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SHEEP MEAT AND PLANT ANTIOXIDANTS IN THE TECHNOLOGY OF HIGH NUTRITIONAL-VALUE MEAT ROULADE: A SYSTEMATIC REVIEW

A.E. Abdurasulova, B.A. Rskeldiev

Almaty Technological University, Almaty, Kazakhstan

Corresponding author: abdurasulova.aigerim@mail.ru

The relevance of this work is due to the need to develop functional meat products with increased nutritional value that are also resistant to oxidative degradation, which is exacerbated in red meat due to the presence of heme pigments and reactive lipid fractions. The research hypothesis is that combining sheep meat with the bioactive components of sea buckthorn and grape seeds will create a biochemically sound antioxidant platform for meat roulade, reducing oxidative losses and stabilising quality during storage. The aim of the article is to critically synthesise current data on the nutritional value and technological characteristics of lamb, as well as on the composition and functional effects of sea buckthorn and grape seeds in meat systems. The methods included a systematic review of publications from 2015 to 2025, searching in English, Russian, and Kazakh and selecting works containing analytical quality indicators. The results show that the bioactive fractions of sea buckthorn (vitamin C at around 300-600 mg/100 g, carotenoids at 5–36 mg/100 g, as well as phenolic compounds) and the polyphenolic complex of grape seeds (proanthocyanidins - 50-200 mg/g in extracts, flavanols and dietary fibre) are most consistently associated in studies with a reduction in oxidation markers, more stable colour characteristics and a variable, dose-dependent effect on textural and technological indicators. The most controllable form of application for roll systems appears to be extracts, which ensure accurate dosing and uniform distribution of bioactive components. Future studies will be based on optimising the amount of plant antioxidants added and the stages of addition, heat treatment and packaging, while controlling the trade-offs between antioxidant effect and organoleptic characteristics.

Keywords: sheep meat, meat roulade, functional meat products, sea buckthorn, grape seeds, oxidative stability.

БАРАНИНА И РАСТИТЕЛЬНЫЕ АНТИОКСИДАНТЫ В ТЕХНОЛОГИИ МЯСНОГО РУЛЕТА ПОВЫШЕННОЙ ПИЩЕВОЙ ЦЕННОСТИ: СИСТЕМНЫЙ ОБЗОР

А.Е. Абдурасулова, Б.А. Рскелдиев

Алматинский технологический университет, г. Алматы, Казахстан,
e-mail: abdurasulova.aigerim@mail.ru

Актуальность работы обусловлена необходимостью разработки функциональных мясных продуктов с повышенной пищевой ценностью и одновременно устойчивой к окислительной деградации, которая в красном мясе усиливается из-за присутствия гемовых пигментов и реакционноспособных липидных фракций. Гипотеза исследования состоит в том, что сочетание баранины с биоактивными компонентами облепихи и виноградных косточек позволит сформировать биохимически обоснованную антиоксидантную платформу для мясного рулета, обеспечивающую снижение окислительных потерь и стабилизацию качества при хранении. Цель статьи — критически синтезировать современные данные о пищевой ценности и технологических особенностях баранины, а также о составе и функциональных эффектах облепихи и виноградных косточек в мясных системах. Методы включали системный обзорный анализ публикаций 2015–2025 гг. с поиском на английском, русском и казахском языках и отбором работ, содержащих аналитические показатели качества. Результаты показывают, что биоактивные фракции облепихи (витамин С порядка 300-600 мг/100 г, каротиноиды 5–36 мг/100 г, а также фенольные соединения) и полифенольный комплекс

виноградных косточек (проантоцианидины, флаванолы и пищевые волокна) в исследованиях наиболее устойчиво ассоциируются со снижением маркеров окисления, более стабильными характеристиками цвета и вариабельным, дозозависимым влиянием на текстурно-технологические показатели. Наиболее управляемой формой внесения для рулетных систем представляются экстракты, обеспечивающие точную дозировку и равномерное распределение биоактивных компонентов. Будущие исследования будут основаны на оптимизации количество вносимых растительных антиоксидантов и на этапах внесения, режима термообработки и упаковки при контроле компромиссов антиоксидантный эффект – органолептические характеристики.

Ключевые слова: баранина, мясной рулет, функциональные мясные продукты, облепиха, виноградные косточки, окислительная стабильность.

