at four maturities and reported a reduction of 20% in cob digestibility from the first to the fourth maturity. The decrease in digestibility has commonly been attributed to high NDF content, lignification on the cell wall, and reduction in soluble carbohydrates (Hunt et al., 1989).

Due to the presence of cob and husk (200–300 g/kg on a DM basis), the concentrations of NDF and starch in snaplage have greater variation (180–230 g/kg of DM and 480–600 g/kg of DM, respectively) compared to other kernel processing methods, such as high-moisture corn and reconstituted corn (Akins and Shaver, 2014; Daniel et al., 2019). The H4 and H5 hybrids, had greater proportions of cob and husk, and because of that, the snaplage from these hybrids had a greater NDF concentrations and lower $NDFD_{30h}$ compared to the other hybrids (Table 8). The starch concentration increased in the kernel and in the snaplage as maturity progressed (Tables 4 and 8, respectively). The magnitude of the increase from M1 to M2 was greater than from M2 to M3. From M1 to M2, the starch content of snaplage increased 33.9 g/kg of DM, whereas from M2 to M3 the increase was 15.0 g/kg of DM (Table 8). At M2, most kernels had achieved physiological maturity and, at that stage, they stopped starch synthesis (James and Myers, 2009).

Not only the starch concentration, but also the digestibility of this carbohydrate is important (Ferraretto, 2017). Starch digestibility and the efficiency with which energy from the kernel is used by ruminants vary because of several factors. The vitreousness of the endosperm, kernel maturity, the extent to which the kernel is processed, and storage time alter starch digestibility (McAllister et al., 1993; Ngonyamo-Majee et al., 2009; Giuberti et al., 2013; Kung et al., 2018). In this research, the isSD decreased as maturity advanced, as confirmed in other studies that assessed whole-plant corn silage and high-moisture corn. The increase in DM content as maturity progresses is associated with the increase in the vitreous endosperm proportion and the prolamin concentration (Philippeau, and Michalet-Doreau; 1997; Ferraretto et al., 2018). Prolamin acts as a physical barrier to enzymatic hydrolysis, and it reduces the surface accessibility of starch to enzyme and/or ruminal bacteria by blocking the absorption sites or by influencing enzyme binding (Owens et al., 1986; McAllister et al., 1993). The isSD of snaplage after 90 d of storage was greater than that of the fresh ear for all hybrids and maturities (Tables 2 and 8). During silage conservation, the hydrophobic prolamin is degraded primarily by bacteria and endosperm enzymes (Junges et al., 2017), increasing the digestibility of starch. Along with an increase in prolamin concentration, there was a reduction in kernel moisture, which seems to negatively affect starch digestibility as maturity advanced by impairing the growth of microorganisms during silage fermentation. This can be seen by the reduction in the fermentation end products from M1 to M3 (Table 7). Furthemore, the concentration of NH_3-N has been positively correlated with starch digestibility in high-moisture corn (Ferraretto et al., 2014). At M3, ammonia concentration was, on average, 50% lower than at M1 and M2.

From M1 to M3 there was an increase in starch concentration; however, the digestibility of this carbohydrate decreased as maturity progressed as previously discussed. Considering these two variables, about 70% of total starch was degraded at all maturities. Under farm conditions, some harvesting management strategies could be adopted to optimize starch energy when considering feeding snaplage to dairy cows and to beef cattle. Lactating dairy cows have less dietary starch digestion in the total digestive tract compared to beef steers (Owens and Soderlund, 2007). Dairy cows have a greater feed intake and faster outflow of ruminal contents, and because of that, the snaplage harvested at M1–M2 may be more appropriate, since at that stage (600–650 g/kg of DM) isSD was greater at 7 h of incubation. Conversely, beef cattle have lower intake and retention time is greater. Harvesting snaplage at M2–M3 (650–700 g/kg of DM) may work better in beef feedlots, because the starch concentration in snaplage is increased and the gastrointestinal tract has more time to degrade starch. The type of hybrid also affected the isSD. The H2 and H3 hybrids had the greater starch degradability. Differences in relative abundance of floury and vitreous endosperm are well-known to affect starch degradability (Philippeau and Michalet-Doreau, 1998; Corrêa et al., 2002). Although a statistical analysis has not been performed to compare vitreousness among the hybrids, H1, H2, and H3 showed less vitreous endosperm (on average, 623 g/kg of DM) than H4 and H5 (on average, 680 g/kg of DM; Table 1).

