Toughness and fibrousness of harvested asparagus is a major factor in determining spear quality (5, 8). The length of storage for both fresh-market and processing asparagus often is limited by progressive toughening of the spear (4). Progressive toughening and fiber development move the natural snapping point upward from the cut end to the tip, which decreases the usable portion of the spear (4). Toughness is due to fiber development and lignification, and increases with distance from the tip and with storage time (5, 10, 12). However, some reports have shown no significant increase in fiber content or toughness in spears during storage at 0°C for up to 6 days (8).

The problem of measuring fibrousness in asparagus has been reviewed (4, 9). Wiley et al. (12) showed that the peak cutting force using a single blade shear-press cell was highly correlated (r = 0.90) with fiber determination by the maceration (rapid blender) method. This correlation was confirmed by Werner et al. (11). In addition, the blender method was shown to correlate extremely well (r = −0.94) with sensory evaluation of asparagus fibrousness (3, 8).

An increase in toughness was observed in segmented (i.e., wounded) whole asparagus spears (7). Since toughness in asparagus has been reported to result from increased PAL activity and lignin synthesis (5), which are induced by wounding, experiments were designed to investigate the effect of an inhibitor of aromatic amino acid synthesis on toughness. The post-emergence herbicide glyphosate (Roundup) inhibits the enzyme 5-enolpyruvylshikimate-3-phosphate synthase (EC 2.5.1.19) that catalyzes the reversible transfer of the enolpyruvate moiety of phosphoenolpyruvate to the 5-hydroxy group of shikimate 3-phosphate (1, 6). The product of this reaction can be converted
to aromatic amino acids, related aromatic compounds, and lignin.

**Materials and Methods**

Asparagus spears were harvested from commercial or Univ. of California, Davis research fields during the middle of the normal season (MH = middle harvest) and at the end of the season (LH = late harvest). Freshly harvested spears without visual defects were trimmed to 21 cm in length and weighed. Spears were arranged by weight, numbered consecutively with a marking pen, and, starting with the lightest spear, segregated into groups containing as many spears as there were treatments. One spear from each group was assigned to each glyphosate concentration. In most experiments, nine to 15 spears (i.e., blocks) were subjected to each of the five to six glyphosate concentrations (treatments) for each sampling period. This procedure was used to reduce the effect of spear diameter on toughness in the data analysis (4).

Spears were placed cut end down into 500-ml glass jars containing 50 ml of glyphosate solution. Three dilution series were made from a stock 480 g-liter$^{-1}$ glyphosate solution. The dilutions were 64, 16, 4, 1, 0.25, and 0.0 g-liter$^{-1}$; 10.0, 1.0, 0.1, 0.01, and 0.00 g-liter$^{-1}$; and 1.0, 0.25, 0.06, 0.016, 0.004, and 0.0 g-liter$^{-1}$. The first series was used only in preliminary experiments because the 64 and 16 g-liter$^{-1}$ concentrations caused tissue damage. Jars were covered loosely with plastic film to

![Fig. 1](image-url)  
Fig. 1. Effect of glyphosate on shear force at different positions along asparagus spears harvested in the middle of the season and stored at 2.5° for 10 days (A) and 20 days (B). Glyphosate concentrations given in g-liter$^{-1}$. The vertical bar over each position represents the LSD at the 5% level for those measurements (n.s. = no significant differences).

![Fig. 2](image-url)  
Fig. 2. Effect of glyphosate on shear force at different positions along asparagus spears harvested late in the season and stored at 2.5° for 10 days (A) and 20 days (B). Glyphosate concentrations given in g-liter$^{-1}$. The vertical bar over each position represents the LSD at the 5% level for those measurements (n.s. = no significant differences).

![Fig. 3](image-url)  
Fig. 3. Effect of glyphosate on percent fiber dry weight at different positions along asparagus spears stored at 2.5° for 20 days. Glyphosate concentrations given in g-liter$^{-1}$. Bars within a position topped by the same letter are not statistically different at the 5% level. Means were separated by Duncan's multiple range test.

Results and Discussion

Glyphosate applications reduced toughness as determined by shear force measurements in spears from both harvests (Figs. 1 and 2). Spears from the MH were more tender (Fig. 1) than spears from the LH (Fig. 2), with maximum shear forces of 75 vs. 190 kg, respectively. The glyphosate effect was more pronounced after 20 days of storage than after 10 days for both MH and LH spears. After 10 and 20 days, the effect between the control and 1 g-liter\(^{-1}\) was significant at all positions tested in MH spears (Fig. 1). In LH spears, the effect was significant up to 5 cm after 10 days, and up to 7 cm after 20 days (Fig. 2 A and B, respectively). It was not determined whether reduced effectiveness was because of a lack of toughening, inactivity of glyphosate, or failure of glyphosate to be translocated into these tissues.

A shear force of ~30 kg has been equated with properly snapped asparagus spears (11). MH spears treated with 1 g-liter\(^{-1}\) glyphosate for 10 days had a shear force near 30 kg at 7 cm, whereas controls dropped below 30 kg at 11 cm (Fig. 1). Since the spears were 21 cm in length, the usable portions were 14 and 10 cm, respectively. In this case, 1 g-liter\(^{-1}\) glyphosate increased the usable portion by 40%. After 20 days of storage, the effect was even more pronounced. Spears treated with 1 g-liter\(^{-1}\) had shear force below 30 kg at 5 cm, whereas controls were at 11 cm. This concentration of glyphosate increased the usable portion 60%, from 10 cm for the control to 16 cm for the treated spears.

