The Influence of Yeast Strain on the Chemical, Chromatic, and Sensory Characteristics of 'Wodarz' Apple Cider

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The Influence of Yeast Strain on the Chemical, Chromatic, and Sensory Characteristics of 'Wodarz' Apple Cider

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Abstract: A regionally developed and adapted dessert apple, 'Wodarz', was explored for its potential in apple cider production because of its consistent productivity when other apple cultivars have struggled with North Dakota's climate. Due to the importance of yeast strain on the perceived quality of fermentation products, five commercial yeast strains, three wine yeasts (EC1118, Maurivin B, and 71B), and two cider yeasts (WLP775 and WY4766) were evaluated for their impact on the physicochemical properties, color, and sensory characteristics of 'Wodarz' cider. By assessing dynamic changes, such as spectral properties and sugar content, a comparison among yeasts was conducted across multiple dimensions. The lightness, chroma, and hue all showed variations throughout fermentation, though not across the final ciders. However, differences in the final color of the ciders were identified via ΔE calculations. Each yeast contributed different aromas and tastes to the final ciders. Among yeast strains, EC1118 had the strongest aroma intensity. Despite having subdued aroma intensity, 71B had strong acidity tastes and WLP775 had strong fruity tastes. Thus, our research suggests that yeast strains are an applicable factor in determining the final sensory attributes of local 'Wodarz' cider. This is the first report of fermentation outcomes using 'Wodarz' apples for cider. 'Wodarz' can be aromatically described using terms such as apple, honey, herbal, rose, and floral and fruit notes. The overall taste of 'Wodarz' cider is characterized by apple, honey, and rose notes followed by black pepper and grass.

Keywords: cider; hard cider; 'Wodarz'; *Saccharomyces* spp.

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1. Introduction

Apple cider is a traditional beverage worldwide, and its consumption is increasing regionally, nationally, and globally. Currently, fermented hard apple cider is experiencing a resurgence in popularity due to the global growth of the alternative alcoholic beverage industry and consumer preferences [1]. Strategies that can be used to maximize apple cider quality remain a consistent focus for producers.

Apple cultivar, ripeness, and fermentation strategy influence the quality of apple beverages, including fermented apple ciders [2]. Apple variety is usually assigned to one of the categories in the Long Ashton system. Based on acidity and tannin content, apples are categorized as bittersharp, bittersweet, sharp, and sweet [3]. Apple variety is frequently a primary attribute influencing apple cider quality and volatile compositions [4]. The ripening of fruit influences the chemical and phenolic compositions of apples within a given cultivar [5]. The chemical composition, especially sugar content, organic acids, and nitrogen content, influence fermentation performance and cider aroma [6].

The fermentation process also impacts cider quality and sensory profiles. Among the key factors for the chemical outcomes of fermented products are the selection of

yeast strain and the fermentation conditions, which play essential roles in influencing the development of sensory properties in ciders [4,7,8]. Yeast metabolites include esters, higher alcohols, fatty acids, volatile acids, volatile phenols, and sulfur compounds [9,10]. The produced compounds are influenced by the yeast strains, fermentation conditions, and nutrient availabilities [11]. The chemical properties, especially the phenolic content, are responsible for cider color, bitterness, mouthfeel, and astringency, which are directly related to sensory perception [12]. The different flavor and aroma characteristics are modulated by the differential biosynthetic pathways of yeast during metabolisms [13,14]. The phenolic composition of apple ciders, especially the formation of free hydroxycinnamic acids, has been associated with different yeast strains [8]. Across yeast, *Saccharomyces* and non-*Saccharomyces* produce different yeast-derived metabolites, such as alcohols and volatile compounds, altering the chemical and sensory outcomes of fermentation on apple ciders [15,16]. While the influence of yeast on grape wine and apple cider fermentation has been examined, it remains a critical question for cider producers working with new cultivars as they strive to understand the impact of yeast strains on key cider characteristics and consumer preferences.

Yeast strains influence titratable acidity, pH, total phenolic content, and sensory profiles [12]. The base chemistry of cider and its attributes are derived from apple varieties, but yeast strains influence the flavor profile that depends on these properties, in a process often driven by volatile compounds [17]. Sensory descriptors and analytical variables are illustrative means of providing information on cider flavors and tastes. The olfactometric intensities of some compounds, such as methionol and 4-ethylphenol, are significantly correlated with different odor sensory characteristics in cider [18]. Compounds with fruity aromas may come from either fruit or be synthesized via microbes during fermentation [19]. Compounds like 2-phenyllethanol provide floral and rose aromas in ciders [18,20]. In addition to flavors, yeast strains also influence the color of cider. In some work, yeast strains have varied in their adsorption of anthocyanins, influencing the chromatic properties [21–23]. Commercial yeast strains influence different apple cultivars in fermentation, demonstrating that yeast strains are a main factor involved in the organic acid and polyphenol profiles of apple wines [24]. Despite this, there remains a need for more information on the effects of different yeast strains on the final cider characteristics, considering the diversity of apples adapted to different growing environments.

With the resurgence of apple growing and apple cider production in North America, growers and cidermakers have been actively exploring more cultivars and techniques for hard cider fermentation. Common cider apple cultivars are often bittersweet European cultivars, with limited evidence of survival and sustainable production in challenging climatic conditions [25]. 'Wodarz' (syn. Wodarz 83) is a consistently productive apple tree that is extremely cold-hardy and tolerant of disease pressures found in eastern North Dakota [26] (Figure 1). 'Wodarz' was jointly released by North Dakota State University and the R.L. Wodarz family of Wyndmere, ND, USA. Because of its irregularity in shape, this cultivar has only received limited regional attention despite desirable eating qualities. With regional interest in cider production increasing and considering its adaptation to the conditions of North Dakota, 'Wodarz' has been identified as a possible fruit source for the regional cider industry. Here, we provide the first evaluation of the chemistry of 'Wodarz' cider and its sensory attributes using commercial wine and cider yeast strains. This study provides fundamental and practical information for regional apple producers and cideries.