ҚОЙ ЕТІ ЖӘНЕ ӨСІМДІК ТЕКТІ АНТИОКСИДАНТТАР ЖОҒАРЫ ТАҒАМДЫҚ ҚҰНДЫЛЫҒЫ БАР ЕТ РУЛЕТІНІҢ ТЕХНОЛОГИЯСЫНДА: ЖҮЙЕЛІ ШОЛУ

А.Е. Абдурасулова✉, Б.А. Рскелдиев

Алматы технологиялық университеті, Алматы, Қазақстан,
e-mail: abdurasulova.aigerim@mail.ru

Жұмыстың өзектілігі тағамдық құндылығы жоғары және сонымен қатар тотығу деградациясына төзімді функционалды ет өнімдерін әзірлеу қажеттілігімен байланысты, өйткені қызыл ет құрамындағы гем пигменттері мен реакцияға қабілетті липидтік фракциялар тотығу үдерістерін күшейтеді. Зерттеу гипотезасы қой етін шырғанақ пен жүзім сүйектерінің биоактивті компоненттерімен біріктіру ет рулетіне арналған биохимиялық тұрғыдан негізделген антиоксиданттық платформаны қалыптастырып, тотығу шығындарын азайтуға және сақтау кезінде сапаны тұрақтандыруға мүмкіндік береді деген тұжырымға негізделеді. Мақаланың мақсаты — қой етінің тағамдық құндылығы мен технологиялық сипаттамалары, сондай-ақ облепиха мен жүзім сүйектерінің құрамы және олардың ет жүйелеріндегі функционалдық әсерлері жөніндегі заманауи деректерді сыни тұрғыдан жинақтау. Зерттеу әдістері 2015-2025 жылдар аралығындағы жарияланымдарға жүйелі шолу жүргізуді, ағылшын, орыс және қазақ тілдерінде деректер іздеуді және сапаның аналитикалық көрсеткіштері келтірілген еңбектерді іріктеуді қамтыды. Алынған нәтижелер шырғанақтың биоактивті фракциялары (С дәрумені шамамен 300-600 mg/100 g, каротиноидтар 5-36 mg/100 g, сондай-ақ фенолдық қосылыстар) және жүзім сүйектерінің полифенолдық кешені (проантоцианидиндер, флаванолдар және тағамдық талшықтар) зерттеулерде тотығу маркерлерінің төмендеуімен, түс көрсеткіштерінің неғұрлым тұрақты болуымен және құрылымдық-технологиялық сипаттамаларға дозасына тәуелді өзгермелі әсерімен ең тұрақты түрде байланысты екенін көрсетті. Рулет типті жүйелер үшін биоактивті компоненттердің дәл мөлшерленуін және біркелкі таралуын қамтамасыз ететін енгізу формасы ретінде экстрактылар ең басқарылатын нұсқа болып табылады. Болашақ зерттеулер өсімдік текті антиоксиданттардың енгізілетін мөлшерін, енгізу кезеңдерін, термиялық өңдеу мен қаптау режимдерін оңтайландыруға, сондай-ақ антиоксиданттық әсер мен органолептикалық қасиеттер арасындағы өзара ымыраны бақылауға бағытталатын болады.

Түйін сөздер: қой еті, ет рулеті, функционалды ет өнімдері, шырғанақ, жүзім сүйектері, тотығу тұрақтылығы..

Introduction. In modern meat science, the concept of functional meat products has shifted from simple fortification toward nutrient-dense, technologically stable matrices that can retain quality during processing and storage. A central scientific problem is that many of the nutrients that make meat valuable coexist with pro-oxidant drivers (heme iron, unsaturated lipids, oxygen exposure during comminution), which accelerate lipid oxidation, impair colour stability, and generate

off-flavours which ultimately shortening shelf life and reducing consumer acceptance [1].

Sheep meat is often positioned as a nutrient-dense red meat because it supplies complete proteins and a spectrum of micronutrients. In a recent lamb loin dataset, Kenenbay et al. reported iron around 2,0-2,2 mg, zinc around 3,0-3,3 mg, vitamin E around 1,0-1,4 mg, and vitamin B_{12} around 0,50–0,60 mg, illustrating the micronutrient "core" that motivates lamb-based functional products [2]. At the same time, sheep meat can be technologically vulnerable because intramuscular fat composition includes a meaningful PUFA fraction, which supplies oxidation substrates. In the same work, PUFA accounted for roughly 21,8-23,5% of total fatty acids in intramuscular fat, a range that is nutritionally attractive but chemically reactive in oxygenated, iron-rich matrices [3].