All snaplages harvested over three maturities had satisfactory results regarding the fermentation profiles and LAB counts (Kung et al., 2018). However, the amount of substrate for LAB fermentation may have been lower at M3 compared to M1 and M2 due to the lower concentrations of lactate and NH_3-N at the third maturity level (Table 7). Monosaccharides, such as glucose and fructose, are the primary substrate of interest for LAB fermentation and growing, but their concentrations decline as plant maturity progresses (Buxton and O'Kiely, 2003). As previously discussed, at M3, the moisture content was lower in relation to M1 and M2, and silage fermentation requires appropriate moisture to allow microbial activity (Pahlow et al., 2003). As the aerobic stability of silages is linked to the fermentation profile (Pahlow and Muck, 2009), the snaplage from M3 was more stable (124h) than the snaplage from M1 and M2 (on average, 75 h). As the lactic acid concentration was lower at M3, there was less substrate for lactate assimilating yeasts to promote deterioration (Pahlow et al., 2003).

5. Conclusion

Based on the results of this study, corn hybrids that have kernels with low vitreous endosperm and high kernel proportion should be prioritized to maximize starch availability in snaplage. Ear maturity dramatically affects the fermentation, aerobic stability, and nutritive value of snaplage. The NDF digestibility of cob and husk and the starch degradability of kernels decreased from 600 to 700 g/kg of DM. This reduction in starch degradability is explained by less intense fermentation as maturity advanced. Therefore, DM content greater than 700 g/kg may place snaplage production at risk.

Author statement

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Conflict of interest

All authors declare no potential conflicts of interest.

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Table 1

Corn hybrids characteristics used in the first and second crop years.

Identification of hybrids	Vitreousness (g/kg of DM)	Cycle[1]	Technology[1]
H1	614	Early	PowerCore[2]
H2	622	Early	VtPro2[3]
H3	633	Early	PowerCore
H4	678	Normal	VtPro3[4]
H5	681	Normal	VtPro3

[1] Specifications according of the manufacturing companies; [2] Transgenic corn hybrid with three protein insecticide (cry1F, cry1A.105, and cry2Ab2) against lepidopteran pests; [3] Transgenic corn hybrid with two protein *Bacillus thuringiensis*, against lepidopteran pests; [4] Transgenic corn hybrid with protection against lepidopteran pests and pests in the roots.

Table 2

Characteristics of fresh chopped whole ear at ensiling (mean and standard deviation of 6 samples).[1]

Item[2]	M1					M2					M3				
	H1	H2	H3	H4	H5	H1	H2	H3	H4	H5	H1	H2	H3	H4	H5
DM (g/kg)	575 ± 11.3	592± 10.9	575± 11.4	609± 11.3	603± 12.1	635± 10.8	643± 11.1	633± 12.0	649± 12.1	651± 10.6	674± 11.8	685± 11.6	675± 11.1	694± 12.2	686± 11.6
Ash (g/kg DM)	12.1± 2.09	11.5± 2.59	14.8± 1.78	13.2± 3.52	11.2± 0.96	16.5± 2.10	15.3± 1.63	16.4± 1.22	15.2± 1.72	12.9± 2.39	15.1± 1.94	17.0± 2.20	18.0± 1.48	16.7± 2.20	14.8± 2.48
CP (g/kg DM)	67.2± 4.13	70.0± 5.70	71.7± 7.49	71.3± 5.44	70.9± 4.67	72.8± 6.40	72.3± 7.69	73.2± 5.55	68.7± 4.83	65.2± 4.30	68.3± 4.83	75.5± 3.84	71.8± 3.30	73.6± 4.52	72.8± 3.58
aNDF (g/kg DM)	192± 20.9	188± 17.1	207± 17.6	208± 18.5	198± 24.4	212± 17.9	221± 18.9	202± 22.3	196± 17.7	229± 13.6	228± 22.2	235± 14.9	221± 17.9	224± 10.9	223± 16.3
Starch (g/kg DM)	506± 28.3	481± 14.0	506± 25.4	501± 24.4	506± 31.4	537± 39.0	549± 34.4	553± 36.8	541± 34.4	538± 29.0	547± 24.4	556± 37.5	556± 29.4	556± 26.5	555± 25.2
isSD (g/kg starch)[2]	454± 9.22	460± 11.1	494± 16.1	435± 6.71	444± 12.1	434± 8.07	452± 13.5	475± 25.6	431± 11.5	440± 29.8	394± 9.56	441± 9.19	448± 6.52	448± 7.31	431± 13.2