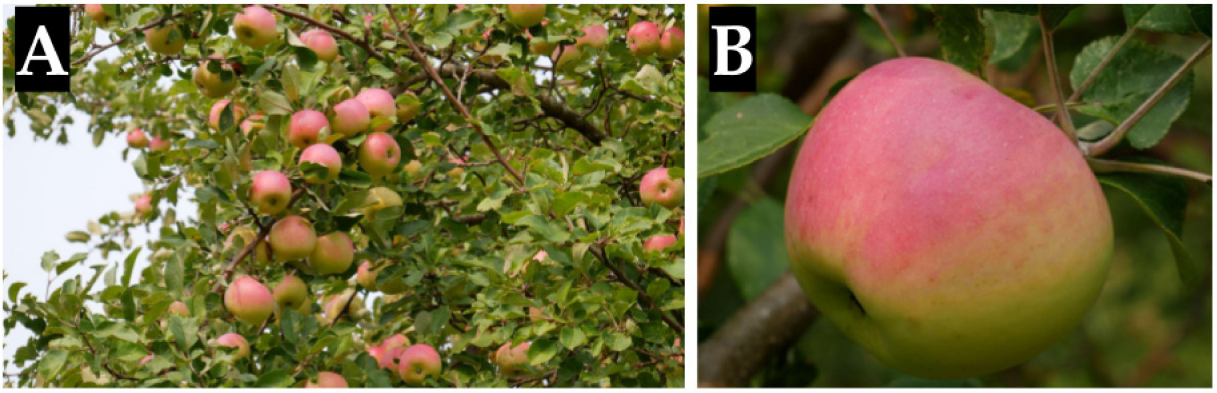

Figure 1. Fruit on a productive branch of 'Wodarz' apple (**A**) and individual fruit (**B**).

2. Materials and Methods

2.1. Orchard

Mature 'Wodarz' apple trees were initially field planted at the North Dakota State University Horticulture Research Farm near Ayr, ND, USA, in 1988. Soil for the research orchard is a mixture of Antler (fine-loamy, mixed, superactive, frigid Aeric Calciaquolls)-Wyard (fine-loamy, mixed, superactive, frigid Typic Endoaquolls) loams, and Warsing sandy loam (fine-loamy, mixed, superactive, frigid Oxyaquic Hapludolls), with a 0 to 2 percent slope [23]. Rejuvenating pruning was conducted in the summer of 2019, beyond which the orchard received no management or chemical inputs aside from biweekly mowing based on the last 10 years of records. Three field replicates of 40 kg apples were hand-harvested from 'Wodarz' apple trees on 14 September 2020. The fruit was held in a refrigerated walk-in cooler at 2 °C for two days until processing.

2.2. Cider Making

On 16 September 2020, individual field replicates were processed using a motorized apple shredder (model WE208, Speidel, Ofterdingen, Germany) and pressed using a 20 L stainless steel bladder press (Speidel, Ofterdingen, Germany).

Field replicate cider musts were manually transferred to three 23 L carboys and dosed with sulfur dioxide (SO_2) at a rate of 40 mg L^{-1}. Musts were transported to Fargo, ND, and each of the three field replicates was homogeneously mixed prior to being transferred into five 5.3 L capacity fermenters (Little Big Mouth Bubbler® Northern Brewer, MN, USA); each fermenter contained 3.5 L of musts. For each of the three replicates, the five fermenters were then inoculated with five commercial yeast strains, including EC1118 (Lalvin; Lallemand Inc., Montreal, QC, Canada), Maurivin B (Lalvin), 71B (Lalvin), WLP775 (Whitelabs, San Diego, CA, USA), and WY4766 (Wyeast, Salton City, CA, USA), which were chosen based on regional feedback from cidermakers. Dehydrated commercial yeast strains were inoculated at a rate of 0.264 g L^{-1} following rehydration. For prepackaged yeast strains, commercial recommendations were followed for the re-initiation of yeast activity. One day after inoculation, fermenting musts received 0.264 g L^{-1} of a yeast nutrient supplement (Fermaid® K, Lallemand Inc., Montreal, QC, Canada).

Fermentation was conducted at 17 °C, and frequent monitoring of fermentation was conducted using a DMA 35 digital density meter (Anton Paar, Graz, Austria). An additional 10 mL sample of each fermentation was collected at each fermentation monitoring event (every 2 d initially and then periodically towards the end of fermentation). The samples were frozen at −20 °C until fermentation dynamic analysis was conducted, including chemical and chromatic properties. Fifteen days after inoculation, as ciders approached the completion of primary fermentation, the ciders were racked into sanitized, argon-purged, clear 1.89 L glass vessels fitted with three-piece airlocks; they were held at 17 °C for approximately two more weeks. Then, they were transferred via gentle pouring to sanitized, argon-purged, clear 1.5 L clear glass vessels held at 17 °C for 10 additional

weeks to allow for any final fermentation to complete. Bentonite (LD Carlson, Kent, OH, USA) was added at a concentration of 0.96 g L^{-1} to clarify these apple ciders prior to final bottling. Ciders from each vessel were then bottled into two individual 651 mL amber glass bottles and sealed with oxygen-scavenging crown caps until sensory analysis and high-performance liquid chromatography (HPLC) analysis.

2.3. Cider Chemical Analysis

The soluble solid content (SSC) of the cider must was recorded using a Pal-1 digital refractometer (Atago Co., Tokyo, Japan). Cider pH was monitored using an Orion Star A111 pH meter (Thermo Fisher Scientific, Waltham, MA, USA). Total acidity was measured with a PAL-BX | ACID5 apple brix-acidity meter (Atago Co., Tokyo, Japan). The results were measured as a percentage (grams of malic acid equivalent/100 g). Meanwhile, pre-fermentation measurements also included measurements with enzymatic kits of malic acid, sorbitol, sucrose, fructose, glucose, ammonia, and primary amino nitrogen (Megazyme, Bray, County Wicklow, Ireland). Pre-fermentation samples were analyzed for each of the three field replicates.

2.4. Cider Color Analysis

Multiple spectral properties of the fermentation products were evaluated to obtain an understanding of the apple cider composition and characteristics. An assessment of total phenolics was conducted according to Iland et al. [27] following the dilution of 100 µL of cider in 10 mL of 1M HCl; measurements were recorded using 10 mm pathlength polymethyl methacrylate UV-cuvette cells (UV-Cuvette semi-micro, BrandTech® Scientific, Inc., Essex, CT, USA) measured in a UV-Vis spectrophotometer (Genesys ™ 10S UV-Vis Spectrophotometer, ThermoFisher Scientific, Waltham, MA, USA). CIELab color coordinates were calculated with MSCV® software, obtaining values for lightness (L*), chroma (C*), hue (h*), red-green (a*), and yellow-blue (b*) based on measurements collected from undiluted samples in 10 mm pathlength polymethyl methacrylate UV-cuvette cells (UV-Cuvette semi-micro, BrandTech® Scientific, Inc., Essex, CT, USA) [28,29]. Final cider sorbitol content was assessed enzymatically with a d-sorbitol/xylitol kit (Megazyme, Bray, County Wicklow, Ireland). The final residual sugars (glucose, fructose), acids (malic acid, lactic acid, acetic acid), ethanol, and glycerol content of the ciders were determined via high-performance liquid chromatography (HPLC) according to previously described methods [28].