Sea buckthorn (*Hippophae rhamnoides*) is scientifically interesting for meat applications because it combines multiple antioxidant compounds. Sea buckthorn contains phenolics-radical scavenging and metal chelation, carotenoids-quenching of reactive species and contribution to colour tone, and vitamin C-redox cycling and potential support of metmyoglobin reduction depending on dose and matrix conditions. In a recent compositional synthesis, Olas et al. highlighted sea buckthorn berries as a notably vitamin-rich raw material, reporting vitamin C values that can reach approximately 275 mg/100 g, alongside lipid-soluble antioxidants such as vitamin E around 3,54 mg/100 g [4]. Mechanistically, these compounds may influence meat quality through several routes - termination of lipid peroxyl radicals by phenolic hydrogen donation, chelating Fe^{3} , lowering catalytic redox cycling that accelerates peroxide decomposition and modulating pH via organic acids [5].

Grape seeds represent a high-value secondary resource from viticulture and wine processing, aligning with circular-economy logic while offering dense polyphenolic chemistry. A recent valorisation review reported that grape by-products commonly exhibit high total phenolic content, with representative ranges for different fractions often reaching the hundreds of mg GAE/100 g, supporting their use as antioxidant carriers in foods. The dominant antioxidant "identity" of grape seed materials is typically associated with proanthocyanidins (condensed tannins) - polymeric flavanols that can suppress oxidation by radical scavenging, metal chelation, and interruption of chain propagation. Verma et al. summarised proanthocyanidins as oligopolymeric flavanol structures with broad bioactivity and technological relevance, which is directly applicable to red meat systems where oxidation is often the limiting factor for quality stability [6, 7].

Given mutton's nutrient density and red-meat bioavailability advantages, its susceptibility to oxidative and colour degradation, and the complementary antioxidant profiles of sea buckthorn and grape seeds, we hypothesise that a mutton-based meat roulade can be strengthened nutritionally while improving oxidative and quality stability through targeted inclusion of these plant resources.

According to the hypothesis, the aim of this systematic review is to map and critically synthesise contemporary evidence on lamb meat quality constraints relevant to processing and storage, sea buckthorn-derived ingredients as multifunctional antioxidant inputs, and grape seed ingredients as polyphenol-forward stabilisers and framing a biochemical rationale for their combined use in nutrient-dense lamb product development.

Materials and methods. A structured literature search for systematic review was performed in Scopus, Web of Science Core Collection, PubMed, and ScienceDirect, and the reference lists of influential papers addressing sheep meat quality, safety, and storage were additionally screened to identify other relevant studies. To strengthen regional representation, peer-reviewed articles published in Kazakhstani journals listed by the Science and Higher Education Quality Assurance Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan as recommended outlets for reporting primary scientific results were also included. The search was limited to the last 10 years.

To minimize language bias and capture locally specific evidence, searches were conducted in English, Russian, and Kazakh. The search strategy combined terms describing the raw material, the product concept, the plant additives, and outcome domains. Variants of «sheep meat» or «lamb» or «mutton» were used alone and also together with terms describing the target product («meat roulade», «rolled meat», «restructured meat product», «meat roll») and the additives («sea buckthorn» or «Hippophae rhamnoides» and «grape seed» or «grape seed extract»), along with keywords representing the outcome domains with equivalent terminology in Russian and Kazakh. Boolean logic, truncation, and platform-specific filters were adjusted to each database.

Studies were excluded if they used matrices irrelevant to meat products or did not employ a meat model system, as well as works that lacked analytical assessment of meat quality, including physicochemical, oxidative, colour, texture, microbiological, or sensory parameters. Studies that were not peer-reviewed full-text articles, such as abstracts without complete data, or that did not provide sufficient methodological detail for interpretation, were also excluded. In addition, research focused on additives unrelated to the scope of this review, that is, without a clear connection to sea buckthorn bioactives or grape-seed-derived phenolic fractions, was omitted unless such studies were cited only to provide contextual background.