[1] M1, Maturity 1 (600 g/kg); M2, Maturity 2 (650 g/kg); M3, Maturity 3 (700 g/kg).

[2] DM = dry matter; CP = crude protein; aNDF = neutral detergent fiber using α-amylase and sodium sulfite; isSD = ruminal *in situ* starch degradation at 7 h.

Table 3

Effects of corn hybrids, maturity stage and their interactions on agronomic traits.

Item	Maturity[1]	Hybrid					Means	SE	*P*-value		
		H1	H2	H3	H4	H5			Hybrid	Maturity	H x M
Yield (t/DM/ha)	M1	18.7	18.2	16.7	16.9	17.9	17.5^{B}	0.30	0.35	0.01	0.57
	M2	18.4	18.5	18.7	18.5	18.5	18.5^{AB}				
	M3	19.8	19.7	18.7	18.9	19.4	19.6^{A}				
	Means	18.9	18.8	18.1	18.1	18.3					
Kernel proportion[2] (g/kg of DM)	M1	714^{Bab}	724^{Ba}	713^{Bab}	710^{Bab}	692^{Bb}	711	0.97	0.01	<0.01	0.03
	M2	755^{Aa}	732^{ABab}	745^{Aab}	735^{Aab}	724^{Ab}	735				
	M3	742^{Aab}	785^{Aa}	725^{ABb}	740^{Aab}	721^{Ab}	745				
	Means	731	747	727	728	712					
Cob proportion[2] (g/kg of DM)	M1	156	137	128	138	139	140^{A}	0.66	<0.01	<0.01	0.39
	M2	136	119	106	131	129	124^{B}				
	M3	131	110	111	120	116	115^{B}				
	Means	142^{a}	124^{c}	114^{c}	129^{b}	134^{ab}					
Husk proportion[2] (g/kg of DM)	M1	130	142	162	142	139	145	0.73	<0.01	0.46	0.75
	M2	118	147	149	140	139	137				
	M3	127	136	152	139	147	141				
	Means	121^{b}	147^{a}	154^{a}	141^{a}	142^{a}					

[a,b] Means with different lowercase letters in corn hybrids differ by Student's t test ($P \leq 0.05$).

[A,B] Means with different capital letters in maturity stage differ by Student's t test ($P \leq 0.05$).

[1] M1, Maturity 1 (600 g/kg); M2, Maturity 2 (650 g/kg); M3, Maturity 3 (700 g/kg).

[2] Proportions were based on whole ear.

Table 4

Effects of corn hybrids, maturity stage and their interactions on the chemical composition of kernels.