2.5. Sensory Analysis

This study was reviewed and approved by North Dakota State University IRB Federal Wide Assurance with the Department of Health and Human Services (FWA00002439). Informed consent was obtained from each subject prior to their participation in this study. The selected panelists represented research scholars, wine and cidermakers, and grape and apple growers who were familiar with wine and cider consumption and tasting. Prior to the cider evaluation, an introductory session was held to train the panelists, familiarizing individuals with the questionnaires and the meaning of each evaluated attribute. The tasting panelists included twelve men and three women, aged 35–60 years old, and the sensory evaluation of fermented 'Wodarz' cider was conducted in May 2021. Sensory evaluation and the number of panelists were limited due to sample volume; however, it was carried out as such due to the importance of the regionally developing interest in 'Wodarz' and the use of other dessert apples and yeast strains.

In total, each taster evaluated fifteen coded samples (five yeast strains × three field replicates) relating to smell and taste at room temperature (20–21 °C) using international tasting glasses (30 mL/sample). For accuracy, four sessions with three 10 min breaks were conducted during the total evaluation processes. During each session, 3 to 4 samples were evaluated by each taster. Based on a preliminary evaluation, a cider evaluation sheet was developed containing a cider aroma evaluation and a tasting evaluation that considered common aroma and taste classifications categories. The criteria for aroma evaluation

included aroma intensity, fruity aroma, floral aroma, spice aroma, vegetal aroma, and yeast aroma. The tasting evaluation included acidity, floral taste, fruity flavor, spice taste, sweetness, and vegetal flavor. Each attribute was evaluated by means of a five-point scale from the lowest to the highest.

The researchers developed a list of descriptors for taste and aroma based on a preliminary evaluation of common descriptors for wine and ciders; these descriptors were accumulated and transformed to check how they applied to the descriptor worksheets [30–32]. The panelists were provided with worksheets to check all of the descriptors that applied to specific cider samples. The aroma and taste descriptors included the following: aniseed, apple, apricot, banana, basil, black pepper, cherry, cinnamon, elderflower, fig, grape, grass, hay, herbal, honey, honeydew, kiwi, lemon, mint, mushroom, orange, peach, pear, pineapple, plum, prune, raisin, resin, rose, vanilla, watermelon, and yeast. While efforts to develop formal cider sensory lexicons, terminology, and evaluation criteria are ongoing, standardized methods are undergoing development [31–35].

2.6. Statistical Analysis

The data were analyzed and graphed using R software version 4.0.5 [36]. Following analysis of variance using lme4 v1.1–3.1 with yeast strain as the main effect and replicate as random, the mean values were calculated with standard error. Where means were significantly different ($p \leq 0.05$), LSmeans were separated via Tukey's HSD using emmeans v1.8.5. The figures were created using ggplot2 package v0.9.0. Selected aroma and taste descriptors were plotted in R using packages tm v0.7–11, SnowballC v0.7.1, wordcloud v2.6, RColorBrewer v1.1–3, and RCurl v1.98–1.12.

3. Results and Discussion

3.1. Initial Characteristics of 'Wodarz' Apple

The soluble solids content (SSC) represents the amount of sugars in fruit. 'Wodarz' had a relatively high content of sugars, with approximately 10.1° Brix (Table 1). Fructose (58.4 g L^{-1}) and sucrose (36.0 g L^{-1}) were the predominant sugars. In addition to these, glucose (3.9 g L^{-1}) also contributed to approximately 98.2 g L^{-1} of fermentable sugars. Sorbitol (about 4.6 g L^{-1}), a sugar alcohol with a sweet taste, was also present in the 'Wodarz' apple cider must.

Table 1. Initial sugar and sorbitol characteristics of 'Wodarz' apple cider musts.

Glucose (g L^{-1})	Fructose (g L^{-1})	Sucrose (g L^{-1})	Fermentable Sugars (g L^{-1})	Sorbitol (g L^{-1})	SSC (°Brix)
3.9 ± 1.60	58.4 ± 5.9	36.0 ± 3.4	98.2 ± 4.8	4.6 ± 1.1	10.1 ± 0.2

The assessment of acid traits prior to fermentation revealed that the pH of 'Wodarz' apple must was approximately 3.74 (Table 2). The total acidity of apples commonly falls around 5–10 g L^{-1}; however, for 'Wodarz', it was only 2.7 g L^{-1}. The malic acid content in 'Wodarz' was 3.35 g L^{-1}, which was also lower than the common apple cultivar 'Fuji' fruits (6–7 g L^{-1}) [37]. The low level of acid present and the relatively high pH may warrant adjustment pre-fermentation in future research and commercial applications using 'Wodarz' apples for cider production. While the total acidity differs from the malic acid content, this is to be expected due to the variation between the availability of hydrogen ions for measurement when using meters or titration while residing in a solution compared to the total sum of all acid compounds in their associated and dissociated forms [38]. Similar differences have been observed in other work focused on apples, where the reported malic acid content differs substantially compared to total or titratable acidity measurements of acid content [39,40].

Table 2. Initial acid characteristics of 'Wodarz' apple cider musts.

pH	Total Acidity (g L^{-1}) [1]	Malic Acid (g L^{-1})
3.74 ± 0.07	2.7 ± 0.1	3.35 ± 0.91

[1] Total acidity expressed as malic acid equivalents.

The primary amino nitrogen content was approximately 19.5 mg L^{-1} in musts (Table 3). In normal fermentation, assimilable nitrogen, including ammonia and amino acids, may exceed 350 mg in total when being used as a yeast nutrient to avoid sluggish fermentation [41]. Here, extra nitrogen supplementation was added to assist yeast fermentation in 'Wodarz' apple musts. The pre-fermentation total phenolics were over 14.0 AU, and the single-fruit mass of 'Wodarz' apples was approximately 121.5 g.

Table 3. Initial nitrogen, phenolic, and fruit mass characteristics of 'Wodarz' apples and apple cider musts.