Records retrieved from databases were compiled and deduplicated. Titles and abstracts were screened for relevance to ovine/red-meat systems, sea buckthorn or grape seed–derived ingredients, and quality outcomes. Full texts were then assessed against the eligibility criteria. From each included study, data were extracted on meat matrix and product type, additive form and preparation (extract, powder, pomace, oil-associated fraction), dose level and incorporation stage, and outcome measures.

Preference in interpretation was given to studies with clearly described processing conditions, validated analytical methods, and storage trials reflecting realistic shelf-life scenarios. Where findings were inconsistent, differences were interpreted in relation to matrix composition, dose, incorporation stage, and thermal/storage conditions rather than treating outcomes as directly comparable.

Results and discussion. Multiple independent studies consistently confirm that lamb is a nutrient-dense red meat, providing high-quality protein together with bioavailable micronutrients. Junkuszew et al. analysed sheep breeds and reported a dry matter range of 24,11-27,13%, which implies moisture 72,87-75,89 g/100 g. In the same muscles, intramuscular fat was 4,60-5,50 g/100 g, total protein was 19,95-22,18 g/100 g, and ash were 0,71-1,06 g/100 g, showing that lean lamb muscle is primarily a high-water, high-protein matrix with moderate intramuscular lipid [8]. At the biochemical level, lamb's protein fraction is characterised by a dense pool of essential amino acids (EAAs) that support both human nutrition and meat functionality – water binding, gelation, texture formation. Total essential amino acids of 24,17-27,20 g/100 g (dry matter) and non-essential amino acids of 35,13-39,48 g/100 g (dry matter). Among abundant contributors were glutamic acid 9,03-9,62, leucine 4,31-4,80, and lysine 3,69-4,17 g/100 g (dry matter). Such an amino acid distribution is relevant not only nutritionally but also sensorially, because glutamate-associated pathways contribute to savoury perception after proteolysis [9].

From a lipid biochemistry perspective, lamb's nutritional profile is strongly shaped by ruminant lipid metabolism (biohydrogenation and isomerisation in the rumen) and by feeding system. In lamb Longissimus dorsi, Sabbioni et al. reported PUFA 25% of total fatty acids, a PUFA/SFA ratio of 0,68, with n-3 = 8% and n-6 =14%, alongside favourable composite lipid indices- atherogenic index = 0,56-0,67 and thrombogenic index = 0,78-0,96. Biochemically, higher PUFA and n-3 fractions increase membrane fluidity and nutritional value, but also raise susceptibility to lipid peroxidation-so oxidative stability becomes a key quality dimension in lamb during storage and cooking [10].

All studies included in the tables underwent screening and were selected based on the inclusion/exclusion criteria specified in Materials and Methods.

Table 1 - Comparative chemical composition of lamb, beef and pork meat

Parameters	Mutton	Source	Beef	Source	Pork	Source
Moisture, g/100 g	68,1	[11]	72,4	[13]	74,9	[16]
Protein, g/100 g	18,5	[11]	19,1	[13]	18,2	[16]
Fat, g/100 g	12,1	[11]	12,27	[13]	12,34	[16]
Ash, g/100 g	0,99	[11]	1,2	[13]	1,07	[16]
Calcium, mg/100 g	7,27	[11]	4,39	[14]	10	[16]
Iron, mg/100 g	1,6–2,4	[11]	1,39	[14]	0,8	[16]
Potassium, mg/100 g	301	[11]	367	[14]	330	[16]
Magnesium, mg/100 g	20,8	[11]	21,3	[14]	20,4	[16]
Sodium, mg/100 g	67,5	[11]	40,4	[14]	50,1	[16]
Phosphorus, mg/100 g	193	[11]	163	[14]	220	[16]
Zinc, mg/100 g	3,08	[11]	5,28	[14]	2,4	[16]
Selenium, нg/100 g	12,3	[11]	12,5	[14]	21	[16]
Thiamine (B1), mg/100 g	0,14	[12]	0,06	[15]	0,72	[17]
Riboflavin (B2), mg/100 g	0,07	[12]	0,12	[15]	0,21	[17]
Niacin (B3), mg/100 g	3,32	[12]	2,4	[15]	4,7	[17]
Pantothenic acid (B5), mg/100 g	0,15	[12]	0,12	[15]	0,47	[17]
Pyridoxine (B6), mg/100 g	0,54	[12]	0,2	[15]	0,72	[17]
Folate (B9), mkg/100 g	4,16	[12]	5,9	[15]	5,2	[17]
Cyanocobalamin (B12), mkg/100 g	2,53	[12]	0,61	[15]	1,12	[17]
α-Tocopherol (E), mg/100 g	0,31	[12]	0,21	[15]	0,26	[17]