Item[1]	Maturity[2]	Hybrid					Means	SE	*P*-value		
		H1	H2	H3	H4	H5			Hybrid	Maturity	H x M
DM (g/kg)	M1	659	659	654	674	673	665^{C}	4.73	0.02	<0.01	0.43
	M2	695	710	692	720	720	707^{B}				
	M3	736	761	741	756	745	749^{A}				
	Means	697^{c}	709^{b}	696^{c}	717^{a}	716^{a}					
Ash (g/kg of DM)	M1	18.3	15.8	16.3	17.7	15.0	16.5	1.87	0.03	0.54	0.07
	M2	23.7	11.8	15.3	14.9	16.6	16.6				
	M3	17.2	10.8	14.4	16.7	16.9	15.6				
	Means	19.7^{a}	12.8^{c}	15.3^{b}	17.1^{ab}	16.5^{b}					
CP (g/kg of DM)	M1	90.6	80.1	82.3	84.1	80.1	80.5	4.45	0.56	0.09	0.13
	M2	77.6	79.5	84.7	83.2	87.9	85.2				
	M3	77.2	83.5	80.1	83.7	84.6	82.4				
	Means	82.8	81.1	82.4	83.6	84.4					
aNDF (g/kg of DM)	M1	139^{Aa}	116^{Cb}	137^{Aa}	137^{Aa}	136^{Ba}	133	6.87	0.65	0.20	0.05
	M2	124^{Bb}	128^{Bb}	131^{Ab}	126^{Bb}	148^{Aa}	131				
	M3	137^{Aa}	139^{Aa}	135^{Aa}	136^{Aa}	137^{Ba}	135				
	Means	134	133	128	140	131					
Starch (g/kg of DM)	M1	590^{Bc}	592^{Bc}	573^{Bc}	622^{Bb}	657^{Aa}	607	10.2	<0.01	<0.01	0.01
	M2	666^{Ab}	669^{Ab}	682^{Aab}	703^{Aa}	668^{Ab}	678				
	M3	683^{Aab}	669^{Ab}	681^{Aab}	703^{Aa}	680^{Aab}	683				
	Means	645	647	643	669	676					

^{a,b} Means with different lowercase letters in corn hybrid differ by Student’s t test ($P \leq 0.05$).

^{A,B} Means with different capital letters in maturity stage differ by Student’s t test ($P \leq 0.05$).

[1] DM = dry matter; CP = crude protein; aNDF = neutral detergent fiber using α-amylase and sodium sulfite.

[2] M1, Maturity 1 (600 g/kg); M2, Maturity 2 (650 g/kg); M3, Maturity 3 (700 g/kg).

Table 5

Effects of corn hybrids, maturity stage and their interactions on the nutritive value of cob.

Item[1]	Maturity[2]	Hybrid					Means	SE	*P*-value		
		H1	H2	H3	H4	H5			Hybrid	Maturity	H x M
DM (g/kg)	M1	465	402	518	519	499	481^{B}	3.63	0.01	0.01	0.71
	M2	494	468	554	544	498	512^{AB}				
	M3	507	483	538	543	531	520^{A}				
	Means	491^{b}	449^{c}	543^{a}	535^{b}	509^{b}					
Ash (g/kg of DM)	M1	11.0	8.3	11.9	17.5	11.4	12.1	0.16	0.24	0.11	0.06
	M2	9.4	11.3	9.1	9.6	11.9	10.1				
	M3	12.8	14.4	9.5	12.4	10.8	12.0				
	Means	11.1	11.4	10.2	13.2	11.5					
CP (g/kg of DM)	M1	22.0	18.1	18.7	19.3	20.0	19.6	0.29	0.46	0.09	0.58
	M2	19.6	19.7	20.5	18.1	19.3	19.4				
	M3	19.4	22.1	19.3	21.1	22.9	21.0				
	Means	20.4	20.0	19.5	19.5	20.7					
aNDF (g/kg of DM)	M1	788	753	771	773	769	771^{C}	1.19	0.09	<0.01	0.26
	M2	815	761	799	798	799	793^{B}				
	M3	826	832	817	813	804	819^{A}				
	Means	809^{a}	784^{b}	796^{a}	792^{b}	790^{b}					
$NDFD_{30h}$ (g/kg of NDF)	M1	232	272	289	249	262	261^{A}	14.3	0.15	<0.01	0.57
	M2	236	246	284	235	218	244^{AB}				
	M3	212	201	241	198	194	209^{B}				
	Means	226	239	271	227	224					

[a,b] Means with different lowercase letters in corn hybrids differ by Student's t test ($P \leq 0.05$).