PAN (mg of N L^{-1})	Ammonia (mg L^{-1})	Total Phenolics (AU)	Single Fruit Mass (g)
19.50 ± 2.19	1.40 ± 0.29	14.53 ± 1.00	121.50 ± 6.38

PAN stands for primary amino nitrogen. AU stands for absorbance units.

3.2. Fermentation Color Spectral Dynamic Changes

3.2.1. Lightness Changes during Fermentation

In general, the lightness of the apple cider increased throughout the fermentation process (Figure 2). EC1118 cider showed the largest lightness change from day 1 to day 3, but after day 3, lightness began to slow for one day, and after day 4, it started to increase again. This might indicate that the yeast strain grew rapidly, which influenced the lightness of 'Wodarz' cider during the fermentation process. Quite similarly, after day 9, all strains worked slowly and smoothly, increasing the lightness until the end of the fermentation process on day 30. At the end of fermentation, 71B cider showed the highest lightness, while EC1118 cider was the least clear. Further, WY4766, WLP77F, and Maurivin B ciders had medium lightness: from 65 to 80 lightness. Lightness variations are often related to the differences in thickness between various zones in the fermentation products and are important to the acceptability of final cider in fermented and unfermented cider products; as such, lightness shifts and the relative clarity of ciders are frequently monitored throughout production processes and at completion due to their importance as part of CIELAB and role in visual differentiation [42–46].

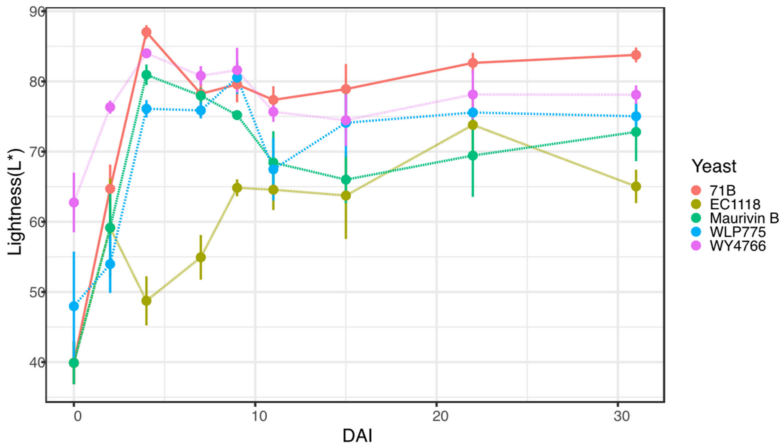

Figure 2. Evolution of L* (lightness) of 'Wodarz' apple cider during fermentation with five different yeast strains. DAI = days after inoculation with yeast strain. Lightness (L*) represents the lightness changes during fermentation process. Bars indicate the standard error of the mean for individual treatment with three replicates.

3.2.2. Chroma Changes during Fermentation

High chroma indicated the clear, bright color of 'Wodarz' apple cider (Figure 3). Maurivin B and WLP775 ciders had similar chroma trends, showing the highest peak of chroma at day 4 with a sharp drop in chroma from day 4 to day 7. This was followed by smooth changes until the end of fermentation. Contrastingly, EC1118, 71B, and WY4766 ciders showed similar trends in terms of chroma levels during the whole fermentation process. The differences in the final products indicated that the chroma level was close to 70 except in the final sampling date of 71B, with a lower chroma of less than 65. This indicated that 71B-fermented cider had less intensity compared to other yeast-fermented ciders.

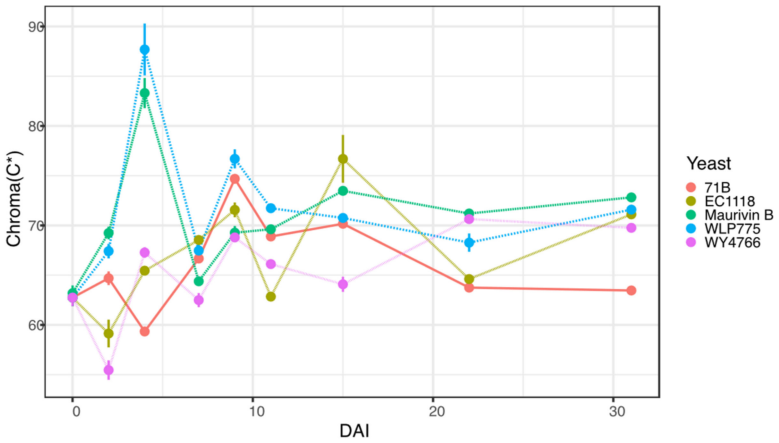

Figure 3. Evolution of C* (chroma) of 'Wodarz' apple cider during fermentation with five different yeast strains. C* represents chroma of apple cider. DAI = days after inoculation with yeast strain. Bars indicate the standard error of the mean for individual treatment with three replicates.

Chroma represents the quality of a color's purity, intensity, or saturation. The color of apple juices is mainly due to the influence of polyphenolics and oxidation on color formation [47]. Apple cider color can also be influenced by by-products added during fermentation. Earlier research indicated that ciders with apple pomace were lighter than apple-juice-fermented ciders [45]. Yeast strains have been reported to influence the color of 'Dolgo' apple cider [28]. It is worth conducting more research to understand the mechanism of yeast strain's influence on color.

3.2.3. Hue Changes during Fermentation

Hue refers to the dominant color. The final sampling dates had quite similar ranges of hue, from 80 to 88 (Figure 4). The hue results indicated that the samples were basically yellow to slightly greenish in color. Hue changes were shown in Maurivin B cider, with a hue peak of around 94; 71B cider had a hue peak of about 88; WY4766 cider had a hue peak of 87.5; and WLP775 cider had a hue peak of 84 at day 4. In general, the apple cider colors were similar, between yellow and green. In this study, subtle hue differences were detected from the highest hue in 71B-fermented ciders compared to the lowest hue in WY4766-fermented ciders towards the conclusion of fermentation.

Colorimetry is used in the color characterization of apple beverages. The impact of pH and oxygen influenced the anthocyanin content and yellow compound formation in apple juice [48]. Whether the influence of the yeast strain is correlated with pH, oxygenation, color extraction, stability, or alternative factors, such as phenolic compounds, needs to be studied in the future [48].