A consistent biochemical advantage of lamb over pork is iron density, which matters because iron in meat is largely present as heme iron (higher bioavailability than non-heme forms). Junkuszew et al. reported lamb iron 2,60-2,93 mg/100 g, while Aaslyng et al. report lean pork loin iron 1,6–2,4 mg/100 g and beef loin iron 2,40 mg/100 g. Practically, this places lamb far above pork and at least comparable to beef in total iron, supporting lamb as a strong option when dietary iron adequacy is a priority [18].

A more “technological” advantage of lamb versus pork is that its matrix naturally combines moderate intramuscular fat with a high EAA density, which supports both flavour development and a firm protein network after cooking. Intramuscular fat 4,60-5,50 g/100 g and with EAA/NEAA ratio = 0,68-0,72, a balance that helps explain why lamb can maintain sensory richness without requiring high fat levels typical of some pork products. Compared with very lean beef (2,27 g fat/100 g), lamb’s higher intramuscular lipid fraction can improve perceived juiciness and flavour intensity-while still staying within a moderate fat range [19].

Sea buckthorn (*Hippophae rhamnoides*) is biochemically unusual among edible berries because its core matrix combines high acidity, moderate sugars and very high levels of redox-active micronutrients. In a compositional survey of sea buckthorn fruits, Tkacz et al. reported total soluble solids around 3,38-5,67 g/100 g, with

glucose 1,82-3,13 g/100 g and fructose 0,90-1,71 g/100 g, while the sum of organic acids reached 0,97-2,80 g/100 g. This sugar-acid architecture explains both the characteristic sharp taste and the technological value of sea buckthorn as a naturally acidic, antioxidant-rich ingredient [20].

A key nutritional hallmark is ascorbic acid (vitamin C), which in sea buckthorn can reach physiologically meaningful levels for a realistic serving size. Bośko et al. quantified ascorbic acid at 300-600 mg/100 g of fruit, a 50-100 g portion can plausibly deliver tens to less than 100 mg vitamin C [21]. Biochemically, ascorbate acts as a two-electron reductant supporting the cellular antioxidant network, and it also serves as an enzymatic cofactor (e.g., hydroxylation reactions in connective-tissue metabolism). Importantly for a review, reported vitamin C values vary strongly with genotype and harvest conditions; Jaroszewska et al. summarize ranges where measured vitamin C spans roughly 61-159 mg/100 g, reinforcing that region must be treated as a major effect modifier [22].

Beyond vitamins, sea buckthorn is rich in polyphenols, especially flavonol derivatives, which matter because they participate in radical scavenging, metal chelation, and redox-signalling modulation. In berry extracts from multiple cultivars, Criste et al. reported total phenolics 10,12-18,66 mg GAE/g and flavonoids 6,57-9,01 mg QE/g, showing cultivar-dependent but consistently high phenolic density for an edible fruit [23]. From a human-nutrition angle, these phenolics are relevant not only as direct antioxidants, but also because many act as substrates for gut microbial metabolism, generating smaller phenolic acids that can influence inflammatory and metabolic signalling.

Sea buckthorn's carotenoid system adds a second, lipophilic antioxidant layer with provitamin-A potential. Zenkova et al. showed that total carotenoids differed sharply by variety (5,63 to 35,78 mg/100 g), and they identified zeaxanthin as a predominant compound, reaching 27,78 mg/100 g in one cultivar, lutein up to 4,74 mg/100 g and β-carotene around 0,17-1,94 mg/100 g [24]. Functionally, carotenoids are efficient physical quenchers of singlet oxygen and interceptors of lipid radicals in membranes and lipoproteins-mechanisms that complement vitamin C's aqueous redox role and help explain why sea buckthorn is repeatedly positioned as a multi-compartment antioxidant food.