A similar comparison was not done for LH spears because glyphosate had no effect at distances up the spear where the shear force was near 30 kg (Fig. 2). Increasing glyphosate concentrations resulted in decreased shear force at each location for each storage period, but the shear force of control tissue and tissue treated with the highest glyphosate concentration at adjacent positions did not overlap. Thus, the maximum benefit in LH spears was ~2 cm of additional usable spear.

Glyphosate significantly reduced the percentage of fiber dry weight from LH spears held for 20 days (Fig. 3). As with shear force, the effect diminished with distance up the spear. Tissue centered at 1 and 5 cm had significantly less fiber than control tissue when treated with 0.01 g-liter\(^{-1}\), and still less fiber when treated with 10 g-liter\(^{-1}\). Tissue centered at 9 cm had significantly less fiber when treated with 0.1 g-liter\(^{-1}\), with no further significant reduction at higher concentrations.

Percent fiber dry weight from LH spears held for 20 days was highly correlated \((r = 0.95)\) with shear press values from the same tissue (Fig. 3). This value agrees favorably with the correlation shown by Kramer et al. for the blender method of fiber analysis and shear press values (3).

Lignin was assayed in tissue centered at 1, 5, and 9 cm from LH spears treated with 0, 0.1, and 10 g-liter\(^{-1}\) glyphosate for 20 days (Table 1). As expected, the content of lignin decreased with increasing glyphosate concentration and with distance from the cut end of the portion of the spear used in the assay. The residual fiber was dried at 50°C until constant weight. Lignin content of the fiber was assayed with a FTA-300 load cell and a CA-1 single blade shear cell following the procedure of Johnson et al. (2).

Fiber was extracted by grinding tissue in 70% methanol and filtering. Three extractions were required to remove all colored material. The final filtration was done with pre-dried and weighed filter paper. The final filtration was done with pre-dried and weighed filter paper. The residual fiber was dried at 50°C until constant weight was achieved. Lignin content of the fiber was assayed following the procedure of Johnson et al. (2).

Each experiment was repeated at least once with similar results. Data were subjected to analysis of variance, and 5% LSD values were used to segregate differences among treatment means.

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Table 1. Effect of glyphosate on lignin and soluble solids content of different portions of asparagus spears stored at 2.5° for 20 days.

<table>
<thead>
<tr>
<th>Glyphosate concen (g-liter(^{-1}))</th>
<th>mg lignin per g fresh wt</th>
<th>Percent soluble solids</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-2 cm</td>
<td>4-6 cm</td>
</tr>
<tr>
<td>0.0</td>
<td>2.62 a</td>
<td>1.68 a</td>
</tr>
<tr>
<td>0.1</td>
<td>2.14 b</td>
<td>1.42 b</td>
</tr>
<tr>
<td>10.0</td>
<td>1.82 c</td>
<td>1.01 c</td>
</tr>
</tbody>
</table>

*The distance from the cut end of the portion of the spear used in the assay.

**Means in columns followed by the same letter are not statistically different at the 5% level. Means were separated by Duncan's multiple range test.

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Fig. 4. Correlation between shear press values and percent fiber dry weight for asparagus spears stored at 2.5° for 20 days.
Inhibition of Ethylene Synthesis and Action in Ripening Tomato Fruit by Ethanol Vapors

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Abstract. Exposure of whole fruit, slices, or pericarp disks of tomato (Lycopersicon esculentum Mill.) to 0.5 to 3.0 ml absolute ethanol vaporized in a 4-liter container for 3 hr significantly reduced the climacteric rise in CO₂ and C₂H₄ production, lycopene synthesis, and chlorophyll loss. Inhibition of ripening occurred whether fruit were at the mature-green or breaker-turning stage. Whole fruit recovered and ripened normally after a delay that was related to the tissue ethanol concentration. Treated slices did not ripen normally, and exposure to 16 μl C₂H₄/liter did not promote ripening. The level of ACC was 14-fold higher in treated slices, while C₂H₄ production was reduced 70%. Treatments with AVG and ACC indicated that ethanol inhibited ACC conversion to C₂H₄. Chemical names used: 1-aminocyclopropane-1-carboxylic acid (ACC); 5-(F)-2-amino-4-(2-aminoethoxy)-3-butyric acid (AVG).

Application of C₂H₄ to mature, unripe tomato fruit promotes natural ripening with an accompanying climacteric rise in CO₂ and C₂H₄ production. Fruit ripening also is accompanied by increased production of acetaldehyde and ethanol (7) and by other volatile compounds, many of which contribute to the characteristic aroma and flavor of ripe fruits.

Application of acetaldehyde, ethanol, or other biologically produced volatile compounds to mature fruit can accelerate ripening and improve fruit quality. For example, acetaldehyde vapors (3000 μl·liter⁻¹) promoted softening of pear fruit under conditions that inhibited C₂H₄ action (7). Postharvest ethanol treatments reduced the astringency of Japanese persimmon fruit (Diospyros kaki L.) (5). Application of methanol or ethanol vapors to harvested blueberries, tomatoes, or pears increased...