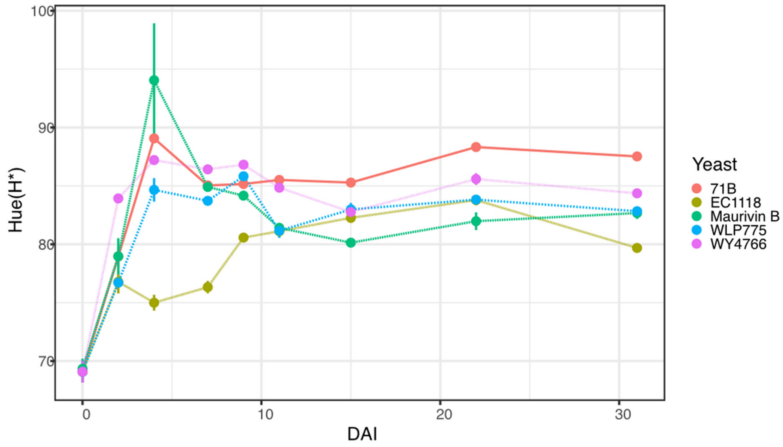

Figure 4. Evolution of H* (hue) of 'Wodarz' apple cider during fermentation with five different yeast strains. H* represents the hue of apple cider. DAI = days after inoculation with yeast strain. Bars indicate the standard error of the mean for individual treatment with three replicates.

3.2.4. Sugar Reduction during Fermentation

During fermentation, yeast will transform sugar into ethanol. Although the five yeast strains showed similar sugar transformation trends, with exponential changes from day 1 to day 10, afterwards, sugar transformation flattened (Figure 5). From day 1 to day 10, the performance of EC1118 yeast was extinguished since it transformed sugar the fastest. Maurivin B was slowest at the beginning, followed by the quicker strains of WLP775, WY4766 and 71B. In the final product, EC1118, 71B, and WY4766 ciders showed °Brix approaching zero, indicating that the transformation of sugar was complete. However, Maurivin B and WLP775 yeasts had not completely transformed sugar into ethanol at the final sampling date, with higher °Brix (1.7–3.5). Ciders were maintained through further racking and transferring; they were not monitored again for SSC or ethanol concentration until final sample collection at sensory screening. As the common yeast strains for wine and cider fermentation, the 71B and EC1118 commercial yeast strains transformed sugar into ethanol quicker than other cider yeast strains.

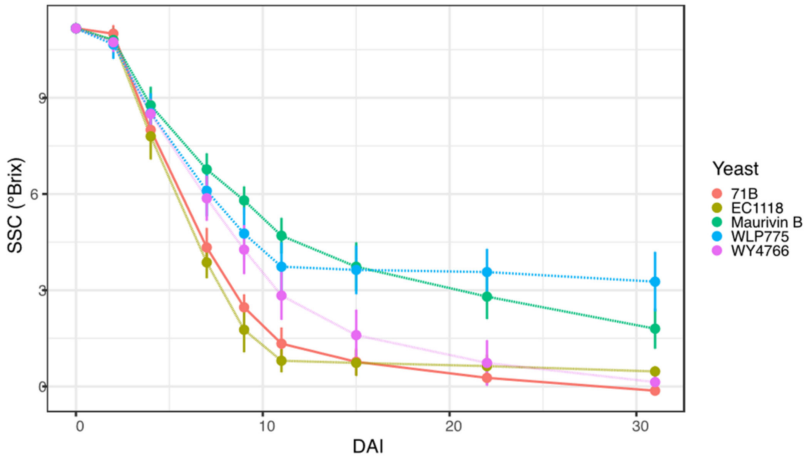

Figure 5. Sugar SSC (soluble solid content) changes during fermentation process with five different yeast strains. DAI = days after inoculation with yeast strain.

3.3. Final Cider Chemistry

No significant differences were detected among yeast strains for final sugar content in 'Wodarz' ciders (Table 4). Ciders retained from 0.00 to 2.80 g L^{-1} of glucose, 0.00 to 15.90 g L^{-1} of fructose, and 0.07 to 18.70 total g L^{-1} of residual sugar. The mean

values across all 'Wodarz' ciders were 0.27 g L^{-1} for glucose, 3.01 g L^{-1} for fructose, and 3.29 total g L^{-1} for residual sugars. The residual sugar content of Maurivin B and WLP775 was lower than that found in the final sampling event during the fermentation process, indicating that both ciders continued fermentation while being held for an extended period in airlocked vessels. This delayed completion of fermentation may have stemmed from low ambient temperatures (approximately 17 °C) that may have been lower than required for rapid fermentation by these two yeasts. Furthermore, while nitrogen supplementation was employed, future work may revisit nitrogen dosing timing and rate as methods to ensure fast and healthy fermentation in low-YAN-content dessert apples, such as 'Wodarz', when repurposed for hard cider. While not statistically different, the content of glucose, fructose, and cumulative residual sugar was greatest in WLP7775; thus, while it completed further fermentation following initial sampling, some of the WLP7775 ciders retained a relatively high rate of residual sugar.

Table 4. The final cider sugar properties of 'Wodarz' apple ciders fermented using five yeast strains.

Yeast	Glucose (g L^{-1})	Fructose (g L^{-1})	Residual Sugar (g L^{-1})
71B	0.08 ± 0.01 ns [1]	2.91 ± 1.16 ns	2.98 ± 1.15 ns
EC1118	0.08 ± 0.01	2.62 ± 0.97	2.70 ± 0.97
Maurivin B	0.05 ± 0.03	0.82 ± 0.45	0.88 ± 0.43
WLP775	1.08 ± 0.96	8.34 ± 3.97	9.41 ± 4.82
WY4766	0.09 ± 0.02	0.37 ± 0.37	0.45 ± 0.36
Mean (Min–Max)	0.27 (0.00–2.80)	3.01 (0.00–15.90)	3.29 (0.07–18.70)
F	1.351	2.8169	2.5347
p	0.3315	0.09924	0.1224

[1] ns = not significant.