[A,B] Means with different capital letters on maturity stage differ by Student's t test ($P \leq 0.05$).

[1] DM = dry matter; CP = crude protein; aNDF = neutral detergent fiber using α-amylase and sodium sulfite; $NDFD_{30h}$ = *in vitro* neutral detergent fiber digestibility

[2] M1, Maturity 1 (600 g/kg); M2, Maturity 2 (650 g/kg); M3, Maturity 3 (700 g/kg).

Table 6

Effects of corn hybrids, maturity stage and their interactions on the nutritive value of husk.

Item[1]	Maturity[2]	Hybrid					Means	SE	*P*-value		
		H1	H2	H3	H4	H5			Hybrid	Maturity	H x M
DM (g/kg)	M1	486^{Bb}	609^{Cab}	543^{Bb}	642^{Ba}	677^{Ba}	588	12.1	<0.01	<0.01	<0.01
	M2	680^{Aa}	654^{Ba}	699^{Aa}	739^{Aa}	672^{Ba}	689				
	M3	663^{Ab}	772^{Aa}	693^{Ab}	770^{Aa}	759^{Aa}	731				
	Means	645	603	678	703	717					
Ash (g/kg of DM)	M1	18.7	18.9	19.9	20.7	15.7	18.8	0.81	0.05	0.44	0.07
	M2	17.4	17.7	18.4	22.3	16.4	18.4				
	M3	19.2	18.1	20.5	19.8	17.1	18.8				
	Means	18.4^{a}	18.2^{a}	19.6^{a}	20.1^{a}	16.5^{b}					
CP (g/kg of DM)	M1	19.9	18.0	19.6	20.4	18.9	19.3	0.67	0.35	0.41	0.93
	M2	21.2	17.9	20.5	21.1	18.2	19.8				
	M3	18.7	18.9	19.3	19.4	18.5	18.5				
	Means	19.5	18.1	19.8	20.3	18.4					
aNDF (g/kg of DM)	M1	814	809	815	825	835	819^{B}	0.69	0.04	<0.01	0.32
	M2	826	827	840	839	838	837^{A}				
	M3	834	846	843	855	847	841^{A}				
	Means	825^{b}	828^{b}	831^{b}	838^{a}	840^{a}					
$NDFD_{30h}$ (g/kg of NDF)	M1	321^{Aa}	334^{Aa}	285^{Aa}	336^{Aa}	324^{Aa}	320	11.1	0.28	<0.01	0.02
	M2	245^{Ba}	243^{Ba}	309^{Aa}	240^{Ba}	237^{Ba}	257				
	M3	260^{Ba}	222^{Ba}	259^{Ba}	238^{Ba}	250^{Ba}	246				
	Means	271	284	284	271	270					

[a,b] Means with different lowercase letters in corn hybrids differ by Student's t test ($P \leq 0.05$).

[A,B] Means with different capital letters on maturity stage differ Student's t test ($P \leq 0.05$).

[1] DM = dry matter; CP = crude protein; aNDF = neutral detergent fiber using α-amylase and sodium sulfite; $NDFD_{30h}$ = *in vitro* neutral detergent fiber digestibility

[2] M1, Maturity 1 (600 g/kg); M2, Maturity 2 (650 g/kg); M3, Maturity 3 (700 g/kg).

Table 7

Effects of corn hybrids, maturity and their interactions on the fermentation end products, microbial counts, losses, and aerobic stability of snaplage