In a controlled dietary intervention, Huang et al. showed that increasing sea buckthorn oil intake raised circulating trans-palmitoleic acid by 26,6%, confirming that sea buckthorn oils measurably alter circulating lipid markers in humans [25].

Sea buckthorn contributes minerals and may support metabolic outcomes through combined fiber-polyphenol-lipid mechanisms. In compositional measurements, Kim et al. reported high potassium 600,918 mg/100 g, with notable calcium 169,546 mg/100 g, magnesium 120,321 mg/100 g, phosphorus 135,445 mg/100 g, and iron 3,203 mg/100 g [26]. On the functional side, a randomized crossover trial by Ren et al. in individuals with impaired glucose regulation found that after sea buckthorn fruit puree, fasting plasma glucose changed from 6,04 to 5,80 mmol/L, and the between-condition comparison for fasting plasma glucose was significant ($p = 0,045$), suggesting a modest but detectable glycemic signal in a real dietary context [27].

In meat systems, sea buckthorn is typically introduced through two practical formats, each targeting a slightly different set of mechanisms (Table 2). First, water-compatible extracts or juices are incorporated directly into the comminuted phase during mixing, so the bioactives become distributed throughout the protein-fat matrix. Second, dry powders (extract powders or pomace powders) are added at the dry blending stage or during final mixing before stuffing or forming. This route increases the local concentration of solids and can change hydration dynamics.

Across studies, the most consistently affected outcomes are markers of oxidative stability, because sea buckthorn supplies multiple redox-active pools. In biochemical terms, lipid oxidation in meat is a chain process initiated by reactive oxygen species and catalysed by heme iron and other transition metals. It propagates through

formation of lipid radicals (L•), peroxyl radicals (LOO•) and hydroperoxides (LOOH), eventually yielding secondary aldehydes measured by TBARS. Sea buckthorn phenolics can donate electrons or hydrogen atoms to terminate LOO• radicals (chain-breaking antioxidant action), while also chelating Fe^{2} /Fe^{3} , reducing Fenton-type initiation. At the same time, carotenoids can quench singlet oxygen and intercept radicals in lipid regions, and ascorbate can regenerate oxidized antioxidant forms-although its role is dose-and matrix-dependent because in the presence of free iron, strong reducers can sometimes show pro-oxidant behaviour. Practically, this is why sea buckthorn additions frequently translate into lower TBARS, POV, AV and improved colour stability in chilled storage, especially in systems with higher fat or higher heme pigment load.

Table 2 - Application of sea buckthorn and its effects in meat systems

Meat or product type	Sea buckthorn form	Dose and incorporation stage	Results	Source
Horse meat, chunked delicacy “Jaya”	Dry sea buckthorn extract (powder)	3% (w/w), mixed into formulation prior to processing	TBARS reduced by 26,5–44,7%, remaining 0,26–0,49 mg MDA/kg; AV 0,28–0,59 mg KOH/g; POV 0,11–0,55 meq O_2/kg; hardness decreased 1,41–1,33;	[28]
Cooked-smoked sausages	Sea buckthorn extract (with hemp protein as co-ingredient)	0,005% – 0,015% added during batter formulation before stuffing	Best sensory acceptance reported at 0,01%. Total microbial counts within acceptable limits up to 36 days, supporting shelf life under 0–4 °C	[29]
Pork sausages	Sea buckthorn extract	3 mL/kg and 5 mL/kg, incorporated during mixing	pH: 6,55(control) and 6,18 (5 mL/kg); colour day: L* 67,91 (control), 66,54 (3 mL/kg) and 66,28 (5 mL/kg); Firmness: 385,96 N (control), 371,77 N (3 mL/kg) and 407,99 N (5 mL/kg);	[30]
Beef burgers	Sea buckthorn berry juice	Juice incorporated at the patty formulation stage (before cooking)	Cooking loss decreased from 41,2% (control) to 38,9%. Yield increased from 58,8% to 62,0%. Antioxidant activity in burgers reported in the range 42–440 µmol/L/100 g.	[31]
Chilled beef under super-chilled storage	Sea buckthorn pomace extract	SBP extract 0% / 1% / 2% / 3% (w/w)	Shelf life prolonged from 25 to 35 days with 3% extract film. Higher L* and a* maintained.	[32]
Pork sausages	Sea buckthorn extract	Extract used at 3 mL/kg and 5 mL/kg (incorporation into sausage system)	Extract characterised by TPC 677,58 g GAE/kg and DPPH inhibition 65,04%. Authors report reduced malondialdehyde (MDA) formation in sausages (oxidation), while antimicrobial impact was not evident	[33]