Acidity and pH affect the flavor of ciders and are highly correlated with the susceptibility of ciders to microbial spoilage [49]. For the evaluated acidity metrics in 'Wodarz' ciders, acetic acid was the only trait that varied by yeast strain (Table 5). 'Wodarz' ciders had a mean pH of 4.02, with a sample range from 3.84 to 4.30. The total acidity of the ciders ranged from 2.0 to 3.9, with a mean of 3.2 g L^{-1}. Specific measurements of malic acid content did not differ among the yeast strains; 'Wodarz' ciders had a mean of 4.59 g L^{-1} malic acid and a sample range of 1.60 to 5.75 g L^{-1}. Variation in acid content metrics, such as the difference between cider total acidity and malic acid content, mimics the variation in musts. While sulfur was used to inhibit the conversion of malic acid to lactic acid, no additional inhibitory chemicals were implemented. The incidental conversion of malic acid to lactic acid occurred in some samples based on lactic acid quantification, indicating potential spontaneous infection with lactic acid bacteria such as *Oenococcus oeni*. 'Wodarz' ciders had a mean quantity of 0.37 g L^{-1} lactic acid with a sample range from 0.07 to 1.68 g L^{-1}. The acetic acid content varied for 'Wodarz' ciders based on yeast strain, with EC1118 ciders having the greatest acetic acid content (0.56 g L^{-1}) and all other ciders having lower levels. Compared to the common apple ciders used in European apple cider, 'Wodarz' had lower acidity [50,51]. 'Wodarz' is usually treated as a dessert apple; therefore, acid adjustment may help complete the 'Wodarz' cider flavor.

The final percent ethanol content for 'Wodarz' ciders ranged from 4.63 to 5.58, with a mean of 5.22 (Table 6). The glycerol content varied by yeast treatment; 71B ciders had the greatest level (5.34 g L^{-1}), while the other two cider strains, WLP775 and WY4766, had the lowest glycerol content (both 4.14 g L^{-1}). Overall, 'Wodarz' ciders ranged from 3.53 to 5.63 g, L^{-1} with a mean of 4.66 g L^{-1} glycerol. The sorbitol content was greatest for WY4766-fermented ciders (7.05 g L^{-1}) and lower for 71B-fermented ciders (3.46 g L^{-1}). While sorbitol is a non-fermentable polyol sugar alcohol, the yeast strains may vary in the production of sorbitol oxidizing enzymes, and this may have contributed to the differences in the total sorbitol content observed. The total phenolics of the final ciders did not vary by yeast strain; 'Wodarz' ciders had a mean total phenolic content of 14.62 AU. Glycerol and

sorbitol were altered by yeast strain. Both sorbitol and glycerol have favorable impacts on wine quality. The results indicated that although WY4766 cider had higher sorbitol, the cider contained lower glycerol. A contradictory relationship was also observed in 71B-fermented ciders, which had the greatest glycerol content but the lowest sorbitol content.

Table 5. Acid properties of 'Wodarz' apple ciders fermented using five yeast strains.

Yeast	pH	Total Acidity (g L^{-1}) [1]	Malic Acid (g L^{-1})	Lactic Acid (g L^{-1})	Acetic Acid (g L^{-1})
71B	4.01 ± 0.03 ns [2]	3.2 ± 0.2 ns	5.04 ± 0.16 ns	0.10 ± 0.02 ns	0.17 ± 0.09 b
EC1118	4.06 ± 0.12	2.9 ± 0.2	3.64 ± 1.02	0.69 ± 0.49	0.56 ± 0.04 a
Maurivin B	4.05 ± 0.05	3.3 ± 0.1	4.70 ± 0.16	0.25 ± 0.11	0.08 ± 0.04 b
WLP775	3.96 ± 0.06	3.1 ± 0.6	4.78 ± 0.53	0.50 ± 0.30	0.07 ± 0.04 b
WY4766	4.00 ± 0.04	3.6 ± 0.2	4.80 ± 0.16	0.28 ± 0.09	0.08 ± 0.02 b
Mean	4.02	3.2	4.59	0.37	0.19
(Min–Max)	(3.84–4.30)	(2.0–3.9)	(1.60–5.75)	(0.07–1.68)	(0.00–0.63)
F	0.7414	0.7513	1.0646	0.7731	19.074
p	0.5898	0.5793	0.4231	0.567	0.0003748

[1] Total acidity expressed as malic acid equivalents. [2] Values and standard error in a column followed by different letters indicate means were significantly different using means separation of Tukey's HSD; ns = not significant.

Table 6. Ethanol, glycerol, sorbitol, and total phenolic content of 'Wodarz' apple ciders fermented using five yeast strains.

Yeast	Ethanol (% *v*/*v*)	Glycerol (g L^{-1})	Sorbitol (g L^{-1})	Total Phenolics (AU)
71B	5.27 ± 0.16 ns [1]	5.34 ± 0.15 a	3.46 ± 1.24 b	13.67 ± 0.62 ns
EC1118	5.09 ± 0.16	4.99 ± 0.14 ab	4.25 ± 0.92 ab	14.18 ± 1.67
Maurivin B	5.33 ± 0.13	4.68 ± 0.01 ab	5.47 ± 1.24 ab	16.74 ± 1.40
WLP775	5.08 ± 0.25	4.14 ± 0.34 b	5.74 ± 1.10 ab	13.20 ± 1.17
WY4766	5.35 ± 0.73	4.14 ± 0.08 b	7.05 ± 0.61 a	15.29 ± 0.25
Mean	5.22	4.66	5.19	14.62
(Min–Max)	(4.63–5.58)	(3.53–5.63)	(2.50–7.75)	(10.85–18.83)
F	0.9810	8.4019	5.2652	1.5347
p	0.4693	0.003078	0.01519	0.2650

[1] Values and standard error in a column followed by different letters indicate means are significantly different with means separated by Tukey's HSD; ns = not significant.

Humans have different preferences in terms of cider color [52,53]. The chromatic characteristics of 'Wodarz' ciders indicated that the yeast strain did not affect the individual CIELAB color coordinates (Table 7). Overall, 'Wodarz' ciders ranged from 86.5 to 98.2, with a mean of 92.9 for L*. The a* value ranged from −5.8 to 0.2, with a mean of −2.2. The b* values of the samples were between 24.8 and 41.9, with a mean of 35.5. The chroma values fell between 25.4 and 41.9, with 35.6 as the overall mean. The sample hue ranged from 89.7 to 103.2, with an overall sample mean of 93.8.

Despite not differing in terms of specific CIELAB characteristics, differences among the ciders were detected when computing ΔE values (Figure 6). Mean cider colors were differentiable; WY 4766 cider was most different from 71 B cider (ΔE = 6.6) and most similar to WLP 775 cider (ΔE = 2.0). The most similar ciders were 71B and EC1118 based on ΔE values (1.8). Yeast strains contribute to anthocyanin extraction during fermentation but could also reduce colors via the adsorption of pigments [54]. Prior work reported that WLP775 fermented kiwi wines had different color vividness in comparison with other yeast-fermented kiwi wines [55]. In this study, WY4766-fermented ciders had significant differences from 71B- and EC1118-fermented ciders.