Item	Maturity[1]	Hybrid					Means	SE	*P*-value		
		H1	H2	H3	H4	H5			Hybrid	Maturity	H x M
DM (g/kg)	M1	573	577	576	590	601	583^{C}	0.28	<0.01	<0.01	0.08
	M2	625	628	629	650	638	634^{B}				
	M3	681	677	680	687	678	681^{A}				
	Means	626^{b}	627^{b}	628^{b}	642^{a}	639^{a}					
pH	M1	3.84^{Ba}	3.71^{Ba}	3.82^{Ba}	3.85^{Ba}	3.86^{Ba}	3.81	0.01	<0.01	<0.01	<0.01
	M2	3.91^{Aa}	3.87^{Ab}	3.92^{Aa}	3.91^{Ba}	3.95^{Ba}	3.92				
	M3	3.99^{Aa}	4.00^{Aa}	4.02^{Aa}	4.12^{Aa}	4.12^{Aa}	4.05				
	Means	3.91	3.86	3.96	3.92	3.97					
Lactic acid (g/kg of DM)	M1	63.5	61.6	60.0	57.1	54.9	59.4^{A}	1.19	0.04	<0.01	0.61
	M2	52.4	51.1	50.1	52.7	43.6	50.1^{B}				
	M3	35.9	37.6	40.3	36.2	35.1	37.1^{C}				
	Means	50.6^{a}	50.1^{a}	50.1^{a}	48.7^{ab}	44.5^{b}					
Acetic acid (g/kg of DM)	M1	3.37^{Aa}	3.52^{Aa}	2.94^{Aab}	2.42^{Aab}	2.17^{Bb}	2.88	0.07	<0.01	<0.01	0.02
	M2	2.29^{Ab}	2.04^{Bb}	3.15^{Aa}	2.07^{Ab}	2.35^{Aa}	2.38				
	M3	1.97^{Bb}	2.56^{Aa}	2.67^{Aa}	2.05^{Aab}	2.20^{Aa}	2.29				
	Means	2.54	2.70	2.92	2.18	2.24					
Ethanol (g/kg of DM)	M1	9.41^{Aa}	8.69^{Ab}	9.01^{Aa}	8.60^{Ab}	8.28^{Ab}	8.79	0.23	0.15	<0.01	0.04
	M2	7.75^{Bb}	8.60^{Aa}	8.80^{Aa}	7.96^{Bb}	8.06^{Aa}	8.23				
	M3	6.83^{Ca}	6.92^{Ba}	7.09^{Ba}	6.91^{Ca}	6.91^{Ba}	6.93				
	Means	8.00	8.07	8.3	7.85	7.75					
NH$_3$-N (g/kg total N)	M1	47.6	39.5	35.7	33.6	34.7	38.2^{A}	1.26	0.01	<0.01	0.48
	M2	29.8	32.4	27.1	23.6	22.2	27.1^{B}				
	M3	18.1	16.4	15.4	13.1	13	15.2^{C}				
	Means	31.9^{a}	29.4^{ab}	26.1^{b}	23.4^{b}	23.3^{b}					

LAB ($\log_{10}$ CFU/g)	M1	5.31	5.26	4.96	5.25	4.93	5.18	0.23	0.90	0.31	0.84
	M2	4.70	5.13	5.05	5.13	5.11	4.95				
	M3	5.11	5.10	5.15	4.93	4.76	5.07				
	Means	5.04	5.16	5.05	5.13	4.98					
Yeasts ($\log_{10}$ CFU/g)	M1	3.35	3.50	3.56	3.70	3.40	3.50	0.10	0.77	0.11	0.17
	M2	3.41	3.71	2.8	3.23	3.00	3.23				
	M3	3.38	3.10	3.51	3.01	320	3.24				
	Means	3.38	3.43	3.29	3.31	3.20					
Molds ($\log_{10}$ CFU/g)	M1	2.35	2.00	2.26	2.71	2.10	2.28	0.35	0.49	0.89	0.16
	M2	2.00	3.07	2.47	1.76	1.92	2.24				
	M3	2.61	2.50	2.02	1.91	1.87	2.18				
	Means	2.32	2.52	2.25	2.13	1.96					
Weight losses (g/kg)^1	M1	47.2	45.4	43.5	54.2	45.1	47.4^A	5.73	0.07	<0.01	0.75
	M2	40.9	34.6	34.6	32.8	37.1	35.8^B				
	M3	29.1	34.6	27.8	26.1	29.8	29.4^C				
	Means	39.1	38.2	35.3	37.7	37.3					
Aerobic stability (h)	M1	61.7	70.1	75.2	73.2	73.8	70.8^C	4.60	0.62	<0.01	0.17
	M2	94.1	77.8	70.3	82.6	74.5	79.8^B				
	M3	95.1	129	131	133	133	124^A				
	Means	83.6	92.3	92.6	92.4	91.1					
DM losses (g/kg)^2	M1	76.3	96.7	83.2	82.2	72.4	82.2^A	4.43	0.32	<0.01	0.23
	M2	47.9	37.5	50.7	53.5	33.2	44.4^B				
	M3	62.7	23.9	34.4	37.1	32.1	38.3^B				
	Means	56.1	52.7	62.3	45.5	54.6					