Grape seeds (*Vitis vinifera L.)* are nutritionally meaningful mainly because they concentrate dietary fibre and plant secondary metabolites. In a compositional study of defatted grape seed meal,

Baca-Bocanegra *et al.* reported moisture 11,78%, ash 2,87%, dietary fibre 22,86%, protein 10,76%, lipid 1,30%, and available carbohydrates 50,43%. This profile is typical of an ingredient where nutritional value is not driven by fat or simple sugars, but by fibre-associated physiological effects and by co-localised phenolics bound to the cell-wall matrix [34].

Table 3 - Application of grape seed and its effects in meat systems

Meat or product type	Form of grape seed ingredient	Dose and incorporation method	Results	Source
Pig liver pâté, heat-treated,	Grape seed extract	50 / 200 / 1000 mg/kg, incorporated into the meat batter during mixing	Baseline TBARS 0,4–3,3 mg MDA/kg; higher extract level resulted in lower oxidative deterioration.	[38]
Dry-cured pork sausage (“chorizo”)	Grape seed extract	Extract dose range - 0,05–1,0 g/kg; incorporated during vacuum mincing	TBARS 0,4 mg MDA/kg; hardness decreased, with minimum values reported at 0,20 g/kg. TVC in extract-treated batches up to 7,88–7,97 log CFU/g.	[39]
Ground beef, retail display storage	Grape seed extract	250 mg/kg, added during minced meat mixing	TBARS (control) - 0,96 mg MDA/kg on day 6; with extract - 0,82 mg MDA/kg on day 6.	[40]
Meat patties (85% beef + 15% pork fat)	Grape seed extract	0,10 / 0,25 / 0,50 / 0,75 g/kg; extract pre-dissolved in water and incorporated during mixing before patty forming	Colour on day 10 a* = 8,62 (control) and 13,20 (0,75 g/kg). TBARS maintained within 0–0,51 mg MDA/kg.	[41]
Dry-cured pork neck, long-term storage	Grape seed extract	Dose variants GSE-1 / GSE-2 / GSE-5. Incorporated into the meat mass at the beginning of processing	After 2 months TBARS 0,72 mg MDA/kg (control) and 0,42 mg MDA/kg (GSE-5), ascorbic acid - 0,53 mg MDA/kg.	[42]
Beef–pork sausage model system	Grape seed extract	0,125 / 0,25 g per 250 g meat batter added during mixing. Some treatments combined with ascorbic acid	TBARS shows 0,43 mg MDA/kg (GSE 0,125 g/250 g), 0,41 mg MDA/kg (GSE + AA); and 0,45 mg MDA/kg (control).	[43]
Smoked pork sausage	Grape seed extract	Extract incorporated during mixing	Reported reductions TBARS by 30,3%, expressible water by 26,4%. Sensory score higher by 18,0%; TVC moulds also decreased.	[44]

The lipid fraction of grape seeds is also biochemically relevant when the oil is recovered. Carmona-Jiménez *et al.* quantified grape seed oil yields of 12,46-22,52 g oil/100 g dry seed and showed that the oil is strongly skewed toward unsaturated fatty acids (USFA 82-84%), with PUFA 64,04-69,44% and MUFA 16,43-20,27%. Linoleic acid dominated at 65,55-69,00%, while oleic acid ranged up to about 20,13%. In the same research line, grape seed oils were

reported to contain total tocopherols 196,2-248,0 mg/kg oil, supporting Vitamin-E-linked antioxidant functionality of the lipid phase [35]. Ivanov *et al.* measured high concentrations in grape seed-derived ingredients, reporting total phenolic content 111,22 mg GAE/g, total flavonoids 51,50 mg QE/g, and total proanthocyanidins 170,45 mg CE/g [36]. These compounds are rich in pyrogallol hydroxyl groups, which enables radical scavenging via electron transfer, and metal chelation, which can slow Fenton-type propagation of oxidation in biological and food systems.