Table 7. Chromatic properties of 'Wodarz' apple ciders fermented using five yeast strains.

Yeast	Lightness (L*)	Red (a*)	Yellow (b*)	Chroma (C*)	Hue (h°)
71B	93.7 ± 1.7 ns [1]	−2.2 ± 0.8 ns	32.3 ± 0.9 ns	32.4 ± 0.9 ns	93.9 ± 1.3 ns
EC1118	94.6 ± 1.8	−2.8 ± 1.7	33.7 ± 4.5	34.0 ± 4.3	95.7 ± 4.0
Maurivin B	93.3 ± 2.1	−2.5 ± 1.2	36.8 ± 4.2	36.9 ± 4.0	94.4 ± 2.4
WLP775	91.5 ± 2.7	−1.5 ± 0.6	36.4 ± 4.1	36.4 ± 4.1	92.5 ± 1.1
WY4766	91.2 ± 2.2	−1.7 ± 0.8	38.4 ± 0.4	38.4 ± 0.4	92.6 ± 1.2
Mean	92.9	−2.2	35.5	35.6	93.8
(Min–Max)	(86.5–98.2)	(−5.8–0.2)	(24.8–41.9)	(25.4–41.9)	(89.7–103.2)
F ratio	0.4708	0.2550	0.5646	0.5836	0.3355
p	0.7564	0.9001	0.6956	0.6835	0.8480

[1] Values and standard error in a column followed by different letters indicate means are significantly different with means separated by Tukey's HSD; ns = not significant.

	71B	EC1118	Maurivin B	WLP 775	WY 4766
71B	0.0	1.8	4.5	4.7	6.6
EC1118	1.8	0.0	3.4	4.3	5.9
Maurivin B	4.5	3.4	0.0	2.1	2.8
WLP 775	4.7	4.3	2.1	0.0	2.0
WY 4766	6.6	5.9	2.8	2.0	0.0

Figure 6. Mean colors of 'Wodarz' apple ciders fermented using five yeast strains and the calculated ΔE values for relative difference of color between any pair of yeast strains.

3.4. Sensory Analysis

The aroma evaluation of 'Wodarz' ciders indicated that EC1118 had the strongest overall aroma intensity compared to the other yeast-strain-fermented products (Figure 7). Overall, a floral aroma was detected more frequently than other aroma descriptors. It was mentioned that floral aroma was frequently detected in Maurivin B-fermented ciders by the yeast producers.

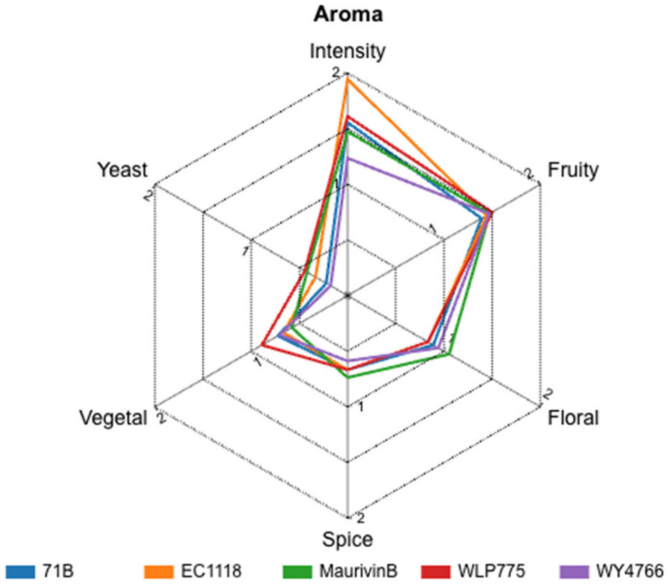

Figure 7. Aroma evaluation comparison among five yeasts for fermented 'Wodarz' cider. The spider chart consists of equiangular spokes, where each spoke represents one descriptor of cider aroma. The position of the spot on the spoke is proportional to the values of the corresponding descriptor.

WLP775 is a standard yeast for dry ciders and may retain the flavors from apples [56]. Prior work demonstrated that cider produced using WLP775 exhibits higher flocculation behaviors than BY4743, but there is no research for WLP775 focused on its contribution to cider flavor [57]. In this research, WLP775 cider had a distinguished vegetal aroma, whereas Maurivin B-fermented ciders had higher levels of floral aromas detected. 71B and EC1118, two common commercial *Saccharomyces cerevisiae* yeast strains, differentially alter juice volatiles and contribute to the formation of new volatile compounds [58]. In this study, EC1118 provided the highest aroma intensity for 'Wodarz' apple ciders, but no distinguished aroma groups were detected in its ciders. WY4766 cider yeast is profiled as a crisp and dry fermenting yeast with pronounced fruity aromas. In 'Wodarz' cider, WY4766 lacked pronounced aroma traits compared to the other yeasts.

The tasting evaluation of the 'Wodarz' cider differed from its aromatic characterization (Figure 8). Overall, WLP775 ciders were the greatest in terms of fruity tastes compared to the other treatments. Both EC1118 and WLP775 showed distinguished sweetness. The 71B-fermented cider had the greatest level of acidity detected. The sweetness noted in WLP775 ciders may be derived from residual sugars; although there was no statistical difference in sugar content, WLP775 ciders had the greatest numerical quantities of sugar (Table 4). Prior work on apple cider fermentation has demonstrated the importance of yeast strain on fermentation rate and organoleptic characteristics; fermentation rate may influence stuck fermentations and residual sugar levels [59].

The main specified description for fermented 'Wodarz' aroma and taste from the panelists were apple and honey, followed, with other terms, such as herbal, rose, elderflower, apricot, hay, grass, pear, and raisin. Rarer terms included stone fruits such as plum, peach, and cherry.

When tasting 'Wodarz' apple ciders, the main characteristics included apple, honey, rose, grass, and black pepper, followed by pear, mint, and other tastes. This complexity provides 'Wodarz' with a unique aroma and taste. The five different yeasts produced different aromas and tastes in the final 'Wodarz' cider products (details not provided). This characterization of aromas and tastes represents a first for 'Wodarz' cider, and can be further enhanced through future work focusing on specific descriptors and an analysis of the driving chemical compounds [60–63].