^{a,b} Means with different lowercase letters in corn hybrids differ by Student’s t test ($P \leq 0.05$).

^{A,B} Means with different capital letters on maturity stage differ by Student’s t test ($P \leq 0.05$).

^{1}M1, Maturity 1 (600 g/kg); M2, Maturity 2 (650 g/kg); M3, Maturity 3 (700 g/kg).

^{2}DM losses during the storage period; ^{2}DM losses at 168 h of aerobic exposure.

Table 8

Effects of corn hybrids, maturity, and their interactions on the nutritive value of snaplage.

Item^{1}	Maturity^{2}	Hybrid					Means	SE	*P*-value		
		H1	H2	H3	H4	H5			Hybrid	Maturity	H x M
Ash (g/kg of DM)	M1	15.3	20.6	15.8	15.5	12.7	15.8^{A}	0.73	0.11	0.03	0.15
	M2	13.2	15.3	15.9	15.8	13.1	14.7^{B}				
	M3	11.3	11.7	15.3	14.5	12.4	13.1^{B}				
	Means	13.1	15.4	15.7	14.9	12.8					
CP (g/kg of DM)	M1	83.4	76.1	78.5	78.5	79.8	79.1^{A}	1.89	0.05	<0.01	0.23
	M2	74.3	72.3	76.5	75.3	76.8	74.7^{B}				
	M3	73.1	72.1	73.3	78.1	76.4	74.4^{B}				
	Means	76.6^{a}	73.4^{b}	76.3^{a}	77.3^{a}	77.7^{a}					
aNDF (g/kg of DM)	M1	212	192	219	242	229	219^{A}	4.05	<0.01	0.04	0.22
	M2	212	206	185	225	203	206^{B}				
	M3	231	205	199	234	238	221^{A}				
	Means	218^{a}	201^{b}	201^{b}	233^{a}	223^{a}					
NDFD$_{30h}$ (g/kg of NDF)	M1	523	565	537	492	523	523^{A}	16.80	<0.01	<0.01	0.07
	M2	533	504	492	467	469	493^{A}				
	M3	458	498	480	451	472	471^{B}				
	Means	505^{a}	522^{a}	503^{a}	470^{b}	480^{ab}					
Starch (g/kg of DM)	M1	516	516	486	506	492	503^{A}	13.2	<0.01	0.02	0.28
	M2	586	531	516	550	549	546^{B}				
	M3	559	549	538	566	570	556^{B}				
	Means	554^{a}	532^{b}	513^{c}	541^{ab}	537^{ab}					
isSD (g/kg of starch)^{2}	M1	728	802	878	731	775	783^{A}	22.5	<0.01	0.01	0.14
	M2	710	772	796	642	734	731^{AB}				
	M3	631	759	780	625	723	703^{B}				
	Means	690^{b}	778^{a}	818^{a}	666^{b}	744^{ab}					

^{a,b} Means with different lowercase letters in hybrids differ by Student's t test ($P \leq 0.05$).

^{A,B} Means with different capital letters in maturity stage differ by Student's t test ($P \leq 0.05$).

[1] DM = dry matter; CP = crude protein; aNDF = neutral detergent fiber using α-amylase and sodium sulfite; $NDFD_{30h}$ = *in vitro* NDF digestibility; isSD = ruminal *in situ* starch degradation at 7 h.

[2] M1; Maturity 1 (600 g/kg), M2; Maturity 2 (650 g/kg) and M3; Maturity 3 (700 g/kg).