Human evidence (mostly from grape seed extracts) suggests measurable effects on vascular and redox endpoints. In a meta-analysis of randomised controlled trials, Foshati *et al.* found that grape seed extract supplementation reduced diastolic blood pressure by 2,20 mmHg and heart rate by 1,25 bpm, and increased flow-mediated dilation by 1,02%, while the pooled reduction in systolic blood pressure (3,55 mmHg) was not statistically significant [37]. Mechanistically, these outcomes align with polyphenol-driven modulation of endothelial nitric oxide bioavailability, reduced oxidative quenching of NO, and attenuation of low-grade inflammation.

In meat systems, grape seed ingredients are most often introduced as grape seed extract during the mixing stage, so the phenolic fraction becomes uniformly distributed within the protein-fat matrix before forming and subsequent processing (Table 3). Across product types, the most reproducible impact is on oxidative stability, typically tracked by TBARS. Mechanistically, this aligns with the chemistry of grape seed polyphenols which can quench lipid peroxyl radicals (LOO•) as chain-breaking antioxidants and chelate transition metals, thereby reducing initiation and propagation of lipid peroxidation driven by heme iron and non-heme catalysts. The numeric signals in the table are consistent with that model. Even when results are reported as relative changes, Zhou et al. still observed a 30,3% TBARS reduction, which is the same direction expected from phenolic-driven suppression of lipid oxidation [44].

Because lipid oxidation and pigment oxidation are coupled, grape seed additives also frequently affect colour stability and premature browning behaviour. Xin et al. reported that redness on the raw surface at day 10 increased from 8,62 (control) to 13,20 at 0,75 g/kg, while TBARS stayed within 0-0,51 mg MDA/kg-a pattern consistent with lowering oxidative pressure on myoglobin and slowing conversion toward metmyoglobin (brown), particularly at the oxygen-exposed surface [41]. In parallel, texture and water-binding outcomes can shift because polyphenols can interact with myofibrillar proteins, potentially altering protein-protein aggregation and water immobilisation during drying or heating. That helps explain why Zhou et al. saw reduced expressible water by 26,4% alongside improved sensory scores [44].

Conclusion. Analysis of the literature allows us to construct a convincing scientific rationale for the selection of raw materials and functional components. Lamb, as a meat ingredient for roulade, is particularly vulnerable to lipid and pigment oxidation due to the release of heme catalysts. In this context, sea buckthorn and grape seeds form a complementary antioxidant platform: sea buckthorn combines phenolic compounds, ascorbic acid, carotenoids and organic acids, potentially affecting the redox balance and colour stability, while grape seeds provide ‘polyphenolic support’ (proanthocyanidins) capable of breaking peroxide oxidation chains and binding transition metal ions, inhibiting the decomposition of hydroperoxides and the accumulation of secondary oxidation products. A comparison of studies shows that the most controllable and reproducible method of introducing both additives is in extract form, as it ensures accurate dosing, uniform distribution of bioactive substances in the protein-fat system, and minimises the risk of undesirable effects of dispersed particles on the cut and texture of roll products.

Based on this, subsequent studies are expected to show a decrease in oxidative degradation markers, more stable colour parameters and a reduction in the formation of rancid aroma tones during storage, as well as the preservation of technological suitability due to a reduction in losses during heat treatment

and textural characteristics. Subsequent studies should focus on optimising extract doses and key technological conditions with mandatory control of the trade-offs between antioxidant effect and organoleptic indicators. This approach will allow us to quantitatively substantiate the functional viability of the lamb and plant antioxidants composition and develop a reproducible technological scheme for meat rolls with high nutritional value.

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Information about the authors

Abdurasulova A.E. - PhD student, Master of Technical Sciences, Almaty Technological University, Almaty, Kazakhstan, e-mail: abdurasulova.aigerim@mail.ru;

Rskeldiyev B.A. - Doctor of Technical Sciences, Professor, Almaty Technological University, Kazakhstan, Almaty; e-mail: berdan_r@mail.ru.

Сведения об авторах

Абдурасулова А.Е. - магистр, докторант, Алматинский технологический университет, Алматы, Казахстан, e-mail: abdurasulova.aigerim@mail.ru;

Рскелдиев Б.А. - д.т.н., профессор, Алматинский технологический университет, Алматы, Казахстан, Алматы, e-mail: berdan_r@mail.ru.