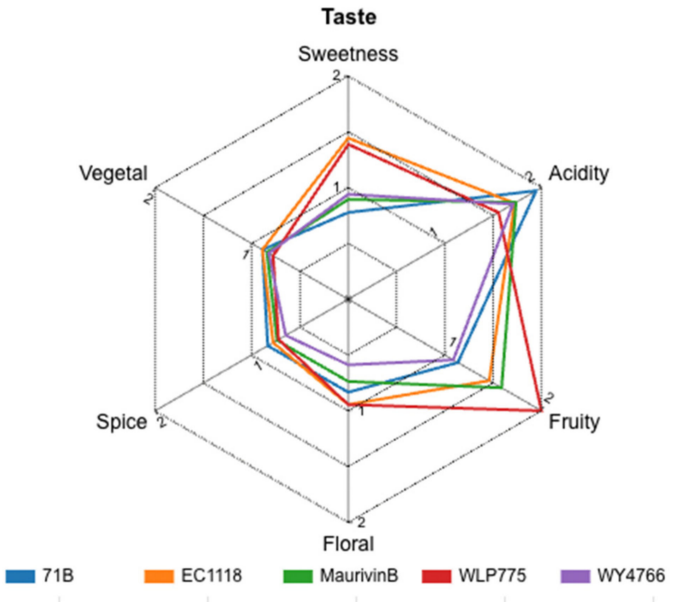

Figure 8. Tasting evaluation comparison among five yeasts for fermented 'Wodarz' cider. Taste metrics include sweetness, acidity, vegetal, spice, fruity, and floral. The spider chart consists of equiangular spokes, where each spoke represents one descriptor of cider aroma. The position of the spot on the spoke is proportional to the values of the corresponding descriptor.

Principal component analysis (Figure 9) indicated that each yeast strain had a differential correlation with specific aromas and taste characteristics in the apple ciders. Yeast EC1118 was distinguished by aroma intensity, while WLP775 was distinguished by fruity taste, sweet taste, yeast aroma, and vegetal aromas in fermented 'Wodarz' ciders. Maurivin B and WY4766 produced ciders with distinguishing floral aromas, and 71B-fermented ciders aligned with acidity and vegetal tastes, farther from the fruity aromas.

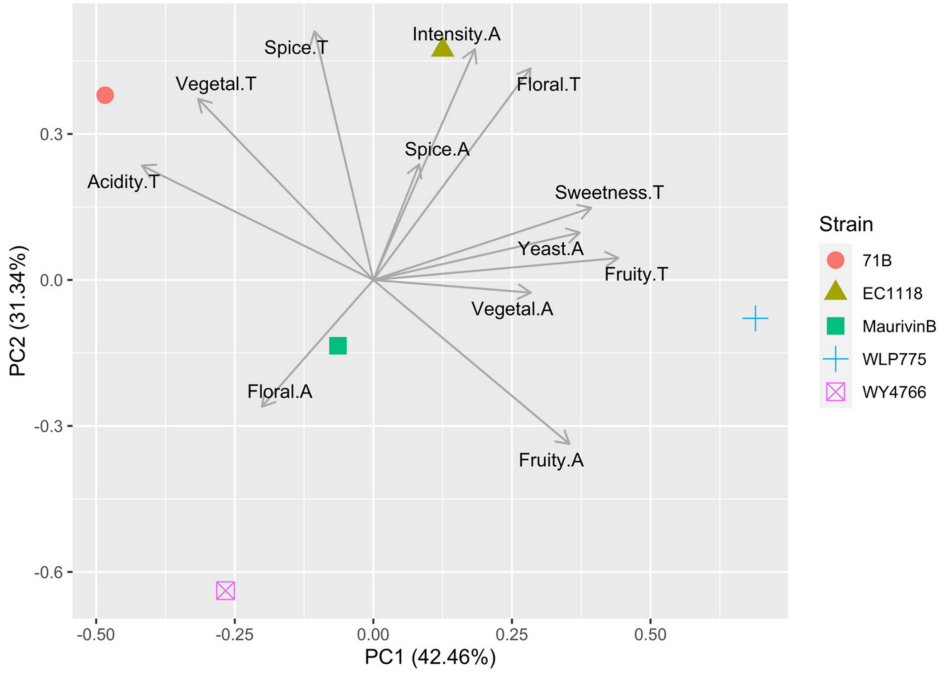

Figure 9. Principle component analysis (PCA) of the aroma and taste descriptors perceived during sensory analysis. '*.A' indicates aroma descriptors; '*.T' indicates taste descriptors.

In addition to 'Wordarz', many other dessert apples are grown productively as backyard and landscape plants in the region, such as 'Dakota Gold', 'Zestar', 'Hazen', 'Wealthy', 'Goodland', 'Northern Lights', 'Haralson', 'Haralred', 'Honeycrisp', and 'Sweet Sixteen' and the crabapples 'Dolgo', 'Chestnut', and 'Centennial' [64,65]. Any variety of apples that is consistently productive in North Dakota may benefit the value-added cider industry, regardless of traditional use, as cidermakers can adapt fermentation and marketing to make the most of the cultivars available to them.

To maximize cider quality and consumer appeal with non-traditional cider apple cultivars, such as 'Wodarz', continued work, including but not limited to fermentation conditions, fermentation strategies, and sensory attribute identification, needs to be conducted [66,67]. Within the realm of *Saccharomyces* spp., regional research has explored different yeast strains when fermenting 'Dolgo' crabapple with the goal of deacidification and color maximization [28]. Cidermakers may alter their yeast populations, using multiple strains and species or, alternatively, blending single-strain ferments to increase complexity. Outside of *Saccharomyces* spp., cider quality may be altered via the addition of non-*Saccharomyces* organisms that are widely used in wine fermentation, such as *Torulaspora delbrueckii*, *Metschnikowia* spp., *Lachancea thermotolerans*, and even *Oennoccocus oeni*, depending on their goals [68–73].

4. Conclusions

'Wodarz' is a regionally grown apple cultivar with a history of local production in the harsh climate of North Dakota. The recent expansion of cider production and apple cultivation has led to a focus on identifying adapted apples and fermentation techniques to meet local demands. This research on the fermentation of 'Wodarz' cider using different yeast strains provides an initial understanding of the effect of yeast on the chemistry and sensory characteristics of 'Wodarz' cider. The yeast strains explored provide a starting point for regional cidermakers' decision-making and establish a baseline for future work with 'Wodarz' apples. This forms a foundation for the development of a future lexicon as regional cideries show continued interest in maximizing the quality of cider from 'Wodarz' apples.

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